United States
Department of
Agriculture

Forest Service

Southern
Research Station

General Technical
Report SRS–98

# History and Legacy of Fire Effects in the South Carolina Piedmont and Coastal Regions

Lindsay H. Fairchilds and Carl C. Trettin

## Authors:

**Lindsay H. Fairchilds**, Ecologist and Research Associate, College of Charleston, Department of Geology and Environmental Geosciences, Charleston, SC; **Carl C. Trettin**, Project Leader and Soil Scientist, USDA Forest Service, Southern Research Station, Center for Forested Wetlands, Charleston, SC.

**Cover photo**: Prescribed burn on the South Carolina Department of Natural Resources Webb Center in Hampton County, SC. Prescribed fires serve a variety of functions for wildlife management areas. Photo courtesy of South Carolina Department of Natural Resources.

December 2006

Southern Research Station
200 WT Weaver Blvd.
Asheville, NC 28804

# History and Legacy of Fire Effects in the South Carolina Piedmont and Coastal Regions

Lindsay H. Fairchilds and Carl C. Trettin

# Contents

# History and Legacy of Fire Effects in the South Carolina Piedmont and Coastal Regions

**Lindsay H. Fairchilds and Carl C. Trettin**

**Abstract**

Agriculture, fire suppression, and urbanization have drastically altered natural forest processes and conditions since humankind settled in the Southeastern United States. Today, many of South Carolina's forests are dense and overstocked, with high fuel loads. These conditions increase the susceptibility of forests to southern pine beetle attack and wildfire. These threats are further complicated by rapid urbanization and forest fragmentation, processes that are increasing South Carolina's wildland-urban interface at a rapid rate. Prescribed fire is an effective, economical, and widely used tool for reducing fuel loads and encouraging desired vegetative communities in forest landscapes. However, research into the effects of prescribed fire often generates more questions than answers. This paper considers fire effects on soil erosion, nutrients, and vegetation from a historical perspective. We examined historical fire regimes, land use changes, and fire research. The majority of literature indicates that soil erosion does not occur unless a severe climatic event follows prescribed fire. There is also evidence of a fertilization effect in the soil following prescribed fire, although this is typically of short duration and accompanied by some nutrient loss in the forest floor. Effects of prescribed fire on the productivity, composition, and regeneration of vegetation are more complex and ambiguous. Effects are primarily determined by antecedent local conditions and fire severity and intensity. Knowledge of past land use and fire's biological and historical roles in land use change can support effective decision making. This knowledge will provide guidance for sustainable management of forest resources and reduction of hazardous forest fuel conditions.

**Keywords**: Fire, fire effects, fire history, prescribed burn, wildland-urban interface.

## Introduction

Decades of wildfire suppression have led to large fuel accumulations and have changed the structure and composition of many forest communities in South Carolina. Forest research and management over the past 30 years show that prescribed fire is an effective and economical tool for reducing fuel loads and encouraging desired plant communities. Prescribed fire achieves management goals by reducing wildfire and therefore human health and safety risks, increasing abundance and diversity of desirable understory species, and improving wildlife habitat and esthetics. In recognition of a need for more management of fuels and habitat, President Bush signed the Healthy Forests Restoration Act of 2003 to reduce the threat of destructive wildfires, help save lives, and protect threatened or endangered species, acknowledging prescribed fire as one of the major tools to achieve these goals.

The challenges for improving forest conditions and reducing fuel loads are significant, and are complicated by forest fragmentation and urban growth. These land use changes also undermine implementation of effective landscape-scale prescriptions. Urbanization in the South is forecast to continue at its current rate of 1.1 million acres per year (conversion of forest or agricultural land to urban or industrial use; Wear and Greis 2002), and much of the development will occur in the Coastal Plain. For example, a study forecasts that urban land use will triple in the Charleston area in the next 30 years (Allen and Lu 2003), and this change in land use is certain to cause a loss of forest land. The influx of people and businesses into the forested landscape also increases the border area and proximity between human communities and the forest; this area is termed the wildland-urban interface. Additionally, the recent epidemic of the southern pine beetle that began in the late 1990s was recognized in the Healthy Forests Restoration Act. In 2003, South Carolina had a record loss of $225 million in pines killed by the southern pine beetle (South Carolina Forestry Commission 2003). This loss could be alleviated by opening dense, stressed pine stands and encouraging herbaceous vegetation, and prescribed burning produces both of these effects. Accordingly, the high fuel loads and development pressures make it necessary to focus management treatments on reducing fuel loads and sustaining the value of managed forest tracts.

Photo courtesy of South Carolina Forestry Commission.

*Fire in the "Wildland-Urban interface" is concern for fire mangers. The Legends fire in Myrtle Beach, SC, resulted in a neighborhood evacuation.*

There is uncertainty about the long-term effects of prescribed fire on ecosystem functions, largely because most studies have been conducted over short periods (e.g., 2 to 5 years) and because research has produced conflicting results. Christensen (1987) wrote that "the literature on fire is a bit like the holy scripture; by careful selection of results, one can 'prove,' for example, that fire increases, decreases, or has no effect on nutrient availability . . . ." If we are truly concerned about sustainability, then understanding the effects of fire on multiple generations of plant communities is an imperative. The objective of this paper is to examine historical fire regimes and available research on fire effects on soil erosion, nutrients, and productivity in South Carolina. This synthesis is intended to give land managers and the public a knowledge base for developing sustainable land management prescriptions.

## Location and Physiographic Provinces

South Carolina has two dominant physiographic regions: the Coastal Plain and the Piedmont (fig. 1). A small Blue Ridge region exists in the upper northwestern corner of the State and will be discussed with the Piedmont section. The Piedmont region begins at the foothills of the Blue Ridge Mountains along the Brevard fault line and makes up about two-thirds of northwestern South Carolina. Soils in the Piedmont may be deep or shallow to bedrock, but much of this area is characterized by poor and shallow soils that have been affected by 150 to 300 years of agricultural disturbance (Richter and others 2000). These areas are steep to gently sloping and are often dissected by networks of gullies. Piedmont forests are generally classified as oak-pine associations where hardwoods have taken over the once even-aged old-field pine stands. Dominant species include scarlet, southern red, and white oak; Virginia, loblolly, and shortleaf pine; and hickories. Many stands in the Piedmont are small privately owned tracts (Meyers and others 1986).

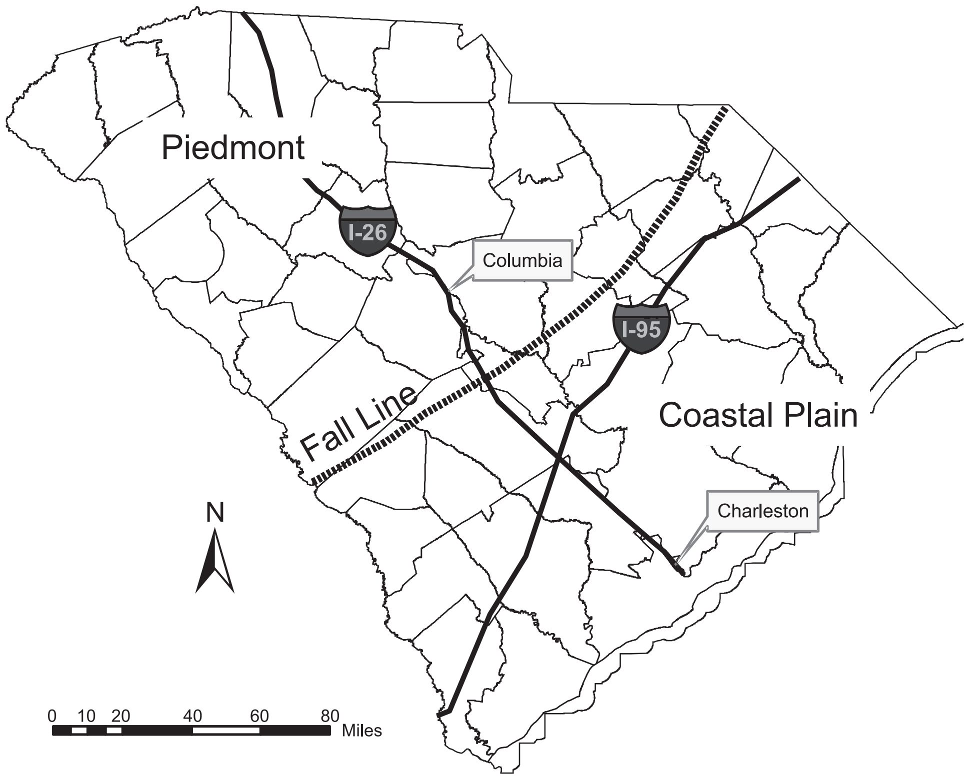



Figure 1—South Carolina physiographic regions.

The South Carolina Coastal Plain transition occurs at the fall line that runs from southwest to northeast through the center of the State. Soils of this area are sandier and slopes broader and flatter. In this paper, areas classified as flatwoods and tidewater regions are interpreted as suborders of the Coastal Plain. Coastal Plain forests are classified as the southeastern evergreen forest association and consist predominantly of longleaf, loblolly, shortleaf, and pond pines. Other major species include various oaks, hickories, sweetgum, and red maple (Meyers and others 1986).

## History of Fire in South Carolina

### Presettlement Period

It is believed that humans arrived in Eastern North America about 12,000 years ago, in the Pleistocene (Delacourt and Delacourt 1987). There is evidence that natural fires maintained the pine-grassland ecosystem in the Southeast before the coming of humans (Cooper 1961; Komarek 1965, 1974; Van Lear and Waldrop 1989). During the presettlement period (defined as the period before first European settlement), fires were ignited periodically by lightning strikes (Komarek 1964, 1965, 1974) and occurred most commonly in the spring and summer (during the growing season). These fires were only constrained by natural fuel breaks created by water or topography. Because such fuel breaks are less common in the flatter Coastal Plain, this area had a higher fire frequency than did the Piedmont, which is more dissected (Frost 1993).

Native Americans are also reported to have used controlled fire to manage the natural landscape. In South Carolina, the Chickasaws, Cherokees, Creeks, and Westos altered the natural landscape to suit wildlife, settlement, and agricultural needs (Silver 1990). Christensen (1981) estimated that lightning-caused fires and fires set by aboriginal peoples burned the understory of longleaf forests at a

Photo courtesy of South Carolina Forestry Commission.

