Fire Ecology and Management of Shortleaf Pine

Ronald E. Masters, Director of Research
Tall Timbers Research Station

Shortleaf pine (*Pinus echinata*) occurs across a wider variety of climates, soils, topography, moisture regimes and fire regimes and thus community types, than any other pine species in North America with the possible exception of ponderosa pine (*Pinus ponderosa*). In spite of its adaptability it has declined in prevalence in the south primarily because of land use objectives that replace this species with pine species that have faster growth characteristics in the short-term on industrial forest landholdings and on many non-industrial private lands. Also the history of selectively logging of this preferred pine species without attention to regeneration in mixed stands across its range has contributed to declines. **Fire suppression has played a major role in declines** of this species as fire intolerant and shade tolerant species have supplanted shortleaf as canopy dominants following selective logging and negligence toward regeneration of this species. To maintain canopy dominance **shortleaf is dependant on frequent fire** on better sites to give it a competitive advantage over hardwoods and other pines that may be associated with this species. On nutrient deficient shallow soils and exposed topographic sites, or following small to large scale natural disturbance some element of shortleaf may be able to persist in the absence of fire. Typically in these settings shortleaf will persist in a mixture with other tree species in the absence of fire. Because of its adaptability and the various plant associations in which it occurs, shortleaf has been considered as either fire adapted, fire dependent, fire resistant, fire resilient and erroneously, fire intolerant (see Little and Mergen 1966, Givnish 1981, McCune 1988, Lawson 1990, Keeley and Zedler 1998).

- **Shortleaf Pine Community Description**
- **Historic Fire Regimes of Shortleaf Pine**
- **Fire Effects On Shortleaf Pine**
- **Management Considerations for Wildlife**
- **Managing Shortleaf Pine with Prescribed Fire**

Shortleaf Pine Community Description

Ecosystem Distribution and Extent

Shortleaf pine (*Pinus echinata*) has the **widest geographic range of the southern pines** (Mattoon 1915, Lawson and Kitchens 1983). See Figure 1 for range map (after Mattoon 1915, Haney 1962, Silker 1968, Little 1981, Lawson 1990). Following the latest period of glaciation shortleaf pine reached its current northwest limit in Missouri some 4,000 years ago and southern pines in general reached their current distributional limits in the east, a relatively recent 2,000 years ago (Buckner 1989, Delcourt and Delcourt 1991). While Mattoon (1915) listed shortleaf as occurring in 24 states and encompassing 1.14 million km^2 (440,000 mi^2) recent authors cite its **historical and current geographical distribution** as encompassing 22 states (Haney 1962, Lawson and Kitchens 1983, Lawson 1990). Some evidence indicates it may have once occurred in Michigan (Fowells 1965). This species occurs from extreme southeastern New York west, sporadically through parts of Pennsylvania and the south central part of southern Ohio, then in southwest Illinois and southern Missouri south and west through eastern Oklahoma and east Texas, east through interior states and the Gulf states, then north through the Atlantic states to Delaware and New Jersey (Mattoon 1915, Sargent 1965, Sternitzke and Nelson 1970, White 1980, Williston and Balmer 1980, Lawson 1990). Shortleaf pine is currently listed as endangered in the state of Illinois (http://dnr.state.il.us/espb/datelist.htm).

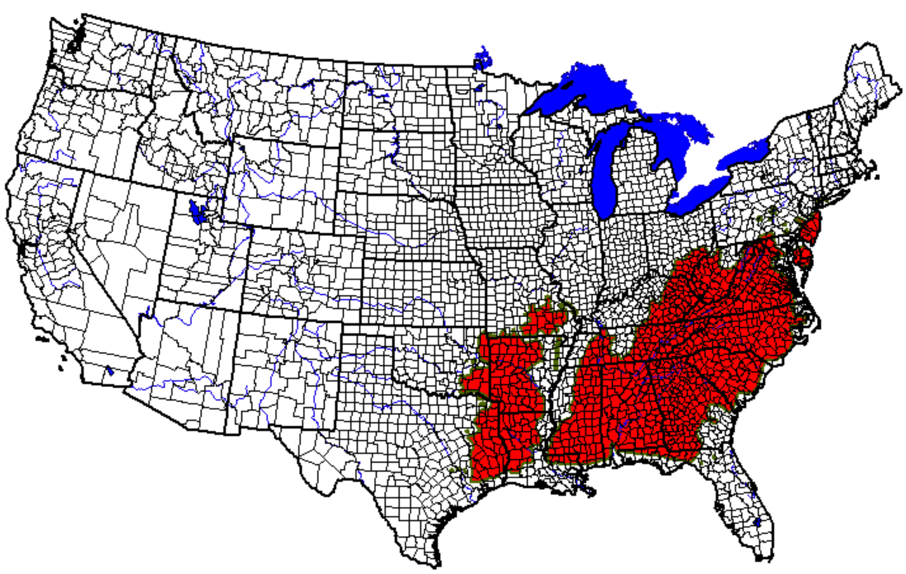

Figure 1. Natural range of shortleaf pine (after Mattoon 1915, Brinkman and Smith 1968, Silker 1968, Little 1971, Haney 1962, Lawson 1990).

Shortleaf pine occurs across a number of **physiographic regions** including the eastern and western Gulf Coastal Plain, the Atlantic Coastal Plain, Piedmont, Southern Appalachians and the interior highlands of the Ozark Plateau and Ouachita Mountains (Mattoon 1915, Harlow and Harrar 1969, Nelson and Zillgett 1969, White 1980, Guldin 1986). Shortleaf does not occur in the Mississippi Valley (White 1980) which separates eastern and western populations by a distance varying from 50 to 225 km (31 to 140 mi). The **highest concentrations** of this species are found west of the Mississippi River in the Interior Highlands of Arkansas and eastern Oklahoma and also the upper Coastal Plain of southern Arkansas, northern Louisiana and east Texas (Mattoon 1915, Sargent 1965, Sternitzke and Nelson 1970, Guldin 1986). Concentrated populations also occur in the Piedmont and upper Coastal Plain in Virginia, North Carolina and South Carolina (White 1980, Guldin 1986, Nelson and Zillgitt 1969, Lawson 1990).

Marked declines, from 20-40 percent of the original range, in the **extent** of shortleaf pine as a relatively pure type were noted as early as 1915 as a result of extensive logging and land use change (Mattoon 1915). Substantial declines occurred from the 1900s to the 1950s with the onset of logging particularly in the Ouachita highlands of Arkansas (Smith 1986). Further declines have been noted in extent and frequency of occurrence in the south and east (White 1980). The wide-spread planting of loblolly pine (*Pinus taeda*) north of its native range and in industrial forest operations has, in part, been responsible for some declines (Guldin 1986) as conversion to loblolly plantations have been made based on short-term growth and yield characteristics (Williston and Balmer 1980). Also, in the eastern part of the range, loblolly has been favored over shortleaf on sites where littleleaf disease was common as loblolly is less susceptible (Campbell et al. 1953). The industrial perspective also limits the use of fire in managed stands (Masters et al. 2005).

The wide spread planting of loblolly north of its range also has implications for maintaining genetic integrity of shortleaf in the heart of its range as these two species readily hybridize west of the Mississippi and a high proportion of hybrid individuals have been reported from central Arkansas (Lawson 1990, Chen et al. 2003, 2004). Shortleaf also has been reported to naturally hybridize with pond pine (*Pinus serotina*), spruce pine (*Pinus glabra*), and pitch pine (*Pinus rigida*) (Dorman 1976, Little 1979). **Fire suppression** across its range has allowed midstory hardwoods to supplant this species canopy dominance in many areas and prevent regeneration by this relatively shade intolerant species.

Environment

Climate

As expected, given its wide geographical distribution, shortleaf pine occurs throughout a **wide range of climatic conditions**, including subtropical humid and temperate continental climates (Trewartha 1968). Average annual temperatures range from 21ºC (70ºF) in southeast Texas to 9ºC (48ºF) in New Jersey (Mattoon 1915, Lawson 1990). Potential temperature extremes across its range from northeastern winter lows to southwest summer highs span 57ºC (134ºF) (Mattoon 1915). The northern limit of distribution corresponds with the 10ºC (50ºF) isotherm (Guldin 1986). The northern and western limits of shortleaf roughly coincide with the average annual rainfall isohyets of

114 cm (45 in) and 102 cm (40 in) respectively (Mattoon 1915). Average annual rainfall extremes range from less than 94 cm (37 in) in southeast Oklahoma to over 203 cm (80 in) in the southern Appalachians (Nelson and Zillgitt 1969, Guldin 1986). The rainfall zone averaging about 127 cm (50 in) in the southern Piedmont, south central Arkansas and northern Louisiana is where individuals of this species show their best development (Matoon 1915, Guldin 1986, Lawson 1990). The species also tolerates a range of seasonal precipitation patterns throughout the year (Guldin 1986), from relatively well distributed rainfall across all months in the northeast and southeast to near annual drought conditions in late summer in the western portion of its range. To the west in east-central Oklahoma and in east-central Texas several small islands of shortleaf extend westward and are disjunct from the main body of its western distribution, 32 and 145 km respectively (20 and 90 miles), and extending in Texas to the average rainfall zone of 89 cm (35 in) (Silker 1968). These pine islands are associated with pockets of a podzolic soil type similar to that found in the main body of its range in east Texas and eastern Oklahoma and in other parts of its range (Billings 1938, Silker 1968, Nelson and Zillgitt 1969). Evapotranspiration on these sites is offset by the moisture storage and retention capacity (moisture availability) of the soils thus allowing shortleaf to persist on these islands (Silker 1968).

Soils and Topography

The wide distribution of shortleaf pine is also related to its **tolerance of a variety of sites,** soils, soil moisture conditions and topography. It performs best on deep, well-drained upland soils such as on the upper Coastal Plain and Piedmont (Mattoon 1915, Harlow and Harrar 1969, Guldin 1986), but typically occurs on a range of well drained sites with from slightly coarse to loamy textured soils and within a soil moisture regime ranging from very dry to moist and where soils are moderately low in fertility and neither strongly acidic or alkaline (Fowells 1965, Harlow and Harrar 1969, Wright and Bailey 1982, McCune 1988, Duryea and Dougherty 1990, Masters et al. 2003). Generally shortleaf does not occur on deep, coarse sands which might be termed excessively drained or on poorly drained, fine textured soils with high clay content (Mattoon 1915, Nelson and Zillgitt 1969, Guldin 1986, McCune 1988, Lawson 1990, Masters et al. 2003).

Shortleaf occurs broadly on Hapludults in the Coastal Plain and Piedmont to Paleudults in the Interior Highlands and western Gulf Coastal Plain, within the Ultisol order, characterized by clay accumulations in subsurface horizons, typically with some slope and moderate to moderately low mineral content respectively. In the southern Appalachians it occurs on Dystrochrepts in the Inceptisols order, characterized by weakly differentiated horizons and low calcium in subsurface horizons and these sites are usually moist (Nelson and Zillgitt 1969). Its southern distribution into peninsular Florida appears to be limited by soil type, which tends to be deep sands that are excessively drained.

Shortleaf pine occurs on a range of **topographic sites** from near sea level to elevations of 914 m (3,000 ft) (Mattoon 1915, Harlow and Harrar 1969). However, its **ecological importance** as a dominant forest type increases on sites where soils are thin and low in nutrient status and on exposed topographic sites prone to disturbances such as drought, at times of the year, and periodic fire and in areas where climatic conditions tend to be somewhat harsh (White 1980, Guldin 1986). On nutrient poor sites, shortleaf apparently has a better developed root system than competitors (McQuilken 1935). It is most prevalent on southern and western exposures in the Interior Highlands of Arkansas and Oklahoma but may occupy all types of sites at all elevations except steep north slopes (Palmer 1924, Johnson 1986, Foti and Glenn 1991, Kreiter 1994). Shortleaf also is a common early sere species establishing within 3-5 years on abandoned agricultural fields where an adjacent seed source is present (Billings 1938).

Ecosystem Description

Species Characteristics, Stand Establishment and Development

Annual seed crops are quite variable across the range of shortleaf (e.g., Mattoon 1915, Little 1940, Shelton and Wittwer 1996). Seed fall may occur across 7 months with most falling October to December (Little 1946). Early research suggested that mineral soil was essential for seedling establishment (Billings 1938) but later findings suggested that while establishment is hastened, mineral soil is not essential for reproduction to become established (Baker 1992). Depending on opening size, seed crop and prevailing winds shortleaf can become well established naturally in adjacent areas without trees.

