CHAPTER 7.

Fuel Management in the Subtropical and Savanna Divisions

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The Subtropical Division (230) and Savanna Division (410), both based on Bailey's (1996) ecoregions, are found in the Southern United States (http://www.na.fs.fed.us/fire/cwedocs/map%20new_divisions.pdf). The Subtropical Division occupies the southern Atlantic and Gulf coastal areas. It is characterized by a humid subtropical climate with hot humid summers (chapter 3). It has no pronounced dry season but precipitation is normally higher during summer. Soils are strongly leached and rich in iron and aluminum oxides. The natural vegetation throughout much of the Subtropical Division is forest. It includes the Outer Coastal Plain Mixed Forest Province, the Southeastern Mixed Forest Province (which occupies the inner Coastal Plain area), and the Lower Mississippi Riverine Forest Province (McNab and Avers 1994).

The Savanna Division is part of the humid tropical domain. In the Eastern United States, it is found only in southern Florida represented by the Everglades Province. It has a hot wet season driven by warm maritime air masses followed by a dry period during the somewhat cooler low sun angle months (Bailey 1996). Soils are mostly organic histosols and sandy inceptisols. The natural vegetation is tall grasses and drought resistant trees and shrubs. The Savannah Division was covered with wet and dry prairie, cypress swamps (*Taxodium distichum*), pine flatwoods (*Pinus* spp.) and rocklands, hardwood and palm hammocks (*Acoelorrhaphe* spp.), and subtropical hardwoods.

A number of different forest and nonforest ecosystems historically occupied the Subtropical Division. Before European settlement, the area was mostly forested; and although many lands were cleared for agricultural and urban uses, forests currently occupy about 60 percent of the area (Conner and Hartsell 2002). Pines dominated the frequently burned forests of the lower and middle Coastal Plains. Other forest communities like cypress and hardwood hammocks were imbedded in this pine matrix. The Piedmont, which lies at a northeast to southwest direction between the Coastal Plain and the Appalachian Mountains, was a mixture of pines, pine-hardwood forests, and the oak-hickory type (*Quercus* spp.–*Carya* spp.). Mesic hardwoods occupied the river terraces and richer bottomlands.

The Subtropical and Savanna Divisions have all of the fire regimes described by Brown (2000), with much of the area burning quite frequently (Frost 2006). Many of the ecosystems had an understory fire regime with frequent low-intensity surface fires that consumed surface fuels but left the overstory unharmed. The fire-return interval in these systems ranged from 1 to 12 years. Because of this frequent fire, the forested areas tended to be open with grass and herbaceous dominated understories. Other forest communities had mixed-severity fire regimes with less frequent but more intense fires

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that killed a substantial portion of the overstory (Wade and others 2000). Other ecosystems had a stand replacement fire regime with periodic intense fires, which killed the overstory but created conditions that favored regeneration.

Marshes and prairies covered quite extensive areas and were maintained by frequent fires. Because the aboveground portion of the dominant life form was killed, these were mostly stand replacement fires. Now they are often burned for ecological benefits rather than fuel management, although fuel management is also important in some situations. Other systems like mixed mesophytic hardwoods, bottomland hardwoods, and subtropical hardwoods normally had a regime with little or no naturally caused fire. Because fires are rare in these systems, fuels management is not needed and they are excluded from this chapter.

The first portion of this chapter briefly describes the former and current extent and fire regime for each major community where fuel management is applied in the Subtropical and Savanna Divisions. This background information on the systems where fuel management is applied is presented by fire-regime type. The second part of the chapter is a discussion of the most often used fuel management techniques in these communities. This is not meant to be a comprehensive prescription of how to apply these techniques, but rather to put into context the potential for cumulative impacts from the different treatments. Those needing more detailed information on using these techniques should consult cited references and additional resources (such as frames.nbii.gov).

Major Ecosystems

Understory Fire Regime

Longleaf pine

Pinus palustris was once the most prevalent pine in the Subtropical Division (Frost 2006), where it dominated 60 million acres (25 million ha) and was a codominant with shortleaf (*Pinus echinata*) and loblolly pines (*Pinus taeda*) on another 30 million acres (12 million ha). Its range extended south from southeastern Virginia to central Florida and west into eastern Texas (Stout and Marion 1993). Longleaf pine was native to a wide range of ecosystems including wet flatwoods and savannas along the Atlantic and Gulf Coastal Plain and higher droughty sand deposits from the fall-line sandhills to the central ridge of Florida. Longleaf pine also grew on more productive upland sites like the red hills area of southern Georgia and the loamy soils of Alabama and Louisiana (Stout and Marion 1993). Longleaf pine even extended onto the mountain slopes and ridges of Alabama and northwestern Georgia (Boyer 1990), where it was found growing at elevations up to 2000 feet (600 m).

Logging of the valuable longleaf pine forests, which began in early settlement times, reached a peak shortly after 1900 (Ware and others 1993). Clearing of forest land for urban and agricultural uses, conversion to loblolly pine (*Pinus taeda)* and slash pine (*Pinus elliottii*) plantations, and harvesting without regeneration all contributed to the continuous decline of this once dominant forest community. Only about 20 million acres (8.1 million ha) of longleaf pine forest remained by 1935 (Wahlenberg 1946), declining to 12 million acres (4.9 million ha) in 1955, 3.7 million acres (1.5 million ha) in 1985 (Kelly and Bechtold 1990), and 3 million acres (1.2 million ha) in 1995 (Outcalt and Sheffield 1996). Longleaf dominated forests recently have been increasing on public lands including the national forests, which contained 820,000 acres (332 000 ha) or 25 percent of remaining longleaf forests in 2006.

In the period before landscape fragmentation, extensive naturally caused fires occurred every 2 to 8 years across much of the South (Abrahamson and Hartnett 1990, Christensen 1981, Ware and others 1993). Mixed pine stands were found along the northern and western edges where fire-return intervals were longest. Longleaf pine

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dominated much of the rest of the landscape because it was more tolerant of these frequent fires than the thinner barked seedlings of loblolly and slash pine, which lacked a fire resistant grass stage (Chapman 1932). Some have argued that longleaf not only needed fire for site domination, but that it actually perpetuated frequent surface fire through the production of long flammable needles that—as litterfall—promoted the spread of frequent surface fires (Landers 1991). Another important component of the fuel matrix in longleaf communities were the grasses, whose living and dead leaves intercepted the shed needles of overstory pines, causing an accumulation of dead biomass in a very flammable configuration. Wildfires spread quickly through this fine-fuel matrix (Abrahamson and Hartnett 1990). They also spread into embedded communities such as seepage slopes, savannas, and canebrakes. Without longleaf to propagate fire on the landscape, these systems degrade and lose their diversity.

Lightning and Native Americans provided the ignition sources for the fires that shaped the vegetation in longleaf communities (Komarek 1968, Robbins and Myers 1992). Seasonal lightning activity is quite variable and weather driven. In central Florida, 75 percent of all annual strikes occur in the summer months of June, July, and August (Hodanish and others 1997); but lightning can occur anytime. Lightning frequency, however does not equate with fire ignitions or the area burned in longleaf ecosystems. The spring months of April and May are often the driest; but although strikes are less frequent in these months, because fuels are dry and precipitation with storms often limited, ignition probabilities are highest. This combined with low humidity and winds that often occur during these months should lead to larger fires from lightning ignitions. This agrees with data for area burned by lightning fires on national forests in Florida, which was greatest during May (Robbins and Myers 1992). Thus, the historical fire regime was one of frequent low-intensity fires burning across vast expanses predominantly during the early growing season but augmented by Native American ignitions during the dormant season.

Slash pine flatwoods

Slash pine is native to the lower Coastal Plain from Georgetown County in South Carolina to Tangipahoa Parish in Louisiana and most of peninsular Florida south to Ft. Lauderdale (Lohrey and Kossuth 1990). It historically dominated the seasonally wet to flooded woodlands; on nearly level, poorly drained sandy soils with dark sandy layers (mostly Spodosols) or clay hardpans (Ultisols) and generally low pH (<4.5). Although dominated by slash pine, these flatwood sites contained some longleaf pine on the dryer fringes where they graded into the longleaf wiregrass (*Aristida beyrichiana*) flatwoods and some swamp blackgum (*Nyssa sylvatica* var. *biflora*) and pond cypress (*Taxodium distichum* var. *nutans*) in the transition zone to wetlands. The understory consisted of evergreen shrubs and trees with saw palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), fetterbush lyonia (*Lyonia lucida*), and loblolly bay (*Gordonia lasianthus*) common dominants. Herbaceous species were sparse, occurring as grasses and forbs scattered among shrubs. Since longleaf pine did not occur south of Lake Okeechobee in Florida, those flatwood forests were dominated exclusively by slash pine (Little 1971). Schultz (1983) estimated the original slash pine flatwood area at about 7 million acres (2.8 million ha) with the largest concentration in Florida and southern Georgia.

These flatwood forests have been heavily impacted over the last three centuries. Much of the slash pine and mixed slash and longleaf pine were cutover from 1780 to 1860. These areas were first logged because they were accessible by water, which was needed to raft logs to the mills (Schultz 1983). Many were logged a second time, along with higher longleaf flatwoods, by crews using temporary railroad spurs and steam skidders from 1870 to 1920. Because slash pine is a prolific seed producer, it rapidly colonized cutover areas and abandoned fields including many areas formerly dominated by longleaf pine (Schultz 1983). Fire control contributed to the increase in slash pine relative to longleaf as it allowed trees to make it through the fire-sensitive seedling stage. Once it became profitable to harvest and use small southern pine for Kraft pulp forestry became more intensive, often resulting in postharvest conversion to plantations

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on heavily site-prepared areas and dramatically altered understories (Schultz 1976). By 1980, 52 percent of all slash pine stands were plantations (Sheffield and others 1983), and this trend has continued. Today slash pine occupies nearly 10 million acres (4 million ha), with 70 percent in privately owned plantations (Miles 2007).

The likely presettlement fire regime for slash pine flatwoods is frequent surface fires every 4 to 6 years, ranging to <8-year intervals or longer in the wettest pond sites. Most of these fires begin in the dryer longleaf wiregrass flatwoods and then carry into the adjoining slash pine flatwood areas if they are dry enough to burn. They generally burned through the understory vegetation but only consumed the dry upper portion of the litter layer. These fires were usually moderate in intensity but during extended drought periods, which occur about every 25 years, could be quite severe because the entire forest floor was dry enough to burn. When this happened, overstory mortality was often high with either total replacement or substantial thinning. Although fire could occur in any season, in presettlement times many lightning fires probably occurred from the dry late spring to early summer. Specific months varied with latitude but were generally from mid-April to June. Once the summer thunderstorm season began, these areas soon became too wet to burn. Native Americans augmented this by setting fires during dry periods of the dormant season.

