FUEL MANAGEMENT IN THE SUBTROPICAL AND SAVANNA DIVISIONS

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INTRODUCTION

These divisions, which are based on Bailey's (1996) ecoregions , are both 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 (see chapter 3 for details on climate and soils). It has no pronounced dry season but precipitation is normally higher during summer. Soils are strongly leached and rich is iron and aluminum oxides. The natural vegetation throughout much of this 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, which this document covers, it is found only in south 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.

A number of different forest and non-forest ecosystems historically occupied the subtropical division. Prior to European settlement the region 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 regions of the lower and middle coastal plains. Other forest types like cypress and hardwood hammocks were imbedded in this pine matrix. The Piedmont portion of this division, which lies at a northeast to southwest direction between the coastal plain and the Appalachian Mountains, was a mixture of pine, pine - hardwood forests, and oak – hickory type. Mesic hardwoods occupied the river terraces and richer bottomlands. The savannah division was covered with wet and dry prairie, cypress swamps, pine flatwoods and rocklands, hardwood and palm hammocks, and sub-tropical hardwoods.

These two divisions have all of the fire regimes described by Brown (2000) with much of this region 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 types had mixed severity fire regimes with less frequent but more intense fires that killed a substantial portion of the overstory (Wade and others 2000). There were also ecosystems that had a stand replacement fire regime with periodic intense fires that killed the overstory but created conditions that favored regeneration.

Marshes and prairies covered quite extensive areas and were maintained by frequent fires. These were mostly stand replacement fires since the above-ground portion of the dominant life form was killed. Now they are often burned for ecological reasons rather than fuel management, although this is also important in some cases. Other systems like mixed mesophytic hardwoods, bottomland hardwoods, and sub-tropical hardwoods normally had an non-fire regime with little or no natural fire. Since fires are rare in these systems, fuels management is not needed and they are excluded from further discussion.

The first portion of this chapter is a brief description (see chapter 2 for detailed descriptions), former and current extent and fire regime for each major forest type where fuel management is applied in the subtropical and savanna divisions of the eastern United States. 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 forest types. This is not a comprehensive prescription of how to apply these techniques, but rather to put in context the potential for cumulative impacts from the different treatments. Those wishing to obtain more detailed information on using these techniques should consult cited references and additional resources like Encyclopedia of Southern Fire Science and Fire and Fire Surrogate Study, which are available at Frames website (frames.nbii.gov).

MAJOR ECOSYSTEMS

Understory Fire Regime

Longleaf pine -- *Pinus palustris* was once the most prevalent pine type in the subtropical division, where it dominating 60 million acres (25 million ha) and was a co-dominant with shortleaf (*P. echinata*) and loblolly pines (*P. taeda*) on another 30 million acres (12 million ha) (Frost 2006). Its range extended south from southeast 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 South 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 northwest Georgia, where it was found growing at elevations up to 2000 feet (600 m) (Boyer 1990).

Logging of the valuable longleaf pine forests that began in colonial times, reached a peak shortly after 1900 (Ware and others 1993). Clearing of forestland for urban and agricultural uses, conversion to loblolly and slash pine (*P. elliottii*) plantations, and harvest without regeneration all contributed to the continuous decline of the once dominant forest type of the south. By 1935, only about 20 million acres (8.1 million ha) of longleaf pine forest remained (Wahlenberg 1946). The amount declined 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) in 2006 or 25 percent of remaining longleaf forests.

Prior to landscape fragmentation extensive natural fires occurred every 2 – 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 dominated much of the rest of the region because it was more tolerant of these frequent fires than its competitors, 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 stands were the grasses. The living and dead leaves of these grasses 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). These wildfires also spread into embedded communities such as seepage slopes, savannas, and canebrakes. Without longleaf to propagate fire on the landscape these system degrade and lose their diversity.

Lightning and Native Americans provided the ignition sources for these fires, which shaped the vegetation of the region (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 during any month. Lightning density, 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 and although there are fewer strikes 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 natural 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 -- *Pinus elliottii* is native to the Lower Coastal Plain from Georgetown County, SC to Tangipahoa Parish, LA 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 flatwoods sites contained some longleaf pine on the dryer fringes where they graded into the longleaf wiregrass flatwoods and some swamp blackgum (*Nyssa sylvatica* var. *biflora*) and pond cypress (*Taxodium distichum* var. *nutans*) in the transition zone to wetland communities. The understory consisted of evergreen shrubs and trees with saw palmetto (*Serenoa repens*), gallberry, fetterbush (*Lyonia lucida*), and loblolly bay (*Gordonia lasianthus*) common dominants. Herbaceous species were sparse occurring as scattered grasses and forbs in spaces between shrubs. Since longleaf pine did not occur south of Lake Okeechobee in Florida, those flatwoods forest were dominated exclusively by slash pine (Little 1971). Schultz (1983) estimated the original slash pine flatwoods area at about 7 million acres (2.8 million ha) with the largest concentration in Florida and south Georgia.

These flatwoods forests have been heavily impacted over the last three centuries. Much of the slash pine and mixed slash and longleaf pine were cut over between 1780 and 1860. These areas were logged first 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 between 1870 and 1920 using temporary railroad spurs and steam skidders. Because slash pine is a prolific seed producer it rapidly colonized cut over 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 there was a shift to more intensive forestry. This often resulted in the replacement of natural stands following harvest with plantations on heavily site prepared areas with a greatly altered understory (Schultz 1976). By 1980 over half or 52 percent of all slash pine stands were plantations (Sheffield and others 1983) and this trend has continued. Today there are nearly 10 million acres (4 million ha) of slash pine with 70 percent in privately owned plantations (Miles 2007).

The likely natural fire regime for slash pine flatwoods is frequent surface fires every 4 - 6 years ranging up 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 flatwoods areas if they are dry enough to burn. They generally burned through the understory vegetation but only the dry upper portion of the litter layer was consumed. 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 happens overstory mortality was often high with either total replacement or substantial thinning. Although fire could occur in any season, in pre-European settlement times many lightning fires probably occurred during the dry late spring to early summer season. Specific months varyed with latitude but were generally from mid-April to June. Once the summer thunderstorm season begins these areas soon became too wet to burn. Native Americans augmented this by setting fires during dry periods of the dormant season.