Shortleaf seedlings are **relatively shade intolerant (**Brinkman and Swarthout 1942, Oosting and Kramer 1946, Jackson and Harper 1955). They are less shade tolerant than slash (*Pinus elliottii*), spruce and loblolly pine but more shade tolerant than longleaf (*Pinus palustris*), and pond pine (Brinkman and Swarthout 1942, Mattoon 1915, Masters et al. 2003). Although some authors have considered this species as shade tolerant that is relative to qualitative descriptions of canopy cover. Adequate light is essential for successful seedling establishment and is more important than moisture regime as seedlings are fairly drought tolerant (Oosting and Kramer 1946). Shortleaf seedlings in any abundance will not become established within stands with a basal area of >23 m²/ha (100 ft²/acre) or about 80% canopy cover (Masters et al. 2005). Billings (1938) noted that in old field stands 50 years of age on the Duke Forest one of the most striking features was the absence of shortleaf reproduction. This was also noted by Masters et al. (1995) in Oklahoma on a virgin (unlogged) wilderness area and elsewhere (Cain and Shelton 1995, Masters et al. 2005). Seedlings may occasionally become established at basal areas less than 23 m²/ha (100 ft²/acre) but a residual stand basal area below about 17 m²/ha (75 ft²/acre) or about 60% canopy cover is essential for successful reproduction to any extent to occur (see Brinkman and Swarthout 1942, Farrar et al. 1984, Baker et al. 1996, Farrar 1996, Guldin 2004, Masters et al. 2005). The optimum range of residual stand basal area for shortleaf seedling establishment and development appears to be between 9-16 m²/ha (40-60 ft²/acre) or 30-50% canopy cover (Brinkman and Swarthout 1942, Masters et al. 2005). Even-aged stands can be naturally regenerated with seed tree cuts or small clearcuts and reach canopy closure at 17 years post harvest on coastal plain sites (Cain and Shelton 2001).

Seedling establishment is promoted by periodic fire (Little et al. 1948, Buell and Cantlon 1953, Cassidy 2004, Masters et al. 2005). **Successful establishment also is**

related to the fire frequency and season within the appropriate range of canopy cover, residual basal area (Masters et al. 2005), **and the presence of competing vegetation** (Cain 1991*b*, Cain 1993, Cain and Shelton 2002). Traditionally, silviculturalists prescribe fall burns when sufficient cones are present, just prior to seed fall and this works well in many areas (e.g. Cain and Shelton 2002). Optimal prescribed fire intervals for regeneration of shortleaf should be between 4 and 6 years (Cain 1993, Masters et al. 2005). The timing of fire introduction into a stand will determine whether the stand will develop even-aged or uneven-aged structure (Masters et al. 2005). If fire is excluded from a shortleaf site that has undergone a complete harvest cut, the stand will develop a dense even-aged stand structure given a sufficient seed source. Stands that develop within the context of timber harvest followed immediately with a 4-year late-dormant season prescribed fire cycle will subsequently develop as an open structured uneven-aged stand. If fire is withheld for 5 years post-harvest, then introduced on an approximate 5-year burning rotation again an uneven-aged stand will develop but at much less density than unburned stands (Masters et al. 2005). Cain (1993) evaluated 3-, 6- and 9- year interval winter prescribed burning and found that the 6-year interval provided the greatest pine density. However, he also noted that the 6-year interval coincided with an abundant seed year.

When fire is withheld for 12 years a similarly structured stand will develop but at greater density than with the 5-year interval (Masters et al. 2005). On the other hand fire frequency at less than a 4-year interval will hamper shortleaf stand development. At a 3-year interval, late-dormant season prescribed burning rotation seedlings can become established and a sparse savanna-like stand may develop if residual basal area is at or below 9 m^2/ha (40 ft^2/acre). However at 1- and 2- year late-dormant season intervals little regeneration will occur even under a similarly sparse overstory of shortleaf pine (Masters et al. 2005). These above described conditions may not be ideal for timber management objectives alone but will maintain or increase wildlife values and other aesthetic values of the stand in additional to allowing a stand to develop (Masters et al. 2003, 2005). For optimal regeneration in uneven-aged stands attention should be paid to the cone crop, stand conditions, current regeneration age and condition rather than implementing a rigid prescribe fire regime (Cain 1993).

Competition from herbaceous species and hardwoods can also hinder pine seedling establishment (Cain 1991*a,b*; Cain and Yaussy 1984; Cain and Shelton 2003*b*). For developing stands and in old growth stands some method of hardwood control is essential for continued dominance of shortleaf in the canopy (Cain and Shelton 1996). Cain and Yaussy (1984) found that annual chemical and mechanical hardwood control repeated for 12 years was not successful in eradicating hardwoods from within mixed loblolly-shortleaf stands.

Old-growth Condition and Forest Structure

Typical old-growth conditions are difficult to characterize because of the variety of sites on which the species could potentially occur and also the variety of species that could potentially co-mingle. In areas and in systems where all natural disturbance processes, including fire, are allowed to freely operate, old-growth stands may be characterized by open canopy pure or nearly pure pine stands with limited midstory and a bluestem dominated understory (See Vogl 1972, Komarek 1974, Fryar 1991, Sparks and Masters 1996, Batek et al 1999, Masters et al 1995). Hardwoods may be present to varying degrees depending on site characteristics (Vogl 1972, Fryar 1991, Kreiter 1994, Masters et al. 1995).

As shortleaf ages it becomes less tolerant of shade and neighboring crowns. By age 50 the crowns of trees develop a distinctly irregular shape and the canopy may be punctuated with numerous gaps (Mattoon 1915). The structure of presettlement stands was variable (Bragg 2002). Stand structure was determined by the range of disturbance that initiated the stand and periodic disturbance events that continued throughout the life of the stand (see Turner 1935, Bragg 2002, Masters et al. 2005). Stands that initiated following catastrophic disturbance typically develop as even-aged stands (Turner 1935) but this also applies to small old-field stands. However, in old growth stands excluded from anthropogenic disturbance canopy dominant old-growth pines undergo senescence and are prone to various bark beetle infestations and thus begin dropping out of the stand with the end result that midstory hardwoods eventually take their place in a relatively short period of time (Kreiter 1994, Masters et al. 1995, Cain and Shelton 1996)

The prevalence of even-aged old-field stands of shortleaf or in a mix with loblolly across the south and the relative shade intolerance of shortleaf has lead many silviculturalists to conclude that even-aged structure in shortleaf was the norm and that this was usual mode of stand initiation and structural development (e.g., Lawson and Kitchens 1983, Guldin 1986). However, early foresters and ecologist reported the normal stand structure in old-growth shortleaf as decidedly uneven-aged (e.g., Turner 1935, Bragg 2002). Stand structure varied along a continuum of even-aged to uneven-aged and varied in density according to the frequency and nature of the disturbance pulse (Turner 1935, Bragg 2002). One common characteristic irrespective of the age-distribution, was the open nature of these forests and the occurrence of numerous canopy gaps depending on site conditions and fire regime (Little 1946, Fryar 1991, Murphy and Nowacki 1997, White and Lloyd 1998, Bragg 2002, Stambaugh et al. 2002). Within this context regeneration may occur as even-aged patches under large canopy gaps, as individuals, or in several distinct age-cohorts of different size classes (Bragg 2002, Stambaugh et al. 2002, Cassidy 2004).

Major Species

Because shortleaf is so widely distributed it grows in association with a high number of community types and tree species from pines to hardwoods. The relative density and distribution of these associate species is dependent on the disturbance regime.

Associated species often include post oak, blackjack oak (*Quercus marilandica*), black oak (*Q. velutina*), mockernut hickory (*Carya tomentosa*) on drier sites and to the west black hickory (*Carya texana*). In the north western part of this geographic area in the uplands shortleaf pine, xeric oaks (*Quercus* spp.) and some hickory (*Carya* spp.)

dominate the overstory with a high percentage of oak on steep north slopes and on post oak (*Quercus stellata*) flats (Johnson 1986). This pine is often emergent on upper slopes. Stand density increases with available moisture. In the southern part of its range, loblolly pine is the most common pine associate. But shortleaf is also associated with longleaf and to a lesser extent spruce, pond and slash pine. In the northeast it is most commonly associated with pitch pine and Virginia pine (*Pinus virginianus*) and to a lesser extent Table Mountain pine (*Pinus pungens*) and eastern white pine (*Pinus strobus*) (Little 1971). These associations follow an environmental gradient of moisture availability, soil type and fire frequency. On drier sites with frequent fire shortleaf will assume canopy dominance. Under a fire regime of less than 3-year intervals and on coarser textured soils longleaf with assume dominance where their ranges overlap (Masters et al. 2005). In longleaf dominated stands associated with shortleaf where fire frequency is lengthened, or excluded the stands will gradually succeed to shortleaf (See Walker 1991, Pyne et al. 1996).

Other species shortleaf is associated with include bear oak (*Q. ilicifolia*), black oak (*Q. velutina*) chestnut oak (*Q. prinis* L.), white oak (*Q. alba*), northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), southern red oak (*Q. falcata*), water oak (*Q. nigra*), willow oak (*Q. phellos*), blackgum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), yellow poplar (*Lirodendron tulipifera*), eastern red cedar (*Juniperus virginiana*), winged elm (*Ulmus alata*), red maple (*Acer rubrum*), white ash (*Fraxinus americana*), and persimmon (*Diospyros virginiana*) (Palmer 1924, Marks and Harcombe 1975, Eyre 1980, Lawson 1990, Masters 1991*a*, White and Lloyd 1998, Murphy and Nowacki 1997, Smith et al. 1997, Rideout and Oswald 2002, Stambaugh et al. 2002).

Small trees, shrubs, and vines that frequently occur in shortleaf stands include serviceberry (*Amelanchier arborea*), rusty blackhaw (*Virburnum rufidulum*), flowering dogwood (*Cornus florida*), hawthorns (*Crataegus* spp.), American beautyberry (*Callicarpa americana*),deerberries (*Vaccinium* spp), greenbriars (*smilax* spp.), grape (V*itis* spp.), Virginia creeper (*Parthenocissus quinquefolia*), poison ivy (*Toxicodendron radicans*), smooth sumac (*Rhus glabra*), winged sumac (*Rhus copallina*), fragrant sumac (*Rhus aromatica*), various St. Johnswort (*Hypericum* spp.), and in the eastern part of its range, mountain laurel (*Kalmia latifolia* L.) (Palmer 1924, Buel and Cantlon 1953, Johnson 1986, Lawson 1990, Masters 1991*a*, Murphy and Nowacki 1997, White and Lloyd 1998, Rideout and Oswald 2002, Stambaugh et al. 2002).

In the understory, various bluestems (*Andropogon* spp. and *Schizachyrium scoparium*), panicums (*Panicum* spp., *Dichanthelium* spp.), nutsedges (*Scleria* spp.), sedges (*Carex* spp.), and legumes (*Lespedeza*, *Desmodium* and other legumes) are conspicuous across its range where fire is an integral part of stand history (Masters 1991*a*, Buel and Cantlon 1953, Sparks 1996, Sparks et al. 1998). Other important forbs include numerous asters (Asteraceae), tick-seed (*Coreopsis* spp.), pussytoes (*Antenaria* spp.), gayfeathers (*Liatris* spp.), sunflowers (*Helianthus* spp.), and wild petunia (*Ruella* spp.) (Masters 1991*a*, Sparks 1996, Smith et al. 1997, Crandall 2003)

Associated Ecosystems

Shortleaf Pine occurs in some 18 Society of American Foresters cover types (Eyre 1980). In three of these shortleaf is listed as a stand dominant. Often it occurs as a mixed type with various species of oaks and hickories (Braun 1950). The oak-pine forest is currently the largest forest type in the eastern United States (Lotan et al. 1978). In spite of its prevalence and importance, little research exists on the management of the oak-shortleaf pine type (Komarek 1981, Murphy and Farrar 1985). Frequent fire can shift forest community composition in the Ouachita Mountains (Little and Olmstead 1931) and in the Ozarks (Guyette and Dey 1997) from an oak-pine mixture to pine dominance. The oak-pine forest is a fire subclimax association and will succeed to an oak-hickory (*Carya* spp.) climax in the absence of fire (Bruner 1931, Little and Olmstead 1931, Braun 1950, Oosting 1956). Although fire is considered a major determinant in shaping the oak-pine ecosystem (Garren 1943, Oosting 1956), little is known about the influence of fire in this cover type in the Piedmont and Cumberland Plateau in the east (Lotan et al. 1978).