Loblolly pine

Loblolly pine has an extensive range stretching from New Jersey along the coast to eastern Texas and inland through the Piedmont to Tennessee and Arkansas. Although loblolly pine is able to grow across a wide area on many different sites, Schultz (1997) estimated that it dominated <5 million acres (2 million ha) of presettlement forests. It was often a co-dominant of uplands with longleaf and shortleaf pine (*Pinus echinata*), or a minor species in upland hardwoods. It was also found as scattered individuals or small groups on river bottoms and swamps growing among the bottomland hardwoods. It was most prevalent on moist sites that burned less frequently than adjoining longleaf-dominated habitats. Nearly pure stands of loblolly pine did exist, primarily through establishment following major disturbance from fire or wind (Skeen and others 1993).

Agricultural clearing and logging by settlers dramatically changed the southern landscape. Loblolly pine is a prolific seed producer that grows quite rapidly on a variety of sites. It was very successful at capturing many former longleaf sites following logging (Schultz 1997). This has been aided in more recent times by fire control measures that give loblolly seedlings an advantage. Loblolly pine was very successful at seeding into abandoned cotton fields, thus the common name of old-field pine, and was also widely established in forest industry plantations. The result was that loblolly replaced longleaf as the most prevalent of the southern yellow pines. By 1989 it had become the most important timber species in the United States (Schultz 1997), dominating 33 million acres (13.4 million ha). Today loblolly pine dominates 46 million acres (18.5 million ha) with 60 percent growing in plantations, many established after intensive site preparation (Miles 2007).

Loblolly pine growing in bottomland areas seldom experienced fire but the uplands of the South burned with some regularity. Low-intensity surface fires occurred every 4 to 12 years (Frost 2006) on these dryer upland locations. Although seedlings <5 years old can be killed by fire, older trees are quite resistant to low-intensity surface fires (Schultz 1997). Less frequent stand replacement wildfires likely occurred at least every 100 years somewhere in a watershed. In fact, loblolly pine was maintained in pure stands by both frequent low-intensity surface fires that kept hardwood competitors in check and periodic severe fire, which created open areas for regeneration. As with other southern pine species, growing season fires were common.

Shortleaf pine

Shortleaf pine has the widest range of any southern pine growing in 22 States from southeastern New York to Florida and west to Texas and inland through Pennsylvania to Ohio and Missouri (Little 1971). It is found on the Coastal Plains and Piedmont

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in the Subtropical Division, and the Interior Highlands in the Subtropical Mountain Division (M230). Like loblolly, a common associate, it is adapted to a wide variety of soil types. Historically it dominated the drier sites west of the Mississippi in Arkansas, Louisiana and eastern Texas. Where ranges overlapped, loblolly pine dominated the moister soils and shortleaf was more prevalent on drier sites (Wade and others 2000). In addition to associations with longleaf and loblolly previously noted, shortleaf was also found in mixtures with pitch (*Pinus rigida*) and Virginia (*Pinus virginiana*) pines in the Northeastern States (Lawson 1990). It was often also found in mixed hardwood stands where it shared dominance with oaks and hickories.

Mattoon (1915) noted that agriculture and logging in the early 1900s produced a decline in shortleaf pine. With the onset of logging in the Ouachita Highlands of Arkansas, substantial declines continued through the 1950s (Smith 1986). Often cutover stands were planted with loblolly pine—even north of its native range and in forest industry operations—which has contributed to a continued loss of shortleaf dominated forests (Guldin 1986). Loblolly has also replaced shortleaf in the eastern part of the range on sites where littleleaf disease (*Phytophthora cinnamomi*) was common because it is less susceptible (Campbell and others 1953). Shortleaf is still quite widespread but is often a minor component of forest stands. It is the dominant overstory tree on 3.2 million acres (1.3 million ha) in mostly naturally regenerated stands and on just 250,000 acres (100 000 ha) of plantations.

Shortleaf is very tolerant of fire. It is a prolific seed producer that forms dense seedling stands that have rapid juvenile growth (Mattoon 1915). Trees >5 feet (1.5 m) tall will survive surface fires unless crown scorch exceeds 70 percent (Wade and others 2000). If young trees are topkilled, they will readily sprout. Older trees—those larger than 4 inches (10 cm) at d.b.h.—have thick bark that protects the bole from surface fires (Walker and Wiant 1966). Because of these characteristics, frequent low-intensity fires give shortleaf a competitive advantage over many hardwoods. The historical fire regime was frequent low-intensity surface fires every 4 to 6 years (Frost 2006). This has also been shown to be the optimal interval for prescribed burns to promote natural regeneration (Masters and others 2005).

Lightning varies considerably in both frequency and seasonal peaks across the broad range of shortleaf pine. It is most frequent on the Coastal Plain, with an early growing season to summer maximum. The northern and western portions of the shortleaf range experience much less lightning in a bimodal distribution, with both a spring peak and a late-summer to early-autumn peak (Masters and others 1995). This ignition source was certainly augmented by Native Americans, which fostered the open grass dominated shortleaf stands by increasing fire frequency (Vogl 1972).

Oak-hickory-pine woodlands

This community is equivalent to Kuchler's (1964) oak-hickory-pine type 111. It was composed of a mixture of species in the overstory with the unifying characteristics of fire resistance. Its historical extent is not known, but it was widespread and prevalent in the Piedmont, upper hilly Coastal Plains, and Interior Highlands. The predominant group was the oaks (Sander and others 1983) including white (*Q. alba*), northern red (*Q. rubra*), and black (*Q. velutina*); and on drier steeper sites scarlet (*Q. coccinea*) and chestnut (*Q. prinus*). On more southerly sites post (*Q. stellata*), blackjack (*Q. marilandica*), bluejack (Q. *incana*), and southern red oak (*Q. falcata*) were common. Hickories included pignut (*Carya glabra*), mockernut (*Carya tomentosa*), shagbark (*Carya ovata*) and bitternut (*Carya cordiformis*). The pine component, when present, was loblolly, shortleaf, pitch, Virginia, or white (*Pinus strobus*). Often, more mesic hardwoods were present, such as yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), ash (*Fraxinus* spp.), and elms (*Ulmus* spp.). The pine component owed its existence to natural disturbances, such as fire and wind, or to extremely poor site conditions (Skeen and others 1993).

This community historically covered most of the Piedmont. It was greatly reduced by agricultural clearing but rebounded following soil depletion and abandonment,

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which fostered an increase in pines relative to hardwoods (Boyce and Knight 1980). As previously noted, loblolly and some shortleaf pine seeded into and captured a substantial number of old-field sites across the South. Significant quantities of oak and hickory were also harvested for lumber and to provide charcoal for the iron smelters that sprang up across the South. Frequent fires, which occurred until effective fire control was implemented in the 1950s, also favored pines. Once fire control was instituted and pine stands began to be harvested, pine coverage declined as hardwoods captured many sites following commercial clearcuts (Boyce and Knight 1980). More recently, significant increases in population in the Piedmont have impacted this forest community. However, the South still contains about 32 million acres (13 million ha) of oak-hickory-pine forest (Miles 2007).

The historical fire frequency in this community was 4 to 6 years with equal ignitions from lightning and Native Americans (Frost 1998). Lighting ignitions were most prevalent on more exposed and drier ridge tops and southern and western slopes. These coincided with the lightning season, which ran from March to October, but were most common during the dry spring. Native Americans also burned significant areas during the late autumn dry period. Their ignitions were more important toward the interior where the landscape is most dissected and less exposed to extensive fires from lightning. Low-intensity fires kept the forests open and favored oaks and pines (Skeen and others 1993). Early settlers continued to burn the woods to provide forage for their livestock. More recently, fires have been mostly prescribed burns to control fuel buildup, favor oaks and pines, and improve wildlife habitat.

Pine rocklands

This community is native to southern Florida, the Bahamas, and Cuba. In southern Florida it once occupied 180,000 acres (72 900 ha) on the Miami Rock Ridge from north of Miami to Homestead and southwest through Long Pine Key in Everglades National Park (Davis 1943). It was also found on the lower Florida Keys and the southeastern portion of Big Cypress National Preserve around Pinecrest (Snyder and others 1990). It occupied the higher elevations formed by outcrops of marine limestone, thus the term rocklands. Vegetation actually grows on the bedrock, rooting within the rocky rubble in thin layers of sand, marl, and organic matter that have accumulated in depressions, crevices, and solution holes. In the lower Florida Keys, more than half of the ground can be exposed rock; in Big Cypress, most of the limestone has a thin covering of sand. The overstory was south Florida slash pine (*Pinus elliottii* var. *densa*), growing in open canopy stands over an extremely diverse understory of tropical and temperate shrubs, palms, grasses, and forbs that included many local endemics (Snyder and others 1990).

Because these pine forests were found on higher and dryer land, they were the first to be cleared for building sites beginning around 1900. Logging was limited until the railroad arrived in 1896, but then most of the pine suitable for harvest was cut over the next half century (Snyder and others 1990). Cleared pinelands were used mainly for citrus production until the 1954 introduction of the rock plow to breakup the limestone bedrock and allow large-scale row crop farming. Fragmentation and fire control have also led to succession of pine forests to hardwood hammock (Stout and Marion 1993). The combination of an expanding urban area, logging, and agricultural clearing reduced the pine rockland forest substantially. Today only 2 percent of the original pine forest remains in the Miami area. Significant areas of intact forest only exist on public lands in Everglades National Park, the Big Cypress National Preserve, and the National Key Deer Refuge on Big Pine Key.

Pine rocklands need periodic fire to control growth of hardwood species, keep the stand open, and foster pine regeneration. These forests accumulate slowly decomposing needles, which are kept from matting by the rough rock surface and understory vegetation. The rocky porous substrate allows rapid drainage, and the open pine canopy fosters rapid drying—characteristics that lead to frequent low-intensity surface fires that consume the litter and understory vegetation (Snyder and others 1990). Pine canopies

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are too open to support crown fires, and the thick bark of mature trees protects the cambium of lower trunks (Hare 1965). Hofstetter (1973) reported that saplings 6.5 to 20 feet (2 to 6 m) tall have a 50-percent survival rate following fire. Seedlings have a grass stage where long needles protect the central bud and can sprout from the root collar if topkilled (Ketcham and Bethune 1963). The aboveground portion of woody understory species and saw palmetto are often consumed or killed by fires but they quickly resprout. Grasses and forbs respond with rapid regrowth and flowering (Robertson 1962). Thus, fire in pinelands does not cause significant changes because the species are predominantly perennials that can rapidly recover.

Historically, fires in pine rocklands were low-intensity surface fires occurring every 2 to 15 years with most areas burning every 3 to 7 years (Hofstetter 1973). Lightning is frequent in southern Florida and was the primary ignition source, often starting fires in wet prairies that swept into adjoining pinelands. Lightning ignitions occurred from May to October during the rainy season but fires were most extensive in late May and June at the end of the dry season before water levels rose (Snyder and others 1990). Native Americans certainly augmented natural ignitions and likely burned at other times outside the normal lightning season. Since 1950, human caused wildfires have been most frequent and burned the most area in April and May.