*Smoke management is a major concern for urban areas near historically burned forest land. This smoke plume was from the Legends fire in Myrtle Beach, SC.*

frequency of 1 to 15 years during presettlement. Frost (1993) estimated the frequency of lightning fires to be 1 to 3 years on the Coastal Plain, 4 to 6 years on the Piedmont, and from 7 years to no burn on uplands. Historically, recurring low-intensity lightning fires sustained fire-tolerant or fire-dependent (pyrophytic) plant communities of longleaf pine savannas (Frost 1993).

Frost (1997) suggested that the impact of fire ignited by Native Americans was greater on the upper Piedmont than in the coastal region, as the upper Piedmont historically did not burn as frequently. Additionally, Native Americans set fires in the fall, winter, and spring in South Carolina (Lawson 1967). This change in seasonal regime reduced fuel potential for lightning-induced summer burns (White 2004). However, it is unlikely that Native Americans significantly altered burn frequency (White 2004).

### Settlement Period

Around 1513, Juan Ponce de Leon began exploration of the bottomlands and Coastal Plain forests; English colonization of the Charleston coast followed around 1608. Hernando de Soto is credited with charting the South Carolina Piedmont frontier. Spanish-commissioned de Soto and his crew of over 600 men worked a route up to the South Carolina Piedmont through the Gulf side of Florida around 1540 (Walker 1991).

Early accounts from settlers indicate that longleaf pine–wiregrass and longleaf pine–bluegrass communities dominated in coastal South Carolina, while the Piedmont had longleaf, shortleaf, and loblolly pines with some pine-hardwood transition areas along rivers and streams (Sargent 1884, in White 2004). In his travels, Bartram (1958) described areas of the Southeast as “expansive, airy pine forests . . . of great long-leaved pine . . . the earth covered with grass, interspersed with an infinite variety of herbaceous plants.” Historical accounts place hardwoods such as oaks and hickories along rivers and above the fall line (Hammond 1883).

Europeans brought with them new strains of viruses that led to a decline in Native American populations; some authors speculate that the Native American population was reduced by 90 to 95 percent (Carroll and others 2002).

Colonial land use before 1780 was of relatively low intensity and included hunting, trapping, and woodland grazing for cattle and hogs. Early colonists also exported naval stores, destroying large stands of longleaf pines (Silver 1990). Naval stores production continued until rice cultivation superseded this practice in coastal areas. The entire longleaf pine region (including South Carolina) was fully settled by 1750 (Frost 1993). White (2004) suggests that alteration of fire season and frequency may have been the most important human influence on the environment in the region during this early settlement period, particularly for mesic sites.

After 1780 and with the advent of the cotton gin, land use shifted dramatically (table 1). Corn and cotton cultivation were widespread on the South Carolina Piedmont, while rice and indigo farming dominated in the Low country. Slash-and-burn conversion of forest land to corn and cotton agriculture was "frequent, extensive, and high intensity disturbance" (White 2004). Longleaf pine harvesting occurred on a large scale for wood and fuel, supported by expanding wood markets and infrastructure.

Although the area of forest land was reduced during settlement, some believe the shift in plant communities was the most dramatic change. Fire exclusion replaces diverse longleaf-grassy understory ecosystems with hardwood trees and large shrubs (Komarek 1974, Waldrop and others 1992). Frost (1993) calculated that the area of native longleaf pine forests of the Southeastern United States was reduced from 56 million to 27 million acres between the presettlement period and 1900. Large-scale agricultural abandonment occurred after 1800, and the resultant landscape was highly fragmented and disturbed (White 2004). As agricultural and grazing practices resulted in a dramatically disjointed landscape, the frequency of lightning fires was undoubtedly reduced. Prescribed fire was used to improve existing grazing lands, but this practice was substantially reduced following the Civil War. Farmers used fire to control agricultural infestation of boll weevils in South Carolina, but these efforts were largely unsuccessful. There are also accounts of destructive wildfires in turpentine orchards of longleaf pine, which were located in coastal areas. Although fire was still widespread at the end of the colonial period, it is likely that fire frequency and severity were reduced as fuel breaks resulting from land fragmentation prevented most large fires from burning great areas of forest.

**Table 1—Historical changes in major land use classes in the Southeastern United States and South Carolina**

| Year | Forest land | Cropland | Pasture | Urban [a] | Other [b] |
|---|---|---|---|---|---|
| | *percent* | | | | |
| | Land use distribution in the Southeastern United States over time (modified from Frost [1993]) | | | | |
| Presettlement | 69.3 | — | — | — | 30.7 |
| 1900 | 52.9 | 19.6 [c] | — | 1.0 | 27.5 |
| 1990 | 49.3 | 16.3 | 5.0 | 8.0 | 21.4 |
| | Land use distribution in South Carolina over time (U.S. Department of Agriculture [ n.d.]) | | | | |
| 1945 | 53.4 | 26.5 | 3.2 | 5.0 | 11.9 |
| 1959 | 60.4 | 23.4 | 4.9 | 7.6 | 3.7 |
| 1974 | 64.1 | 18.4 | 3.5 | 8.3 | 5.7 |
| 1997 | 64.4 | 13.1 | 2.4 | 11.1 | 8.9 |

[a] Includes urban, rural transportation, rural parks and wildlife, defense and industrial, miscellaneous farm, and special uses.
[b] Includes unclassified uses such as wetlands, marshes, swamps, bare rock, deserts, tundra, and other uses.
[c] Includes cropland and pasture.

## Contemporary Period

The enactment of fire prevention laws and implementation of wildfire suppression policies began during the early decades of the 1900s. National strategy and public education efforts were aimed at controlling and suppressing fire. In the 1920s, the U.S. Department of Agriculture Forest Service was opposed to burning on forested lands (Pyne 1982). Regeneration efforts prompted foresters to keep site disturbance to a minimum; thus, fire was excluded on these historically disturbed lands. Drought-induced fires that occurred in the 1930s and 1950s provided some evidence of the need for prescribed fire to reduce wildfire hazard (Van Lear and Waldrop 1989). Although some forest managers and researchers understood the benefits of fire much earlier, it was not until the mid-1970s that these benefits were fully acknowledged. Forest regeneration in the absence of fire resulted in a successional shift from longleaf pine to hardwoods and less fire-tolerant species such as loblolly pine on forest lands and reforested agricultural lands (White 2004).

As part of its approach for dealing with the Great Depression and under the Weeks Law of 1911, Franklin Roosevelt's administration approved acquisition of the Francis Marion and Sumter National Forests in 1936 (table 2; fig. 2). These forest lands, totaling about 618,000 acres in South Carolina, were predominantly eroding farmlands or extensively cutover forests. The Civilian Conservation Corps worked to "retire the farmlands, control soil erosion, regulate stream flow, and produce timber" (U.S. Department of Agriculture Forest Service, FMSNF). The land was slowly restored and is considered productive again . The South Carolina Forestry Commission was created by the General Assembly in 1923 with the same ideals of forest land preservation (South Carolina Forestry Commission 2003).

Photo courtesy of South Carolina Foresty Commission.

*Fire managers in the Southeast face many challenges based on land-use changes. Prescribed fires are set to mimic natural historical processes and reduce wildfire fuels.*

**Table 2—National forests and Ranger Districts in South Carolina**

| National Forest<br>Ranger Districts | Area | Location | Counties |
|---|---|---|---|
| | *acres* | | |
| Francis Marion | 252,000 | Southeastern | Berkeley, Charleston |
| Sumter | | | |
| Andrew Pickens | 84,000 | Northwestern | Oconee |
| Enoree | 161,000 | Central | Chester, Fairfield, Laurens, Union, Newberry |
| Long Cane | 119,000 | Western | Abbeville, Edgefield, Greenwood, McCormick, Saluda |

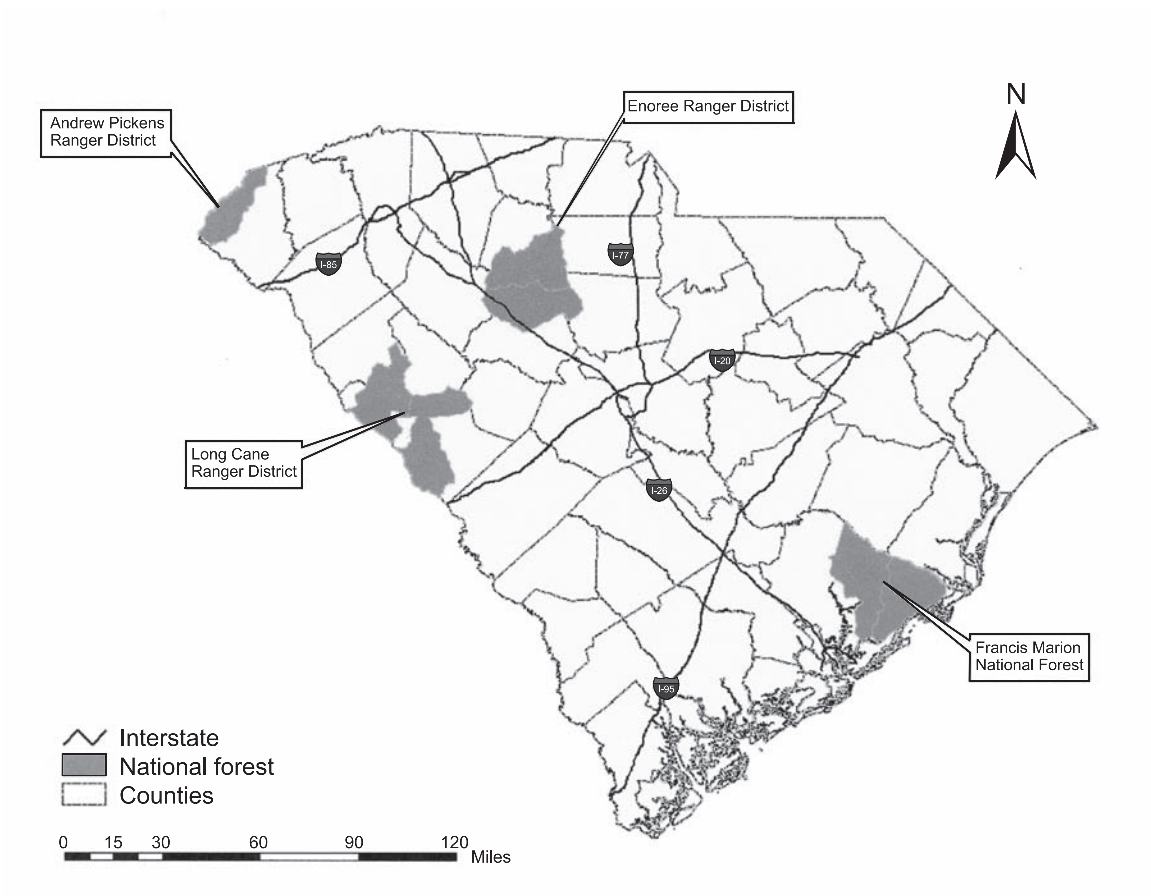



Figure 2—South Carolina map with national forest districts defined.