Historic Fire Regimes of Shortleaf Pine

Shortleaf, because of its wide distribution and site adaptability, **occurs across the widest range of fire regimes of any southern pine** (see Frost 1995,1998; Schmidt et al. 2002). **The understory fire regime is 1-18 years** based on fire chronology studies, historical accounts and the effects of long term fire frequency studies on shortleaf regeneration. However local sites, depending on topographic position within a given physiographic region, may have historically been prone to burn at the more frequent end of the range or at the less frequent end of the range. The **mixed fire regime cycle is likely 2-50 years** somewhat following drought cycles across the range of shortleaf. The **stand replacement fire cycle is likely >100 years** particularly where this species overlaps the range of and is associated with Virginia, pitch and Table Mountain pine.

Based on the classification of Schmidt et al. (2002) **shortleaf pine occurs in three general fire regimes;** Fire Regime I, characterized by low severity, nonlethal surface fire at intervals of 0 to 35 years; Fire Regime III, characterized by mixed severity fire at 35 to 100+ years; and Fire Regime IV, characterized by stand replacement severity fire at 35 to 100+ year intervals (Schmidt et al. 2002). Jackson et al. (1999) considered it within the category of a low-intensity surface fire regime. But Keeley and Zedler (1998) considered shortleaf within the group of pines characterized by a fire regime of predictable stand replacing fires. However these broad categorizations based on morphological and physiological groupings have limited utility in describing the specific historic fire frequency that perpetuates shortleaf because of the high frequency and variable nature of eastern system fire regimes and in particular rapid plant community response in the southeastern U.S. This rapid response is a result of the number of growing days across the region, high rainfall and the response of dominant vegetation types to varying fire frequency. Historically, frequent low-intensity fire maintained open mid-stories without ladder fuels. Various vegetation types, both overstory and understory will assert dominance very rapidly based on fire frequency or lack of fire at much less than a 35 year interval.

Wade et al. (2000) reported that the fire regime for Society of American Foresters (SAF) cover types that included shortleaf as one of the overstory dominants was, 2-15 years for Shortleaf 75, 3-10 years for Loblolly-shortleaf 80, and <10 years for Shortleaf pine-oak 76. Stanturf et al. (2002) also list 2-15 as the fire regime for shortleaf in the south. Garren (1943) indicated that shortleaf along with loblolly thrives in areas of about a 10 year fire interval, but Chapman (1944) suggests that shortleaf could tolerate fire at more frequent intervals because of its ability to sprout. However, in the New Jersey Pine Barrens the burn interval postulated was 16-26 years (Lutz 1934). Frost (1995, 1998) gave general fire frequency regimes that were very nearly associated with physiographic regions, but did not specifically refer to a fire frequency for shortleaf cover types. Associating the range of shortleaf with these general maps gives a range for presettlement fire frequency regimes of from 1 to 100 years. However, throughout most of shortleaf pine's distribution the range of fire frequency was reported as 1-25 years.

The most **accurate information about fire regimes comes from fire chronology studies** of tree rings. Even so, fire chronologies are conservative because low intensity surface fires may not cause a fire scar to every tree in a given area (Masters et al. 1995, Jurney et al. 2004). Also trees in sheltered topographic situations may be protected. As one goes back further and further into the tree-ring record sample size declines and in some areas a representative sample of old trees may not be available. Often logging, senescence and natural mortality and even natural disturbances such as fire may limit the sample size available for the oldest periods of time. Relatively few studies have been conducted in shortleaf types and fewer still from east of the Mississippi River.

Masters et al. (1995) developed a fire chronology from tree-rings in mixed shortleaf pine-hardwood stands and found the range of fire frequency in the Ouachita Highlands of southeast Oklahoma to be at 1-12 year intervals with an area mean fire frequency of 3.4 years on a 5,701 ha (14,088 ac) area. The reoccurring theme in this fire chronology was **periods of frequent fire followed by apparent periods of fire absence**. This was much shorter than the 7.3 years mean fire interval from 1788-1817 for one shortleaf pine reported by Johnson and Schell (1985) in central Arkansas and the mean fire frequency of 32 years or less for the area of Hot Springs National Park prior to 1938. They used predominantly shortleaf pine to date fires which is much less prone to fire scarring than the hardwood species used in the above study because shortleaf bark is quite resistant to fire (Splat and Reifsnyder 1962, Lowery 1968). Therefore their results are likely a considerable underestimate. Other studies documenting fire chronology in shortleaf types include work in the Ozark Highlands of Missouri (Guyette and Dey 1997, Batek et al. 1999, Stambaugh et al. 2005). Batek et al. (1999) reported that in the 1800s as fire frequency increased so did relative dominance of shortleaf. They reported a range of fire frequencies from 2-50 years with most (86%) sample trees in the 2-18 year range. One fire chronology study from the Highland Rim in extreme southeast Tennessee on an oak barrens site reports periods of annual burning in the 1700s and 1800s (Guyette and Stambaugh 2005). This area is within the region of historic major importance of shortleaf pine given by Haney (1962) therefore the fire chronology may be applicable only by inference.

Mixed severity fires may play a role in perpetuation of pine dominance over hardwoods in the New Jersey pine barrens (Little and Moore 1945). Severe fires of 15 to 40 year intervals were reported from about 1800 to the mid-1940s and resulted in mixed stands of shortleaf and pitch pine (Little and Moore 1945). Mixed severity fires also are noted to occur in the south where individuals within a stand succumb to even relatively low intensity fires (Ferguson et al. 1961).

Keeley and Zedler (1998:240, 250) placed shortleaf within the group of pine species characterized by predictable stand-replacing fires, based on life-history characteristics and morphological traits. However, this characterization is somewhat flawed because shortleaf historically occurred in sparse, open pine-bluestems stands over much of its range without sufficient ladder fuels to carry a fire to the crowns of dominant trees (see Vogl 1972). As well, shortleaf is unique in that it shares life history, physiological and morphological traits with a number of divergent pine groups (McCune 1988, see also

Jackson et al. 1999, Keeley and Zedler 1998). **Stand replacement fires** do occasionally occur in this type but may be decidedly different than the sweeping crown fires that are typically associated with the designation of stand replacement fire for western forests. Our best guess is that they **may occur at >100 year intervals.** They may be either high intensity crown fires in young regenerating stands, in immature stands, and occasionally in mature stands or they may occur as surface burns under protracted late summer drought with the end result that overstory trees in a given stand are killed (personal observation). Prescribed stand replacement fires have been used to restore mixed pine-hardwood stands in the southern Appalachians of North Carolina where the pine component was represented by Virginia, pitch and shortleaf pines (Vose et al. 1997).

Recorded stand replacement fires since the 1960s in the Ouachita National Forest of Arkansas and Oklahoma include the Walker Mountain Fire, the Eagleton Fire and the Page Fire. The Walker Mountain Fire occurred in September 1965, in Oklahoma and burned 10,000 acres (G. Bukenhofer, U.S. Forest Service, personal communication). The Page Fire occurred near Page, Oklahoma in April 1975 and burned approximately 4,000 acres (G. Bukenhofer, U.S. Forest Service, personal communication). The Eagleton fire, in Arkansas, was a railroad ignited fire on October 30, 1963 and burned 13,673 acres (http://www.oldstatehouse.com/educational_programs/classroom/arkansas_news/detail.asp?id=448&issue_id=32&page=5). However, Turner (1935) reported that crown fires in this region of the country had not been recorded in historical records and therefore attributed several old-growth even-aged stands as the result of tornados in southwest Arkansas. However, the stands were not mapped as to configuration nor were the area of the stands given.

Recent crown fires may, in part, be the result of fire exclusion in regenerating stands. Where frequent fire is commonplace stand structure develops such that open stand conditions prevail and there is an absence of ladder fuels (Guyette and Dey 1997, Masters et al. 2005). The understory is dominated by fire tolerant grasses that are prone to burn with low to moderate intensity surface fire (Vogl 1972, Masters 1991a, Masters and Engle 1994, Masters et al. 1995, Sparks et al. 2002). Even under these open conditions without ladder fuels burning under late summer drought conditions may result in some mortality to overstory shortleaf pine analogous to a mixed fire regime or in some cases a stand replacement event, even though a fire never carries through the canopy.

Historic Fire Season

Lightning Season

The lightning season varies widely in extent and in timing across the range of this species (Schroeder and Buck 1970). In Florida lightning season fires are well documented to occur in the moths of May through late July (Robbins and Myers 1992). Across much of the south and in the southern Appalachians lighting set fires occur in a bimodal distribution most often in late-spring and early summer with a less frequent peak in early fall (Komarek 1964, 1968; Barden and Woods 1974). But in the western extent of shortleaf range lighting set fires occur in a similar bi-modal distribution with the lightning fire season occurring less prominently in early spring and more prominently in late summer-early fall (Foti and Glenn 1991, Masters et al. 1995). Of note in the northern part of the range and in the mid-south is the general paucity of lightning caused fires per unit area (Ison 2000, Schroeder and Buck 1970). The relative amount of area burned by lightning fires is limited north and west of Florida therefore it is not axiomatic that lightning set fires perpetuated shortleaf across its range (See Ison 2000, Schroeder and Buck 1970, Masters et al 1995). The prevalence of fire derived covertypes in an area of limited lightning caused fires lends credence to the hypothesis that anthropogenic fire has an overriding effect in the southern Appalachians and Cumberland Plateau regions (Ison 2000). Lightning set fire prevalence and the unit area burned appear to be somewhat correlated with regional drought patterns (Jackson et al. 1999, Jurney et al. 2004).

Anthropogenic Fire

Although most historic references to anthropogenic fire do not specifically mention shortleaf pine, other than William Bartram in 1773 (see Vogl 1972), specific references noted are located within the historic geographic range and some inferences can be made about Native American use of fire in the type. These accounts may be substantiated somewhat by fire chronologies. However fire chronologies are limited for the eastern U.S. Frequent fire of anthropogenic origin is mentioned in numerous historical accounts in the Interior Highlands of Arkansas, Missouri, and Oklahoma where other pine species do not occur (Beilmann and Brenner 1951*a,b*, Foti and Glenn 1991, Masters et al. 1995). Similar historical accounts also note frequent fire in the Gulf Coastal Plain for east Texas across Louisiana to Georgia and north into the Carolinas and Virginia and in the Cumberland Plateau region (Vogl 1972, Ison 2000, Jurney et al. 2004, Stewart 2002).

In the northeast, U.S. Native Americans were likely the most important source of ignition versus lightning (Frost 1998). Historical references also note annual or more often Native American burning as important in Virginia and in the northeast (Pyne 1982) and in the Piedmont region of the Carolina’s (Logan 1859). Numerous historical references are also made as to frequent Native American burning specifically in New England, New York, Massachusetts, New Jersey, Delaware, Pennsylvania, Ohio, Illinois, Virginia, North Carolina, South Carolina, Georgia, Tennessee, Kentucky, Mississippi, Alabama, Louisiana, Texas and Florida and further that these fires had a profound influence on the plant communities (see Van der Donck 1846, Stewart 1951, 1963, 2002; Day 1953; Harper 1962; Vogl 1972; Guffey 1977; Pyne 1982; Cronon 1983; Russell 1983; Buckner 1989; Van Lear and Waldrop 1989; Campbell et al 1991; DeVivo 1991; Foti and Glenn 1991; Denevan 1992; Hammett 1992*a,b*; Waldrop et al. 1992; Masters et al. 1995, 2003; Frost 2000; Kay 2002; Jurney et al. 2004).

The New Jersey “pine barrens” developed, in part, as a result of frequent aboriginal burning (Pyne 1982, Stewart 2002). Shortleaf is the second most prevalent pine in this system (Somes and Moorehead 1954) and the most valuable timber species (Little 1940). One of the earliest accounts of specific mention of burning in two seasons was made in early historic accounts in Massachusetts (see Hammett 1992*a*). The practice of fall burning just after leaf fall is noted in several places in the east (Lawson 1966, Stewart 2002). This was reportedly done to remove leaf litter to aid in nut gathering (Lawson

1966). Later accounts postulate that severe fires on a 15-40 year interval were responsible for pine presence in oak-pine stands in New Jersey (Little and Moore 1945).