Mixed Severity Fire Regime

Pitch pine

Within the Subtropical Division pitch pine is native to Coastal Plain areas of Maryland and Delaware through southeastern New Jersey but is also found in the Hot Continental Division (220) on Long Island and Cape Cod (Little and Garrett 1990). It was most common on infertile soils including sands and gravels deposited on glacial outwash plains or as alluvial or marine sediments. The Pine Barrens of New Jersey contained the largest concentration of pitch pine growing on glacial deposits ranging from excessively to poorly drained sands and gravels. The historical extent of pitch pine is not known, but the Pine Barrens alone contained >1.1 million acres (450 000 ha), where pitch pine was likely a major overstory species in many historical communities. Depending on site and fire history, trees ranged from 39 feet (12 m) tall in more fertile swamps to dwarfsize, <11.5 feet (3.5 m), on the driest most frequently burned sand plains. Common associates included chestnut oaks, white oaks, black oaks, northern red oaks, bear oaks (*Q. ilicifolia*), and Virginia pine with an understory of woody species like bear oak, dwarf chinkapin oak (*Q. prinoides*), blueberries (*Vaccinium* spp.), and huckleberries (*Gaylussacia* spp.).

Nearly all lands in the Northeastern United States have been impacted by 400 years of human use, which included clearing, cultivating, grazing, logging, and burning. Initially fire frequency also increased, associated with land clearing (Parshall and others 2003). Because the pitch-pine barrens were most prevalent on infertile soils, they were rarely plowed—especially in the New Jersey Pine Barrens—but were heavily harvested for firewood, fence posts, railroad ties, and building material (Howard 2003). Beginning in the mid-1800s, many cleared areas were abandoned and pitch pine became established on former pine barrens (Motzkin and others 2002). More recently, aggressive fire control has caused a decrease in open pitch-pine stands and an increase in oak and other hardwoods (Copenheaver and others 2000). Although pitch-pine dominated forests are still common in the barrens, the absence of fire has changed them (Hall and others 2002). The need for prescribed fire is widely recognized, but the practice is becoming increasingly difficult because of fragmentation from residential development (Jordan and others 2003).

Barrens were historically dominated by pitch pine because it is very fire adapted. A thick bark protects it from fire. Buds on the bole can produce new foliage. Additional adaptations are the ability to sprout, serotinous cones that release seed following fire, and cone production at very young ages—3 to 4 years—for sprouts (Little and Garrett 1990). The large flat expanses of droughty soils allowed fires to easily propagate across

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the landscape, thereby increasing burn frequency. Thus, the central part of the Pine Barrens where dwarf pine is common, are estimated to have a historical fire-return interval of mostly stand replacement fires every 6 to 8 years (Givnish 1981). The more isolated areas of pitch pine and scrub oak (*Q. berberidifolia*) likely burned every 15 to 25 years with fires that killed a portion of the overstory. Native Americans burned areas of the barrens near their villages in spring and autumn on a 2- to 10-year interval with lower intensity understory burns, which produced open pitch pine stands with relatively large trees (Wade and others 2000). However, Parshall and Foster (2002) concluded that natural ignitions alone were sufficient to maintain the historical barrens.

Sand pine

Sand pine (*Pinus clausa*) scrub historically occupied three areas in Florida, inland peninsula, coastal peninsula, and coastal panhandle (Myers 1990). Ocala sand pine (*Pinus clausa* var. *clausa*) was endemic to peninsular Florida, with the largest concentration on the central ridge. It occupied a large portion of what is now the Ocala National Forest (where it was referred to as the Big Scrub) and was once prevalent on the Lake Wales Ridge (Brendemuehl 1990). Historically, smaller patches of scrub were found along the coast on old dunes stretching from St. John's County south to the northern portion of Dade County on the east coast, and from near Cedar Key south to Naples on the west coast. Sand pine scrub is a xerophytic, evergreen plant community found on excessively well drained, nutrient poor entisols (deep droughty infertile sands of marine and aeolian origin) of the quartzipsamment classification. Ocala sand pine forests have an overstory of predominantly even-aged sand pine with twisted and leaning trunks growing over an understory of evergreen shrubs. Typical understory species include myrtle oak (*Q. myrtifolia*), sand live oak (*Q. geminata*), Chapman oak (*Q. chapmanii*), turkey oak (*Q. laevis*), rusty lyonia (*Lyonia ferruginea*), rosemary (*Ceratiola ericoides*), scrub palmetto (*Sabal etonia*), and saw palmetto. Herbs and grasses are very sparse in mature scrub habitats, but lichens (*Cladonia* spp.) can form extensive patches on the forest floor. Lake Wales scrub is very similar except it often has few or no emergent sand pine.

Choctawhatchee sand pine (*Pinus clausa* var. *immuginata*) was the dominate tree in scrubs growing on sandy soils along the Gulf Coast (including offshore islands) of northwestern Florida from the Apalachicola river westward into Alabama (Brendemuehl 1990). This scrub has an overstory dominated by sand pine with an occasional longleaf pine or large sand live oak. Regeneration is a continuous process, which results in a relatively large number of trees in the intermediate and suppressed crown classes and fewer dominants (Outcalt 1997). Midstory oaks were a prominent feature of these sand pine stands with sand live oak the most common. Beneath the midstory was a tall shrub layer dominated by sand pine regeneration, oaks, and lesser numbers of ericaceous shrubs. The forest floor was composed of mostly pine litter with a few herbs growing between patches of lichens.

Because of their droughty infertile soils, scrub habitats were used only infrequently by Native Americans and early settlers (Myers 1990). Later discoveries that they were well suited to citrus production caused many in the lower portion of Florida's central ridge to be cleared. Coastal scrubs in peninsula areas were converted to urban use as Miami, Tampa, and other major cities developed. More recently, extensive areas have been disappearing to housing developments, golf courses, and other urban uses. A large concentration of sand pine remains however, occupying >250,000 acres (100 000 ha) on the Ocala National Forest (Brendemuehl 1990).

Because of its poor form, Ocala sand pine was not commercially harvested until the Kraft pulp industry became well established in the 1950s. Since that time significant areas have been harvested, but were regenerated on public lands. Choctawhatchee sand pine was restricted to the coastal areas by frequent fires; a combination of harvesting and fire suppression has allowed it to capture many areas of former longleaf pine forest (McCay 2000). Significant areas have also been planted with Choctawhatchee sand

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pine across the Florida panhandle. Thus, there is more Choctawhatchee sand pine now than existed in presettlement times. Longleaf once covered an estimated 85 percent of Eglin Air Force Base but now occupies about 15 percent compared to sand pine, which has increased from 10 to 40 percent or 185,000 acres (75 000 ha).

Although Ocala sand pine scrub experiences primarily stand replacement fires every 10 to 35 years, some level of fire occurs at shorter or longer intervals. Because of its sparse ground cover and compacted litter layer, sand pine scrub is virtually fire proof much of the time. However, every 10 to 100 years—usually during the spring drought—high winds and extreme conditions result in a catastrophic wildfire (Hough 1973) that kills the sand pine overstory and burns off the understory (Myers 1990). The resulting heat opens the many serotinous cones contained in the crowns of the sand pine, which releases the seed for establishment of the next stand (Cooper 1951). Because it produces cones at 3- to 5-years old, even young stands can reseed burned sites. Occasionally in stands with sparse sand pine cover, less intense fires result in only partial overstory mortality. Historically, Choctawhatchee sand pine grew on coastal areas, where fires were rare and less intense because of the less flammable understory. Most fires in the panhandle scrub were understory or mixed, killing only a portion of the overstory. Unlike Ocala, most of the cones open when mature so seeds are shed annually and will reestablish in areas opened by fire caused mortality.

Pond pine

Pinus serotina is native to the Coastal Plain from the southern tip of New Jersey south through the Delmarva Peninsula across the Carolinas and Georgia to central Florida and west into the southeastern corner of Alabama (Bramlett 1990). It once occupied a significant area of poorly drained sites. The largest concentration was in North Carolina, where pond pine was the dominant overstory on 2.5 million acres (1 million ha) of raised bogs (Richardson 1981) or pocosins, characterized by organic soils with sandy humus, peat, or muck surface horizons (Richardson and Gibbons 1993). Pond pine also grew in the wettest portions of woodlands, wet flatwoods, savannas, bay forests, shrub bogs, and swamps (Wade and others 2000) where it was often embedded in communities dominated by other southern pines, cypress, swamp conifers like Atlantic white-cedar (*Chamaecyparis thyoides*), and bottomland hardwoods like swamp tupelo (*N. biflora*) and sweetbay (*Magnolia virginiana*). Pocosins often have a thick understory layer of evergreen shrubs and smilax vines. Common shrubs species are gallberry, swamp titi (*Cyrilla racemiflora*), wax myrtle (*Myrica cerifera*), and coastal sweetpepperbush (*Clethra alnifolia*). Switchcane (*Arundinaria gigantea* ssp. *tecta*), which sprouts prolifically following fire, was abundant on some frequently burned sites (Bramlett 1990).

Pond pine was cut extensively like other southern pines during the major logging of the Southern United States from the 1800s to 1920. This logging however, was not as destructive as other operations: a large portion of the original pond pine pocosin habitat has been lost to peat mining, drainage, and conversion to pine plantations or row crops. In North Carolina just 695,000 acres (281 000 ha) of the pocosin remained undisturbed by humans in 1980 (Richardson and others 1981). Conversion to plantations and agricultural crops has continued to reduce pocosin habitat. In addition, a reduction in fire has allowed shrubs to increase in dominance at the expense of grasses (Frost 2002). Even though it is recognized that pocosins need periodic fire, the expansion of urban areas is making prescribed burning ever more difficult.

Pond pine is the most fire adapted of the Coastal Plain southern pines. It has the ability to sprout if topkilled and will produce new foliage from dormant buds under the bark following intense fires (Bramlett 1990). It also produces serotinous cones that store seed that is released following fire. The historical fire-return interval is highly variable with a range from 5 to 150 years. Wet flatwood and savanna sites have the shortest fire frequency of 3 to 10 years (Florida Natural Areas Inventory 1990), woodlands burn every 10 to 20 years (Sutter and Kral 1994), pocosins every 13 to 50 years (Frost 1995),

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and bogs and swamps every 50 to 150 years (Florida Natural Areas Inventory 1990). Currently wildfires are common in the spring, but can occur whenever drought conditions arise (Wade and Ward 1973). Fires were probably most common in the spring, which is often a dry period when the water table and fuel moisture are lowest. Fires were quite intense because of the fuel loads and the flammability of the shrubby or grassy understory. However, most were mixed severity fires where a portion of the overstory pond pine survived because of its adaptations. Stand replacement fires occurred during extreme droughts when the underlying peat was dry enough to burn and the resulting high severity ground fire consumed accumulated organic matter, killing the overstory and shrub layer (Wade and others 2000).