Aside from a slow and steady conversion of agricultural use to forest use, land use in South Carolina remained relatively stable between 1945 and 1980. Between 1980 and 1992, a shift from agricultural to forest use continued in the upper South Carolina Coastal Plain, but rapid population growth and urbanization around Myrtle Beach and Charleston provided the main change on the Coastal Plain. Since the 1980s, land use patterns in the southern forest landscape have changed substantially. Generally, forest land decreases driven by urbanization have been offset by conversion of agricultural land to timber production (Wear 2002).

Currently, total forest land constitutes about 12.5 million acres or about two-thirds of the land in South Carolina (Smith and others 2004). Smith and others (2004) also estimated that nonindustrial private landowners own > 9.1 million acres of this land (fig. 3). These privately owned tracts are often much smaller than publicly owned ones and are prime candidates for residential development. This is important as increased fragmentation has led to a larger area of wildland-urban interface, increasing the threat to human health and safety and the need to reduce fuels.

Loblolly-shortleaf currently covers 44 percent of the forest land in South Carolina, longleaf-slash 4 percent, the oak-pine association 12 percent, oak-hickory 20 percent, and bottomland hardwoods 20 percent (Connor and Sheffield 2000) (fig. 4). The main impact of fire in the southeastern pine region has been the maintenance of pine forest (Smith and others 2000).

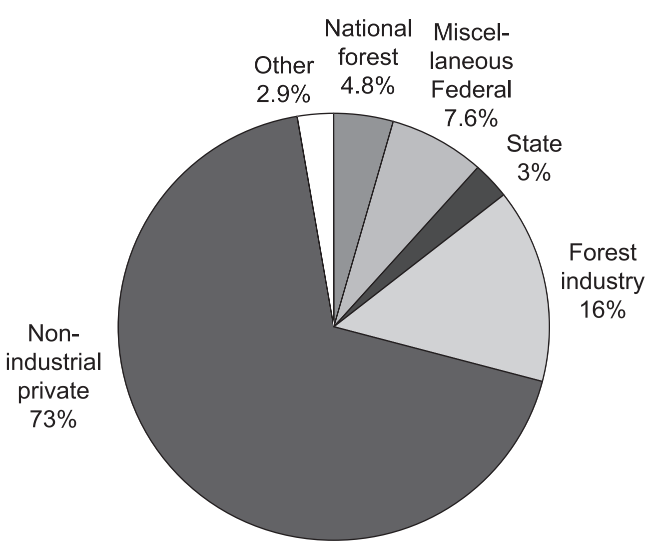



Figure 3—Area of forested land by ownership class in South Carolina. Adapted from Smith and others (2004).

The South Carolina Forestry Commission (2003) estimates that about 30,000 acres of forest land are burned by wildfire, and another > 400,000 acres are prescribed burned annually (table 3). If that approximately 3.4 percent of forest land that is prescribed burned annually were uniformly rotated each year, these figures would theoretically suggest a 29-year fire frequency for South

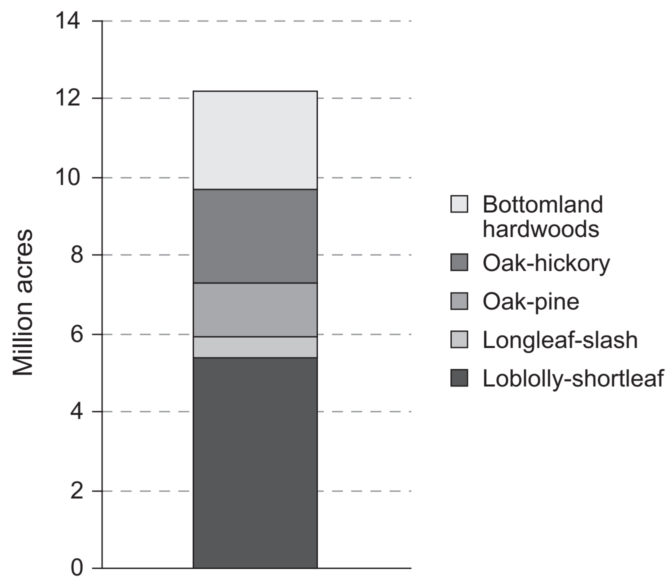



Figure 4—Forest land cover in South Carolina (Conner and Sheffield [2000]).

**Table 3—Summary of annual fire use in South Carolina**

| Fire type and location | Total number of fires | Total acres | Forest land burned[a] |
|---|---|---|---|
| | | | *percent* |
| **Wildfire**[b] | | | |
| **Statewide** | **4,950** | **29,009** | **0.2** |
| **Prescribed fire**[c] | | | |
| **Statewide** | **13,306** | **420,126** | **3.4** |
| Coastal | 6,296 | 227,522 | 1.9 |
| Pee Dee | 4,157 | 121,868 | 1.0 |
| Piedmont | 2,853 | 41,727 | 0.3 |

[a] Numbers taken from Francis Marion and Sumter National Forests 2002 statistics and represent numbers from the national forests.
[b] Numbers taken from 5-year average, FY 1998 to 2002, South Carolina Forestry Commission.
[c] Numbers taken from FY 2002 prescribed fire summary, South Carolina Forestry Commission.


*A backing fire like this one from Santee State Park, Orangeburg County, SC, burns into the wind for a lower intensity, slower moving precribed burn.*

Carolina (slightly shorter in coastal areas and longer in the Piedmont). A more reasonable estimate calculated by excluding bottomland hardwoods (2.5 million acres) and planted pine plantations (3.0 million acres; Connor and Sheffield 2000) indicates that the burn frequency may be 16 years. Van Lear and Waldrop (1991) recommend a 3- to 5-year fire frequency after trees are large enough to survive prescribed burning. Looking at the occurrence of fire in the Southeast, Outcalt (2000) found that 86 percent (40,095 acres) of public and 30 percent (29,160 acres) of private longleaf pine stands (where longleaf is still the dominant tree) were burned in the last 5 years. He also said that regular periodic burning should soon eliminate the existing backlog of unburned publicly controlled sites. Burning on private lands is not anticipated to increase, given the public's resistance to changes in understory condition, smaller size of private tracts, and smoke management and legal concerns. Almost all wildfires that occur today in South Carolina are caused by people, with < 10 percent caused by lightning in 2003 (South Carolina Forestry Commission 2003).

## Variability in Fire Regime and Type

Forest fire characteristics vary widely and can have dramatically different effects based on climate, fuel load, antecedent moisture conditions, and topography. These differences are manifest in fire intensity and severity. Fires are often defined by regime, burn type, and seasonality. Fire intensity and fire severity are defined differently based on duration of exposure and heat generated. Fire intensity is the actual thermal ignition energy (upward) that determines crown scorch (Stanturf and others 2002) and is often defined by flame height. Fire severity refers to the actual ground damage or the downward energy dispersal (Van Lear and Waldrop 1989, Wells and others 1979) and is often determined by fire residence time or speed. Higher fuel or woody debris load will generally lead to a longer smoldering time, thus increasing fire severity.

Fire regimes are of three kinds, in order of increasing severity: understory, mixed, and stand replacement (Brown 2000; table 4). Another way to classify burns is by fire type. Surface, ground, and crown fire are the common terms for fire types (Stanturf and others 2002; table 4). Typically, fire regime and type parallel one another (i.e., an understory fire is typically a ground fire).

One purpose of prescribed burning is hazardous fuel reduction to lessen the chance of higher intensity ground or crown fire. Other purposes include protection of critical plant and animal species through habitat management for wildlife, vegetation, and/or pests. The type of fire prescribed is based on climate, wind direction, fuel load and moisture, tract characteristics, and burn objectives. Common types include heading, backing, or flanking burns. Head fires burn upslope or with the wind and are relatively high in intensity but fast moving. Backing fires move backward into the wind or downslope and have lower flame intensity and speed. Flanking fires move parallel to the slope or perpendicular to the wind direction and often accompany other burning types (Stanturf and others 2002). Prescribed fires are generally of low intensity and low severity and are conducted when fuel and soil moisture levels are moderate or high. Prescribed fires burn along the forest floor and in the understory; typically 50 percent of available fuel is consumed (Carter and Foster 2004).

The effect of burn season on fire characteristics is more ambiguous. Some research indicates that growing-season fires are more effective than dormant season burns in reducing fuel loads and controlling hardwoods. However, there is some concern that these hotter burns result in tree scorch and mortality, and they are more difficult to control in terms of health and human safety dangers. Fire regime, fuel load and moisture, and frequency and seasonality of burn all influence the effects of fire on ecosystems.

## Fire Effects in South Carolina Forests

### Erosion

Following widespread agricultural abandonment, erosion ranged from very severe to severe in the upper Piedmont and was moderate or not significant on the Coastal Plain (South Carolina State Planning Board 1944, cited in White 2004). The Piedmont erosion was described as uphill undercut gully erosion that resulted in extensive sediment movement into streams and rivers (Trimble 1974; White 2004) and reduced productivity in upland areas as vast quantities of nutrients were washed offsite (Metz 1954; Richter and others 2000). Additionally, deposition to coastal areas covered the once fertile South Carolina bottomlands with sand (Metz 1958; Trimble 1974). Reforestation led to stabilization of these eroded lands, but sustainability is the challenge for modern-day forest managers.