Loblolly pine – *Pinus taeda* has an extensive natural range stretching from New Jersey along the coast to east Texas and inland through the Piedmont to Tennessee and Arkansas. Although able to grow across a wide area on many different sites, Schultz (1997) estimated that before European settlement loblolly pine dominated no more than 5 million acres (2 million ha) of southern forests. It was often a minor species of uplands found with longleaf, shortleaf or 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 due to establishment following major disturbance from fire or wind (Skeen and others 1993).

Colonization dramatically changed the southern landscape through agricultural clearing and logging. 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 was aided in recent times by fire control measures that give loblolly seedlings an advantage. Loblolly pine was also very successful at seeding into abandoned cotton fields, thus the common name of old-field pine. Loblolly pine was also widely planted in industrial forest plantations. The result was 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 dominating 33 million acres (13.4 million ha) (Schultz 1997). 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 southern region burned with some regularity. There were low intensity surface fires every 4 to 12 years (Frost 2006) on these dryer upland locations. Although seedlings less than 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 – *Pinus echinata* 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). Within the subtropical division it is found on the coastal plains and piedmont and in the subtropical mountain division the interior highlands physiographic regions. 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 east Texas. Where ranges overlapped loblolly pine dominated the moister soils while 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 (*P. virginiana*) pines in the northeast (Lawson 1990). It was often also found in mixed hardwood stands where it shared dominance with oaks and hickories.

Mattoon (1915) noted a decline in shortleaf pine due to agriculture and logging in the early 1900s. With the onset of logging in the Ouachita highlands of Arkansas, substantial declines continued through the 1950s (Smith 1986). Often cutover stands were planting with loblolly pine even north of its native range and in industrial forest 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 was common as loblolly 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 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 over 5 feet (1.5 m) tall will survive surface fires unless crown scorch exceeds 70 percent (Wade and others 2000). If young trees are top-killed they will readily sprout. Older trees, i.e. those larger than 4 inches (10 cm) at dbh, have thick bark that protects the bole from surface fires (Walker and Wiant 1966). Because of these characteristics frequent low intensity fires give it a competitive advantage over many hardwoods. The historic 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 with an early growing season to summer maximum on the coastal plain. In the northern and western portions of the range there is much less lightning and it has a bimodal distribution with both a spring and a late summer to early fall 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 cover type 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 extent prior to European settlement is not known, but it was widespread and prevalent in the piedmont, upper hilly coastal plains and interior highlands. The predominant group were the oaks including white (*Quercus alba*), northern red (*Q. rubra*), black (*Q. velutina*) and on drier steeper sites scarlet (*Q. coccinea*) and chestnut (*Q. prinus*) (Sander and others 1983). 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 (*C. tomentosa*), shagbark (*C. ovata*) and bitternut (*C. cordiformis*). The pine component when present was loblolly, shortleaf, pitch, Virginia, or white (*P. strobus*). There were often more mesic hardwoods like yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), ash (*Fraxinus* spp.), and elms (*Ulmus* spp.). The pine owed its existence to natural disturbance such as fire and wind or to extremely poor sites (Skeen and others 1993).

This type historically covered most of the piedmont physiographic province. It was greatly reduced by agricultural clearing but rebounded following soil depletion and abandonment. This land use 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 region. Significant quantities of oak and hickory were also harvested for lumber and for charcoal production for the iron smelters that sprang up across the region. Frequent fires, which occurred until effective fire control was implemented in the 1950's, also favored pines. Once fire control was instituted and pine stands began to be harvested, pine coverage declined as many sites were captured by hardwoods following commercial clear-cuts (Boyce and Knight 1980). More recently there has been a significant increase in population in the piedmont region that is impacting this forest type. However, the region still contains about 32 million acres (13 million ha) of oak –hickory – pine forest (Miles 2007).

The natural fire frequency in this type 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 south and west 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 of this forest during the late fall dry period. Native American ignitions were more important toward the interior where the landscape is most dissected and less exposed to extensive fires from lightning. Across the region 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 south Florida it once occupied 180,000 acres (72,900 ha) (Davis 1943) on the Miami Rock Ridge from north of Miami to Homestead and southwest through long pine key in Everglades National Park. It was also found on the lower 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, and thus the term rocklands. Vegetation actually grows on the bedrock, rooting within the rocky rubble in thin layers of sand, marl and organic matter, which has accumulated in depressions, crevices and solution holes. In the lower keys over 50 percent of the ground can be exposed rock while 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 including many local endemics (Snyder and others 1990).

Since these pine forests were found on higher and dryer land they were the first to be cleared for building sites beginning around 1900. There was only limited logging 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 development of the rock plow in 1954. This machinery was used to breakup the limestone bedrock allowing large scale row crop farming. Fragmentation and fire control have also lead 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, Big Cypress National Preserve and National Key Deer Refuge, which is located 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 that are kept from matting by the rough rock surface and understory vegetation. The rocky porous substrate allows water to quickly drain and the open pine canopy fosters rapid drying. These characteristics lead to frequent low intensity surface fires that consume the litter and understory vegetation (Snyder and others 1990). Pine canopies 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 saplings from 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 the ability to sprout from the root collar if top killed (Ketcham and Bethune 1963). The above ground 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 south Florida and was the primary ignition source often starting fires in wet prairies that sweep 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 during 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 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 region of New Jersey contained the largest concentration of pitch pine growing on glacial deposits ranging from excessively to poorly drained sands and gravels. The historic extent of pitch pine is not known, but the barrens region alone contained over 1.1 million acres (450,000 ha) where pitch pine was likely a major overstory species in many of the historic communities. Depending on site and fire history, trees ranged from dwarf, less than 11.5 feet (3.5 m), on the driest most frequently burned sand plains to 39 feet (12 m) tall in more fertile swamps. Common associates included bear (*Quercus ilicifolia*), chestnut, white, black, and northern red oaks 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 US have been impacted by 400 years of human use, which included clearing, cultivating, grazing, logging, and burning. Initially there was also an increase in fire frequency 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 barrens region, but it was 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). Recently, effective 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 pine barrens region, they are changing do to lack of fire (Hall and others 2002), The need for prescribed fire is widely recognized but this 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. It has a thick bark to protect it from fire, buds on the bole that can produce new foliage, the ability to sprout, serotinous cones that release seed following fire, and cone production at very young ages, i.e. 3 to 4 years for sprouts (Little and Garrett 1990). The large flat expanses of droughty soils allowed fires to easily propagate across the landscape, thereby increasing burn frequency. Thus, the central region of the barrens where dwarf pine is common, are estimated to have a historic 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 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 both spring and fall on a 2 to 10 year interval with lower intensity understory burns, which produced open pitch pine stands with relatively large pines (Wade and others 2000). However, Parshall and Foster (2002) concluded that natural ignitions alone were sufficient to maintain the barrens prior to European settlement.