Pine-grassland community development was attributed in part to frequent burning by Native Americans and persisted across the south well into the 1900s as a result of the adoption of the practice by early settlers for managing free ranging livestock (Vogl 1972, Waldrop et al 1992, Johnson and Hale 2002). This practice also was noted in the mid-south and was responsible for development of shortleaf pine-oak barrens in Kentucky (Campbell et al. 1991). **Annual burning throughout the shortleaf pine region was commonly practiced in the early 1900s** (Mattoon 1915). Annual burning by early settlers during this period was noted as common from Oklahoma, Texas, to Florida, the Atlantic southern states and into Kentucky (Little and Olmstead 1931, Campbell et al. 1991, Stewart 2002).

This practice continued to be commonplace in areas that were settled later such as the Ouachita Highlands of Oklahoma until the 1930s (Little and Olmstead 1931) and 1940s (Masters et al. 1995). In the, 1920s it was estimated that anywhere from ½ to ¾ of the entire upland area in southeastern Oklahoma were burned annually (Little and Olmstead 1931). Frequent fire of anthropogenic origin was also the norm in the Missouri Ozarks during this period (Guyette and Dey 1997, Stambaugh et al. 2005) (1851-1930) with a mean fire interval of 1.56 (Range= 1-6 years) in one part of the region (Stambaugh et al. 2005). However in the Boston Mountains adjacent to the Arkansas River in west central Arkansas, there was a decline in anthropogenic fire commensurate with settlement (Guyette and Spetich 2003). Declines following settlement were also noted in New Jersey (Little 1946).

Effects of Fire Suppression

Shifts in Species Composition

Across the range of shortleaf the influence of fire suppression must be considered in light of the settlement history, logging practices and changes in fire frequency associated with settlement and land use patterns. Following settlement, in the western part of shortleaf geographic range, many areas underwent periods of near annual burning followed by near complete removal of shortleaf pine through extensive logging efforts (Smith 1986, Cunningham and Hauser 1989). In some cases cut over land was annually burned for cattle forage with as much as 50 to 75% of the land area in eastern Oklahoma burned each year in the 1920s (Little and Olmstead 1931). Gradually wildfire suppression and cessation of woods burning became more common, in effect releasing oaks and favoring oak dominance on sites formerly dominated by shortleaf (Guyette and Dey 1997). In the Ozarks a reduction in shortleaf pine abundance was documented due to reduction in fire frequency following aggressive burning that eliminated shortleaf regeneration (Guyette and Dey 1997). In the Ouachita Highlands, in areas of mixed pine and oak, logging was completed at a later date and evidently fire suppression was not so effective early on (Masters et al. 1995). As fire frequency and area burned slowly decreased, pines were able to regenerate and assume dominance (Kreiter 1994). However, with fire exclusion the species composition tends to be a homogeneous mixture across the landscape. Single or few species dominated cover types decline as shade tolerant and fire intolerant species gain a foothold within stands and spread out from sheltered sites (Kreiter 1994).

In the northeast, accounts of annual or more often burning by aboriginal people were responsible for maintaining clearings, barrens and deserts and following human displacement these areas quickly sprung up in forests (Pyne 1982). In the relatively few areas that did not undergo extensive logging, ecosystem shifts have been noted where dominant canopy pines are supplanted with more shade tolerant and fire-intolerant hardwood species across the range and in the east with fire intolerant conifers like eastern white pine and various hardwoods. Such shifts with other species have been noted in the Ouachita Highlands (Kreiter 1994, Masters et al. 1995), in the Southern Appalachians of North Carolina (Vose et al. 1997), western coastal plain (Cain and Shelton 1996), and the Cumberland Plateau of east Tennessee (Cassidy 2004) with replacement species including various oaks, maples and other shade tolerant species.

Altered Fire Behavior

Fire suppression leads to altered fire behavior in shortleaf pine types. When fires are suppressed shade tolerant hardwood species crowd the midstory and begin moving into the overstory, filling in available canopy gaps. This results in increased canopy cover and changes in fuel composition and architecture. With an increase in canopy cover, surface fuels change from dominance by perennial herbaceous plants with an erect architecture to a more compact fuel bed with a variable hardwood leaf litter component (See Masters and Engle 1994; Masters et al. 1995; Engle et al. 1996; Sparks et al. 1999, 2002). Fireline intensity is substantially lower in dense stands with hardwood leaf litter than in open canopied stands with bluestem dominated understories for dormant season or growing season burns (Engle and Stritzke 1996, Engle et al. 1996). It appears that the greater a hardwood leaf component the less effective subsequent fires will be for control of under- and mid-story hardwoods (See Engle et al. 1996; Sparks et al. 1999, 2002). As hardwood leaf litter increases in percent composition of the surface fuels at some point the stand may become essentially fire proof except under extreme conditions.

Fire Effects On Shortleaf Pine

Adaptations

Shortleaf pine is generally recognized as being **a fire adapted species** (Garren 1943, Masters et al. 2003). It has also been termed **fire resistant** (Lawson 1990) or having characteristics of a **fire resilient** species (McCune 1988). But at least one author erroneously considered it fire-intolerant (Givnish 1981). Shortleaf is not as well adapted to fire as longleaf but more so than either loblolly or slash pine. As with most other southern pines the thick platy bark gives considerable resistance from fire injury to the cambium. Shortleaf develops thick bark very early in the seedling and sapling stage and is an excellent self-pruner (Guldin 1986). These attributes are thought to be adaptations to frequent low-intensity surface fire (Schwilk and Ackerly 2001). It is also **one of the few pines that will sprout from the base following top-kill** (Garren 1943, Fowells 1965). This trait has been observed in trees up to 8 years of age (Mattoon 1915) and about 2.4 m (8 ft) tall in the south (Garren 1943). However in southern New Jersey trees up to 30 years of age have been noted to sprout (Little and Somes 1956). The sprouting trait is often cited as being an adaptation to fire (Keeley and Zedler 1998) but then again hardwoods in general aggressively sprout when top killed, many of which are considered fire intolerant. Some evidence suggests that summer prescribed burns will prevent sprouting of shortleaf (Cain and Shelton 2000).

By definition serotinous cones refer to cone persistence (Harlow and Harrar 1969) or the retention of viable seed in closed cones over a period of time (Pyne et al. 1996). However, by usage, cone serotiny has come to mean those with a waxy or resinous coating that open only related to heat from an intense fire (see Givnish 1981, Keeley and Zedler 1998, Schwilk and Ackerly 2001). Shortleaf cones are somewhat persistent (Harlow and Harrar 1969) but not considered serotinous in the current usage of this term..

Bud configuration and location enables shortleaf to rapidly recover from fire (Little and Somes 1956, Little and Mergen 1966). In the first 1-2 years of seedling development in open-grown conditions, a basal double crook exhibiting lateral growth at the root collar develops below ground line with a number of attendant dormant buds (Little and Mergen 1966). These dormant buds are well protected underneath the soil surface and survive even high intensity fires. When competition is severe or in shady situations, it may take individual stems up to 9 years to develop this crook (Little and Somes 1956). Most seedlings will develop this crook but those that are open grown develop it in a shorter period of time (Little and Mergen 1966). However the propensity of shortleaf to sprout is quite variable. Sprouting ability is related to presence of a well-developed crook, a well developed root collar and overall seedling vigor and less as a result of age or height of the seedling (Little and Somes 1956).

Dormant buds are also found along the main stem and main branches. Where these latent buds receive some protection, the plant will sprout from either location even if completely defoliated by fire (Mattoon 1915, Little and Somes 1956). Trees developing from sprouts normally develop good form and produce a commercial product (Mattoon 1915, Little and Somes 1956). Masters et al. (2005) observed abundant sprouting in densely stocked 4 year-old seedlings that developed as a result of seed tree and selective cuts, when subjected to a late growing season burn in an Oklahoma study. However in the same area Nickles et al. (1981) were able to successfully top-kill competing shortleaf in an early regeneration setting using prescribed fire and herbicide.

Mature shortleaf are notably resistant to mortality from crown scorch (Komarek 1981) and will survive if terminal buds are not killed even if the complete crown is scorched (Wade and Johansen 1986). However Cain and Shelton (2003*a*) noted that diameter and thus volume growth were reduced by half in mixed stands of loblolly and shortleaf when crown scorch was about 75%. Also the needles of shortleaf apparently do not burn as readily as other southern pines (Komarek 1981). Apparently some combination of needle configuration and lower flammability provides protection for the terminal buds.

Effects of Fire Frequency

Shortleaf will tolerate well frequent low-intensity fire (Masters et al. 2005). Hermann (1995) found no decrease in survivorship of mixed shortleaf-loblolly dominated stands after 35 years of annual dormant season burning. Other studies found little or no mortality to mature overstory shortleaf with a 3-year burning interval (e.g., Sparks et al. 1999). Short-term (8 years) diameter growth and volume yield of shortleaf were increased in a New Jersey study with fire every 2-3 years while thinning without fire has little to no effect on shortleaf growth (Somes and Moorehead 1954). In a review of the effects of fire on shortleaf growth rates Huebschmann (2000) found mixed results with some studies reporting declines, some increases and some with no change to shortleaf growth.

Effects of Fire Season

Although normally very fire resistant, mortality following low intensity fires in October was noted in mature shortleaf and loblolly in an area long excluded from fire and which had heavy domelike litter accumulations from sloughed bark and needle cast at the base (Ferguson et al. 1961). In this case fuel moisture was low (6%) and evidently residence time was long. Mortality may have been a combination of basal cambium injury and injury to fine rootlets that had developed in the organic layer. A key to the mortality here was that fire had been long excluded from the site, fuel accumulations were high and fuel moistures were very low. Other studies that examined both late-growing and late-dormant season fire did not report mortality to overstory shortleaf under a range of fireline intensities although other parameters were the focus of their studies (Sparks et al. 1999, 2002).

Effects of Fire Intensity

As suggested above, shortleaf is resistant to even relatively high intensity fire that may completely scorch the crown of a given mature tree (Komarek 1981). Trees 60-years old showed no loss of growth when subjected to light to moderate intensity summer burns (Yocum 1972). However young trees may suffer as much as a 75% growth loss following a prescribed burn (Garren 1943). Only in the rare occasion of low fuel moisture and high fuel loads have low intensity fires resulted in overstory mortality to shortleaf (Ferguson et al. 1961).

Management Considerations for Wildlife

Shortleaf pine provides habitat for a large number of species from early seral stages through late seral stages. Well spaced seedlings of less than about 1,730 stems/ha (700 stems/ac) and in young sapling stands up to about 2 m (6.5 ft) and canopy closure provide some value as cover for early seral species such as many small mammals, cotton-tailed rabbit (*Sylvalagus floridanus*) and northern bobwhite (*Colinus virginianus*) and saplings provide beneficial escape and bedding cover for white-tailed deer (*Odocoileus virginanus*) in naturally or artificially regenerated stands (Masters 1991*a,b*; Masters et al. 1997). Use of these stands is extended when prescribed fire is introduced early and at least on a 3-year late-dormant season cycle. Elk (*Cervus elaphus*) populations also use dense sapling stands in areas where elk restoration efforts are underway (Masters et al. 1997). Deer and elk also use saplings as territorial marking sites or antler rubbing sites during the rut. When high stem densities develop, use by either species will decline rapidly with canopy closure where fire is excluded (Masters 1991a, b; Masters et al. 1997).

Early succession songbird species such Northern bobwhite and Bachman's sparrow (*Aimophila aestivalis*) make some use of sparse regenerating stands as long as adequate ground cover and some scattered hardwood brush is present. Where ground cover is predominantly needle litter in dense sapling stands, species like prairie warbler (*Dendroica discolor*) and hooded warbler (*Wilsonia citrina*) have been noted. Periodic burning on at least a 3-year rotation in young sapling stands ensures that numerous small mammals, bobwhite, turkey and numerous songbirds will continue to use the stands as they develop (R. E. Masters, Tall Timbers Research Station, unpublished data).