Soil erosion is an ongoing process in forested landscapes, although forested lands generate only a small fraction of the sediment produced by more intensive land uses (Yoho 1980). Patric (1976) estimated erosion in undisturbed

**Table 4—Common fire regimes and types and their properties**[a]

| Fire regime and type | Forest type | Characteristics |
|---|---|---|
| Fire regime | | |
| Understory | Southern pine, oak-hickory, pine-oak | Less than 80 percent dominant vegetation mortality |
| Mixed | Hardwood, conifer | Selective, 20–40 percent vegetation mortality |
| Stand replacement | Oak-gum-cypress, spruce-fir, etc. | Greater than 80 percent dominant vegetation mortality |
| Fire type | | |
| Surface | Moister, lower fuel loads | Fast-moving, low-intensity, organic material often remains |
| Ground | Dry fuel conditions | Slow-creeping, smoldering, exposes soil |
| Crown | Drought, low humidity, high load, ladder fuels | Tree and shrub mortality, organic material consumption |

[a] Adapted from Stanturf and others (2001).


Southern Research Station photo.

*Early prescribed fire studies on the Santee Experimental Forest in the Francis Marion National Forest.*

eastern forest land at between 110 and 220 pounds per acre per year in a review of erosion rates from forested plots and small watersheds in 18 different studies. These low natural rates of soil erosion may be accelerated by the interaction between local site and climatic conditions and common forest disturbances such as management operations or wildfire (Grace and Carter 2001; Yoho 1980). It is widely recognized that the majority of sediment erosion comes from forest roads, skid trails, log landings, and burned areas (Elliot 2004). Elliot and Robichaud (2001) maintain that erosion in forests is highly variable and driven by a few extreme events each decade. Geomorphology, especially slope, also plays a role in soil's potential for erosion. Fire may accelerate erosion by reducing protective surface cover and altering soil physical and chemical properties (Debano 1991). Intense heating by fire can break down clay minerals and phyllosilicates that bind soil particles. A modeling study by Elliot and Robichaud (2001) indicated that erosion following a wildfire is greater by a factor of 100.

Effects of fire on soil erosion in the Southeast have only been documented following severe burns or when fuel and soil are dry. Lowdermilk (1930) concludes that increased soil erosion and decreased water infiltration after a fire were caused by destruction of soil cover. Stanturf and others (2001) indicate that fires, such as a broadcast burn, expose mineral soil and accelerate soil erosion, especially on steep terrain. In a study of burn severity in the South Carolina Appalachian Mountains, Robichaud and Waldrop (1994) found that sediment yields were 40 times greater for a high severity treatment than for a lower severity treatment. Severity was classified largely as a function of fuel moisture conditions. In contrast, a study of high-intensity prescribed burning on clearcut logging debris in Southern Appalachia showed no significant effect on erosion, water infiltration capacity, or the weight of the fine root mat (Van Lear and Danielovich 1988).

Although increases in sediment following prescribed fire are described in the literature, the increases in sediment are extremely variable and often considered minimal or not significant, and are highly dependent on slope (table 5). Yoho (1980) found that soil production ranged from 20 to 18,000 pounds per acre per year on prescribed burned areas in the South. Erosion differences are based on

**Table 5—Ranges of sediment erosion in the Southeastern United States**

| Location | Fire | Preburn | Postburn | Percent increase |
|---|---|---|---|---|
| | | - - - - - *pounds/acre/year* - - - - - | | |
| South Carolina Piedmont [a] | Low intensity, March and September | 23.7 | 58.9 | 149 |
| Mississippi Coastal Plain [b] | Low intensity, December | 148 | 868, 408, and 128 [c] | 486, 176, -14 |
| Eastern United States [d] | — | 50–100 | — | — |
| North Carolina Piedmont [e] | — | 320 | — | — |
| South Carolina Piedmont [f] | Low intensity, March | 1.8 | 9.8 | 444 |
| Georgia and South Carolina Piedmont [g h] | Periodic burns | — | 22–507 | — |

— = Data not given.
[a] Douglass and Van Lear (1983).
[b] Ursic (1970).
[c] Watershed III first, second, and third year following burn.
[d] Patric (1976).
[e] Copeley and others (1946).
[f] White (2003).
[g] Brender and Cooper (1968), Cushwa and others (1971).
[h] Adapted from Yoho (1980).

variability in soils, topography, stormflows, disturbance severity, and conservation practice. Yoho also noted that periodic prescribed fires seldom cause severe increases in sediment movement. In a study on the South Carolina Piedmont, Douglass and Van Lear (1983) found that single and repeated low-intensity, dormant-season burns did not significantly affect runoff or soil export. In a study in the Sumter National Forest, there was no evidence of erosion increases on established gullies following low-intensity growing-season burns (Cushwa and others 1971). Brender and Cooper (1968) found that summer and winter burns of high and low intensity had little to no effect on soil movement in a study in the Georgia Piedmont.

There is not much erosion research on the Coastal Plain; the region is relatively flat, and this reduces concern about soil movement. The only study we consider here was conducted by Ursic (1970), who found that a single prescribed burn and culling of hardwoods increased sedimentation by an average of 400 pounds per acre on three watersheds in Mississippi's upper Coastal Plain. These effects diminished after 3 years. This finding indicates that there is greater susceptibility to erosion following prescribed fire and that this increase is eliminated by regrowth of vegetation. Elliot and Robichaud (2001) indicate that forest erosion occurs only following a disturbance and drops about 90 percent every year thereafter.

### Nutrient Loss and Soil Productivity

Many soils of the South Carolina Piedmont are shallow and depleted of nutrients, especially nitrogen (N), due to prior cultivation, erosion, fertilizer inputs and washout, and crop harvests (Richter and others 2000). Accordingly, ensuring that current silvicultural prescriptions do not lower soil productivity is a forest management concern.

Fire can alter soil nutrients availability directly, by altering physical and chemical properties, or indirectly, as increased microbial activity is stimulated by burning. Mechanisms of nutrient loss include volatilization by forest floor combustion, surface removal by erosion, and leaching through the soil profile. The effects of fire and fuels treatments on soil fertility depend largely on burn severity and intensity. Some research indicates that low-temperature fires may result in fertilization or improvement in mineral soil properties (Johnson and Curtis 2001). Conversely, hot fires may reduce site fertility through oxidation of the forest floor, by creating convection currents that carry ash away.

Photo courtesy of Sumter National Forest.

*Fire effects study conducted in 2001 on the Enoree Ranger District, Sumter National Forest.*

The impact of prescribed fire on the dynamics within the N cycle has been studied in great depth. Nitrogen is particularly important because it limits productivity in many southeastern forests. Although the majority of N in a stored system is organic, the N taken up by roots (used for growth) is mostly inorganic ($NH_4^+$ and $NO_3^-$). Fire alters the distribution of soil N through volatilization and leaching, and by conversion into different N compounds. Common N transformations include mineralization, the conversion from organic forms to $NH_4^+$, and nitrification, the conversion of $NH_4^+$ to $NO_3^-$. The depletion of phosphorus (P), which is commonly lost to volatilization or particulate ash, is also of particular interest for South Carolina forests, as many southern pine forests are P deficient (Jokela and others 1991). Therefore, P is widely recognized as a limiting nutrient for southern coastal soils.

Research results are varied and often conflicting, but the majority of reports indicate that prescribed fire has minor, if not insignificant, effects on soil fertility and productivity in southern pine forests (McKee 1982; Metz and others 1961; Stone 1971; Tuininga and others 2002; Wells 1971). Nevertheless, in a recent review of productivity response to prescribed fire in southern pine forests, Carter and Foster (2004) conclude that the long-term impact of nutrient loss and changes in soil productivity has received too little attention, and that the losses of nutrients appear to "exceed considerably the rate of replacement by natural processes." They argue that although initial nutrient increases may result in short-term increases in productivity, fire may lower the overall productivity or timber yield in the long run unless these losses are mitigated by fertilization or competition control. The effect of nutrient availability is also complicated beyond the assessment of pool size, since interactions among vegetation (e.g., litter quality), microbial processes, and soil chemical and physical properties may also be expected to exist. Carter and Foster (2004) also caution that many of the studies of prescribed fire on southern forested soils are characterized by experimental design flaws (pseudoreplication) and a short monitoring phase. Discussions of alterations to the forest floor and mineral soil are presented separately below.

## Forest Floor

Surface fires in southern pine stands typically result in consumption of 25 to 50 percent of the organic matter present in the forest floor, although this varies with frequency of burn (Brender and Cooper 1968; Lewis 1974; Wells 1971; table 6). Most research shows a nutrient reduction in the forest floor following burning (Binkley and others 1992; McKee 1991). The magnitude of nutrient loss is positively and linearly correlated with fuel consumption (Hough 1981, Raison and others 1985a, Schoch and Binkley 1986 in Carter and Foster 2004). Raison and others (1985b) estimated understory and litter losses of 55 to 75 percent N, 37 to 50 percent P, 43 to 66 percent potassium (K), 30 to 34 percent calcium (Ca), and 25 to 50 percent magnesium (Mg). Raison and others (1985b) also found that the gaseous form of P, representing 30 to 90 percent of the total volatilized P, could be lost from the ecosystem. The portion of particulate P returned to the forest floor is redistributed (Cook 1994 in Carter and Foster 2004).