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 (*Quercus myrtifolia*), sand live oak (*Q. geminata*), Chapman's 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 off-shore islands, of northwest 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). Mid-story oaks were a prominent feature of these sand pine stands with sand live oak the most common. Beneath the mid-story 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 its droughty, infertile soils, scrub habitats were used only infrequently by Native Americans and early settlers (Myers 1990). It was later discovered that they were well suited to citrus production and many in the lower portion of Florida's central ridge were cleared for this purpose. Coastal scrubs in peninsula regions were converted to urban use as major cities such as Miami and Tampa 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 over 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 1950's. Since that time significant areas have been harvested, but were regenerated on public lands. Choctawhatchee sand pine was restricted to the coastal regions by frequent fires. A combination of harvest and effective 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 pine across the Florida panhandle. Thus, there is more of this type now than existed in historic times before European settlement. On Eglin Air Force Base, longleaf once covered an estimated 85 percent of the area but now occupies about 15 percent while sand pine has increased from 10 to 40 percent or 185,000 acres (75,000 ha).

Ocala sand pine scrub has primarily stand replacement fires from 10 to 35 years but some fires occur at shorter or longer intervals. Because of its sparse ground cover and compacted litter layer, much of the time sand pine scrub is virtually fire proof. However, every 10 to 100 years, usually during the spring drought, high winds and extreme conditions result in a catastrophic wildfire (Hough 1973). This fire kills the sand pine overstory and burns off the understory (Myers 1990). The heat from the fire 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 that killed only a portion of the overstory. Unlike Ocala, most of the cones will open when mature so seed are shed annually and will re-establish 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 southeast corner of Alabama (Bramlett 1990). It once occupied a significant area of poorly drained sites in this region with the largest concentration in North Carolina where it was the dominant overstory on 2.5 million acres (1 million ha) of raised bogs called pocosins (Richardson 1981). Pocosins had 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 where it was often embedded in communities dominated by other southern pines, bottomland hardwoods like swamp tupelo and sweetbay (*Magnolia acuminata*), or swamp conifers like Atlantic white-cedar (*Chamaecyparis thyoides*) and cypress (Wade and others 2000). Pocosins often have a thick understory layer of evergreen shrubs and smilax vines. Common shrubs species are gallberry, titi (*Cyrilla racemiflora*), waxmyrtle (*Myrica cerifera*), and sweet pepperbush (*Clethra alnifolia*). Switch cane (*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 US from the 1800's 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 in a natural state in 1980 (Richardson and others 1981). Conversion to plantations and agricultural crops has continued so even less remains today. There has also been a reduction in fire, which has allowed shrubs to increase in dominance at the expense of grasses (Frost 2002). Even though its 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 top-killed 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 natural 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 (FNAI 1990), woodlands burn every 10 to 20 years (Sutter and Kral 1994), pocosins every 13 to 50 years (Frost 1995), and bogs and swamps from 50 to 150 years (FNAI 1990). Currently wildfires are common in the spring, but can occur whenever drought conditions arise (Wade and Ward 1973). Natural fires were probably most common in the spring because this 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. Because of its adaptations however, most were mixed severity fires where a portion of the overstory pond pine survived. 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 often overlain by peat or muck. Cypress ponds or domes are isolated depressions ranging in size from 2.5 to 25 acres (1 to 10 ha) 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*), titi, waxmyrtle 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 southwest Florida where it occupies 370,000 acres (150,000 ha) (Muss and others 2003). 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 to the dry season. In addition ponds and strands are found imbedded in pyric flatwoods types that burn quite frequently and they 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 when it was 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 period 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 1900's (Dennis 1988). Recently, logging has become quite widespread, however with the development of commercial production of cypress mulch for the landscape industry. Many pond cypress domes have been clear-cut over the past 20 years to furnish trees that are ground up for mulch (Black and others 1993). Pond cypress does have the ability to stump sprout and thus should regenerate most harvested areas (Terwilliger and Ewel 1986). Alteration of hydrology by drainage began much sooner 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 a pine flatwoods type vegetation.

Stand Replacement Fire Regime

Dry prairie – This community is found only in south Florida with the largest concentrations historically along the Kissimmee River, west and south of Lake Okeechobee, and the region north of Charlotte Harbor in Sarasota and Manatee counties. Harper (1927) estimated it covered 1,285,000 to 1,927,500 ac (520,000 to 780,000 ha) but more recent data indicate it once occupied about 2,051,000 ac (830,000 ha) (Shriver and Vickery 1999). Also called palmetto prairie, it is a treeless grass dominated community that occurred on broad flat regions 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 region 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 (*Aristida beyrichiana*) with scattered saw palmetto and patches of runner oak (*Quercus minima*). Other common plants include bottlebrush three awn (*A. spiciformis*), broomsedge (*Andropogon virginicus*), fetterbush, coastal plain lyonia (*Lyonia* f*ruiticosa*), dwarf blueberry (*Vaccinium myrsinities*), and yellow eyed grasses (*Xyris* spp.)

Today only about 10 percent or 385,500 ac (156,000 ha) of intact palmetto prairie remain in south 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 natural 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 (Hufffman and Blachard 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 re-sprout quickly and re-vegetate 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). The southern region of Florida were 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 historic 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 re-moistened (Beckage and Platt 2003).