Once a shortleaf stand enters the post size-class, use by wildlife will decline dramatically in dense stands if fire is excluded. At age 12-15 depending on the site index, many songbird species characteristic of later stages of succession will once again begin using the canopies of shortleaf stands as well as stands of other southern pine species (R. E. Masters, Tall Timbers Research Station, unpublished data). The importance of fire in retaining early sere wildlife species was recently shown in a study that examined northern bobwhite use of these types of stands. Following only 3-4 seasons of fire exclusion, northern bobwhite began avoiding stands (600–700 stems/acre) that were once heavily used (Walsh 2004).

A host of song birds use the canopies of pole sized stands and to a much lesser extent the understory where frequent fire is used. The songbird species complement in pole stands is similar to mature stands (Wilson et al 1995, Masters et al. 2002). In mature stands excluded from fire both species richness and density of small mammals and songbirds decline markedly as midstory hardwoods develop and as the herbaceous layer declines from litter buildup and shading by hardwoods (Masters et al. 2002). However mature shortleaf pine-bluestems stands, which may be characterized by abundant herbaceous ground cover, basal areas less than 16 m^2/ha (70 ft^2/ac), little to no hardwood midstory, and managed with late-dormant season fire at three year intervals, show dramatic increases in both richness and density of small mammals and songbirds (Wilson et al.

1995; Masters et al.1998, 2002). Low basal area pine-bluestem stands managed with frequent fire also provide more than adequate forage for white-tailed deer (Masters et al. 1993, 1996) of high nutritional quality (Masters 1991*a*) and are used to a greater extent than unburned closed-canopy sites (Masters et al. 1997). At least 11 species of breeding birds are considered pine-grassland obligates and are benefited by pine-bluestem management (Wilson et al. 1995, Conner et al. 2002, Cram et al. 2002, Masters et al. 2002). These include, red-cockaded woodpecker (*Picoides borealis*), red-headed woodpecker (*Melanerpes carolinus*), brown headed nuthatch (*Sitta pusilla*), Northern bobwhite, prairie warbler, pine warbler (*Dendroica pinus*), Eastern bluebird (*Sialia sialis*), Bachman's sparrow, chipping sparrow (*Spizella passerine*), Eastern wood-pewee (*Contopus virens*), indigo bunting (*Passerina cyanea*) (see Wilson et al. 1995, Cram et al. 2002, Masters et al. 2002). These species are distinctly disadvantaged by fire exclusion and following mid- to upper midstory development will cease use of these stands (Wilson et al 1995). This suite of species has declined more precipitously than any other group of songbirds in eastern North America (Jackson 1988). Midstory hardwood development has been directly associated with cavity tree abandonment by red-cockaded woodpeckers and subsequent populations declines (Masters et al. 1989, Jackson et al. 1986).

As a food resource, shortleaf pine seed provides an important and preferred food source for northern bobwhite (R. E. Masters, Tall Timbers Research Station, unpublished data) and for numerous small mammals (Stephenson et al. 1963) including gray squirrel and numerous ground feeding song birds (Martin et al. 1951). Extensive consumption of shortleaf seed by many songbirds and small mammals has been reported as a hindrance to suitable seedling establishment from either natural seed fall or direct seeding of sites (Lawson 1990).

Snags are important for primary and secondary cavity nesting songbirds (e.g., red-headed woodpecker and eastern bluebird, respectively) (Masters et al. 2002). Snags may be created or consumed by fire. An important consideration in prescribed burning when snag retention is a management objective is the fact that snags are 1,000 hr fuels. Burning when these fuels have high moisture content (>25%) (Scott and Burgan 2005) or when KBDI is low will prevent consumption.

Managing Shortleaf Pine with Prescribed Fire

Using Prescribed Fire to Control Insects and Diseases

Relatively few insects and disease cause serious problems in shortleaf (Tainter 1986). The major threats include the southern pine beetle (*Dendrococtonus frontalis*) in the south and west and littleleaf disease in the eastern Piedmont states and across the mid-south (Campbell et al. 1953, Harlow and Harrar 1969, Tainter 1986, Zarnoch et al. 1994). The later two are potentially serious (Tainter 1986) especially in plantation stands and in overstocked stands under stress.

The Nantucket pine-tip moth (*Rhyancionia frustrana*) can be a serious problem in young plantation grown pines where sites have been mechanically prepared and particularly when in combination with herbaceous weed control (Tainter 1986). Shortleaf stands that were naturally regenerated using fire have not been reported with serious incidences of this moth.

The southern pine beetle is by far the most injurious to shortleaf of all insects (Tainter 1986). Shortleaf are particularly susceptible when undergoing stress. Outbreaks are common in over stocked stands, following lightning strikes, mechanical injury to the bark, excessive fire damage, extremely slow growth rates, drought stress, and the incidence of disease (Tainter 1986). In particular, outbreaks of southern pine beetle may be associated with littleleaf disease (Campbell et al. 1953, Tainter 1986). The use of a thinning from below and introduction of prescribed fire on a 3 to 5 year cycle lowers the susceptibility of the stands to southern pine beetle attack (Stanturf et al. 2004). Maintaining high basal area stands of loblolly at > 23 m^2/ha (>100 ft^2/ac) was found to increase losses due to bark beetle infestation (Cain and Shelton 2003*a*) and is presumed to be true for shortleaf as well.

Littleleaf disease was first recognized in 1934 in Alabama (Walker and Wiant 1966, Tainter 1986). It has not been reported west of the Mississippi River. This condition expresses itself in trees as young as 20 years of age but most commonly in 30 to 50 years of age (Campbell et al. 1953). The symptoms include short needles and overall reduced and yellow foliage with trees typically dying in 3–10 years. This condition is considered a disease by most authorities but has been termed a “decline phenomena” by others because of the unique combination of factors for symptoms to be expressed (Mueller-Dombois et al. 1983). It occurs on nutrient deficient, poorly drained, and poorly aerated soils with high clay content or with clay subsoil, but is also associated with the soil fungus *Phytophthora cinnamoni* (Copeland and McAlpine 1955). These combined factors evidently impede nitrogen uptake (Lawson 1990). Symptoms may be alleviated with the application of high amounts of nitrogen (Lawson 1990). Long term strategies have included retaining hardwoods within these stands because of leaf litter contribution to the soil building presence and exclusion of these stands from prescribed fire (Walker and Wient 1966, Campbell et al. 1953). However there is no direct evidence to suggest prescribed fire exacerbates this condition. Selective breeding from progeny of resistant trees has shown some success (Zarnoch et al. 1994).

Annousus root rot (*Heterobasidion annosum*) is another problem disease in shortleaf but of lesser importance than the above (Tainter 1986). Prescribed fire can be used to control this disease only somewhat (Froelich et al. 1978). One other notable disease is red heart (*Phellinus pinii*) which generally occurs in trees older than 80 years (Tainter 1986). Trees infected with this disease are selectively chosen for cavity trees by the endangered red-cockaded woodpecker (Jackson 1977).

Key Issues in the Implementation of Prescribed Burning

Prescribed fire is commonly used within shortleaf types as a method for hazardous fuel reduction, for ecosystem restoration, as a silvicultural tool, management of competing hardwoods and herbaceous vegetation, for wildlife habitat management, improve access, aesthetics, for improved grazing, to perpetuate fire-dependant species and to maintain ecosystem health (Van Lear 1985, Masters 1991a, Wade 1989, Masters et al. 2003). Frequent fire typically less than 12 year intervals on more exposed sites and less than 4-year intervals on better sites are essential to maintain shortleaf as a type.

The largest issue which looms in the implementation of prescribed fire is achieving prescribed fire targets both on public and on private lands (Palmer et al. 2004). Even with our knowledge about the benefits of fire for ecosystem perpetuation the application of fire on the land is not keeping up with what is necessary. This leads to ecosystems that are departed from reference condition structure and function and ultimately degraded (Schmidt et al. 2002). On private lands lack of implementation of burns is related to state and local regulations regarding burning. It is also related to the issue of strict liability for those conducting burns (Palmer et al. 2004). As the wildland urban interface expands and urban areas encroach upon wildlands many in the public are intolerant of smoke because of the perception of physical danger and potential health risks (Wade 1993, Palmer et al. 2004).

Associated with this is the administration of the 1970 Clean Air Act by the Environmental Protection Agency (EPA) (Achtemeier et al. 1998). This law limits the various types of pollutants that are acceptable in air across different regions of the country. Of concern are the regional limits of particulate matter and carbon monoxide in smoke. Currently the smoke from wildfire and from prescribed fire is viewed as equivalent by EPA when reported findings suggest otherwise (K. Robertson, Tall Timbers Research Station, personal communication). Burn bans are increasingly being put in place in counties surrounding high urban populaces where air quality issues are paramount (Palmer et al. 2004). Additional research is needed to arrive at standards that are acceptable for both the health of the citizenry and for the health of regional forests.

Another issue about implementation of prescribed burns is related to the current ecological debate over the appropriate season to burn. Because of the recent push to burn in the growing season, managers may forego burning because of the fewer number of suitable burn days or the risk associated with burning during the growing season (Sparks et al. 1998, 2002; Glitzenstein et al. 2003). As these authors have suggested fire in any season is preferable to no fire in fire adapted or fire-dependant systems. Fire frequency should take precedence over fire season when these two are at issue (Glitzenstein et al. 2003). Where possible a mixture of both growing and dormant season prescribed fire at frequent intervals will insure perpetuation of shortleaf and associated species (Masters et al. 1995, 2005; Sparks et al. 1998, 1999, 2002).

References

Achtemeier, G. L., W. Jackson, B. Hawkins, D. D. Wade, and C. McMahon. 1998. The smoke dilemma: a head on collision. *Trans. North American Wildlife and Natural Resources Conference* 63:415-421.

Baker, J. B. 1992. Natural regeneration of shortleaf pine. Pages 102-112 *in* Brissette, J. C. and J. P. Barnett (eds). Proceedings: shortleaf pine regeneration workshop. GTR-SO-90. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station, New Orleans, LA.

Baker, J. B., M. D. Cain, J. M. Guldin, P. A. Murphy, and M. G. Shelton. 1996. Uneven-aged Silviculture for the loblolly and shortleaf pine forest cover types. General Technical Report SO-118. U.S. Department of Agriculture, Forest Service. Southern Research Station. Asheville, NC. 65p.

Barden, L. S., and F. W. Woods. 1974. Characteristics of lightning fires in southern Appalachian forests. *Proceedings Tall Timbers Fire Ecology Conference* 13:345-361.

Batek, M. J., A. J. Rebertus, W. A. Schroeder, T. L. Haithcoat, E. Compas, and R. P. Guyette. 1999. Reconstruction of early nineteenth-century vegetation and fire regimes in the Missouri Ozarks. *Journal of Biogeography* 26:397-412.

Beilmann, A. P., and L. G. Brenner. 1951*a*. The changing forest flora of the Ozarks. *Ann. Missouri Bot. Garden* 38:283-291.

Beilmann, A. P., and L. G. Brenner. 1951*b*. The recent intrusion of forests in the Ozarks. *Ann. Missouri Bot. Garden* 38:261-282.

Billings, W. D. 1938. The structure and development of old field shortleaf pine stands and certain associated physical properties of the soil. *Ecological Monographs* 8(3):437-500.

Bragg, D. C. 2002. Reference conditions for old-growth pine forests in the Upper West Gulf Coastal Plain. *Journal of the Torrey Botanical Society* 129(4):261-288.

Braun, E. L. 1950. Deciduous forests of eastern North America. Blakiston Co., Philadelphia, Pa. 596pp.

Brinkman, K. A. and P. A. Swarthout. 1942. Natural reproduction of pines in east Central Alabama. Alabama Agricultural Experiment Station. Circular 86. Auburn, AL.

Brinkman, K. A., and R. C. Smith. 1968. Managing shortleaf pine in Missouri. Station Bulletin 875. University of Missouri-Columbia, Agriculture Experiment Station. Columbia, MO 35p.

Bruner, W. E. 1931. The vegetation of Oklahoma. *Ecological Monographs* 1:99-188.

Buckner, E. 1989. Evolution of forest types in the southeast. Pages 27-33 in T. A. Waldrop, ed. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. General Technical Report SE-58. U.S. Department of Agriculture Forest Service. Asheville, NC.

Buell, M. F., and J. E. Cantlon. 1953. Effects of prescribed burning on ground cover in the New Jersey pine region. *Ecology* 34(3):520-528.