Cypress ponds and savannas

These areas are dominated by pond cypress, which is native to the Coastal Plain from Virginia to southern Florida and west to southeastern Louisiana (Wilhite and Toliver 1990). They occupy poorly to very poorly drained infertile soils that range from sands to clays and are often overlain by peat or muck. Cypress ponds or domes are isolated depressions ranging from 2.5 to 25 acres (1 to 10 ha) that are found on generally flat expanses of the coastal lowlands (Ewel 1998). They are not generally influenced by perennial flowing streams, but rather are wet because of excessive precipitation and perched water tables. The overstory is predominately pond cypress but often contains swamp blackgum and lesser amounts of sweetbay and loblolly bay with slash pine on the slightly higher rims. The understory is dominated by woody species including yaupon (*Ilex vomitoria*), swamp titi, wax myrtle, and gallberry (Wilhite and Toliver 1990). Cypress savannas containing small, slow growing pond cypress over a grassy dominated understory occur on larger broad flat areas like the Big Cypress National Preserve in southwestern Florida (Muss and others 2003), where it occupies 370,000 acres (150 000 ha). During the wet season these systems are inundated with slowly flowing water but become dry and readily flammable during droughts.

For all habitats, the water level fluctuates considerably from the wet season to the dry season. In addition, ponds and strands are found imbedded in pyric flatwood communities that burn quite frequently and have an understory dominated by ericaceous shrubs with waxy leaves. Therefore, historically they burned regularly, about every 20 years, with both understory and mixed severity fires (Ewel 1990). The most severe fires occurred in areas with accumulated peat and in conditions that were dry enough for partial or complete consumption (Cypert 1961). The cypress savanna also burned every 5 to 15 years with understory surface fires. These periodic fires kept hardwoods from encroaching, because pond cypress is more resistant to fire than hardwoods and will sprout from adventitious branches following burning. Historically most fires occurred in savannas during the spring and early summer dry periods when conditions were favorable for lightning ignited fires. Wildfires ignited by humans are more common now during the very dry dormant season. Fire severity has also increased due to widespread drainage, which can lead to replacement of pond cypress by willows (*Salix* spp.) and eventually mixed hardwoods (Wade and others 1980). Cypress ponds however, likely have less fire than historically since much of the burning in surrounding communities is done during the dormant season when they are too wet to ignite (Kirkman and others 2000). This could lead to fuel accumulations and more severe wildfires when they do burn. Pond cypress was harvested mainly for poles and posts during the extensive logging era of the 1900s (Dennis 1988). Recently, logging has become quite widespread, however, with the development of commercial production of cypress mulch for the landscape industry, and many pond cypress domes have been clearcut for mulch over the past 20 years (Black and others 1993). Pond cypress has the ability to stump sprout and thus should regenerate most harvested areas (Terwilliger and Ewel 1986). Alteration of hydrology by drainage began much earlier and has been more widespread than harvesting. This leads to dryer conditions, an invasion by pines and more frequent fires that change the area to pine flatwood vegetation.

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Stand Replacement Fire Regime

Dry prairie

This community is found only in southern Florida with the largest concentrations historically along the Kissimmee River, west and south of Lake Okeechobee, and the area north of Charlotte Harbor in Sarasota and Manatee counties. Harper (1927) estimated it covered 1,285,000 to 1,927,500 acres (520 000 to 780 000 ha) but more recent data (Shriver and Vickery 1999) indicate it once occupied about 2,051,000 acres (830 000 ha). Also called palmetto prairie, it is a treeless grass dominated community that occurred on broad flat landscapes where fire was very frequent because there were no major natural fire barriers. Interspersed throughout the community were areas occupied by wet prairie, ephemeral depression ponds, marshes, flatwoods, and mesic hammocks. Soils were sandy, poorly to somewhat poorly drained, acidic, and nutrient poor. The subtropical climate of the area has a pronounced wet and dry season. During the wet season the water table often is at or above the soil surface, while during the dry season it is a meter or more below the surface (Abrahamson and Hartnett 1990). The diverse ground cover of palmetto prairie is dominated by wiregrass with scattered saw palmetto and patches of runner oak (*Quercus minima*). Other common plants include bottlebrush threeawn (*Aristida spiciformis*), broomsedge bluestem (*Andropogon virginicus*), fetterbush lyonia, coastal plain staggerbush (*Lyonia fruticosa*), shiny blueberry (*Vaccinium myrsinites*), and yelloweyed grasses (*Xyris* spp.)

Today, only about 10 percent or 385,500 acres (156 000 ha) of intact palmetto prairie remain in southern Florida (Shriver and Vickery 1999) with the largest patches found on public lands like Myakka River State Park and Kissimmee Prairie State Preserve Park. Much of the original area has been lost to conversion for agriculture to citrus, vegetables or improved pasture. Many other areas have been heavily impacted by cattle grazing and disruption of the historical fire regime. In the absence of frequent fire, this community is taken over by invading trees and emergent shrubs and converts to pine or palm flatwoods or hardwood hammock (Huffman and Blanchard 1991). Some area has also been taken for urban development.

The wiregrass, saw palmetto, and ericaceous shrubs that dominate this community are very flammable, fueling stand replacement burns, but they also resprout quickly and revegetate the site (Abrahamson and Hartnett 1990). Historically, these fires were very frequent occurring every 1 to 2 years. Harper (1927) indicated that dry prairie burned almost every year and others also report very frequent fires (Abrahamson and Hartnett 1990). Southern Florida, where palmetto prairie is found, has one of the highest incidences of lightning in the country, which served as a natural ignition source. Since there was little in the historical landscape to stop fires, an ignition could burn a very large area. Most fires occurred during the transition from dry to wet season, which is April to June, as the thunderstorms returned but the landscape was not yet remoistened (Beckage and Platt 2003).

Freshwater marsh

In the Southeastern States, inland freshwater marshes are associated with rivers, lakes, shallow basins, and other depressions (McPherson 2008). Tidal freshwater marshes occur along the Atlantic and Gulf coasts. Marshes develop wherever topography and impermeable soils limit runoff or infiltration (Kushlan 1990). They are found on sandy alluvial soils with variable amounts of peat or marl. The historical extent is not well known but they did cover many thousands of acres across the Southern United States. The hydroperiod is variable but all marshes have sufficiently long periods of inundation to limit encroachment of many wood plants. Dominant vegetation is quite diverse with emergent aquatic species in the lower marsh while higher zones have extensive dense stands of graminoids like sand cordgrass (*Spartina bakeri*) and maidencane (*Panicum hemitomon*) with scattered patches of shrubs (Fisher 2008). Inland

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marshes have seasonal fluctuations in water level dependent on evapotranspiration and rainfall patterns while tidal marshes experience daily fluctuations driven by the tides.

Tidal marshes are still quite common in the South (Wade and others 2000) covering about 1,976,835 acres (800 000 ha). Inland marshes however have been heavily impacted by drainage and conversion to agricultural uses. Marshes along the St. Johns and Kissimmee river systems in Florida for example have been reduced by >70 percent (Kushlan 1990). Other areas have had an influx of nutrients from agricultural or urban areas that enriches marshlands, encouraging the growth of cattails (*Typha* spp.), allowing them to replace native vegetation on marshlands across the South. Disruption of the normal fire regime also changes vegetation by favoring woody species growth. Trees and shrubs are also encouraged by drainage of marshlands for flood control that shortens the period of flooding. The combination of reduced fire and less flooding has resulted in significant areas along major river drainages becoming dominated by wax myrtle, coastal plain willow (*Salix caroliniana*), or red maple (*Acer rubrum*). More recently with the realization of the importance of wetland ecosystems, concerted efforts have been made to remove flood control structures and restore the channel and floodplain marshes along the Kissimmee River (Toth 1993).

Fire has been an important driver in this system but different types of marshes burned with differing frequencies (Kushlan 1990). Higher zones typically dry annually and likely burned every 1 to 6 years (Frost 1995). The wetter lower zones and areas with significant peat accumulation likely burned only during periodic droughts (Kushlan 1990). Landscape location is also important with tidal marshes burning every 3 to 5 years where fire can enter from adjacent uplands but frequency declines quickly for isolated areas behind channels (Schafale and Weakley 1990). Fire frequency of smaller isolated marshes depends on fire-return interval for the surrounding community. Fires are stand replacement, but even the plants found on wetter lower zones regrow quickly, taking advantage of the nutrient flush and reduced competition (Kushlan 1990).

Everglades sawgrass and marl prairies

These freshwater marsh communities found in southern Florida in the Savanna Division are unique because of their size, location and special character. The Everglades are also known as the "river of grass" because excess precipitation historically flowed slowly southward along a path 50 miles wide and 120 miles long (80 by 193 km) through a mostly grass dominated freshwater marsh. A subtropical climate prevails, with a wet rainy season characterized by almost daily thunderstorms from mid May to October when 80 percent of rainfall occurs followed by a dry period with little rainfall (Gunderson and Loftus 1993). Marl prairies, which are normally flooded 3 to 7 months per year, are found on shallow inorganic soils over the limestone bedrock, which is close to the surface throughout southern Florida (Olmsted and others 1980). On slightly deeper areas, inundation slows decomposition forming organic peat soils where sawgrass communities are dominant. This sawgrass marsh was the most prevalent vegetation of the Everglades, once covering 1,976,835 acres (800 000 ha) of southern Florida. It was dominated by the grasslike sedge, called sawgrass (*Cladium jamaicense*) because of the sharp edges on its leaf blades (Kushlan 1990). Composition varies from sites with nearly pure sawgrass, which grows up to 10 feet (3 m) high, to a mixture of 30 species. Other common associates are Gulf Coast spikerush (*Eleocharis cellulosa*), blue waterhyssop (*Bacopa caroliniana*), Tracy's beaksedge (*Rhynchospora tracyi*), switchgrass (*Panicum virgatum*), maidencane, and saltmarsh morning-glory (*Ipomoea sagittata*). The marl prairie is a mixture of many species usually <3 feet (1 m) tall (Jenkins 2008), including Muhly grass (*Muhlenbergia filipes*), sawgrass, black bogrush (*Schoenus nigricans*), Tracy's beaksedge, and Florida little bluestem (*Schizachyrium rhizomatum*). This community once covered about 445,000 acres (180 000 ha) of southern Florida in the Everglades (Davis 1943).

Beginning in the early 1900s, efforts were made to drain the Everglades to make the area available for agriculture and urban development. To date more than half of the area has been drained. Everglades National Park was established to protect the unique area

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and its biota. Together with the conservation areas north of the park, about 20 percent of the original Everglades is protected (Davis and Ogden 1994). Even the protected areas however, have been impacted by 1,250 miles (2000 km) of canals, levees, and spillways that control water flow into them. To avert flooding, water is funneled off a good portion of the landscape during the rainy season, but stored in other areas for urban use during the dry season. The result is flow through the marshes of Everglades National Park has been reduced to about 10 percent of historical amounts. Less water can lead to increased drying and loss of peat through oxidation or by combustion during wildfires. Enrichment from fertilizers flushing from vegetable and sugar cane fields to the north also impact marsh vegetation (Davis and Ogden 1994). Enrichment coupled with the more severe wildfires can lead to replacement of sawgrass with cattails (McPherson 2009). Sawgrass also tends to decline on the conservation areas used to store excess water from deeper water and more prolonged inundation (Gunderson and Loftus 1993).