Freshwater Marsh – In the southeast 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 historic 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 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 covering about 1,976,835 ac (800,000 ha) (Wade and others 2000). 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 over 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 replaced 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 natural 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 types found in south Florida in the Savanna division are unique because of the their size, location and special character. The everglades is 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. The region has a subtropical climate with a wet rainy season with almost daily thunderstorms from mid May to October when 80 percent of rainfall occurs followed by a dry period with little rainfall (Gunderson and Lofus 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 south 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 south Florida. It was dominated by the grass like sedge called sawgrass (*Cladium jamaicensis*) because of the sharp edges on its leaf blades (Kushlan 1990). Composition varies from sites with nearly pure sawgrass, which grows up to 10 ft (3m) high, to a mixture of 30 species. Other common associates are spikerush (*Eleocharis celllosa*), water hyssop (*Bacopa caroliniana*), beak rush (*Rhynchospora tracyi*), switchgrass (*Panicum virgatum*), maidencane and saltmarsh morning-glory (*Ipomea sagitatta*). The marl prairie is a mixture of many species usually less than 3 ft (1 m) tall, including Muhly grass (*Muhlenbergia filipes*), sawgrass, black bogrush (*Schoenus nigricans*), beak rushes (*Rhynochospora* spp.) and Florida bluestem (*Schizachyrium rhizomatum*) (Jenkins 2008). This community once covered about 445,000 ac (180,000 ha) of south Florida in the everglades basin (Davis 1943).

Beginning in the early 1900's efforts were made to drain the everglades to make the area available for agriculture and urban development. To date over half of the of the area has been drained. Everglades National Park was established to protect the unique area 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 1250 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 historic 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 more patchy 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 extent of the area covered by canebrakes before European arrival 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. Bartram (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 ft (9 m) tall up 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 an ubiquitous material that native Americans used for many daily items from firewood to containers. When traveling, if a river to 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 greenbrier (*Smilax laurifolia*), gallberry, swamp cyrilla (*Cyrilla racemiflora*), waxmyrtle 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 historic 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 southern region 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, 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, its 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/day (3cm), 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 re-establishment. 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 accomplishments. In most applications it is used to achieve multiple objectives. Fuel treatment in all vegetation types depends on where the site is located, its current condition and desired outcomes. In forested ecosystems when the major goal is wildfire hazard reduction, it’s applied with the objectives of reducing surface fuels, increasing distance to the live crown, lowering crown density and/or increasing the dominance of large fire resistant trees (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.

Fuels reduction was first used in this region mostly for 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 a strong relationship between area burned by wildfires and the intensity of those fires with the time since the last prescribed burn. Recent work has also documented that tree mortality from wildfires under extreme conditions is lower in sites recently prescribed burned (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 in the discussion above most of the ecosystems native to this region are adapted to fire either quite frequently or at least periodically. If fire is removed, then they change in undesirable ways that affect the habitat often reducing biodiversity and contributing to the decline of endangered species. This has lead 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 southern U.S. is blessed with a long growing season and plentiful precipitation, and therefore the forest and grassland ecosystems are quite productive. This leads to a rather 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/acre (25 sq m/ha) accumulates forest floor quite rapidly and will contain 6.6 tons/acre (14.8 MT/ha) in just 4 years (Table 1). In addition it has another 2.7 tons/acre (6 MT/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/acre (24.4 MT/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 support 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 them difficult to burn or to control wildfire. 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 types accumulate fuel very quickly and its fine nature and arrangement make 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 types from wet flatwoods to droughty sandhills and in all physiographic provinces from 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 are burned every 3 to 4 years on sandhills, flatwoods and wet coastal sites. More productive mesic uplands are typically burned on a 2 to 3 year cycle especially those lands managed for wildlife production. More frequent fires are also applied to areas with excess fuel accumulations and/or midstory hardwoods (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 temperatures were lower. For the last 15 years however, many more areas are being burned during the growing season, which is more effective at reducing hardwoods (Waldrop and others 1987). Because of differences in affects due to season, its best to include variation rather than repeatedly burn a particular site at the same time. Growing season burns are avoided by many quail plantations to limit nest loss.

Although private lands are often still burned with drip torches and strip headfires or flanking fires, there has been a general trend on public lands of burning in larger blocks. Today many of the burns are ignited using helicopters that quickly create many spot fires, which allows 500 to 2500 acres (200 to 1000 ha) to be burned as a unit in one day. This firing technique impacts more of the watershed at one time, but also more closely mimics the larger size of natural fires in longleaf communities prior to 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 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 and only about 37 percent are burned every 5 years (Outcalt 2000) or 148,000 acres (60,000 ha) annually.

Slash Pine Flatwoods – Since 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 of 1 to 4 years with most sites burned every 3 or 4 years. More frequent burning is necessary during restoration treatments to reduce fuel loads and palmetto and woody understory cover, while increasing herbaceous growth. Because young saplings with a ground level diameter of less than 2 inches (5 cm) can be killed by surface fires (Johansen and Wade 1987), burning is not done in young plantation or naturally regenerated stands until trees are 3 to 5 years old. Historically most burning was conducted during the dormant season but more is now being done during the growing season, especially on public lands because of ecological benefits and because most managers 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 using more helicopter ignited spot firing that treats larger blocks in a single burn. Thus, slash pine flatwoods are often burned as part of a larger burn along with adjacent longleaf pine dominated stands. There is some prescribed burning on private areas but forest industry stopped burning most of its plantations because of liability issues from smoke on roads. However, burning in slash pine dominated stands is still a big portion of total burning in the region because slash pine has been planted extensively and captured a lot of former longleaf area following logging and fire control during the first half of the 1900s. There are 1.63 million acres (660,000 ha) of slash pine on public lands with two-thirds in natural stands. Assuming an average fire return interval of 5 years, there are 326,000 acres (132,000 ha) burned annually.

Loblolly Pine – This species is not really considered to be fire dependent and was historically confined to wetter or sheltered sites where surface fires were not as frequent. However, it is tolerant of fire once saplings attain a ground level diameter of 2 inches (5 cm) (Wade 1993). Once past this stage stands can and 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. This is sufficient to reduce fuel loads, especially in plantations after crown closure, which 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 are more effective than dormant season for top-killing hardwoods (Wade and others 2000) and reducing hardwood rootstocks, if applied at least every 2 years (Waldrop and others 1987). Growing season fires are avoided by many private owners to protect nests of turkey (*Meleagris gallopavo*) and bobwhite quail.