Cain, M.D. 1991*a*. Hardwoods on pine sites: competition or antagonistic symbiosis. *Forest Ecology and Management* 44:147-160.

Cain, M.D. 1991*b*. The influence of woody and herbaceous competition on early growth of naturally regenerated loblolly and shortleaf pines. *Southern Journal of Applied Forestry* 15:179-185.

Cain, M.D. 1993. A 10-year evaluation of prescribed winter burns in uneven-aged stands of *Pinus taeda* L. and *P. echinata* Mill.: woody understory vegetation response. *International Journal of Wildland Fire* 3:13-20.

Cain, M.D., and M.G. Shelton. 1995. Thirty-eight years of autogenic, woody understory dynamics in a mature, temperate pine-oak forest. *Canadian Journal of Forest Resources* 25:1997-2009.

Cain, M.D., and M.G. Shelton. 1996. The R.R. Reynolds research natural areas in Southeastern Arkansas: a 56-year case study in pine-hardwood overstory sustainability. *Journal of Sustainable Forestry* 3(4):59-73.

Cain, M.D. and M.G. Shelton. 2000. Survival and growth of Pinus and Quercus seedlings in response to simulated summer and winter prescribed burns. *Canadian Journal of Forest Resources* 30:1830-1836.

Cain, M.D., and M.G. Shelton. 2001. Secondary forest succession following reproduction cutting on the Upper Coastal Plain of southeastern Arkansas, USA. *Forest Ecology and Management* 146:223-238.

Cain, M.D. and M.G. Shelton. 2002. Does prescribed burning have a place in regenerating uneven-aged loblolly-shortleaf stands? *Southern Journal of Applied Forestry* 26(3):117-123.

Cain, M.D. and M.G. Shelton. 2003*a*. Effects of Alternative Thinning Regimes and Prescribed Burning in Natural, Even-aged Loblolly-Shortleaf Pine Stands: 25 year results. *Southern Journal of Applied Forestry* 27:18-29.

Cain, M.D., and M.G. Shelton. 2003*b*. Fire effects on germination of seeds from *Rhus* and *Rubus*: competitors to pine during natural regeneration. *New Forests* 26:51-64.

Cain, M.D., and D.A. Yaussy. 1984. Can hardwoods be eradicated from pine sites? *Southern Journal of Applied Forestry* 8:7-13.

Campbell, J. J. N., D. D. Taylor, M. E. Medley and A. C. Risk. 1991. Floristic and historical evidence of fire maintained, grassy pine-oak barrens before settlement in southeastern Kentucky. Pages 359-375. *in* S. C. Nodvin and T. A. Waldrop, (eds.). Fire and the environment: ecological and cultural perspectives. Proc. of an International Symposium. General Technical Report SE-69. U.S. Department of Agriculture, Forest Service, Southeast Forest Experiment Station, Asheville, N.C.

Campbell, W. A., O. L. Copeland, Jr., and G. H. Hepting. 1953. Managing shortleaf pine in littleleaf disease areas. Station Paper No. 25. U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station. Asheville, NC. 12p.

Cassidy, P. D. 2004. Dynamics and development of shortleaf pine in east Tennessee. Ph.D. Dissertation. University of Tennessee, Knoxville, TN. 99p.

Chapman, H. H. 1944. Fire and pines. *American Forests* 50:62-64, 91-93.

Chen, J., C.G. Yauer and Y. Huang. 2003. Observations on mitochondrial DNA inheritance and variation among three *Pinus* species. *Forest Genetics* 10:271-276.

Chen, J., C.G. Tauer, G. Bai, Y. Huang, M.E. Payton, and A.G. Holley. 2004. Bidirectional introgression between *Pinus taeda* and *Pinus echinata*: evidence from morphological and molecular data. *Canadian Journal of Forest Research* 34:2508-2516.

Conner, R.N., C.E. Shackelford, R.R. Schaefer, D. Saenz, and D.C. Rudolf. 2002. Avian community response to southern pine ecosystem restoration for red-cockaded woodpeckers. *Wilson Bulletin* 114(3):324-332.

Copeland, O. L., Jr., and R. G. McAlpine. 1955. The interrelations of littleleaf, site index, soil, and groundcover in Piedmont shortleaf pine stands. Ecology 36(4):635-641.

Crandall, R. M. 2003. Vegetation of the Pushmataha Wildlife Management Area, Pushmataha County, Oklahoma. M. S. Thesis. Oklahoma State University, Stillwater. 114p.

Cram, D. S., R. E. Masters, F. S. Guthery, D. M. Engle, and W. G. Montague. 2002. Northern bobwhite population and habitat response to pine-grassland restoration. *Journal of Wildlife Management* 66:1031-1039.

Cronon, W. 1983. Changes in the Land: Indians, colonists, and the ecology of New England. Hill and Wang, New York.

Cunningham, R. J., and C. Hauser. 1989. The decline of the Missouri Ozark forest between 1880 and 1920. Pages 34-37 in T. A. Waldrop, ed. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. General Technical Report SE-58. U.S. Department of Agriculture Forest Service. Asheville, NC.

Day, G. M. 1953. The Indian as an ecological factor in the northeastern forest. *Ecology* 34(2):329-346.

Delcourt, H. R. and P. A. Delcourt. 1991. Late Quaternary Vegetation History of the Interior Highlands of Missouri, Arkansas, and Oklahoma. Pages - *in* D. Henderson and L. D. Hedrick, editors. Proc: Restoration of Old Growth Forests of the Interior Highlands of Arkansas and Oklahoma. Winrock International. Morrilton, Ark.

Denevan, W. M. 1992. The pristine myth: the landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82:369-385.

DeVivo, M. S. 1991. Indian us of fire and land clearance in the southern Appalachians. Pages 306-312 *in* S. C. Nodvin and T. A. Waldrop, eds. Fire and the environment: ecological and cultural perspectives: Proc. Intl. Symp. U.S. For. Serv. Southeast. For. Exp. Stn., Gen. Tech. Rep. SE-69., Asheville, NC.

Dorman, K. W. 1976. The genetics and breeding of southern pines. U.S. Department of Agriculture, Forest Service. Agriculture Handbook No. 471. Washington, DC.

Duryea, M. L., and P. M. Dougherty. 1990. Forest regeneration manual. Kluwer Academic Publishers, Dordrecht, The Netherlands. 433p.

Engle, D. M., and J. F. Stritzke. 1996. Fire behavior and fire effects on eastern redcedar in hardwood leaf-litter fires. International Journal of Wildland Fire 5:135-141.

Engle, D. M., T. G. Bidwell, and R. E. Masters. 1996. Restoring Cross Timbers ecosystems with fire. Trans. North American Wildlife and Natural Resources Conference 61:190-199.

Eyre, F. H., editor. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC.

Farrar, R. M., Jr., 1996. Fundamentals of uneven-aged management in southern pine. Misc. Public. No. 9. Tall Timbers Research Station, Tallahassee, FL. 63p.

Farrar, R. M., Jr., P. A. Murphy, and R. Colvin. 1984. Hope Farm woodland: 33-year production in an uneven-aged loblolly-shortleaf pine stand. *Journal of Forestry* 82(8):476-479.

Ferguson, E. R., C. B. Gibbs, and R. C. Thatcher. 1961. "Cool" burns and pine mortality. *Fire Control Notes* 21(1):27-29.

Foti, T. and S. Glenn. 1991. The Ouachita Mountains Landscape at the Time of Settlement. Pages 49-65 *in* D. Henderson and L. D. Hedrick, editors. Proc. Conference on Restoring Old Growth Forest in the Interior Highlands of Arkansas and Oklahoma. Winrock International, Morrilton, Ark.

Fowells, H. A., compiler. 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture, Agriculture Handbook No. 271. Washington, D.C. 762p.

Froelich, R. C., C. S. Hodges, and S. S. Sackett. 1978. Prescribed burning reduces the severity of annousus root rot in the South. *Forest Science* 24:93-100.

Frost, C. C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. *Proceedings Tall Timbers Fire Ecology Conference* 19:39-60.

Frost, C. C. 1998. Presettlement fire frequency regimes of the United States: first approximation. *Proceedings Tall Timbers Fire Ecology Conference* 20:70-81.

Frost, C. C. 2000. Studies in landscape fire ecology and presettlement vegetation of the southeastern United States. Ph.D. Dissertation. University of North Carolina, Chapel Hill. 620p.

Fryar, R. D. 1991. Old Growth Stands of the Ouachita National Forest. Pages xx-xx *in* D. Henderson and L. D. Hedrick, editors. Proc: Restoration of Old Growth Forest in the Interior Highlands of Arkansas and Oklahoma. Winrock International. Morrilton, Ark.

Garren, K. H. 1943. Effects of fire on vegetation of the southeastern United States. *Botanical Review* 9:617-654.

Givnish, T. J. 1981. Serotiny, geography, and fire in pine barrens of New Jersey. Evolution 35(1):101-123.

Glitzenstein, J. S., D. R. Streng, and D. D. Wade. 2003. Fire frequency effects on longleaf pine (Pinus palustris P. Miller) vegetation in South Carolina and northeast Florida, USA. *Natural Areas Journal* 23:22-37.

Guffey, S. Z. 1977. A review and analysis of the effects of pre-columbian man on the eastern North American forests. *Tennessee Anthropologist* 2(2)121-137.

Guldin, J. M. 1986. Ecology of shortleaf pine. Pages 25-40 *in* P. A. Murphy, editor. Proceedings: symposium on the shortleaf pine ecosystem. March 31 – April 2, 1986, Excelsior Hotel, Little Rock, Arkansas. Arkansas Cooperative Extension Service, Monticello, Ark.

Guldin, J. M. 2004. Reproduction cutting methods for naturally regenerated pine stands in the south. Pages 83-95 *in* H. M. Rauscher and K. Johnsen, editors. Southern forest science: past, present, and future. U.S. Department of Agriculture Forest Service. General Technical Report SRS-75. Ashville, NC.

Guyette, R. P. and D. C. Dey. 1997. Historic shortleaf pine (Pinus echinata Mill.) abundance and fire frequency in a mixed oak-pine forest (MOFEP, Site 8). Pages 136-149 *in* B. L. Brookshire and S. R. Shifley, editors. Proceedings of the Missouri Ozark Forest Ecosystem Project Symposium: An experimental approach to landscape research. U.S. Department of Agriculture Forest Service North Central Forest Experiment Station General Technical Report NC-193, St. Paul, MN.

Guyette, R. P. and M. A. Spetich. 2003. Fire history in oak-pine forests in the Lower Boston Mountains, Arkansas, USA. *Forest and Ecology Management* 180:463-474.

Guyette, R. P. and M. C. Stambaugh. 2005. Arnold Air Force Base Historic barrens forest structure and fire regimes assessment-interim report 2. Prepared by Missouri Tree-Ring Laboratory. University of Missouri, Columbia, MO.

Hammett, J. E. 1992*a*. Ethnohistory of aboriginal landscapes in the southeastern United States. *Southern Indian Studies* 41:1-50.

Hammett, J. E. 1992*b*. The shapes of adaptation: historical ecology of anthropogenic landscapes in the southeastern United States. *Landscape Ecology* 7:121-135.

Haney, G. P. 1962. A revised shortleaf pine bibliography. Paper 155. U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 74p.

Harlow, W. M., and E. S. Harrar. 1969. Textbook of Dendrology. Fifth edition. McGraw Hill, New York. 512p.

Harper, R. M. 1962. Historical notes on the relation of fires to forests. *Proceedings Tall Timbers Fire Ecology Conference* 1:11-29.

Hermann, S. M. 1995. Stoddard fire plots: lessons for land management thirty-five years latter. Pages 13-20 in L. A. Brennan, K. Gainey, and T. Pruden, editors. Proceedings of the Tall Timbers Game Bird Seminar. Tall Timbers Research Station, Tallahassee, FL. 91p.

Huebschmann, M. M. 2000. Restoring the shortleaf pine–bluestem grass ecosystem on the Ouachita National Forest: an economic evaluation. Ph.D. Thesis, Oklahoma State University, Stillwater. 141p.

Ison, C. R. 2000. Fire on the edge: prehistoric fire along the escarpment zone of the Cumberland Plateau. Pages 36-45 *in* Proceedings: Workshop on fire, people, and the central hardwoods, landscape. GTR-NE-274. U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station, Newtown Square, PA.