Fire is needed to maintain the sawgrass and marl prairies, which historically had stand replacement burns every 2 to 15 years (Jenkins 2008). Most large fires were lightning ignited, occurring from April to June at the transition from dry to wet season (Gunderson and Snyder 1994). Fires in wetter months were smaller and patchier because of wetter conditions. Sawgrass is highly adapted to fire, as it will burn even over standing water. Its meristem is protected by a spongy leaf base that is often below water or will absorb water from below during most dry periods. It regrows rapidly after a fire, often reaching preburn levels within 2 years (Wade and others 1980). Fire is also important for controlling woody species invasions into marl prairies. There has been a shift in fire season throughout the Everglades caused by humans with a significant number of fires now occurring during the driest portion of the dry season before lightning and associated rainfall return. Ground fires that consume the underlying peat are also more common due to accidental fires during drier months but mostly because many areas have been dried by drainage.

Canebrakes

The presettlement extent of area covered by canebrakes is not known; but based on numerous accounts of early explorers, it was thousands of acres (Platt and Brantley 1997). This bottomland community dominated by cane (*Arundinaria gigantea*) was found along every major river and stream in the Southeastern United States. William Bartram, the early American naturalist and author (Van Doren 1928), made repeated references to vast cane tracts or meadows including traveling through a cane meadow for 20 miles (32 km) in Alabama. Along major rivers cane formed pure stands 30 feet (9 m) tall up to 4 inch (10 cm) in diameter so thick that it was necessary to cut a path to traverse these areas (Platt and Brantley 1997). Cane was a ubiquitous material that Native Americans used for many daily items from firewood to containers. When traveling, if a river too deep to wade was encountered, they relied on the ever-present cane to make a raft for crossing (Hudson 1976). Large canebrake savannas with dense cane beneath a sparse hardwood canopy were found on terraces of alluvial floodplains, where flooding was frequent but inundation periods short. Although cane will grow on a wide range of soils it did best on these fertile, deep and well drained soils found along rivers and streams (Barone and others 2008). Common associate species of cane include laurel greenbrier (*Smilax laurifolia*), gallberry, swamp titi, wax myrtle, and saw palmetto (Shoonover and Williard 2003). Switch cane was also found as an understory species in a number of other evergreen and deciduous forests outside the floodplains.

The vast canebrakes of the historical landscape are gone. The scattered patches that remain cover about 2 percent of its former area (Noss and others 1995). They disappeared from overgrazing, agricultural conversion, altered fire regimes, and flood control. Cane was an important forage crop for settlers' livestock. It is the highest yielding native forage in the South and remains green and palatable throughout the year (Hilmon and Hughes 1965). However, it is very sensitive to overgrazing and rapidly declines if utilized continuously (Shepherd and others 1951). Range burning, which early cattlemen did annually, exhausted the carbohydrate reserves of the underground rhizomes,

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converting cane to savanna grasslands (Platt and Brantley 1997). Because it was found on fertile soils, many sites were converted to fields for crop production. Other areas, because of fire suppression, became shrub or forest dominated sites where these woody species shaded out the cane. Finally when dams and other flood control structures were constructed, they drowned many remaining canebrakes or stopped the periodic flooding they needed to keep them healthy.

Canebrakes require disturbance from periodic flooding and fire to remain viable (Brantley and Platt 2001). Some believe that the vast canebrakes found by early European explorers were the result of Native American agriculture and existed because of abandoned fields and regular burning (Platt and Brantley 1997). Others however, postulate the Native Americans picked the areas where cane was found for their fields because it indicated fertile sites (Hudson 1976). Thus, old fields covered with cane were simply converting back to their former cover. Regardless, it is known that canebrakes need regular burning to remain healthy and the Native Americans burned them every 7 to 10 years. This kept woody shrubs and trees in check and allowed the cane to flourish. Cane is quite flammable with the culms burning easily. Following fire, it quickly resprouts from underground rhizomes and can grow up to 1.2 inches per day (3 cm), rapidly reoccupying an area and out competing other species. As noted above, annual burning will eventually eliminate cane and because most reproduction is vegetative there is not a seed bank for reestablishment. A fire-return interval of 10 years is recommended to maximize productivity (Hughes 1966).

Fuels Management

Fuel treatments can be used to accomplish a number of objectives like ecosystem restoration, wildfire hazard reduction, wildlife habitat improvement, insect or disease control, aesthetic improvement, forage production, or silvicultural enhancements. In most applications, it is used to achieve multiple objectives. In all vegetation types, the fuel treatment depends on where the site is located, its current condition, and the desired outcomes. If the major goal is wildfire hazard reduction in forested ecosystems, the objectives will be to reduce surface fuels, increase distance to the live crown, lower crown density, increase the dominance of large fire resistant trees, or a combination of all four (Agee and Skinner 2005). In grassy ecosystems, the major goal is often to control woody species, which can quickly capture an area in the absence of fire.

Originally, fuels reduction was most often limited to wildlife habitat improvement, championed by Stoddard (1931), for bobwhite quail (*Colinus virginianus*) production. Another early application was to reduce the potential for uncontrolled wildfires, with use increasing as the benefits were recognized. Early research (Davis and Cooper 1963) showed that the area burned and the intensity of wildfires was strongly related to with the amount of time since the last prescribed burn. Recent work has also documented that tree mortality from wildfires under extreme conditions is lower in sites where prescribed fire had recently been applied (Outcalt and Wade 2004a). Fuel treatments have also long been part of silvicultural prescriptions used, for example, to control hardwoods in pine stands or to prepare seedbeds for pine regeneration. As noted above, most native ecosystems are adapted to fire either quite frequently or at least periodically. If fire is excluded, then they change in undesirable ways that affect the habitat, often reducing biodiversity and contributing to the decline of endangered species. This has led to a concerted effort to restore many fire dependent ecosystem—such as longleaf pine (Brockway and others 2005), which usually requires reduction in accumulated fuels.

The South is blessed with a long growing season and plentiful precipitation, ensuring that its forest and grassland ecosystems are quite productive but also leading to a rapid accumulation of potential fuels. Fuel levels are determined by site productivity, overstory density, and years of accumulation. A typical slash pine plantation with basal area of 110 square feet per acre (25 m^2/ha) rapidly accumulates forest floor and will contain 6.6 tons per acre (14.8 t/ha) in just 4 years (table 1) and has another 2.7 tons per

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Table 1. Fuel accumulation in surface layers measured over time at varying intervals for a range of vegetation types of the Subtropical Division (Bailey 1996), expressed on a dry weight basis

Vegetation type	Component	Years of fuel accumulation											Reference
		1	2	3	4	5	6	7	10	15	20	30	
		tons/acre (t/ha)											
Slash pine	Litter[a]	2.3 (5.15)	4 (8.96)	5.4 (12.10)	6.6 (14.78)	7.6 (17.02)	9.3 (20.83)	11.1 (24.86)	12.7 (28.45)	13.2 (29.57)	—	—	McNab and others (1978)
Loblolly pine	Litter[a]	2.1 (4.70)	3.5 (7.84)	4.6 (10.30)	5.4 (12.10)	6 (13.44)	7.1 (15.90)	7.4 (16.58)	7.4 (16.58)	—	—	—	Wade and others (2000)
Slash/longleaf flatwoods	Understory	0.5 (1.12)	2 (4.48)	2.6 (5.82)	—	2.8 (6.27)	—	—	3.6 (8.06)	6.6 (14.78)	8.4 (18.82)	—	Wade and others (2000)
Longleaf flatwoods	Litter	2.19 (4.91)	3.71 (8.31)	8 (17.92)	3.99 (8.94)	5.12 (11.47)	—	—	—	—	18.75 (42.00)	27.18 (60.88)	Ottmar and Vihnanek (2000)
Longleaf flatwoods	Understory	1 (2.24)	1.28 (2.87)	3.32 (7.44)	3.75 (8.40)	3.41 (7.64)	—	—	—	—	3.42 (7.66)	5.54 (12.41)	Ottmar and Vihnanek (2000
Longleaf sandhill	Litter	1.59 (3.56)	—	1.73 (3.88)	—	—	—	—	—	—	8.97 (20.09)	—	Ottmar and others (2003)
Longleaf sandhill	Understory	0.32 (0.72)	—	1.02 (2.28)	—	—	—	—	—	—	1.25 (2.80)	—	Ottmar and others (2003)
Loblolly pine plantation	Litter	—	—	—	6.35 (14.22)	—	—	—	—	—	—	—	Scholl and Waldrop (1999)
Loblolly pine plantation	Understory	—	—	—	0.16 (0.36)	—	—	—	—	—	—	—	Scholl and Waldrop (1999)
Loblolly pine plantation	Litter	—	—	—	6.22 (13.93)	—	—	—	—	—	—	—	Scholl and Waldrop (1999)
Loblolly pine plantation	Understory	—	—	—	0.54 (1.21)	—	—	—	—	—	—	—	Scholl and Waldrop (1999)
Longleaf wiregrass	Litter	—	1.21 (2.71)	—	—	—	—	—	—	—	—	—	Ottmar and Vihnanek (2000)
Longleaf wiregrass	Understory	—	1.59 (3.56)	—	—	—	—	—	—	—	—	—	Ottmar and Vihnanek (2000)
Marl prairie	Litter and understory	0.6 (1.4)	—	1.7 (3.75)	—	—	1.7 (3.75)	—	—	1.7 (3.9)	—	—	Herndon and Taylor (1986)

— = No data available.
Note: Litter is all dead surface fuel including leaves, needles, twigs, branches, and stems; understory is all living plants <4.5 feet tall (1.5 m).
[a] Basal area = 110 square feet per acre (25 m^2/ha).

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acre (6 t/ha) in understory fuel. Higher density stands produce more litterfall and therefore have higher forest floor fuel loads. For example, the same slash pine plantation with double the stocking would contain 10.9 tons per acre (24.4 t/ha) of forest floor fuel after 4 years without a fire. Sites with poorer soils, like longleaf pine sandhills—with their droughty, nutrient poor sands—accumulate much less fuel and therefore will be subject to less intense fires, even if not burned for extended periods. Pocosins with their shrub dominated understory can have very high fuel loads in this layer (table 2), making prescribed burning and wildfire control difficult. This is also true to a lesser extent for the palmetto-gallberry fuel type found in longleaf and slash pine flatwoods (Wade and others 2000). Grassland accumulates fine fuels very quickly in an arrangement that makes it particularly flammable. Thus, fuel treatments must consider both the rate of accumulation and the type of material.