On public lands large blocks of loblolly dominated forest can be burned using helicopter ignition, if there are no young seedlings and saplings that must be protected. There is still considerable prescribed burning 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. There are currently 6.4 million acres (2.6 million ha) of loblolly forests in public ownership with 70 percent in natural stands. Based on an estimated average fire return interval of 6 years, public land managers would burn about 432,000 acres (175,000 ha) of loblolly pine stands annually.

Shortleaf Pine – Much of the remaining shortleaf pine is found in the piedmont and western highlands of this division on the drier ridges. As with other southern pines it underwent a period of fire suppression, which allowed hardwoods and other species to capture many natural sites. Recently burning has been more prevalent with the goal of restoring natural community structure and returning shortleaf to more productive sites. Because it is quite resistant to surface fires, it can be burned every 2 to 5 years. For seedling establishment burns should be every 4 to 6 years (Masters and others 2005). This allows saplings to grow beyond the size where fire will cause high mortality rates. Stands can be burned at longer intervals of 12 years, but this will result in denser stands with a less open structure compared to a 5 year fire return interval (Masters and others 2005). Shorter fire returns of 3 years produce a grass dominated understory but stocking will be less than optimal 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 every 3 years greatly improved wildlife habitat, but there is also a need for variation with burning in all seasons on a frequent basis for maintaining this forest type (Masters 2007).

Prescribed burning in shortleaf pine stands on public lands has been mostly by hand ignition or with torches attached to ATV's. Because of safety issues and the need to increase area burned each year, helicopter burning using ping pong ball spot ignition is being used to burn larger blocks of forest. Average burn unit size has increased on the Ouachita National Forest to 620 acres (250 ha) with some as large as 7400 acres (3000 ha). There are about 951,000 acres (385,000 ha) of shortleaf pine on public lands with 91 percent of natural origin. Assuming an average fire return interval of 5 years yields 190,000 acres (77,000 ha) burned annually. There is also some burning on private lands but virtually none on forest industry property.

Oak - Hickory - Pine Woodlands – The role of fire in perpetuating this type was only recently recognized (Lorimer 1993). Recent research has shown that prescribed burning can be used to aid establishment of regeneration, which can latter be released by subsequent burns (Wade and others 2000). Burn frequency depends of goals and initial conditions with annual or biennial burns used to reduce shading by competing hardwoods and open up the stand to promote establishment of oak and hickory seedlings. In stands with established regeneration, a shelterwood cut is often needed to enhance growth of oak and hickory regeneration. Fire should be withheld until oak seedlings are 0.8 inches (2 cm) in root collar diameter. Then a growing season burn is applied to kill the regeneration layer, which removes less fire tolerant species but oaks and hickories will 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 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 problem. The justification for burning is to restore former habitats that likely existed largely because of Native American burning. Therefore, public resistance to prescribed burning in this habitat on federal and state properties remains. Some managers however, are burning mixed stands of this type with many of the first fires applied during the dormant season, to remove excess fuel accumulations. Ignition is often with drip torches and backing or flanking fires from ridge tops. The total area is not yet large, but it is growing as the importance of fire is recognized and with the support of outside environmental and conservation groups.

Pine Rocklands –What remains of these fire dependent systems are mostly on public lands, which are burned frequently, every 3 to 5 years, to control understory hardwoods and maintain ecosystem health. A slightly longer fire free period may be necessary to allow young slash pine seedlings to become large enough to survive fire (Olmsted and Loop 1984). This also fits with the need for variation to more closely mimic presettlement fire frequency (Snyder and others 1990). Historically managers 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, while at Big Cypress Preserve the largest burns are done during this June and July period, but significant areas of pinelands are also burned in late winter to early spring (January and February). Research has shown that fire intensity and not season determines how effective burning is for reducing understory hardwoods (Snyder 1986). 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. Thus, other factors are more critical than season of burn.

In Everglade National Park burns are ignited by helicopter or with vehicle mounted torches. Burns are managed using natural features of the landscape to determine burn areas. Thus, burn size has been increasing and now are several hundred acres 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 with some over 7400 acres (3000 ha) and encompassing multiple community types.

Mixed Fire Regime Communities – Prescribed burns have been conducted in pitch pine barrens since the 1950's to reduce fuel loads and the danger from catastrophic wildfires (Buell and Cantlon 1953). Burns were initially 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 because successive annual growing season burns are more effective for restoration as they will reduce hardwood sprouts and kill many root stocks (Popp 1987). Once fuel loads are reduced and hardwoods restored to a low level, burns can be on a longer interval of 10 to 15 years. Many of the remaining pitch pine stands are small fragments of former forests and large burns are possible only in some of the more extensive barrens of New Jersey.

Sand pine is the most fire sensitive of the southern pines, but the Choctawhatchee variety can still be prescribed burned. Eglin Air Force Base began low intensity understory dormant season burns of sand pine to control fuel loads and improve access in the 1960's (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 5000 acres (300 to 2000 ha), which included both habitat types and are conducted in all seasons on suitable burn days. Prescribed burning is also used extensively on the Ocala National Forest to control invasion of sand pine into longleaf sandhills. In addition 2900 acres (1160 ha) of sand pine scrub is being managed as scrub jay (*Aphelocoma coerulescens*) habitat. Stand replacement prescribed burns are used in this area with 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 (3,000 to 5,000 ha).