Jackson, J. A. 1977. Red-cockaded woodpecker and pine red heart disease. *Auk* 94:160-163.

Jackson, J. A. 1988. The southeastern pine forest ecosystem and its birds: past present, and future. Pages 119-159 *in* J. A. Jackson, editor. Bird Conservation 3. International Council Bird Preservation. University of Wisconsin Press, Madison.

Jackson, J. A., R. N. Conner, and B. J. S. Jackson. 1986. The effects of wilderness on the endangered red-cockaded woodpecker. Pages 71–78 *in* Kulhavy, D.D. and R.N. Conner (eds.). Wilderness and Natural Areas in the Eastern United States: A Management Challenge. Nacogdoches, TX: Center for Applied Studies, School of Forestry, Stephen F. Austin State University.

Jackson, J. F., D. C. Adams, and U. B. Jackson. 1999. Allometry of constitutive defense: a model and a comparative test with tree bark and fire regime. *The American Naturalist* 153(6):614-632.

Jackson, L. W. R., and R. S. Harper. 1955. Relation of light intensity to basal area of shortleaf pine stands in Georgia. Ecology 36(1):158-159.

Johnson, A. S. and P. E. Hale. 2002. The historical foundations of prescribed burning for wildlife: a southeastern perspective. Pages 11-23 *in* W. M. Ford, K. R. Russell, and C. E. Moorman, editors. The role of fire in non-game wildlife management and community restoration: traditional uses and new directions: proceedings of a special workshop. Annual Meeting of The Wildlife Society, Nashville, Tenn. USDA For. Ser. Northeast Research Station. General Technical Report NE-288.

Johnson, F. L. 1986. Woody vegetation of southeastern LeFlore County, Oklahoma, in relation to topography. *Proceedings of the Oklahoma Academy of Science* 66:1-6.

Johnson, F. L. and G. D. Schnell. 1985. Wildland Fire History and the Effects of Fire on Vegetative Communities at Hot Springs National Park, Arkansas. Report to National Park Service, Santa Fe, NM., Okla. Biological Survey., University of Oklahoma, Norman, Okla. 49 pp.

Jurney, D. R. Evans, J. Ippolito, and V. Bergstrom. 2004. The role of wildland fire in portions of southeastern North America. *Proceedings Tall Timbers Fire Ecology Conference* 22:95-116.

Kay, C. E. 2002. False gods, ecological myths, and biological reality. Pages 238-261 *in* C. E. Kay and R. T. Simmons, editors. Wilderness and Political Ecology: Aboriginal Land Management-Myths and Reality. University of Utah Press.

Keeley, J. E., and P. H. Zedler. 1998. Evolution of life histories in *Pinus*. Pages 219-250 in D. M. Richardson, editor, Ecology and Biogeography of *Pinus*. Cambridge University Press, United Kingdom.

Komarek, E. V. 1964. The natural history of lightning. *Proceedings Tall Timbers Fire Ecology Conference* 3:139-183.

Komarek, E. V. 1968. Lightning and lightning fires as ecological forces. *Proceedings Tall Timbers Fire Ecology Conference* 8:169-197.

Komarek, E. V. 1974. Effects of fire on temperate forests and related ecosystems: southeastern United States. Pages 251-277. *in* T.T. Kozlowski and E. E. Ahlgren, editors. Fire and Ecosystems. Academic Press, New York, NY.

Komarek, E. V. 1981. Scorch in pines. Manage. Note 2. Tall Timbers Research Station. Tallahassee, Fl. 7pp.

Kreiter, S. D. 1994. Dynamics and Spatial Patterns of a Virgin Old-growth Hardwood-pine Forest in the Ouachita Mountains, Oklahoma, from 1896-1994. M.S. Thesis. Oklahoma State University, Stillwater.

Lawson, J. 1966. A new voyage to Carolina. March of America Facsimile Series Number 35. University Mirofilms, Inc. Ann Arbor, MI. 259p.

Lawson, E. R. 1990. Pinus echinata Mill. shortleaf pine. Pages 316-326 *in* R. M. Burns and B. H. Honkala, technical coordinators. Silvics of North America. Volume 1. Conifers. U.S. Department of Agriculture, Forest Service. Agriculture Handbook No. 654. Washington, DC.

Lawson, E. R., and R. N. Kitchens. 1983. Shortleaf pine. Pages 157-161 *in* R. M. Burns, tech. compiler. Silvicultural systems for the major forest types of the United States. U.S. Department of Agriculture, Forest Service. Agriculture Handbook No. 445. Washington, DC.

Little, E. L., Jr. 1971. Atlas of United States Trees. Volume 1. Conifers and Important Hardwoods. U.S. Department of Agriculture, Forest Service. Miscellaneous Publication No. 1146. Washington, DC. unpaged.

Little, E. L., Jr. 1979. Checklist of United States trees (native and naturalized). U.S. Department of Agriculture, Forest Service. Agriculture Handbook 541. Washington, DC. 375p.

Little, E. L., Jr. 1981. Forest trees of Oklahoma. Pub. No. 1, Rev. ed. no. 12. State Div. of Agriculture, Oklahoma Forestry Division, Oklahoma City, Okla. 240pp.

Little, E. L., Jr., and E. E. Olmstead. 1931. An ecological study of the southeastern Oklahoma protective unit, Oklahoma Forest Service. (Manuscript edited by W. T. Penfound, Univ. Oklahoma Library) 53pp.

Little, S. 1940. Seed fall of shortleaf pine. U.S. Department of Agriculture Forest Service. Technical Note No. 27. Allegheny Forest Experiment Station, Philadelphia, PA. 1p.

Little, S. 1946. The effects of forest fires on the stand history of New Jersey's pine region. U.S. Department of Agriculture Forest Service, Experiment Station Research Forest Management Paper No. 2. Northeastern Forest Experiment Station, Philadelphia, PA. 43p.

Little, S., J. P. Allen, and E. B. Moore. 1948. Controlled burning as a dual-purpose tool of forest management in New Jersey's Pine Region. *Journal of Forestry* 46:810-819.

Little, S. and F. Mergen. 1966. External and internal changes associated with basal-crook formation in pitch and shortleaf pines. *Forest Science* 12(3): 268-75.

Little, S., and E. B. Moore. 1945. Controlled burning in south Jersey's oak-pine stands. *Journal of Forestry* 43:499-506.

Little, S., and E. B. Moore. 1949. The ecological role of prescribed burns in the pine-oak forests of southern New Jersey. *Ecology* 30: 223-233.

Little, S. and H. A. Somes. 1956. Buds enable pitch and shortleaf pines to recover from injury. U.S. Department of Agriculture Forest Service, Experiment Station Research Paper 81. Northeastern Forest Experiment Station, Upper Darby, PA.

Logan, J.H. 1859. A history of the upper country of South Carolina from the earliest periods to the close of the War of Independence. S.G. Courtenay and Company, Charleston, SC.

Lotan, J. E., M. E. Alexander, S. F. Arno, R. E. French, O. G. Langdon, R. M. Loomis, R. A. Norum, R. C. Rothermel, W. C. Schmidt, and J. V. Wagtendonk. 1978. Effects of fire on flora - A state-of-knowledge review. U.S. Department of Agriculture Forest Service, General Technical Report WO-16. 71pp.

Lowery, R. F. 1968. The effect of initial stem temperature on time required to kill cambium of shortleaf pine. M. S. Thesis. University of Missouri, Columbia, MO. 52pp.

Lutz, H. J. 1934. Ecological relations in the pitch pine plains of southern New Jersey. *Yale University School of Forestry Bulletin* 38:1-80.

Marks, P.L., and P.A. Harcombe. 1975. Community diversity of coastal plain forests in southern east Texas. *Ecology* 56:1004-1008.

Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. American wildlife and plants. McGraw-Hill Publishing, New York, NY. 500p.

Masters, R. E. 1991a. Effects of timber harvest and prescribed fire on wildlife habitat and use in the Ouachita Mountains of eastern Oklahoma. Ph.D. Thesis, Oklahoma State Univ. Stillwater. 351 pp.

Masters, R. E. 1991b. Effects of fire and timber harvest on vegetation and cervid use on oak -pine sites in Oklahoma Ouachita Mountains. Pages 168-176. *in* S. C. Nodvin and T. A. Waldrop, (eds.). Fire and the environment: ecological and cultural perspectives. Proc. of an international symposium. U.S. Department of Agriculture, Forest Service, General Technical Report SE-69. Southeast For. Exp. Sta., Asheville, N.C.

Masters, R. E., and D. M. Engle. 1994. BEHAVE-evaluated for prescribed fire planning in mountainous oak-shortleaf pine habitats. *Wildlife Society Bulletin* 22:184-191.

Masters, R. E., D. M. Engle, and R. Robinson. 1993. Effects of timber harvest and periodic fire on soil chemical properties in the Ouachita Mountains. Southern Journal of Applied Forestry 17:139-145.

Masters, R. E., R. L. Lochmiller, and D. M. Engle. 1993. Effects of timber harvest and periodic fire on white-tailed deer forage production. *Wildlife Society Bulletin* 21:401-411.

Masters, R. E., R. L. Lochmiller, S. T. McMurry, and G. A. Bukenhofer. 1998. Small mammal response to pine-grassland restoration for red-cockaded woodpeckers. *Wildlife Society Bulletin* 28:148-158.

Masters, R. E., J. E. Skeen, and J. A. Garner. 1989. Red-cockaded woodpecker in Oklahoma; an update of Wood's 1974-77 Study. *Proceedings Oklahoma Academy of Science* 69:27-31.

Masters, R. E., J. E. Skeen, and J. Whitehead. 1995. Preliminary fire history of McCurtain County Wilderness Area and implications for red-cockaded woodpecker management. Pages 290-302 *in* D. L. Kulhavy, R. G. Hooper, and R. Costa. (eds.). Red-cockaded woodpecker: Species recovery, ecology and management. Center for Applied Studies, Stephen F. Austin University, Nacogdoches, TX.

Masters, R. E., W. D. Warde, and R. L. Lochmiller. 1997. Herbivore response to alternative forest management practices. Proc. Annual Conference Southeastern Association of Fish and Wildlife Agencies 51:225-237.

Masters, R. E., C. W. Wilson, G. A. Bukenhofer, and M. E. Payton. 1996. Effects of pine-grassland restoration for red-cockaded woodpeckers on white-tailed deer forage production. *Wildlife Society Bulletin* 24:77-84.

Masters, R. E., C. W. Wilson, D. S. Cram, G. A. Bukenhofer, and R. L. Lochmiller. 2002. Influence of ecosystem restoration for red-cockaded woodpeckers on breeding bird and small mammal communities. Pages 73-90 in W. M. Ford, K. R. Russell, and C. E. Moorman, editors. The role of fire in non-game wildlife management and community restoration: traditional uses and new directions: proceedings of a special workshop. Annual Meeting of The Wildlife Society, Nashville, Tenn. U.S. Department of Agriculture Forest Service Northeast Research Station. General Technical Report NE-288.

Masters, R. E., K. Robertson, B. Palmer, J. Cox, K. McGorty, L. Green, C. Ambrose. 2003. Red Hills Forest Stewardship Guide. Tall Timbers Research Station Misc. Publ. 12. Tall Timbers Research, Inc., Tallahassee, FL.

Masters, R. E., K. Hitch, W. J. Platt, and J. A. Cox. 2005. Fire – The missing ingredient for natural regeneration and management of southern pines. Proceedings of the Joint Conference, Society of American Foresters and Canadian Institute of Forestry, Edmonton, Alberta, Canada. October 2-6, 2004. CD-ROM unpaged.

Mattoon, W. R. 1915. Life history of shortleaf pine. U.S. Department of Agriculture Bulletin No. 244. Washington, D.C. 46p.

McQuilken, W. E. 1935. Root development of pitch pine with some comparative observations on shortleaf pine. *Journal of Agricultural Research* 51(11):983-1016.

McCune, B. 1988. Ecological diversity in North American pines. *American Journal of Botany* 75(3):353-368.

Mueller-Dombois, D, J. E. Canfield, R. A. Holt, and G. P. Buelow. 1983. Tree-group death in North American and Hawaiian forests: a pathological problem or a new problem for vegetative ecology? *Phytocoenologia* 11(1):117-137.

Murphy, P. A., and R. M. Farrar, Jr. 1985. Growth and yield of uneven-aged shortleaf pine stands in the Interior Highlands. U.S. Department of Agriculture Forest Service Res. Pap. SO-218. 11pp.