Prescribed Burning

Longleaf pine

Prescribed burning is used in all longleaf pine communities from wet flatwoods to droughty sandhills and from the Atlantic Coastal Plain to the montane area of the ridge and valley. Frequency is tied to fuel accumulation rates with a fire-return interval of 1 to 4 years (table 3), but most stands are burned every 3 to 4 years on sandhills, flatwoods, and wet coastal sites. More productive mesic uplands, especially those lands managed for wildlife production, are typically burned on a 2- to 3-year cycle. More frequent fires are also applied to areas with excess fuel accumulations or midstory hardwoods or both (Brockway and others 2005, Outcalt 2006). The goal is to reduce wildfire hazard and restore the ecosystem to a more herbaceous-dominated understory, which can then be maintained with less frequent fire. Historically much of this burning was applied during the dormant season when weather was more predictable and air temperatures were

Table 2. Typical fuel loads on a dry weight basis in select vegetation types of the Subtropical Division and the Savanna Division (Bailey 1996)

Vegetation type	Component	Age	Tons per acre	Tons per hectare	Reference
Choctawhatchee sand pine	Litter	Stand age 15 years	9.45	21.17	Ottmar and others 2003
Choctawhatchee sand pine	Understory	Stand age 15 years	2.99	6.70	Ottmar and others 2003
Choctawhatchee sand pine	Litter	Stand age 58 years	24.84	55.64	Ottmar and others 2003
Choctawhatchee sand pine	Understory	Stand age 58 years	5.96	13.35	Ottmar and others 2003
Oak and hickory	Litter	Age of rough unknown	5.68	12.72	Scholl and Waldrop 1999
Oak and hickory	Understory	Age of rough unknown	0.5	1.12	Scholl and Waldrop 1999
Pocosin woodland	Litter	Age of rough unknown	4.28	9.59	Ottmar and Vihnanek 2000
Pocosin woodland	Understory	Age of rough unknown	3.62	8.11	Ottmar and Vihnanek 2000
Pocosin high	Litter	Age of rough unknown	3.85	8.62	Ottmar and Vihnanek 2000
Pocosin high	Understory	Age of rough unknown	19.3	43.23	Ottmar and Vihnanek 2000
Pocosin low	Litter	Age of rough unknown	2.79	6.25	Ottmar and Vihnanek 2000
Pocosin low	Understory	Age of rough unknown	9.97	22.33	Ottmar and Vihnanek 2000
Oak-pine	Litter	Age of rough unknown	6.32	14.16	Ottmar and others 2003
Canebrake	Understory	4 years	7.0	15.7	Hughes 1966
Sawgrass	Litter and understory	Age of rough unknown	12.5	28.0	McPherson 2008

Note: Litter is all dead surface fuel including leaves, needles, twigs, branches and stems; understory is all living plants <4.5 feet tall (1.5 m) except in canebrake and sawgrass where it includes all grass.

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Table 3. Types of fuel treatments used in different vegetation types in the Subtropical Division and the Savanna Division (Bailey 1996)

	Treatment				
Vegetation type	Prescribed burn[a]	Mechanical[b]	Manual	Harvesting[b]	Herbicide[c]
Longleaf sandhills	Understory 2 to 4 years	Chopping and mulching	Hand clearing	Thinning and clearcutting	Understory and midstory
Longleaf flatwoods	Understory 1 to 4 years	Chopping and mulching		Thinning and clearcutting	Understory
Longleaf uplands	Understory 1 to 4 years	Chopping and mulching	Hand clearing	Thinning and clearcutting	Understory and midstory
Slash pine flatwoods	Understory 1 to 4 years	Chopping and mulching		Thinning	Understory
Loblolly pine	Understory 2 to 5 years	Mulching	Hand clearing	Thinning	Understory and midstory
Shortleaf pine	Understory 3 to 5 years	Mulching	Hand clearing	Thinning	Understory and midstory
Oak-hickory-pine	Understory 3 to 6 years		Hand clearing	Thinning	
Pine rocklands	Understory 3 to 5 years	Mulching	Hand clearing	Thinning and clearcutting	
Pitch pine	Understory 5 to 15 years	Mulching		Thinning	
Ocala sand pine	Stand replacing 15 to 75 years	Chopping		Clearcutting	
Choctawhatchee sand pine	Understory 3 to 5 years			Clearcutting	
Pond pine	Understory 3 to 8 years	Mulching			
Cypress domes	Understory 2 to 5 years				
Cypress savanna	Understory 10 years				
Dry prairie	Stand replacing 1 to 4 years	Chopping			
Freshwater marsh	Stand replacing 2 to 5 years				
Everglades prairie	Stand replacing 3 to 5 years				
Canebrake	Understory 3 to 5 years		Hand clearing	Thinning	

Note: Blanks indicate that type of treatment is not being applied to that forest type.
[a] Type of burn and normal frequency of application.
[b] Typical treatments used in different vegetation types.
[c] Target layer of application.

lower. For the last 15 years however, many more areas are being burned during the growing season, which has been shown to be more effective for reducing hardwoods (Waldrop and others 1987). Because of seasonal differences in responses to burning, the best approach is to vary the time of application rather than repeatedly burning a particular site at the same time of the year. Many quail plantations avoid growing season burns to limit nest loss.

Although private lands are often burned with drip torches and strip headfires or flanking fires, the general trend on public lands has been to burn in larger blocks. Today many of the burns are ignited from helicopters that quickly create many spot fires, allowing 500 to 2,500 acres (200 to 1000 ha) to be burned as a unit in a day. This firing technique impacts more of the watershed at one time, but also more closely mimics the larger size of the fires in longleaf communities that preceded landscape fragmentation. National forest records show 820,000 acres (332 000 ha) of longleaf pine in 2006 with another 300,000 acres (121 000 ha) of longleaf on other Federal properties, mostly

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military installations (Miles 2007). Assuming these are being burned on average at least every 5 years, then about 223,000 acres (90 000 ha) of longleaf are burned annually on public lands. Private lands receive less frequent fire; only about 37 percent are burned every 5 years, or 148,000 acres (60 000 ha) annually (Outcalt 2000).

Slash pine flatwoods

Because this system often has a very similar palmetto-gallberry understory fuel complex and is often mixed with longleaf flatwoods, prescribed burning can be applied with the same frequency as longleaf: 1 to 4 years with most sites burned every 3 or 4 years. More frequent burning is necessary during restoration treatments to reduce both fuel loads and palmetto and woody understory cover while increasing herbaceous growth. Because young saplings with a ground level diameter of <2 inches (5 cm) can be killed by surface fires (Johansen and Wade 1987), burning is not appropriate in young plantations or naturally regenerated stands until trees reach 3 to 5 years old. Most burning was historically applied during the dormant season, but is now being expanded to the growing season, especially to provide ecological benefits on public lands and to increase options for managers, most of whom need every burn day they can get to keep stands within the appropriate fire-return interval. Some variation in season—which includes the growing season—is desirable, but repeated burning annually or biennially during the dormant season will reduce palmetto cover and increase grasses (Outcalt and Wade 2004b).

As noted above, public land managers are increasingly using helicopter-ignited spot firing, which treats large blocks in a single burn. Thus, slash pine flatwoods are often included with adjacent longleaf pine dominated stands in large burns. Prescribed burning has largely been curtailed on many forest industry lands because of liability issues from smoke on roads. However, burning in slash pine dominated stands is still a big portion of total burning on private land because slash pine has been planted extensively and captured much of former longleaf area following logging and fire control during the first half of the 1900s. With 1.63 million acres (660 000 ha) of slash pine on public lands and two-thirds that in naturally regenerated stands, public land managers are estimated to burn 326,000 acres (132 000 ha) annually based on an average fire-return interval of 5 years.

Loblolly pine

This species is not considered to be fire dependent and historically loblolly dominated stands were confined to wetter or sheltered sites where surface fires were not as frequent. However, Wade (1993) showed that it is tolerant of fire once saplings attain a ground level diameter of 2 inches (5 cm), which explains why historically it was a co-dominant with longleaf and/or shortleaf on many areas. Once past this stage, stands have been routinely burned to control hardwood competition, reduce fuel loads, promote forage production, and improve wildlife habitat. Grass-dominated understories can be burned annually but the usual range is 2 to 5 years with the majority burned every 3 to 5 years, which is sufficient to reduce fuel loads—especially in plantations after crown closure—that contain very little understory fuel (table 1). Shorter fire-return intervals are sometimes used to create a grassy herbaceous dominated understory with increased species richness (Glitzenstein and others 2003). Repeated growing-season burns, if applied at least every 2 years (Wade and others 2000), are more effective than dormant season burns for topkilling hardwoods and reducing hardwood rootstocks (Waldrop and others 1987). Many private owners avoid growing-season fires to protect nests of eastern wild turkey (*Meleagris gallopavo*) and bobwhite quail.

If there are no young seedlings and saplings that must be protected, large blocks of loblolly dominated forest on public lands can be burned using helicopter ignition. Considerable prescribed burning continues in loblolly pine stands on private lands for wildlife, esthetics, access improvement, and hazard reduction, but the total amount is unknown. As with slash pine, however, very little is done by forest industry. With 6.4 million acres (2.6 million ha) of loblolly forests in public ownership and 70 percent

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of that in naturally regenerated stands, public land managers are estimated to burn about 432,000 acres (175 000 ha) annually based on an estimated average fire-return interval of 6 years.

Shortleaf pine

Much of the remaining shortleaf pine is found on the drier ridges in the Piedmont and Interior Highlands of the Subtropical Division. As with other southern pines, shortleaf underwent a period of fire suppression, which allowed hardwoods and other species to capture many sites. Recently, burning has increased with the goal of restoring community structure and returning shortleaf to more productive sites. Because it is quite resistant to surface fires, shortleaf can be burned every 2 to 5 years, or every 4 to 6 years for seedling establishment (Masters and others 2005) to allow saplings to grow beyond the size where fire will cause high mortality rates. Although stands can be burned at longer intervals of 12 years, the result will be denser stands with a less open structure (Masters and others 2005). Shorter fire returns of 3 years produce a grass-dominated understory but will also result in less than optimal stocking for timber production. Shortleaf pine can be burned in both dormant and growing seasons (Sparks and others 2002). Masters and others (2002) found late dormant season burns applied every 3 years greatly improved wildlife habitat. However, maintaining the health of the entire forest community requires frequent burning in all seasons (Masters 2007).

Prescribed burning in shortleaf pine stands on public lands has been mostly by hand ignition or with torches attached to all terrain vehicles. Because of safety issues and the need to increase the amount of area burned each year, helicopter burning using ping-pong ball spot ignition is becoming more common on large blocks of forest. Burn units have increased in size on the Ouachita National Forest to 620 acres (250 ha), with some as large as 7,400 acres (3000 ha). With about 951,000 acres (385 000 ha) of shortleaf pine forest in public ownership and 91 percent of that naturally regenerated, public land managers are estimated to burn about 190,000 acres (77 000 ha) annually based on an average fire-return interval of 5 years. Some burning continues on private lands, but virtually none on forest industry property.

Oak-hickory-pine woodlands

The role of fire in perpetuating this community was only recently recognized (Lorimer 1993). Recent research has shown that prescribed burning can be used to aid establishment of regeneration, which can later be released by subsequent burns (Wade and others 2000). Burn frequency depends of landowner goals and initial conditions. Annual or biennial burns are used to reduce shading by competing hardwoods and open the stand to promote establishment of oak and hickory seedlings, or in tandem with a shelterwood cut to enhance growth for stands with established regeneration. Burning should be delayed until oak seedlings are 0.8 inches (2 cm) in root collar diameter, and then applied during the growing season to kill the regeneration layer, which removes less fire tolerant species, leaving the oaks and hickories to sprout and grow. Fire can then be applied as needed to keep competing hardwoods in check, usually every 3 to 6 years.