Pond pine pocosin can be prescribed burned but requires specific conditions where the fire consumes understory shrubs but is not so intense that significant mortality occurs in the overstory. 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 community types. This is especially true on areas with peat accumulations and long unburned areas with high fuel loads. However, some burning is being done on public lands. On the Croatan National Forest the goal is to apply fire at its natural return interval to the wilderness areas, including pond pine type. The goal for areas outside the wilderness for fuel reduction is a fire return interval of 3 to 5 years. They burn around 5000 acres (2000 ha) of pond pine pocosin per year with most burning from November to February. If weather is favorable some burning is also done in February through April. Burn units are 500 to 2000 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 (DoD) are also burning pond pine habitat as part of their overall prescribed burn program. The goal for pond pine woodlands and high pocosins on DoD lands is a 5 – 8 year fire return interval, with a shorter 3 - 5 year interval in areas with endangered plants that require open conditions. Most burns are small units to limit smoke production and provide a range 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. This was quite detrimental as it compromised the hydrology, disturbed the ecotone area, which is the habitat for many rare plant species, and kept fire from entering the cypress zone. This is no longer done on public lands and thus these cypress wetlands receive fire at the same interval as the surrounding habitats, i.e. every 2 – 5 years. Because the cypress community is wetter, most of these fires only burn the edge with depth of penetration controlled by water levels at the time of the burn. Both dormant and growing season burns are used with dormant season favored in areas of high fuel loads from former fire exclusion. Early growing season burns at a shorter frequency are used to foster endangered plants that prefer open habitats. The larger expanses of cypress savanna in south Florida are burned in larger units that contain multiple community types. Late winter to early spring and the early wet season of June and July are the most active burn windows with a fire return interval of about 10 years in cypress savannas.

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. In 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 of this type is found in smaller units and is being burned with ground based ignition rather than helicopters. Public lands are on a 2 - 3 year fire return interval while the private ranchlands that still manage native grasslands burn every 1 or 2 years in winter or early spring to green up the pasture.

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 – 5 years to control invasion by woody species and to reduce fuel loads. Hydrology seems to be equally or more important however, as 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 fall or winter after a killing frost has increased flammability of fuel and to favor vegetation preferred by waterfowl (Gordon and others 1989). Burning when soils are moist is used to avoid igniting ground fires in the organic soils because of problems with control and smoke (Miller and others 1998).

Sawgrass and marl prairies are fire maintained systems that are burned frequently, every 3-5 years, to control fuels and maintain health. Nearly all of this habitat that remains is on public lands where regular burning has been practiced for many years. As with most southern systems, most burning was done during the winter dry season (Gunderson and Snyder 1994) but has now shifted more to the transition period from dry to wet in May and June. In Big Cypress burning is often done with aerial ignition from helicopters 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 fire breaks. To avoid ground fires prescriptions set a minimum soil moisture level of 65 percent.

For many years fire was deliberately excluded from canebrakes type because they burned quite intensely. However, when it can be burned, cane responds favorably to fire in either winter or summer (Platt and Brantley 1997). Although burning every 7 to 10 year is sufficient to maintain this ecosystem, most remnants, which are now being actively managed with fire are burned every 3 to 5 years. This more frequent burning keeps fuel loads down and also helps reduce woody species that increased on most sites during the fire free period. Due to heavy fuel loads and high flammability, the first burn in canebrakes that have not been burned for a long period is normally done when 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 so it is most efficient on areas without large trees, but it can be used in existing stands where the retained overstory is spaced around 10 feet (3 m) or greater. Mowers are best suited to treating smaller understory shrubs. Mulchers come in various sizes that can quickly chew through stems about 6 inches (15 cm) in diameter for a small unit with a front mounted cutter to high horsepower units that can take down trees up to 12 inches (30 cm). Choppers come in a variety of sizes and configurations also, 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 don't remove material from the site, they are used to change the configuration not total fuel load. Thus, the midstory and understory fuel is converted to surface fuel, which may or may not reduce wildfire severity. Most often they are a pretreatment used to prepare the area for a prescribed burn. Reducing the ladder fuels will reduce the potential for crown damage to overstory trees while making a more compact surface fuel will often allow a burn to carry under more moderate weather conditions with a lowered intensity. Therefore, except in some wildland urban interface areas where burning may not be possible because of smoke sensitive areas, these 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 sandhills sites to knock down scrub oak midstory layers that developed during fire free periods. Soil disturbance is limited by selecting a tow unit and chopper that will knock down unwanted trees but then ride mostly on top of these small stems. Chopping has also proven very useful for controlling saw palmetto on flatwoods sites and in palmetto prairie (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. Fuel biomass from palmetto did recover without additional treatment but remained lower on chopped sites that received a second prescribed burn 3 years later. Chopping is also used in Ocala sand pine scrub as a replacement for fire to reduce height of woody stems, which maintains forage and breeding habitat for scrub jays.

Mulching has been used to treat fuels in all the pine dominated types in this region. On longleaf sandhills it is used to reduce midstory scrub oaks, while on upland longleaf sites the target group is often loblolly pine and mesic hardwoods like sweetgum (*Liquidambar styraciflua*). In upland and sandhills longleaf sites in Louisiana mulching reduced midstory hardwood density by 33 percent and understory woody cover by 64 percent (Rummer and others 2002). Mulchers also can be 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 and shortleaf pine types mulching targets hardwoods and small pine seedlings and saplings in high density stands. Shrubs are the target of mulching operations on Pocosin sites. The objective in all these forest types is to reduce the midstory fuel layer so sites can be more easily and safely burned.

Hand clearing is a cleaning and or thinning operation preformed 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 sandhills longleaf type (Provencher and others 2001), especially as a midstory removal tool to improve red cockaded woodpecker (*Picoides borealis*) habitat. Hand crews have also been used to cut invading sand pine seedlings and saplings from longleaf sandhills 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 like brazilian pepper ( ) and melaleuca ( ). Hand clearing has been used to remove privet (*Ligustrum* spp.) that has invaded canebrake sites. These treatments are generally followed up with prescribed burning. Although felling does change fuel configuration, often the goal is more to speed up the restoration process compared to using burning alone.

Harvesting by clear-cutting or thinning, mostly with mechanized equipment is a normal forestry operation, but recently the benefits for restoration and fuel management have become much more prominent. It is being wildly applied for these purposes in pine types across the southern United States. On longleaf sites it is often used to selectively remove other pines, like loblolly or slash, along with midstory and overstory hardwoods that increased during fire suppression periods. On typical longleaf upland sites in Alabama thinning operations reduced hardwood basal area by 55 percent (Outcalt 2005) and was the quickest way to restore stand structure to more natural conditions found in frequently burned longleaf stands. Thinning is also routinely used in piedmont loblolly, shortleaf and pine oak stands to remove excess stems and mesic hardwoods. This is the standard prescription for restoring red cockaded woodpecker habitat in this region. A very intensive form of thinning has been used to remove all sand pine and only leave residual longleaf pine on sandhills sites in Florida (Provencher and others 2000). Cane needs open conditions to flourish, so thinning hardwood overstory is being used as part of the restoration treatment for some bottomlands.