Although reductions in forest floor nutrients are well documented, these have seldom been associated with a significant reduction in the soil nutrient capital. Some research indicates that natural rates of wet and dry nutrient deposition inputs may replenish any losses that result from burning. Jorgensen and Wells (1986) estimated that annual precipitation supplies 5.3 pounds N, 0.4 pounds P, 1.5 pounds K, 1.5 pounds Mg, and 6.4 pounds Ca per acre in

**Table 6—Forest floor fuel consumption and nutrient loss following prescribed fire for selected sites in the Southeastern United States**[a]

| Location and species | Treatment | Fuel consumed | Nutrient loss |
|---|---|---|---|
| | | *tons/acre* | *pounds/acre* |
| South Carolina Piedmont[b] | | | |
| Mature loblolly pine | 1 annual burn | 3.6 | N = 43.8 |
| | 2 annual burns | 2.7 | N = 32.1 |
| | 3 annual burns | 0.6 | N = 5.3 |
| Coastal Plain South Carolina[c] | | | |
| Mature loblolly pine | 20 years of periodic winter burn | — | N = 23.0 |
| Piedmont North Carolina[d] | | | |
| Mature loblolly pine | Low-intensity, growing-season burn | 0.9 | N = 11.8 |
| Coastal Florida and Georgia[e] | | | |
| Slash and longleaf pine | No burn for 1 year | 3.3 | N = 38.4, P = 2.2, K = 8.0, Ca = 22.6, S = 3.4 |
| | No burn for 1–2 years | 2.9 | N = 34.8, P = 1.4, K = 8.0, Ca = 11.5, S = 3.0 |
| | No burn for 5 years | 8.3 | N = 100.0, P = 4.1, K = 31.2, Ca = 20.5, S = 9.6 |
| | No burn for 8 years | 11.3 | N = 173.2, P = 7.5, K = 21.9, Ca = 44.2, S = 15.5 |

— = Not given.

[a] Adapted from Carter and Foster (2004).

[b] Van Lear and others (1990).

[c] Wells (1971).

[d] Schoch and Binkley (1986).

[e] Hough (1981).

Photo courtesy of South Carolina Forestry Commission.

*Prescribed fires, like this one at Santee State Park, Orangeburg County, SC, are typically low intensity and minimize smoke along roadways and urban areas.*

loblolly pine ecosystems. Carter and Foster (2004) believe that this may be an acceptable account of both wet and dry deposition for this system. Other research proposes that forest floor losses are replaced by increased fixation induced by burning and incorporation of N into the mineral soil (Van Lear and Waldrop 1989; Van Lear and others 1990; Waldrop and others 1987; Wells 1971).

### Mineral Soil

**Nitrogen—**Consistently, there have been reports of a fertilization effect in the mineral soil following prescribed fire, attributable to an increase in inorganic N. Schoch and Binkley (1986) conclude that increased decomposition following prescribed fire results in an additional 67 pounds N per acre in the soil one growing season after burning. Other studies report increased N-mineralization rates immediately following the fire (Knoepp and Swank 1993; Schoch and Binkley 1986; Tuininga and others 2002; Wells 1971). This positive effect is seen consistently in the 87 studies used in a recent meta-analysis of fire impacts (Wan and Luo 2001). Wells (1971) credits increased atmospheric deposition and microbial N-fixation for the N gains evidenced in the surface mineral soil. Knoepp and Swank (1993) report that increases in net mineralization of N after fire were positively correlated with burn severity in a Southern Appalachian pine-hardwood stand. They also found that these $NH_4^+$ increases were sustained 12 months following burning (indicating that they were not quickly leached or taken up by plants). Other research indicates that such increases are often variable in magnitude and of short duration (Carter and Foster 2004). Generalizations about N should be made with caution, as N transformations occur quickly under certain environmental conditions. Timing is crucial for determining $NH_4^+$ and $NO_3^-$ concentrations in the soil following burning.

Long-term research on soil fertility in the South may provide broader insight into sustainable productivity, but those studies are lacking. In one study of 30-year cumulative treatment effects on the South Carolina Coastal Plain, Binkley and others (1992) showed that the C:N ratio increased progressively with the increasing frequency of prescribed fire for the forest floor, although no changes were observed in the mineral soil. The implication is that decomposition and net N-mineralization may be constrained in stands with short return intervals at the forest floor level, but remain unchanged for the mineral soil.

A 40-year study in the Santee Experimental Forest in the Coastal Plain of South Carolina shows negligible loss of soil nutrient capital with burning (McKee 1982, Wells 1971). The 40-year report on the Santee study also supports the notion that neither periodicity nor seasonality affected long-term soil nutrient pools adversely (Waldrop and others 1987). However, when temporal changes within treatments were compared longitudinally, the annual burn treatments resulted in a loss of total N from the surface mineral soil (upper 10 cm) of 323 pounds per acre for summer burning and 114 pounds per acre for winter burning (McKee 1982).

**Other nutrients—**A study in young Piedmont loblolly plantations showed that significant amounts of P were lost from the forest floor during burning, although researchers noted that these losses were small relative to quantities of P present in the residual forest floor (Kodama and Van Lear 1980). Some research has reported increases in extractable P on different sites subjected to fires of various types (Lewis 1974; McKee 1982; McKee and Lewis 1983; Moehring and others 1966). In a seedling pot study, McKevlin and McKee (1986) found increased extractable P on Coastal Plain soils after 33 years of annual winter prescribed fire. McKee (1982) found that available phosphorus and exchangeable calcium were higher on periodically burned plots than on unburned plots. However, < 13 percent of the 7 pounds per acre loss of P from the forest floor could be accounted for in the surface mineral soil (McKee 1982). Other cations exhibited gains in the surface mineral soil following the long-term burning treatments on the fire plots, and these gains appear to balance the losses from the forest floor (McKee 1982).

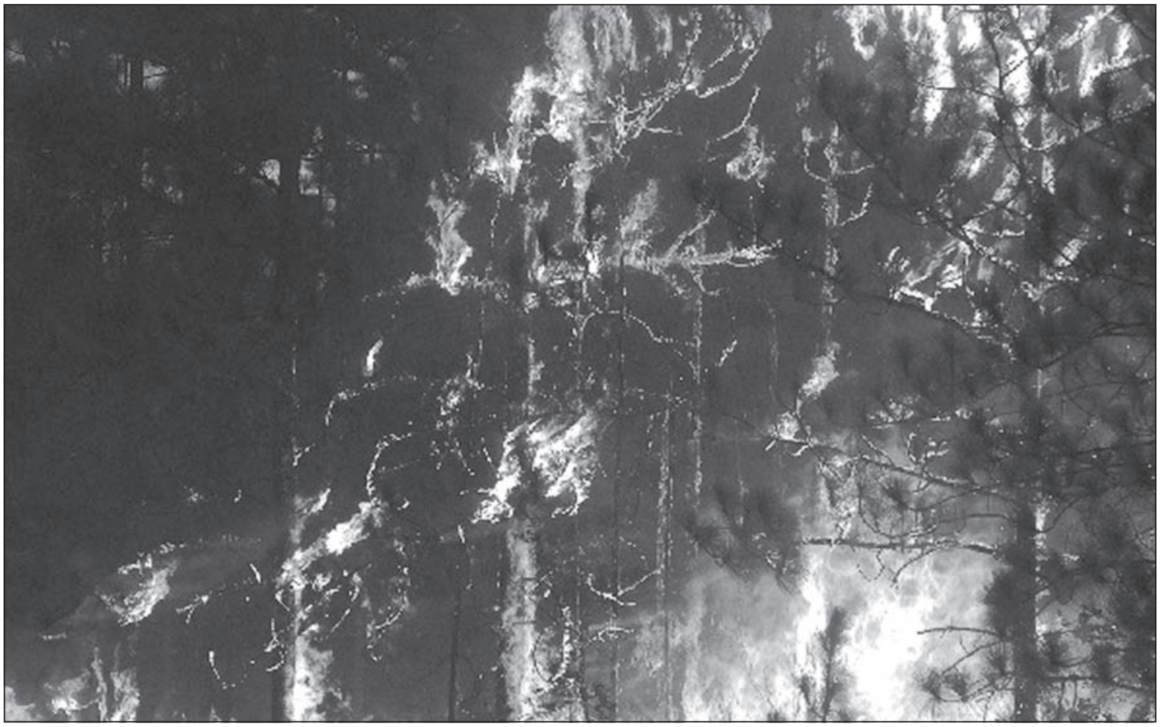
### Vegetation

Chronicled evidence and other literature commonly support the concept that fire was an essential ecological factor in the establishment and maintenance of historical plant communities in the South (Cooper 1961; Waldrop and others 1987, 1992). The altered plant communities present today in the South are a product of disturbance conditions including intensive forestry and other anthropogenic impacts (Jones and Lloyd 1993). The desired outcome of prescribed fire is the re-creation of historical forest structure and composition, accomplished by reducing stand density and supporting a more herbaceous understory with fire. An understanding of how season and intensity of burn affect plant productivity, composition, and regeneration will provide best burn regime recommendations to create the desired vegetative conditions. This will also help management identify the most suitable measures for mitigating anthropogenic influences on forest ecosystems.

### Productivity

Ecosystem productivity is generally correlated with available soil nutrients. Several studies have suggested that prescribed burning could promote pine productivity in pine-dominated ecosystems (Peterson and others 1994; Schoch and Binkley 1986), although there is no definitive evidence of this (Carter and Foster 2004). There has generally been little or no effect on pine growth rates (Waldrop and others 1987) or dynamics (Streng and others 1993) for southern ecosystems. Christensen (1977) found that productivity was stimulated following burning, but diminished after one growing season. A study by Haywood (2002) in central Louisiana found that total pine height for 5- to 6-year-old longleaf pines was significantly greater for the control treatment than for other delayed burning treatments, indicating that delayed burning may decrease site productivity.

Although the need for prescribed fire is generally recognized, there is some disagreement as to which fire regime is most appropriate for sustainable forest productivity. Findings on effects of fire frequency, intensity, and seasonality on productivity of vegetation vary (table 7). In a study of the South Carolina Coastal Plain, Gilliam and Christensen (1986) showed that productivity is dependent on burn season, with winter fires enhancing production and no effect from summer fires directly following burn. Recently, the benefits of growing-season burning to restore desired conditions of vegetation and achieve more effective hardwood exclusion have been weighed against the effects of such burning on long-term vegetative productivity. Although management and public sentiment is often strong and resolute, there is little scientific evidence on the topic (Streng and others




*Fire can travel up higher level vegetation, creating higher intensity crown fires through what are called "ladder fuels." It is important to keep ladder fuels to a minimum to control burns and eliminate risk of wildfire. This image was from a lightning-caused fire in Aiken, SC, that threatened the town in 2004.*

1993). Streng and others (1993) also assert that many burn seasonality studies are inadequate because of problems related to short monitoring periods, statistical analysis methods, use of pseudoreplication, and the influence of confounding variables.