Burning in these habitats has been limited. Many believed that even low-intensity surface fires would damage hardwood stems of large overstory trees. In addition, most of these sites do not need hazard reduction burns because the more mesic hardwoods have captured many former habitats during 50-plus years of fire suppression. The dense shade and the accumulated litter, which is less flammable than pine needles and oak leaves, make these stands less likely to burn. Thus, uncontrolled wildfires are not a danger. The justification for burning is to restore former habitats that likely existed largely because of Native American burning. There is considerable public resistance to prescribed burning in this habitat on Federal and State properties . Some managers conduct the initial burn of mixed stands during the dormant season to remove excess fuel accumulations. Ignition is often with drip torches used to set backing or flanking fires. The total area burned is not yet large, but it is increasing with the growing recognition of the value of fire and with the support of outside environmental and conservation groups.

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Pine rocklands

What remains of these fire dependent systems is mostly on public lands, which are burned frequently, every 3 to 5 years, to control understory hardwoods and maintain ecosystem health. A slightly longer return interval may be necessary to allow young slash pine seedlings to become large enough to survive fire (Olmsted and Loop 1984), also satisfying the need for variation to more closely mimic historical fire frequency (Snyder and others 1990). Managers historically burned many areas during the dry season but began conducting burns during the wet season in 1981. Most burns in Everglades National Park are now conducted during the early part of the wet season (June and July). At Big Cypress Preserve, the largest burns are reserved for this period, but significant areas of pinelands are also burned in late winter to early spring (January and February). Research has shown that fire intensity rather than season determines whether burning is effective for reducing understory hardwoods (Snyder 1986), and other non-seasonal factors are also critical. As has been shown for other southern ecosystems, repeated burning is required to exhaust hardwood root reserves (Gunderson and others 1983). Snyder (1986) also found that understory herbaceous vegetation recovered quickly after both dry-season and wet-season fires.

In Everglades National Park, burns are ignited by helicopter or with vehicle mounted torches. Burns are managed using topographic features of the landscape to determine burn areas. Thus, burns have been increasing in size, and now consist of several-hundred acre tracts rather than individual stands surrounded by artificial barriers like roads or fire lines. Managers also use prescribed natural fire, where lightning ignited fires are allowed to burn with careful monitoring as long as they occur within predetermined prescriptions and are not likely to spread to areas outside park boundaries. Big Cypress Preserve also uses aerial ignition and has increased the size of prescribed burns up to >7,400 acres (3000 ha) and range to include multiple forest communities.

Mixed fire regime communities

Prescribed burns have been conducted in pitch pine barrens since the 1950s to reduce fuel loads and the danger from catastrophic wildfires (Buell and Cantlon 1953). Initial burns were mostly in the winter dormant season at intervals of 1 to 5 years. Dormant-season burns are still used to reduce fuel loads, but growing-season burns are also employed. Popp (1987) showed that successive annual growing season burns are more effective for restoration because they reduce hardwood sprouts and kill many rootstocks. Once fuel loads are reduced and hardwoods restored to a low level, a longer return interval of 10 to 15 years is effective. Because many of the remaining pitch pine stands are small fragments of former forests, large burns are possible only in some of the more extensive barrens of New Jersey.

Although sand pine is the most fire sensitive of the southern pines, prescribed burning is possible for the Choctawhatchee variety. Eglin Air Force Base began low-intensity, dormant-season burns of sand pine to control understory fuel loads and improve access in the 1960s (Britt 1973). More recently, burning has been used primarily to control the spread of sand pine into adjacent longleaf pine habitat. These burns tend to be part of large compartment-size burns of 740 to 5,000 acres (300 to 2000 ha), which include both habitat types and are conducted on suitable burn days in all seasons.

Prescribed burning is also used extensively to control invasion of sand pine into longleaf sandhills on the Ocala National Forest, along with an additional 2,900 acres (1160 ha) of sand pine scrub being managed as Florida scrub-jay (*Aphelocoma coerulescens*) habitat. Stand replacement prescribed burns in this scrub-jay area have a fire-return interval of 15 years. Burns are applied to stand-size areas of 50 to 150 acres (20 to 60 ha) to maintain a mosaic of age classes. In addition, prescribed burns are being ignited in the wilderness areas and then are allowed to burn as long as they are likely to remain inside the boundaries. These burns have been quite extensive covering 7,400 to 12,000 acres (3000 to 5000 ha).

Prescribed burning can be applied in pond pine pocosins to consume understory shrubs, but not if the fire is so intense that significant mortality occurs in the overstory.

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Taylor and Wendel (1964) documented the conditions needed; yet many pond pine stands have gone unburned because they are more difficult to burn than other communities. This is especially true on areas with peat accumulations and long unburned areas with high fuel loads.

Some burning is taking place on public lands. On the Croatan National Forest, the goal is to apply fire at its historical return interval to the wilderness areas, including pond pine, and at a return interval of 3 to 5 years outside wilderness areas. The Croatan burns around 5,000 acres (2000 ha) of pond pine pocosin per year, with most burning from November to February but also extending through April if the weather is favorable. Burn units are 500 to 2,000 acres (200 to 800 ha) with ignition a combination of drip torches to secure the lines followed by helicopter ignition. Other public lands, like Camp Lejeune managed by Department of Defense, are also burning pond pine habitat as part of their overall prescribed burn program. The goal for pond pine woodlands and high pocosins on these lands is a 5- to 8-year fire-return interval, with a shorter 3- to 5-year interval in areas with endangered plants that require open conditions. Most burns are small units to limit smoke production and are applied in an array of conditions. Growing season burns are favored and areas with switch cane are given high priority for burning.

Cypress wetlands are usually imbedded within surrounding longleaf or slash pine dominated communities. Historically, they were often protected from fire by plowed firelines, which compromised the hydrology and disturbed the ecotone area that is the habitat for many rare plant species. This practice has been discontinued on public lands, where cypress wetlands are now burned at the same interval as the surrounding habitats, every 2 to 5 years. Because the cypress community is wetter, most of these fires only burn the edges with depth of penetration controlled by water levels at the time of the burn. Burning takes place in all seasons, but dormant-season fires are favored in areas where former fire exclusion has led to high fuel loads. Early growing season burns at a shorter frequency are used to support the endangered plants that prefer open habitats. The larger expanses of cypress savanna in southern Florida are burned in larger units that include multiple forest communities. Late winter to early spring and the early wet season (June and July) are the most active burn windows with a fire-return interval of about 10 years.

Stand replacement fire communities

Most of the remaining dry prairie is burned frequently, every 1 to 4 years, to control fuel levels and prevent woody species from capturing the site. Until recently most burns were conducted in the dormant season from November to March. Over the last decade, some burning has shifted to the growing season, especially on public areas that need restoration. As with the similar flatwoods, more frequent burning, annually or biennially, will speed reduction of palmetto and competing shrubs when restoring dry prairie sites. Most dry prairie is found in smaller units and is being burned with ground based ignition rather than helicopters. Public lands are on a 2- to 3-year fire-return interval. In contrast, private ranchers still manage native grasslands by burning every 1 or 2 years in winter or early spring to green up their pastures.

Freshwater marsh, like most grass dominated systems that accumulate biomass rapidly, require frequent burning to maintain ecosystem health. Typically, these communities are burned every 2 to 5 years to control invasion by woody species and to reduce fuel loads. Hydrology seems to be as—or more—important however, because flooding is more effective than fire for limiting willow invasion (Miller and others 1998). Many remaining marshes are found on public lands where managers often burn in autumn or winter, after a killing frost has increased fuel flammability, to favor vegetation preferred by waterfowl (Gordon and others 1989). Burning when soils are moist reduces the likelihood of igniting ground fires in belowground organic material, thereby avoiding problems with control and smoke (Miller and others 1998).

Sawgrass and marl prairies are fire maintained systems that are burned frequently, every 3 to 5 years, to control fuels and maintain health. Almost all remaining sawgrass

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and marl prairies are on public lands, where regular burning has been in effect for many years. As with most southern systems, burning was usually confined to the winter dry season (Gunderson and Snyder 1994) but has now shifted more to the transition period from the dry to wet season (May and June). In Big Cypress, aerial ignition from helicopters is common with these systems burned as part of a large block burn. Everglades National Park has also gone to large block burns that cover more of the landscape and use natural firebreaks. To avoid ground fires, prescriptions set a minimum soil moisture level of 65 percent.

For many years, fire was deliberately excluded from canebrakes because they burned quite intensely. However, when it can be burned, cane responds favorably in either winter or summer (Platt and Brantley 1997). Although burning every 7 to 10 years is sufficient to maintain this ecosystem, most remnants under active fire management are burned every 3 to 5 years. This more frequent burning keeps fuel loads down and helps reduce woody species that increased on most sites during the fire exclusion period. Because of heavy fuel loads and high flammability in canebrakes that have not been burned for a long period, the first burn is normally delayed until fuel moisture and humidity are rather high. Because this community exists as mostly isolated patches, hand ignition with drip torches is employed. Some smaller areas are burned by aerial ignition incidental to burning the vegetation that surrounds them.

Mechanical Methods

Mechanical fuel treatments are accomplished with an array of different equipment—including mowers, mulchers, and choppers—developed to cut, chop, shred, or sever mostly midstory and understory fuel layers. This equipment was developed for site preparation, land clearing, or right-of-way maintenance; it is most efficient on areas without large trees, but it can be used in existing stands where the retained overstory spacing is about 10 feet (3 m) or greater. Mowers are best suited to treating smaller understory shrubs. Mulchers come in various sizes; a small unit with a front mounted cutter can quickly chew through stems about 6 inches (15 cm) in diameter and high horsepower units can take down trees up to 12 inches (30 cm). Choppers also come in a variety of sizes and configurations, from small-teethed aerator models to 20-ton double drum offset machines. They knock down and crush understory and midstory fuel layers.

These treatments are most often applied to areas with high fuel loads for hazard reduction and ecosystem restoration. Because they do not remove material from the site, they change fuel configuration but not total fuel load. Thus, the midstory and understory fuel becomes surface fuel, which may or may not reduce wildfire severity. Most often, mechanical treatments are used to prepare the area for a prescribed burn. Reducing the ladder fuels reduces the potential for crown damage to overstory trees, compacting surface fuels often allows the burn to spread under more moderate conditions of higher humidity and fuel moisture with a lowered intensity. Therefore, except in some wildland-urban interface areas where burning may not be possible because of smoke sensitive areas, mechanical treatments are a one-time application to areas subsequently maintained with prescribed burning.