Murphy, P. A. and G. J. Nowacki. 1997. An old-growth definition for xeric pine and pine-oak woodlands. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 7p.

Nelson, T. C., and W. M. Zillgett. 1969. A forest atlas of the south. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station and Southeastern Forest Experiment Station. New Orleans, LA. and Asheville, N.C. 27p.

Nickles, J. K., C. G. Tower and J. F. Stritzke. 1981. Use of prescribed fire and hexazinone (velpar) to thin understory shortleaf pine in an Oklahoma pine-hardwood stand. *Southern Journal of Applied Forestry* 5:124-127.

Oosting, H. J. 1956. The study of plant communities. W. H. Freeman and Co., San Francisco, Calif. 440pp.

Oosting, H. J., and P. J. Kramer. 1946. Water and light in relation to pine regeneration. *Ecology* 27(1):47-53.

Palmer, E. J. 1921. The Forest of the Ozark Region. *Journal of the Arnold Arboretum* 2:216-232.

Palmer, E. J. 1924. The Ligneous Flora of Rich Mountain, Arkansas and Oklahoma. *Journal of the Arnold Arboretum* 5:108-135.

Palmer, W. E., K. M. Robertson, and R. E. Masters. 2004. The culture of fire in the southeast. *Trans. North American Wildlife and Natural Resources Conference* 69:354-368.

Perttula, T. K. 1993. The Long Term Consequences and Effects of the de Soto Entrada on Aboriginal Caddoan Populations. In Proc: De Soto Sym,1988 and 1990;

Pyne, S. J. 1982. Fire in America, A cultural history of wildland and rural fire. Princeton University Press, Princeton, New Jersey. 654pp.

Pyne, S. J., P. L. Andrews, R. D. Laven. 1996. Introduction to wildland fire. John Wiley and Sons, New York. .

Rideout, S., and B. P. Oswald. 2002. Effects of prescribed burning on vegetation and fuel loading in three east Texas state parks. *Texas Journal of Science* 54:211-226.

Robbins, L. E., and R. L. Myers. 1992. Seasonal effects of prescribed burning in Florida: a review. Tall Timbers Research Station Miscellaneous Publication Number 8. Tall Timbers Research, Inc., Tallahassee, FL.

Russell, E. W. B. 1983. Indian-set fires in the forests of the northeastern United States. Ecology 64(1):78-88.

Sargent, C. S. 1965. Manual of the trees of North America. Volume 1. Dover Publications, Inc., New York.

Schmidt, K. M., J. P. Menakis, C. C. Hardy, W. J. Hann, and D. L. Bunnell. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. General Tech. Report. RMRS-GTR-87, U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Schroeder, M. J., and C. C. Buck. 1970. Fire weather: a guide for application of meteorological information to forest fire control operations. Agricultural Handbook 360. U. S. Department of Agriculture Forest Service. Washington, D.C. 229p.

Schwilk, D.W., and D.D. Ackerly. 2001. Flammability and serotiny as strategies: correlated evolution in pines. *Oikos* 94:326-336.

Scott, J. H. and R. E. Burgan. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. General Technical Report RMRS-GTR-153. U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. Ft. Collins, CO.

Shelton, M.G., and M.D. Cain. 1999. Structure and short-term dynamics of the tree component of a mature pine-oak forest in southeastern Arkansas. *Journal of the Torrey Botanical Society* 126:32-48.

Shelton, M.G., and R. F. Wittwer. 1996. Shortleaf seed production in natural stands on the Ouachita and Ozark Mountains. *Southern Journal of Applied Forestry* 20(2):74-80.

Silker, T.H. 1968. Bio-economic assay of conditions related to pine management on tension-zone sites. Pages 3-19 *in* The Ecology of Southern Forests, *Proceedings 17th Annual Forest Symposium*. Louisiana State University, Baton Rouge

Smith, B. A., R. J. Tyrl, and R. E. Masters. 1997. Floristic inventory of the McCurtain County Wilderness Area (Oklahoma). *Oklahoma Academy of Science* 77:99-102.

Smith, K. L. 1986. Sawmill: The story of cutting the last great virgin forest east of the Rockies. University of Arkansas Press, Fayetteville.

Smith, K. G. and J. C. Neal. 1992. Pre-settlement Birds and Mammals of the Interior Highlands. In D. Henderson and L. D. Hedrick, editors. Proc.: Conference on Restoring Old Growth Forest in the Interior Highlands of Arkansas and Oklahoma. Winrock International, Morrilton, Ark.

Somes, H. A., and G. R. Moorehead. 1954. Do thinning and prescribed burning affect the growth of shortleaf pine? U.S. Department of Agriculture Forest Service, Experiment Station Research Note 34. Northeast Forest Experiment Station, Upper Darby, PA.

Sparks, J. C. 1996. Growing-season and dormant-season fire behavior and effects on vegetation in the Ouachita Mountains, Arkansas. M.S. Thesis. Oklahoma State University, Stillwater. 186 pp.

Sparks, J. C., and R. E. Masters. 1996. Fire seasonality effects on vegetation in mid-, tall-, and southeastern pine-grassland communities: a review. Trans. North American Wildlife and Natural Resources Conference 61:230-239.

Sparks, J. C., R. E. Masters, D. M. Engle, M. E. Payton, and G. A. Bukenhofer. 1999. Influence of fire season and fire behavior on woody plants in red-cockaded woodpecker clusters. *Wildlife Society Bulletin* 27(1):124-133.

Sparks, J. C., R. E. Masters, D. M. Engle, and G. A. Bukenhofer. 2002. Season of burn influences fire behavior and fuel consumption in restored shortleaf pine-grassland communities. *Restoration Ecology* 10:714-722.

Sparks, J. C., R. E. Masters, D. M. Engle, M. Palmer and G. A. Bukenhofer. 1998. Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. *Journal of Vegetation Science* 9: 133-142.

Splat, K. W. and W. E. Reifsnyder. 1962. Bark characteristics and fire resistance: A literature survey. U.S. Department of Agriculture, Forest Service, Occasional Paper 193. Southern Forest Experiment Station, New Orleans, LA.

Stambaugh, M.R., Guyette, and C. Putnam. 2005. Fire in the pines. *Park Science* 23(2):43-47.

Stambaugh, M.R., R. Muzika, and R.P. Guyette. 2002. Disturbance characteristics and overstory composition of an old-growth shortleaf pine (*Pinus echinata* Mill.) forest in the Ozark Highlands, Missouri, USA. *Natural Areas Journal* 22:108-119.

Stanturf, J. A., D. D. Wade, T. A. Waldrop, D. K. Kennard, and G. L. Achtemeier. 2002. Background paper: fire in southern forest landscapes. Pages 607-630 in D. N. Wear and J. G. Greis. Southern forest resource assessment. U.S. Department of Agriculture Forest Service General Technical Report SRS-53. Ashville, NC.

Stanturf, J. A., E. S. Gardiner, K. Outcalt, W. H. Conner, and J. M. Guldin. 2004. Restoration of southern ecosystems. Pages 123-131 in H. M. Rauscher and K. Johnsen, editors. Southern forest science: past, present, and future. U.S. Department of Agriculture Forest Service. General Technical Report SRS-75. Ashville, NC.

Sternitzke, H. S., and T. C. Nelson. 1970. The southern pines of the United States. *Economic Botany* 24:142-150.

Stephenson, G. K., P.D. Goodrum, and R. L. Packard. 1963. Small rodents as consumers of pine seed in east Texas uplands. *Journal of Forestry* 61:523-526.

Stewart, O. C. 1951. Burning and natural vegetation in the United States. *Geographical Review* 41:317-320.

Stewart, O. C. 1963. Barriers to understanding the influence of use of fire by aborigines. *Proc. Tall Timbers Fire Ecology Conference* 2:117-126.

Stewart, O. C. 2002. Forgotten fires, Native Americans and the transient wilderness. Edited by H. T. Lewis and M. K. Anderson. University of Oklahoma Press, Norman. 364p.

Tainter, F. H. 1986. Protection of shortleaf pine from insects and disease. Pages 235-247. *in* P. A. Murphy, editor. Proceedings: symposium on the shortleaf pine ecosystem. March 31 – April 2, 1986, Excelsior Hotel, Little Rock, Arkansas. Arkansas Cooperative Extension Service, Monticello, Ark.

Trewartha, G. T. 1968. An introduction to climate, 4th edition. McGraw-Hill. New York, NY.

Turner, L. M. 1935. Catastrophes and pure stands of southern shortleaf pine. Ecology 16(2):213-215.

Van der Donck, A. 1846. A description of the New Netherlands. In New York Historical Society Collection Series 2, Vol. 1, chap. 5, pp 125-242. Reprinted in 1968., edited by R. F. O'Donnel. Syracuse University Press, Syracuse, NY.

Van Lear, D. H. 1985. Prescribed fire - its history, uses and effects in southern forest ecosystems. Pages 57-75 in D. D. Wade, compiler. Prescribed fire and smoke management in the south: conf. proc. U.S. Department of Agriculture For. Ser. South. For. Exp. Stn., Asheville, N.C.

Van Lear, D. H., and T. A. Waldrop. 1989. History, uses and effects of fire in the Appalachians. U.S. Department of Agriculture For. Ser. Gen. Tech. Rep. SE-54. Southeastern Forest Experiment Station, Asheville, NC. 20pp.

Vogl, R. J. 1972. Fire in the southeastern grasslands. *Proceedings Tall Timbers Fire Ecology Conference* 12:175-198.

Vose, J. M., W. T. Swank, B. D. Clinton, R. L. Hendrick, and A. E. Major. 1997. Using fire to restore pine/hardwood ecosystems in the southern Appalachians of North Carolina. Pages 149-154 *in* Proceedings-Fire effects on rare and endangered species and habitats conference, November 13-16, 1995, Coeur d' Alene, ID. International Association of Wildland Fire.

Wade, D. D. 1989. A guide for prescribed fire in southern forests. Technical Publication R8-TP 11. U.S. Department of Agriculture Forest Service, Southern Region, Atlanta, GA. 56p.

Wade, D. 1993. Societal influences on prescribed burning. *Proceedings Tall Timbers Fire Ecology Conference* 18:351-355.

Wade, D.D., B.L. Brock, P.H. Brose, J.B. Grace, G.A. Hoch, and W.A. Patterson. 2000. Fire in eastern ecosystems [Chapter 4] Pages 53-96 *in* Brown, J.K. and J.K. Smith (eds.).

Wildland fire in ecosystems: effects of fire on flora. General Technical Report RMRS-GTR-42-vol. 2. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Ogden, UT.

Wade, D. D. and R. W. Johansen. 1986. Effects of fire on southern pine: observations and recommendations. General Technical Report SE-41. U.S. Department of Agriculture, Forest Service. Asheville, NC 14p.

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

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

Walker, L. C., and H. C. Wiant, Jr. 1966. Silviculture of shortleaf pine. Bulletin No. 9. Stephen F. Austin State College, School of Forestry. Nacogdoches, TX. 59p.

Walsh, W. R. 2004. Response of northern bobwhites to managed forest landscapes. M.S. Thesis, Oklahoma State University, Stillwater.

White, F. 1980. Shortleaf pine 75. Pages 53-54 in F. H. Eyre, editor. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC.

White, D. L., and F. T. Lloyd. 1998. An old-growth definition for dry and dry-mesic oak pine forests. General Technical Report SRS-23. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 42p.

Williston, H. L., and W. E. Balmer. 1980. Shortleaf pine management. Forest Report SA-FR6. U.S. Department of Agriculture, Forest Service. 9pp.

Wilson, C. W., R. E. Masters, and G. A. Bukenhofer. 1995. Breeding bird response to pine-grassland community restoration for red-cockaded woodpeckers. *Journal of Wildlife Manage.* 59:56-67.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501p.

Yocum, H. A. 1972. Burning to reduce understory hardwoods in the Arkansas Mountains. Research Note SO-145. U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station, New Orleans, LA. 3p.

Zarnoch, S. J., J. L. Ruehle, R. P. Belanger, D. H. Marx, and W. C. Bryan. 1994. Growth and crown vigor on 25-year-old shortleaf pine progenies on a littleleaf disease site. Research Paper SE-289. U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station. Asheville, NC. 12p.