### Composition

Fire exclusion alters community composition and structure by increasing understory woody species while decreasing grasses and forbs (Lewis and Harshbarger 1976). Numerous studies have shown that fire is effective in controlling competing vegetation. Results from two long-term dormant season fire studies on the Coastal Plain of South Carolina and Florida indicate that burning as frequently as fuels permit is optimal for maintaining the largest number of native ground-layer plant species (Glitzenstein and others 2003). Van Lear and others (2004) recommend prescribed burning on a 3- to 5-year cycle to open forest stands and reduce the incidence of southern pine beetle.

Research suggests that fire frequency and seasonality affect plant richness and composition, and that increased fire frequency and a summer burning regime are more effective in controlling hardwoods. A 43-year study on intentionally burned plots in the Santee Experimental Forests showed that variation in season and frequency of burning produced significantly different responses in understory growth (Waldrop and others 1992). Hardwood sprouts increased following periodic summer, periodic winter, and annual winter regimes. Only annual summer burning resulted in long-term hardwood mortality and grassland community replacement (White and others 1990). Overstory vegetation was not affected. Winter burning and regular periodic burning, regardless of seasonality, has been found to cause short-term hardwood die-back, with hardwood vegetation resprouting within 1 to 2 years (Waldrop and others 1987).

Some research supports the contention that frequent growing-season burns are needed to achieve the open pine savannah that is often desired by forest managers and landowners (Waldrop and Lloyd 1991). In Georgia's

**Table 7—Fire effects on species composition, regeneration, and productivity as reported in selected literature**

| Study | Location | Term | Burn | Composition | Regeneration | Productivity |
|---|---|---|---|---|---|---|
| Waldrop and others (1992) | South Carolina Coastal Plain | Since 1946 | Factorial annual and periodic summer and winter burns | Summer burns—decreased hardwood stems, increased herbs and grasses; other treatments—increased hardwood stems and shrub density | Stems > 4 inches—no damage; stems 2–4 inches—reduced with all treatments | Unknown |
| Glitzenstein and others (2003) | South Carolina Coastal Plain | Since 1958 | Annual to quadrennial fire frequency; dormant season | Reduced woody cover and biomass; increased herb species with increased fire frequency | Unknown | Unknown |
| Outcalt and Foltz (2004) | Florida Coastal Plain | Preburn and postburn | Growing season; head firing | Unknown | No effect on mortality | Unknown |
| Boyer (1990) | Southwestern Alabama | Preburn and postburn | Two consecutive spring and summer burns | Unknown | 50 percent stem mortality for upland hardwoods after second burn; greater damage to pines than hardwoods after summer burn | Unknown |
| Boyer (1987) | Southwestern Alabama | 10 years monitoring | Biennial spring, summer, and winter burns | Unknown | Unknown | Pine volume growth 23 percent greater for unburned; 33 percent greater after 7th year |
| Cain (1993) | Southern Arkansas | 10 years monitoring | Winter burns | Unknown | 22 percent more pine; fewer hardwood seedlings for burned than for control | Unknown |
| Cushwa and others (1970) | South Carolina Piedmont | Preburn and postburn | Spring and summer burns | Unknown | Seed production greater for summer burn than spring burn or control | No effect on legumes |

Piedmont, periodic summer fires were more effective than periodic winter fires in killing understory hardwoods (Brender and Cooper 1968). Streng and others (1993) found that growing-season fires result in high topkill rates and complete kill for midstory oaks. They also found that growing-season fires promote flowering that can be extrapolated to seed production of dominant grasses and forbs. However, some researchers found that growing season burning had little effect on pine dynamics and no effect on species abundance in the groundcover. Effects of burning season on groundcover species may become apparent only after long periods of repeated burning. Langdon (1981) indicated that the mechanism for long-term hardwood and woody shrub control is root mortality, which is most easily achieved through regular growing-season burning.

Photo courtesy of South Carolina Forestry Commission.

*This fire at Carvers Bay in Georgetown County was set after smoldering from a prescribed burn reignited a fire in the peat.*

### Regeneration

Van Lear and Waldrop (1989) state that herbaceous vegetation thrives on fire-prepared seedbeds, which indicates that regeneration may benefit from prescribed fire. Christensen (1981) states that burning encourages flowering and seed production by native grasses and forbs. The use of multiple low-intensity fires was shown to maintain adequate regeneration of Table Mountain pine from seed in a study in a Southern Appalachian ecosystem (Waldrop and others 1999). Waldrop and others (2002) also found that multiple low-intensity fires may provide the best conditions for pine regeneration. Results from that study suggested that high-intensity fires may hinder the growth of new germinants by reducing mycorrhizal abundance and soil moisture. In a greenhouse study, McKevlin and McKee (1986) found that seedling development benefited from prescribed fire, as height, biomass, and N and P uptake in the greenhouse seedlings was greater on burned soils than on the unburned control. Other studies have suggested that viable pine seeds will become available every 2 to 3 years as long as fires do not kill overstory pines, and this makes regular burning possible (Gray and others 2002). Legumes were more abundant in young Georgia Piedmont loblolly plantations where logging slash was burned (Cushwa and others 1966).

The main regeneration concern is that fire may scorch crowns and retard the growth of pine seedlings. Wade and Johansen (1986) found that diameter growth is not diminished if root damage and crown scorch are minimal. Additionally, most evidence indicates that the thicker bark on pine species makes them much less susceptible to fire damage than hardwoods. Outcalt and Wade (2004) examined mortality rates following a wildfire in Florida. They found that mortality rates were lower on sites that were prescribed burned before the wildfire. This finding indicates that a regular prescribed burning regime will reduce the threat to human and ecosystem health in the event of a severe fire.

## Conclusions

Fire is a natural part of many southern ecosystems, has long been used as a tool by humans, and continues to benefit forest vegetation and fuels in ways that reduce fire risk and ecosystem damage. Selection of the appropriate fire regime, frequency, and type is an important consideration in the management of South Carolina forests. Management must align fire regime selection with their objectives to determine the suitable balance between forest resource protection and reduction of hazardous fuels. A low-intensity dormant-season burn is the safest route to reducing fuel loads, but a growing-season burn may be more effective in controlling hardwoods and slowing fuel accumulation.

Researchers have usually found that there is no significant sediment loss following prescribed burning, and such loss is unlikely in the Southeastern United States in the absence of any severe climatic event. The effects of prescribed fire on productivity are generally varied and inconsistent (Carter and Foster 2004). Negative effects of canopy scorch on growth are easy to detect and understand, but effects of changes in competition, fertility, and soil physical properties are more elusive. In terms of soil nutrients and productivity of vegetation, the majority of research indicates that the fertilization effect is negligible or short term.

Examination of the literature about effects of fire in the Southeastern United States reflects that significant knowledge gaps exist in fire research, particularly with respect to long-term sustainability. Although short-term research on the topic is available and tends to indicate that significant effects do not occur, the experimental methods and short timeframes sometimes cause concern. There is uncertainty about the long-term effects of prescribed fire on ecosystem functions. The sense that prescribed burns provide an overall benefit to the environment and reduce hazards to human health and safety is generally supported by research and accepted by natural resource managers. However, the research and practical field experience suggest that management should undertake prescribed burning with caution and awareness of the potential for disturbance effects. This science-based knowledge will equip management with the tools to ensure sustainable forest resource management and protection.

## Acknowledgments

We would like to thank the staffs of the U.S. Department of Agriculture Forest Service's Francis Marion and Sumter National Forests for their assistance, cooperation, and collaboration, particularly Dennis Law and William Hansen for the facilitation of this work. Additional gratitude is owed to Timothy Callahan and the College of Charleston's Department of Geology and Environmental Geosciences for providing administrative and technical guidance. Funding from the Forest Service, Francis Marion and Sumter National Forests, was provided through the College of Charleston under interagency Forest Service Agreement 03-PA-11081209-070. We would like to recognize and thank Thomas Waldrop and Kenneth Outcalt for providing review and comment.

## Literature Cited


Allen, J.; Lu, K. 2003. Modeling and prediction of future urban growth in the Charleston region of South Carolina: a GIS-based integrated approach. Conservation Ecology 8(2): 2. http://www.consecol.org/vol8/iss2/art2. [Date accessed: November 10, 2004].

Bartram, W. 1958 [1776]. The travels of William Bartram. Harper, F., ed. New Haven, CT: Yale University Press. 727 p.

Binkley, D.; Richter, D.; David, M.B.; Caldwell, B. 1992. Soil chemistry in a loblolly pine forest with interval burning. Ecological Applications. 2: 157-164.

Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? Southern Journal of Applied Forestry. 11(3): 154-157.

Boyer, W.D. 1990. Growing season burns for control of hardwoods in longleaf pine stands. Res. Pap. SO-256. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Research Station. 7 p.

Brender, E.V.; Cooper, R.W. 1968. Prescribed burning in Georgia loblolly pine stands. Journal of Forestry. 66: 31-36.

Brown, J.K. 2000. Introduction and fire regimes. In: Brown, J.K.; Smith, J.K., eds. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-421. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-8. Vol. 2.

Cain, M.D. 1993. Woody species composition in uneven-aged stands of *Pinus taeda* and *P. echinata* as affected by prescribed fire and herbicides. In: Gjerstad, D.H.; Glover, G.G.; Mitchell, R.J. [and others], eds. Proceedings of the international conference on forest vegetation management, Canadian Journal of Forest Research. 23(10): 192-196.

Carroll, W.D.; Kapeluck, P.R.; Harper, R.A.; Van Lear, D.H. 2002. Background paper: historical overview of the southern forest landscape and associated resources. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-053. Asheville, NC: U.S. Department of Agriculture, Forest Service: 583-605. Chapter 24.

Carter, M.C.; Foster, C.D. 2004. Prescribed burning and productivity in southern pine forests: a review. Forest Ecology and Management. 191(1-3): 93-109.

Christensen, N.L. 1977. Fire and soil-plant nutrient relations in a pine-wiregrass savannah on the Coastal Plain of North Carolina. Oecologia. 31: 27-44.

Christensen, N.L. 1981. Fire regimes in southeastern ecosystems. In: Mooney, H.A.; Bonnicksen, T.M.; Christensen, N.L. [and others], technical coords. Fire regimes and ecosystem properties. Gen. Tech. Rep. WO-26 , Washington, DC: U.S. Department of Agriculture, Forest Service: I 12–I 36.