Chopping has been used extensively in longleaf pine ecosystems on all site types (table 3). Small to medium single drum choppers work well on sandhill sites to knock down the scrub-oak midstory layers that developed during the fire exclusion period. Selecting a tow unit and chopper that will knock down unwanted trees but then ride mostly on top of the small hardwood stems will limit soil disturbance. Chopping has also proven very useful for controlling saw palmetto on flatwood sites and in palmetto prairies (Fitzgerald and Tanner 1992). Research at Myakka River State Park (Outcalt and Brockway 2002) shows that chopping will reduce palmetto and shrub cover, while increasing grass cover. In the absence of additional treatment, palmetto fuel biomass did recover but remained lower on chopped sites that were subjected to a second prescribed burn 3 years later. In Ocala sand pine scrub, chopping is a replacement for fire in reducing height of woody stems, thereby maintaining forage and breeding habitat for Florida scrub-jays.

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Mulching has been a fuel-treat option in all pine-dominated communities. It is used to reduce midstory scrub oaks on longleaf sandhills, and loblolly pine and mesic hardwoods like sweetgum (*Liquidambar styraciflua*) on upland longleaf sites. In upland and sandhill longleaf sites in Louisiana mulching reduced midstory hardwood density by 33 percent and understory woody cover by 64 percent (Rummer and others 2002). Mulchers have also been used on long-unburned flatwoods where the saw palmetto has become a true midstory of upright palms, 10 to 13 feet (3 to 4 m) tall. In loblolly-shortleaf pine types mulching targets hardwoods and small pine seedlings and saplings in high-density stands. The shrub layer is the target of mulching operations on pocosin sites. The objective in all these forest communities is to reduce the midstory fuel layer so sites can be more easily and safely burned.

Hand clearing, which can be used for cleaning or thinning stands, is performed with hand tools like axes, saws, or machetes, or with power equipment like brush and chainsaws. It has been used extensively to fell scrub oaks in sandhill longleaf stands (Provencher and others 2001), especially as a midstory removal treatment to improve red-cockaded woodpecker (*Picoides borealis*) habitat. Hand crews have also been employed to cut invading sand pine seedlings and saplings from longleaf sandhill sites on the Ocala National Forest in central Florida. On upland longleaf sites, chainsaws are used to fell invading loblolly pine, sweetgum, and other mesic hardwoods. These felling techniques are also used in loblolly, shortleaf, and pine hardwood systems to remove unwanted stems and reduce overall density. Hand treatments can be used in pine rocklands to remove midstory tropical hardwoods or understory and midstory invasives, such as brazilian peppertree (*Schinus terebinthifolius*) and melaleuca (*Melaleuca* spp.), and to remove privet (*Ligustrum* spp.) on canebrake sites. These treatments are generally followed by prescribed burning. Although felling does change fuel configuration, the goal is more often to accelerate the restoration process compared to using burning alone.

Harvesting by clearcutting or thinning—mostly with mechanized equipment—is a normal forestry operation, but recently the benefits for restoration and fuel management have become much more important and more widely applied in pines across the Southern United States. A common example is on longleaf sites for selectively removing other pines—such as loblolly or slash—along with the midstory and overstory hardwoods that increased during fire suppression periods. On typical longleaf upland sites in Alabama, thinning reduced hardwood basal area by 55 percent (Outcalt 2005) and proved to be the quickest way to restore stand structure to the conditions normally found in frequently burned longleaf stands. Thinning is also routine for removing excess stems and mesic hardwoods in loblolly, shortleaf, and oak-pine stands of the Piedmont; and is the standard prescription for restoring red-cockaded woodpecker habitat. A very intensive form of thinning has been used to remove all sand pine, only leaving residual longleaf pines on sandhill sites in Florida (Provencher and others 2000). To support the open conditions needed by cane to flourish, hardwood overstory has been thinned as part of the restoration treatment for some bottomlands.

Thinning treatments create considerable slash-type fuel, but also reduce midstory layers and create a more open stand with a lower crown density. To remove slash and reduce wildfire hazard, prescribed burns are routinely applied afterward. Often slash is allowed to decay for a period to reduce fire intensity, but burning is also possible soon after thinning operations (Outcalt 2005). Burning has the added benefit of reducing the density of understory hardwood stems, and can stimulate growth of grasses and forbs in loblolly stands after a thinning operation (Waldrop and McIver 2006).

Clearcutting is used mostly in situations where the dominant overstory tree species is poorly adapted to the habitat and needs to be replaced with a different species; for example, removing slash, loblolly, or sand pine from former longleaf pine sites or slash pine from dry prairie. Fuel created by these harvesting operations can be chopped and burned or just burned. With slash or loblolly pine, an alternative to clearcutting is to create openings that are planted with longleaf pine. This keeps large trees on the site that will furnish litterfall to help carry fire, but it also leaves a seed source for competing seedlings, which must be controlled with frequent burns.

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Herbicides

Herbicide treatments, with a variety of modern target-specific formulations aimed at understory and midstory layers, have been applied in pine plantations for some time. Many land managers also use herbicides specifically for fuel reduction. A recent survey in Florida found that 41 percent used this fuel reduction technique (Wolcott and others 2007). Forest industry rarely burns stands following herbicide application because of volatilization of nitrogen and smoke-management issues. Even without followup burns, herbicide treatment reduces fire intensity (Brose and Wade 2002), but offers less protection than regular prescribed burning during severe droughts (Outcalt and Wade 2004a).

Often just the first step in fuel reduction and restoration treatment that includes prescribed burning, herbicide treatment is generally used in areas with dense shrub layer vegetation that is difficult to burn. The objective is to kill the aboveground stems, allow more light to reach the surface, and increase the range of conditions that are favorable for prescribed burning. This approach has the added advantage of significantly accelerating the restoration process and reducing the time that fuel loads are high. On upland longleaf pine sites, herbicide followed by burning has been shown to be more effective than burning alone for sustained reduction of understory shrubs and woody vines (Outcalt and Brockway 2007). Herbicide has also been shown to be quite effective when combined with burning for restoring longleaf wiregrass communities on sandhill sites (Brockway and Outcalt 2000).

Comparisons and Use

Each of the various fuel treatment options has positive and negative impacts that land managers must consider (table 4). Prescribed burning is inexpensive, especially with the economies of scale that come with burning large blocks. It also provides many ecological benefits that cannot be achieved with other treatments, and it causes very little soil disturbance. The major drawbacks are smoke impacts to offsite areas and potential for damage if there is an escape. These are especially troublesome where housing developments are immediately adjacent to forest areas. In these areas, mechanical treatments with choppers, mowers or mulchers are more appropriate as a first treatment and can make subsequent burns easier to conduct and control (Glitzenstein and others 2006). However, these techniques can be more costly and allow more potential for soil disturbance.

Both manual felling and harvesting can be applied to remove specific unwanted species or stems while leaving desirable ones in place. Harvesting has a special advantage in that it produces revenue from the sale of products removed.

Herbicides are quite effective at controlling target vegetation, are fast acting, and often make followup burns easier. Public acceptance of such treatments has been uneven, especially on public lands. In addition, they create dead fuel that may temporarily increase wildfire hazard.

Prescribed burning is the most widely used fuel treatment in the South because of its history of use, its low cost, and the ecological benefits it provides. On Federal properties alone, it was applied annually to 888,000 acres (359 000 ha) in 2006 and 2007. Another 949,000 acres (384 000 ha) were burned by State and other public land managers in 2007 (www.nifc.gov/nicc/sitreprt.pdf). Mechanical fuel treatments are applied to less area but are still used extensively, with an average of 85,690 acres (34 700 ha) treated annually on Federal lands in 2006 and 2007. Treatment amounts for other public lands are not know but can be assumed to be similar—about 10 percent of total area treated with prescribed burns. Mechanical treatments are most often used in the wildland-urban interface. On Federal lands 86 percent of all mechanically treated acres are in this wildand-urban interface. Herbicide application for fuel reduction is widely used, but estimates of annual treated area for public lands are not available. Dubois and others (2003) reported herbicides were used to control hardwoods in 657,000 acres (266 000 ha) of pine plantations in 2002.

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Table 4. Advantages, disadvantages, and costs of fuel treatment options being used in the Southern United States

	Treatment				
Attributes	Prescribed burn	Mechanical	Manual	Harvesting	Herbicide
Advantages	Low cost	Burning easier	Selective	Selective	Effectiveness
	Ecological benefits	Use in urban areas	Use in urban areas	Revenue producer	Burning easier
	Soil disturbance minimal				
Disadvantages	Smoke	Can be costly	Can be costly	Fuel created	Public acceptance
	Potential escapes	Fuel created	Fuel created	Potential site damage	Fuel created
	Resource damage	Equipment breakage			
		Potential site damage			
Cost *(per acre)*	\$23 to \$121[a]	\$120 to \$350[b]			\$68 to \$2,000[c]
		\$35 to \$1,000[c]			

[a] Cleaves and others (2000).
[b] Rummer and others (2002).
[c] Wolcott and others (2007).

Conclusions

The Subtropical and Savanna Divisions, which include the Coastal Plain and Piedmont of the Southern United States, contained a diverse suite of forest and grassland communities before the arrival of Europeans. The common process that shaped and linked most of these communities was fire. For many, fires were frequent, low-intensity processes that maintained health, functioning, and composition. Others had less frequent but more intense mixed- or stand replacement fire regimes. Fire caused by lightning and Native Americans has long been recognized as the reason that longleaf pine was the most abundant forest community (Chapman 1932). Although other southern pines are not as resistant to fire during their seedling stage, fire was necessary on most sites to maintain pine dominance. Pine, oak, and hickory were dominants on many Piedmont sites because fire gave them a competitive advantage over more mesic hardwood species (Skeen and others 1993). Even the very wet communities—cypress domes, seepage savannas, marshes, and bottomland canebrakes—experienced frequent fire, at least on the edges, because they were imbedded in or adjacent to the pine dominated matrix. Thus, most of the South was driven and molded by fire.

European settlement significantly altered the amount, composition, and age structure of southern forests, as did subsequent years of fire exclusion. Today, active management is required if we wish to restore and maintain those key forests that remain (Van Lear and others 2005). Because the South has a long growing season and plentiful precipitation, it is quite productive and accumulates living and dead fuels rapidly. Thus, fuels management on a regular basis is a necessary part of management, required to reduce wildfire hazard and maintain ecosystem health. Because of its low cost and ecological benefits, prescribed burning is the most common fuels management technique used.

Mechanical systems that target understory and midstory layers have also become widespread, especially for treating forests in the wildland-urban interface. This technique, which includes chopping, mulching, mowing, and hand felling, is usually applied to facilitate a subsequent prescribed burn. Thinning is used in a similar fashion when the stems that need to be removed are large enough to have economic value. Herbicides are also applied to select stands, also to accelerate restoration or facilitate burning.

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Most systems are being managed with short fire-return intervals of 3 to 5 years. Other fuel reduction techniques are applied only once if they are followed by burning; otherwise, they need to be reapplied at the same interval of 3 to 5 years. This frequent repetitive treatment over a significant area could cause cumulative effects on the landscape.

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