Thinning treatments create considerable slash type fuel, but 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 following thinning. Often slash is allowed to decay for a period to reduce fire intensity, but it is possible to burn soon after thinning operations (Outcalt 2005). Burning has the added benefit of reducing the density of understory hardwood stems. Burning after thinning can also stimulate growth of grasses and forbs in loblolly stands (Waldrop and McIver 2006). Clear-cutting is used mostly in situations where the overstory is deemed to be off-site and needs to be replaced with a different species such as removing slash, loblolly, or sand pine from former longleaf pine sites or slash pine from dry prairie. Fuel created by these harvesting operation can be chopped and burned or just burned. An alternative with slash or loblolly 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.

Herbicides

Herbicide treatments with a variety of modern target specific formulations aimed at understory and midstory layers have been applied in pine plantations across this region 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 follow-up burns, there is a reduction in fire intensity following herbicide treatment (Brose and Wade 2002) but during severe droughts it offers less protection than regular prescribed burning (Outcalt and Wade 2004a). On public and private lands however, it is often just the first step in fuel reduction and restoration treatment, which is then followed with a prescribed burn. Herbicide is generally used in areas with dense shrub layer vegetation that is difficult to burn. The objective is to kill the above-ground stems, allow more light to the surface, and increase the range of conditions when a prescribed burn can be conducted. It has the added advantage of significantly speeding up the restoration process and reducing the time with high fuel loads. Herbicide followed by burning has been shown to be more effective than burning alone for sustained reduction in understory shrubs and woody vines when treating fuels on upland longleaf pine sites (Outcalt and Brockway 2007). Herbicide has also been shown to be quite effective when combined with burning for restoring longleaf wiregrass communities on sandhills sites (Brockway and Outcalt 2000).

Comparisons and Use

Each of the various fuel treatment options has pluses and minuses that users must consider (Table 4). Prescribed burning is inexpensive especially with economies of scale that come with burning large blocks. It also provides many ecological benefits that can't be obtained with other treatments and 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. Mechanical treatments with choppers, mowers or mulchers are well suited to operation in this zone and can make subsequent burns easier to conduct and control (Glitzenstein and others 2006). These techniques can be more costly and there is 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 attribute compared to all other treatments as it does produce revenue from sale of products removed. Herbicides are quite effective at controlling target vegetation, are fast acting, and often make follow-up burns easier. There is a problem with public acceptance of such treatments, especially on public lands and they do create dead fuel that may temporarily increase wildfire hazard.

Because of it history of use, low cost, and ecological benefits prescribed burning is the most widely used fuel treatment in this region. On federal properties alone it was applied annually to 888,000 acres (359,000 ha) in 2006 and in 2007 (www.forestsandrangelands.gov/reports/fuel-treatments.cfm). Another 949,000 acres (384,000 ha) were prescribed burned by state and other public lands managers in this region in 2007 (www.nifc.gov/nicc/sitreprt.pdf). Mechanical fuel treatments are applied to less area but 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 a similar proportion or about 10 percent of the area treated with prescribed burns. Mechanical treatments are most often used in the wildland interface zone (WUI) with 86 percent of all acres treated by these methods in that zone on federal lands. Herbicide application for fuel reduction is widely used but estimates of annual treated area is not available for public lands. Dubois and others (2003) reported herbicides were used to control hardwoods in 657,000 acres (266,000 ha) of pine plantations in 2002.

SUMMARY

These divisions, which includes the coastal plain and piedmont regions of the southern US, contained a suite of different forest communities before European colonization. The common process that shaped and linked most of these was fire. For many forest types fires were frequent, low intensity processes that maintained the community, although some forest types had less frequent but more intense mixed or even stand replacement fire regimes. Fire from both lightning and Native Americans has long been recognized as the reason longleaf pine was the most prevalent forest type in this area (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. In the piedmont pine, oak and hickory were dominants on many sites because fire gave them a competitive advantage over more mesic hardwood species (Skeen and others 1993). Even the very wet communities like 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, this was a region driven and molded by fire.

European colonization and settlement significantly impacted the amount, composition and age structure of forests of the region. Active management is required to restore and maintain those key forests that remain (Van Lear and others 2005). Because the region 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 WUI. 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 speed up restoration or facilitate burning. Most systems are being managed with short fire return intervals of 3 to 5 years. Other fuel reduction techniques are applied only once except when not followed by burning, when they need to be reapplied at the same interval of 3 to 5 years. Because of the frequent repetitive treatment over a significant area there is the potential for cumulative effects in this landscape.

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Table 2–Typical fuel loads on dry weight basis in select types of subtropical and savanna divisions. Litter is all dead surface fuel including leaves, needles, twigs, branches and stems while understory is all living plants less than 4.5 feet tall (1.5 m) except in canebrake and sawgrass where it includes all grass.

Vegetation Type	Component	Age	Tons/acre	MT/ha	Reference
Choctawhatchee Sand Pine	Litter	stand age 15 yrs	9.45	21.17	Ottmar and others 2003
Choctawhatchee Sand Pine	Understory	stand age 15 yrs	2.99	6.70	Ottmar and others 2003
Choctawhatchee Sand Pine	Litter	stand age 58 yrs	24.84	55.64	Ottmar and others 2003
Choctawhatchee Sand Pine	Understory	stand age 58 yrs	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
Pine Oak	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 & Understory	age of rough unknown	12.5	28.0	McPherson 2008

Table 3–Types of fuel treatments used in different forest types in the subtropical and savanna divisions. Blanks indicate that type of treatment is not being applied to that forest type