Christensen, N.L. 1987. The biogeochemical consequences of fire and their effects on the vegetation of the Coastal Plain of the Southeastern United States. In: Tradaud, L., ed. The role of fires in ecological systems. The Hague, The Netherlands: SPB Academic Publishers: 1-21.

Connor, R.C.; R.M. Sheffield. 2000. South Carolina's forest resources—2000 update. Resour. Bull. SRS-65. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 31 p.

Cook, G.D. 1994. The fate of nutrients during fires in a tropical savanna. Australian Journal of Ecology. 19: 359-365.

Cooper, C.F. 1961. The ecology of fire. Scientific American. 204(4):150-160.

Cushwa, C.T.; Brender, E.V.; Cooper, R.W. 1966. The response of herbaceous vegetation to prescribed burning. Res. Note SE-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Experiment Station. 2 p.

Cushwa, C.T.; Hopkins, M.; McGinnes, B.S. 1970. Response of legumes to prescribed burns in loblolly pine stands of the South Carolina Piedmont. Res. Note SE-140. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.

Cushwa, C.T.; Hopkins, M.; McGinnes, B.S. 1971. Soil movement in established gullies after a single prescribed burn in the South Carolina Piedmont. Res. Note SE-153. Asheville, NC: U.S. Department of Agriculture, Forest Service. 4 p.

Debano, L.F. 1991. The effect of fire on soil properties. In: Harvey, A.E.; Neuenschwander, L.F., comps. Proceedings, Management and productivity of western-montane forest soils. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 151-156.

Delacourt, P.A.; Delacourt, H.R. 1987. Long-term forest dynamics in the temperate zone. Ecological Studies 63. New York: Springer-Verlag. 439 p.

Douglass, J.E.; Van Lear, D.H. 1983. Prescribed burning and water quality of ephemeral streams in the Piedmont of South Carolina. Forest Science. 29: 181-189.

Elliot, W.J. 2004. WEPP Internet interfaces for forest erosion prediction. Journal of the American Water Resources Association. Paper 02021. 40 (2): 299-309.

Elliot, W.J.; Robichaud, P.R. 2001. Comparing the erosion risks from forest operations to wildfire. In: Proceedings of the 2001 international mountain logging and 11th Pacific Northwest Skyline symposium. Seattle: University of Washington: 78-89.

Frost, C.C. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. In: Curulean, S.I.; Engstrom, R.T., eds. Proceedings of the 19th Tall Timbers fire ecology conference: Fire in wetlands: a management perspective. Tallahassee, FL: Tall Timbers Research, Inc.: 39-60.

Frost, C.C. 1997. Presettlement vegetation and natural fire regimes of the Savannah River site. Report. New Ellenton, SC: U.S. Department of Agriculture, Forest Service, Savannah River Forest Station. 179 p.

Gilliam, F.S.; Christensen, N.L. 1986. Herb-layer response to burning in the pine flatwoods of the lower Coastal Plain of South Carolina. Bulletin of the Torrey Botanical Club. 113: 42-45.

Glitzenstein, J.S.; Streng, D.R.; Wade, D.D. 2003. Fire frequency effects on longleaf pine (*Pinus palustris*) vegetation in South Carolina and northeastern Florida, USA. Natural Areas Journal. 23: 33-37.

Grace, J.M. II; Carter, E.A. 2001. Sediment and runoff losses following harvesting/site prep operations on a Piedmont soil in Alabama. In: Proceedings of the 2001 American Society of Agricultural Engineers annual international meeting. Paper 01-8002. St. Joseph, MI: American Society of Agricultural Engineers. 9 p.

Gray, E.A.; Rennie, J.C.; Waldrop, T.A.; Hanula, J.L. 2002. Patterns of seed production in Table Mountain pine. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 302-305.

Hammond, H. 1883. South Carolina: resources and population, institutions and industries. Charleston, SC: State Board of Agriculture of South Carolina. 726 p.

Haywood, J.D. 2002. Delayed prescribed burning in a seedling and sapling longleaf pine plantation in Louisiana. In: Outcalt, K.W., ed. Proceedings of the 11th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 103-108.

Hough, W.A. 1981. Impact of prescribed fire on understory and forest floor nutrients. Res. Note SE-303. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Johnson, D.W.; Curtis, P.S. 2001. Effects of forest management on soil C and N storage: meta-analysis. Forest Ecology and Management. 140: 227-238.

Jokela, E.J.; Allen, H.L.; McFee, W.W. 1991. Fertilization of southern pines at establishment. In: Duryea, M.L.; Dougherty, P.M., eds. Forest regeneration manual. Dordrecht, The Netherlands: Kluwer Academic Publishers: 263-277.

Jones, S.M.; Lloyd, F.T. 1993. Landscape ecosystem classification: the first step toward ecosystem management in the Southeastern United States. In: Applet, G.H.; Johnson, N.; Olson, J.T.; Sample, V.A., eds. Defining sustainable forestry. Chicago: Island Press: 181-201.

Jorgensen, J.R.; Wells, C.G. 1986. Foresters' primer in nutrient cycling: a loblolly pine management guide. Gen. Tech. Rep. SE-37. U.S. Department of Agriculture, Forest Service. 42 p.

Knoepp, J.D.; Swank, W.T. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: N responses in soil, soil water, and streams. Canadian Journal of Forest Research. 23: 2263-2270.

Kodama, H.E.; Van Lear, D.H. 1980. Prescribed burning and nutrient cycling relationships in young loblolly pine plantations. Southern Journal of Applied Forestry. 4: 118-121.

Komarek, E.V. 1964. The natural history of lightning. In: Proceedings of the 3rd Tall Timbers fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 139-183.

Komarek, E.V. 1965. Fire ecology—grasslands and man. In: Proceedings of the 4th Tall Timbers fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 169-220.

Komarek, E.V. 1974. Effects of fire on temperate forests and related ecosystems: Southeastern United States. In: Kozlowski, T.T.; Ahlgren, C.E., eds. Fire and ecosystems. New York: Academic Press: 251-277.

Langdon, O.G. 1981. Some effects of prescribed fire on understory vegetation in loblolly pine stands. In: Wood, G.W., ed. Prescribed fire and wildlife in southern forests. Georgetown, SC: Clemson University, Belle W. Baruch Forest Science Institute: 143-153.

Lawson, J. 1967 [1709]. A new voyage to Carolina. H.T. Lefler, ed. Chapel Hill, NC: University of North Carolina Press. 270 p.

Lewis, W.M., Jr. 1974. Effects of fire on nutrient movement in a South Carolina pine forest. Ecology. 55: 1120-1127.

Lewis, C.E.; Harshbarger, T.J. 1976. Shrub and herbaceous vegetation after 20 years of prescribed burning in the South Carolina Coastal Plain. Journal of Range Management. 29: 13-18.

Lowdermilk, W.C. 1930. Influence of forest litter on run-off, percolation, and erosion. Journal of Forestry. 28: 474:491.

McKee, W.H. 1982. Changes in soil fertility following prescribed burning on Coastal Plain pine sites. Res. Pap. SE-234. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 23 p.

McKee, W.H. 1991. Long-term impacts of fire on Coastal Plain pine soils. In: Nodvin, S.C.; Waldrop, T.W., eds. Fire and the environment: ecological and cultural perspectives: Proceedings of an international symposium. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 405-413.

McKee, W.H.; Lewis, C.E. 1983. Influence of burning and grazing on soil nutrient properties and tree growth on a Georgia Coastal Plain site after 40 years. In: Jones, E.P., ed. Proceedings of the 2nd biennial southern silviculture research conference. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service: 79-86.

McKevlin, M.R.; McKee, W.H. 1986. Long-term prescribed burning increases nutrient uptake and growth of loblolly pine seedlings. Forest Ecology and Management. 17: 245-252.

Metz, L.J. 1954. Forest floor in the Piedmont region of South Carolina. Soil Science Society of America Proceedings. 16: 38-41.

Metz, L.J. 1958. The Calhoun experimental forest. Source: unknown. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 24 p.

Metz, L. J.; Lotti, T.; Klawitter, R.A. 1961. Some effects of prescribed burning on coastal forest soil. Paper 133. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 10 p.

Meyers, R.K.; Zahner, R.; Jones, S.M. 1986. Forest habitat regions of South Carolina from landsat imagery. Clemson, SC: Dept. of Forestry, Clemson University, College of Forestry and Forest Resources. No. 42, 31 p.

Moehring, D.M.; Grano, C.X.; Bassett, J.R. 1966. Properties of forested loess soils after repeated prescribed burns. Res. Note SO-40. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Outcalt, K.J. 2000. Occurrence of fire in longleaf pine stands in the southeastern United States. In: Moser, W.K.; Moser, C.F., eds. Fire and forest ecology: innovative silviculture and vegetation management. Proceedings of the 21st Tall Timbers fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 178-182.

Outcalt, K.W.; Foltz, J.L. 2004. Impacts of growing-season prescribed burns in the Florida pine flatwoods type. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

Outcalt, K.W.; Wade, D.D. 2004. Fuels management reduces tree mortality from wildfires in southeastern United States. Southern Journal of Applied Forestry. 28(1): 28-34.

Patric, J.H. 1976. Soil erosion in the eastern forest. Journal of Forestry. 74: 761-677.

Peterson, D.L.; Sackett, S.S.; Robinson, L.J.; Haase, S.M. 1994. The effects of repeated prescribed burning on Pinus ponderosa growth. International Journal of Wildland Fire. 4: 239-247.

Pyne, S.J. 1982. Fire in America. Princeton, NJ: Princeton University Press. 654 p.

Raison, R.J.; Khanna, P.K.; Woods, P.V. 1985a. Mechanisms of element transfer to the atmosphere during vegetation fires. Canadian Journal of Forest Research. 15: 132-140.

Raison, R.J.; Khanna, P.K.; Woods, P.V. 1985b. Transfer of elements to the atmosphere during low-intensity prescribed fires in three Australian subalpine eucalypt forests. Canadian Journal Forest Research. 15: 657-664.

Richter, D.D.; Markewitz, D.; Heine, P.R.; Jin, V.; Raikes. J.; Tian. K.; Wells, C.G.. 2000. Legacies of agriculture and forest regrowth in the nitrogen of old-field soils. Forest Ecology and Management. 138: 233-248.

Robichaud, P.R.; Waldrop, T.A. 1994. A comparison of surface runoff and sediment yields from low and high-severity site preparation burns. Paper 93019. Journal of the American Water Resources Association. 30(1): 27-34.

Sargent, C.S. 1884. Report on forests of North America. Tenth Census of the United States. Washington, DC: U.S. Department of Agriculture, Interior Census Office, Government Printing Office. Vol. 9.

Schoch, P.; Binkley, D. 1986. Prescribed burning increased N availability in a mature loblolly pine stand. Forest Ecology and Management. 14: 13-22.

Silver, T. 1990. A new face on the countryside: Indians, colonists, and slaves in South Atlantic forests, 1500-1800. Cambridge: Cambridge University Press. 216 p.

Smith, J.K.; Lyon, L.J.; Huff, M.H.; Hooper, R.J.; E.S. Telfer; O.S. Schreiner.. 2000. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep. 42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p. Vol. 1.

Smith, W.B.; Miles, P.D.; Vissage, J.S.; Pugh, S.A. 2004. Forest resources of the United States, 2002. Gen. Tech. Rep. NC-241. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 137 p.

South Carolina Forestry Commission. 2003. Annual report 2002-2003. http://www.state.sc.us/forest/ar2003.pdf. [Date accessed: August 2, 2004].

South Carolina State Planning Board. 1944. The natural resources of South Carolina. Bull. 3, rev. Columbia, SC. 116 p.

Stanturf, J.A.; Wade, D.D.; Waldrop, T.A. [and others]. 2002. Background paper: fire in southern forest landscapes. In: Wear, D.N:, Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 607-630. Chapter 25.

Stone, E.L. Jr., 1971. Effects of prescribed burning on long-term productivity of Coastal Plain soils. In: Proceedings, Prescribed burning symposium. Charleston, SC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 115-129.

Streng, D.R.; Glitzenstein, J.S.; Platt, W.J. 1993. Evaluating the effects of season of burn in longleaf pine forests: a critical literature review and some results from an ongoing long-term study. In: Hermann, S.M., ed. Proceedings of the 18th Tall Timbers fire ecology conference: The longleaf pine ecosystem: ecology, restoration, and management. Tallahassee, FL: Tall Timbers Research, Inc.: 227-263.

Trimble, S.W. 1974. Man-induced soil erosion on the southern Piedmont, 1700-1970. Ankeny, IA: Soil Conservation Society of America. 180 p.

Tuininga, A.R.; Dighton, J.; Gray, D.M. 2002. Burning, watering, litter quality and time effects on N, P, and K uptake by pitch pine (*Pinus rigida*) seedlings in a greenhouse study. Soil Biology & Biochemistry. 34(6): 865-873.

U.S. Department of Agriculture, Forest Service, Francis Marion and Sumter National Forests: A history http://www.fs.fed.us/r8/fms/forest/aboutus/history/html. [Date accessed: September 12, 2004].

Ursic, S.J. 1970. Hydrologic effects of prescribed burning and deadening upland hardwoods in Northern Mississippi. Res. Pap. SO-54. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15 p.

Van Lear, D.H.; Danielovich, S.J. 1988. Soil movement after broadcast burning in the southern Appalachians. Southern Journal of Applied Forestry. 12: 49-53.

Van Lear, D.H.; Douglas, J.E.; Cox, S.K.; Augspurger, M.K. 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina Piedmonts. Journal of Environmental Quality. 14(2): 169-174.

Van Lear, D.H.; Harper, R.A.; Kapeluck, P.R.; Carroll, W.D. 2004. History of piedmont forests: implications for current pine management. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

Van Lear, D.H.; Kapeluck, P.R.; Waide, J.B. 1990. N pools and processes during natural regeneration of loblolly pine. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Sustained productivity of forest soils. Proceedings of the 7th North American forest soils conference. Vancouver, BC: Faculty of Forestry Publication, University of British Columbia: 234-252.

Van Lear, D.H.; Waldrop, T.A. 1989. History, uses, and effects of fire in the Appalachians. Gen. Tech. Rep. SE-54. Asheville, NC: U.S. Department of Agriculture, Forest Service. 20 p.

Van Lear, D.H.; Waldrop, T.A. 1991. Prescribed burning in regeneration. In: Duryea, M. L.; Dougherty, P.M. eds. Forest regeneration manual. Dordrecht, The Netherlands: Kluwer Academic Publishers: 235-250.

Wade, D.D.; Johansen, R.W. 1986. Effects of fire on southern pine: observations and recommendations. Gen. Tech. Rep. SE-41. Asheville, NC. U.S. Department of Agriculture, Forest Service Southeastern Experiment Station. 14 p.

Waldrop, T.A.; Brose, P.H.; Welch, N.T. [and others]. 2002. High-intensity fires may be unnecessary for stand replacement of Table Mountain pine: an overview of current research. In: Outcalt, K.W., ed. Proceedings of the 11th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 137-142.

Waldrop, T.A.; Lloyd, F.T. 1991. Forty years of prescribed burning on the Santee fire plots: effects on overstory and midstory vegetation. In: Nodvin, S.C.; Waldrop, T.A., eds. Fire and the environment: ecological and cultural perspectives: Proceedings of an international symposium. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 45-50.

Waldrop, T.A.; Mohr, H.H.; Brose, P.H.; Baker, R.B. 1999. Seedbed requirements for regenerating Table Mountain pine with prescribed fire. In: Haywood, J.D., ed. Proceedings of the 10th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 369-373.

Waldrop, T.A.; Van Lear, D.H.; Lloyd, F.T.; Harms, W.R. 1987. Long-term studies of prescribed burning in loblolly pine forests of the southeastern Coastal Plain. Gen. Tech. Rep. SE-45. Asheville, NC: U.S. Department of Agriculture, Forest Service. 23 p.

Waldrop, T.A.; White, D.L.; Jones, S.M. 1992. Fire regimes for pine-grassland communities in the southeastern United States. Forest Ecology and Management. 47: 195-210.

Walker, L.C. 1991. The southern forest: a chronicle. Austin, TX: University of Texas Press. 322 p.

Wan, S.H.D.; Luo, Y. 2001. Fire effects on N pools and dynamics in terrestrial ecosystems: a meta-analysis. Ecological Applications. 11: 1349-1365.

Wear, D.N. 2002. Land use. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 153-173. Chapter 6.

Wear, D.N.; Greis, J.G., eds. 2002. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.

Wells, C.G. 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. In: Proceedings of the prescribed burning symposium. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 86-98.

Wells, C.G.; Campbell, R.E.; DeBano, L.F. [and others]. 1979. Effects of fire on soil, a state-of-knowledge review. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service.

White, D.L. 2004. Deerskins and cotton: ecological impacts of historical land use in the central Savannah River area of the southeastern United States before 1950. Final report. New Ellenton, SC: U.S. Department of Agriculture, Forest Service, Savannah River Forest Station. 324 p.

White, D.L.; Waldrop, T.A.; Jones, S.M. 1990. Forty years of prescribed burning on the Santee fire plots: effects on understory vegetation. In: Nodvin, S.C.; Waldrop, T.A., eds. Fire and the environment: ecological and cultural perspectives: Proceedings of an international symposium. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Southeastern Forest Experiment Station: 51-59.

White, L.H. 2003. The effects of prescribed fire and thinning on fuels and erosion in a disturbed South Carolina Piedmont pine forest. Charleston, SC: College of Charleston. 82 p. M.S. thesis.

Yoho, N.S. 1980. Forest management and sediment production in the South—a review. Southern Journal of Applied Forestry. 1980(4): 27-36.

# Appendix A

## Plant Species List

| Common name | Scientific name |
|---|---|
| Longleaf pine | *Pinus palustris* |
| Loblolly pine | *P. taeda* |
| Shortleaf pine | *P. echinata* |
| Slash pine | *P. elliottii* |
| Pond pine | *P. serotina* |
| Table Mountain pine | *P. pungens* |
| Virginia pine | *P. virginiana* |
| Hickory | *Carya* spp. |
| Scarlet oak | *Quercus coccinea* |
| Southern red oak | *Q. falcata* |
| White oak | *Q. alba* |
| Sweetgum | *Liquidambar tyraciflua* |
| Red maple | *Acer rubrum* |
| Bluegrass | *Poa compressa* |
| Wiregrass | *Aristida stricta* |

# Appendix B

## ConversionFactors

| | |
|---|---|
| $Mg/ha^{-1}$ (megagrams [metric tons] per hectare) = 893 pounds per acre | |
| $Kg/ha^{-1}$ (kilograms per hectare) = 0.893 pounds per acre | |

**Fairchilds, Lindsay H.; Trettin, Carl C.** 2006. History and legacy of fire effects in the South Carolina piedmont and coastal regions. Gen. Tech. Rep. SRS–98 Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 27 p.

Agriculture, fire suppression, and urbanization have drastically altered natural forest processes and conditions since humankind settled in the Southeastern United States. Today, many of South Carolina's forests are dense and overstocked, with high fuel loads. These conditions increase the susceptibility of forests to southern pine beetle attack and wildfire. These threats are further complicated by rapid urbanization and forest fragmentation, processes that are increasing South Carolina's wildland-urban interface at a rapid rate. Prescribed fire is an effective, economical, and widely used tool for reducing fuel loads and encouraging desired vegetative communities in forest landscapes. However, research into the effects of prescribed fire often generates more questions than answers. This paper considers fire effects on soil erosion, nutrients, and vegetation from a historical perspective. We examined historical fire regimes, land use changes, and fire research. The majority of literature indicates that soil erosion does not occur unless a severe climatic event follows prescribed fire. There is also evidence of a fertilization effect in the soil following prescribed fire, although this is typically of short duration and accompanied by some nutrient loss in the forest floor. Effects of prescribed fire on the productivity, composition, and regeneration of vegetation are more complex and ambiguous. Effects are primarily determined by antecedent local conditions and fire severity and intensity. Knowledge of past land use and fire's biological and historical roles in land use change can support effective decision making. This knowledge will provide guidance for sustainable management of forest resources and reduction of hazardous forest fuel conditions.

**Keywords**: Fire, fire effects, fire history, prescribed burn, wildland-urban interface.