	Treatment				
Vegetation Type	Prescribed Burn[a]	Mechanical[b]	Manual	Harvesting[b]	Herbicide[c]
Longleaf Sandhills	Understory 2-4 yrs	Chopping and Mulching	Hand clearing	Thinning and Clearcutting	Understory and Midstory
Longleaf Flatwoods	Understory 1-4 yrs	Chopping and Mulching		Thinning and Clearcutting	Understory
Longleaf Uplands	Understory 1-4 yrs	Chopping and Mulching	Hand clearing	Thinning and Clearcutting	Understory and Midstory
Slash Pine Flatwoods	Understory 1-4 yrs	Chopping and Mulching		Thinning	Understory
Loblolly Pine	Understory 2-5 yrs	Mulching	Hand clearing	Thinning	Understory and Midstory
Shortleaf Pine	Understory 3-5 yrs	Mulching	Hand clearing	Thinning	Understory and Midstory
Oak Hickory Pine	Understory 3-6 yrs		Hand clearing	Thinning	
Pine Rocklands	Understory 3-5 yrs	Mulching	Hand clearing	Thinning and Clearcutting	
Pitch Pine	Understory 5-15 yrs	Mulching		Thinning	
Ocala Sand Pine	Stand replacing 15-75 yrs	Chopping		Clearcutting	
Choctawhatchee Sand Pine	Understory 3-5 yrs			Clearcutting	
Pond Pine	Understory 3-8 yrs	Mulching			
Cypress Domes	Understory 2-5 yrs				
Cypress Savanna	Understory 10 yrs				
Dry Prairie	Stand replacing 1-4 yrs	Chopping			
Freshwater Marsh	Stand replacing 2-5 yrs				
Everglades prairie	Stand replacing 3-5 yrs				
Canebrake	Understory 3-5 yrs		Hand clearing	Thinning	

[a] Type of burn and normal frequency of application.

[b] Typical treatments used in different vegetation types.

[c] Target layer of application.

Table 4–Advantages, disadvantages and costs of different fuel treatment options being used in the southern US

Attributes	Treatment				
	Prescribed Burn	Mechanical	Manual	Harvesting	Herbicide
Pros	low cost ecological benefits soil disturbance minimal	burning easier use in urban areas	selective use in urban areas	selective revenue producer	Effectiveness burning easier
Cons	smoke potential escapes resource damage	can be costly fuel created equipment breakage potential site damage	can be costly fuel created	fuel created potential site damage	Public acceptance fuel created
Costs ($/ac)	23-121[a]	120-350[b] 35-1000[c]			68-2000[c]

a Cleaves and others 2000
b Rummer and others 2002.
c Wolcott and others 2007

Table 1–Fuel accumulation over time in surface layers for different forest types of the subtropical division expressed on dry weight basis. Litter is all dead surface fuel including leaves, needles, twigs, branches and stems while understory is all living plants less than 4.5 feet tall (1.5 m)

		Years of Fuel Accumulation												
Vegetation Type	Component	1	2	3	4	5	6	7	10	15	20	30	Reference	Notes
							----tons/acres----							
Slash Pine	Litter	2.3	4	5.4	6.6	7.6	9.3	11.1	12.7	13.2			McNab and others 1978	BA = 110 sq ft/ac
Loblolly Pine	Litter	2.1	3.5	4.6	5.4	6	7.1	7.4	7.4				Wade and others 2000	BA = 110 sq ft/ac
Slash/Longleaf Flatwoods	Understory	0.5	2	2.6		2.8			3.6	6.6	8.4		Wade and others 2000	
Longleaf Flatwoods	Litter	2.19	3.71	8	3.99	5.12					18.75	27.18	Ottmar and Vihnanek 2000	
Longleaf Flatwoods	Understory	1	1.28	3.32	3.75	3.41					3.42	5.54	Ottmar and Vihnanek 2000	
Longleaf Sandhill	Litter	1.59		1.73							8.97		Ottmar and others 2003	
Longleaf Sandhill	Understory	0.32		1.02							1.25		Ottmar and others 2003	
Loblolly Pine plantation	Litter				6.35								Scholl and Waldrop 1999	
Loblolly Pine plantation	Understory				0.16								Scholl and Waldrop l 1999	
Loblolly Pine plantation	Litter				6.22								Scholl and Waldrop 1999	
Loblolly Pine plantation	Understory				0.54								Scholl and Waldrop 1999	
Longleaf wiregrass	Litter		1.21										Ottmar and Vihnanek 2000	
Longleaf wiregrass	Understory		1.59										Ottmar and Vihnanek 2000	
Marl Prairie	Litter & Understory	0.6		1.7			1.7			1.7			Herndon and Taylor 1986	
							----MT/ha----							
Slash Pine	Litter	5.15	8.96	12.10	14.78	17.02	20.83	24.86	28.45	29.57			McNab and others 1978	BA = 25 sq m/ha
Loblolly Pine	Litter	4.70	7.84	10.30	12.10	13.44	15.90	16.58	16.58				Wade and others 2000	BA = 25 sq m/ha
Slash/Longleaf Flatwoods	Understory	1.12	4.48	5.82		6.27			8.06	14.78	18.82		Wade and others 2000	
Longleaf Flatwoods	Litter	4.91	8.31	17.92	8.94	11.47					42.00	60.88	Ottmar and Vihnanek 2000	
Longleaf Flatwoods	Understory	2.24	2.87	7.44	8.40	7.64					7.66	12.41	Ottmar and Vihnanek 2000	
Longleaf Sandhill	Litter	3.56		3.88							20.09		Ottmar and others 2003	
Longleaf Sandhill	Understory	0.72		2.28							2.80		Ottmar and others 2003	
Loblolly Pine plantation	Litter				14.22								Scholl and Waldrop 1999	
Loblolly Pine plantation	Understory				0.36								Scholl and Waldrop 1999	
Loblolly Pine plantation	Litter				13.93								Scholl and Waldrop 1999	
Loblolly Pine plantation	Understory				1.21								Scholl and Waldrop 1999	
Longleaf wiregrass	Litter		2.71										Ottmar and Vihnanek 2000	
Longleaf wiregrass	Understory		3.56										Ottmar and Vihnanek 2000	
Marl Prairie	Litter & Understory	1.4		3.75			3.75			3.9			Herndon and Taylor 1986	