# Restoring Fire-Adapted Forested Ecosystems—Research in Longleaf Pine on the Kisatchie National Forest[1]

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### Abstract
Prescribed burning research on the Kisatchie National Forest, Louisiana spanned the last five decades and led to a greater understanding of fire behavior and the importance of burning in longleaf pine (*Pinus palustris* P. Mill.) forests. Early research found that biennial burning in May favored the growth of longleaf pine seedlings. However, burning over several decades more greatly influenced diversity and productivity of herbaceous plant communities than burning affected long-term pine yields. Thinning sustains productive herbaceous plant understories in older stands because herbage yields decrease about 90 kg/ha with each $m^2$/ha increase in overstory basal area. In recent work, the use of container planting stock and a low incidence of brown-spot needle blight infection (caused by *Mycosphaerella dearnessii* M. E. Barr.) have been important in establishing longleaf pine. Emergence from the grass stage and growth of sapling longleaf pines have been better on recently harvested and prepared sites than on grass-dominated range partly because herbaceous plants are more competitive with longleaf seedlings than small woody plants and prescribed fire intensities are greater on grassy sites than on brushy sites. Differences in fuel types and rapid regrowth of vegetation both influence how prescribed burning affects long-term fuel loads.


## Introduction

Longleaf pine (*Pinus palustris* P. Mill.) is a fire dependent forest type that formerly covered 24 to 38 million ha stretching from eastern Texas to southeastern Virginia, occupying wet poorly drained flatwoods to dry mountain ridges (Landers et al. 1995, Outcalt and Sheffield 1996, Brockway et al. 2005). Today, what was once the most extensive forest ecosystem in North America has been reduced to a remnant 1.5 million ha. The recovery of longleaf pine within the historic range is now necessary to arrest the decline of nearly 200 associated taxa of vascular plants and several vertebrate species (Brockway et al. 1998, Hardin and White 1989, Outcalt and Sheffield 1996).

In this challenging recovery effort, the management of longleaf pine regeneration can be difficult partly because of its unique morphology, in which it develops little above ground for the first two to nine years as the root system develops (Harlow and Harrar 1969, Wahlenberg 1946). The bunch of needles at the

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soil surface resembles a clump of grass, hence, the term "grass stage" to describe the juvenile period of growth. Grass-stage longleaf pine seedlings are susceptible to encroachment by brush and seedlings of other pine species, smothering by dead grass and litter, and brown-spot needle blight infection (caused by *Mycosphaerella dearnessii* M. E. Barr.) (Boyer 1975, Croker and Boyer 1975, Kais et al. 1986, Wahlenberg 1946). Longleaf pine seedlings do not respond to cultural practices meant to increase growth unless brown-spot needle blight is controlled (Derr 1957, Kais et al. 1986).

Prescribed burning can relieve longleaf pine seedlings from these stresses and thereby improve seedling survival (Grelen 1983, Smith 1961). Once the seedlings have well developed root collars (about 2.5-cm diameter), they are able to initiate height growth (Wahlenberg 1946). However, established pine-hardwood brush can still outgrow young longleaf pine seedlings, even after emergence from the grass stage, unless action is taken (Haywood 2000, Haywood and Grelen 2000, Haywood et al. 2001).

It is widely accepted that the management of longleaf pine at the landscape level requires an aggressive prescribed burning program not only to establish longleaf pine but also to keep older stands open and favor the myriad of herbaceous plants native to pine-grassland habitats. This understanding developed partly from the study of prescribed burning on the Kisatchie National Forest over the last five decades. This paper summarizes results from this extended period of research.

## Early Research

### *Fire on the Range*

The bluestem (*Andropogon* spp. and *Schizachyrium* spp.) range extended from northwestern Florida and southern Alabama to eastern Texas, and occupied primarily the Gulf Coastal portion of the longleaf-slash pine timber type (Grelen 1974). It included about four million ha in 1935. By the 1930s, uncontrolled harvesting had denuded most of the original longleaf pine within the bluestem range in Louisiana. The remaining vegetation was being burned repeatedly, overgrazed by cattle, and foraged by other livestock. In 1930, the Kisatchie National Forest was established in large part through the efforts of naturalist Caroline Dormon and as a response to the prevailing "cut out and get out" attitude of the timber industry (Joy 2005). The Civilian Conservation Corps (CCC) helped to replant these cutover lands on the national forest, but the effort focused on establishing loblolly (*P. taeda* L.) pine and slash pine (*P. elliottii* Engelm.) rather than longleaf pine because foresters mistakenly believed that longleaf pine could not be artificially regenerated (Croker 1989). However, longleaf pine recovered naturally where advanced regeneration and seed trees were present on some forestlands (Haywood et al. 2001), albeit on only a fraction of longleaf's native sites (Landers et al. 1995, Outcalt and Sheffield 1996, Brockway et al. 2005). Because of the history of range use by local people, much of the range within the national forest was placed under livestock management and unrestricted grazing and foraging continued on surrounding private lands.

Research in the bluestem range began on the Kisatchie National Forest during the mid-1940s and originally emphasized the effects of prescribed burning on range resources and herbage quality. Duvall and Whitaker (1964) recommended that range managed for cattle be rotationally burned in winter or early spring every three years to top kill brush, control undesirable herbaceous plants, and remove litter, thereby increasing bluestem grass productivity (Grelen and Epps 1967a). In addition, prescribed burning from midspring through early summer materially increased the protein content of bluestem grasses (Grelen and Epps 1967b).

Triennial burning in tandem with moderate cattle grazing kept the range relatively open and improved herbaceous plant richness. However, heavy grazing exposed mineral soil and was detrimental to water infiltration and percolation, increased soil bulk density, and reduced the percentage of large soil pores (Duvall and Linnartz 1967, Linnartz et al. 1966, Wood et al. 1989). Biennial or triennial prescribed burning did not adversely affect long-term soil sediment yields on flat to gently sloping sites, although sediment yields were higher immediately after burning (Dobrowolski et al. 1987). Spring burns had less effect than winter burns on sediment yields.

Despite apparent benefits in keeping the range open, prescribed burns have to be reapplied regularly to control brush, especially if cattle grazing stops. For example, in a prescribed burning study with the highly flammable shrub, wax myrtle (*Morella cerifera* (L.) Small), biennial or triennial burning reduces shrub height, but the shrubs regain stature between burns (*fig. 1,* left) (Haywood et al. 2000). Annual burning is best. However, general fuel conditions often are unable to support annual burning (Haywood and Grelen 2000), and annual burning is difficult to sustain operationally. Eight years of either biennial or triennial burning result in wax myrtles that are smaller in circumference than on no-burn plots (*fig. 1,* right). Overall, biennial burning is more effective than triennial burning.

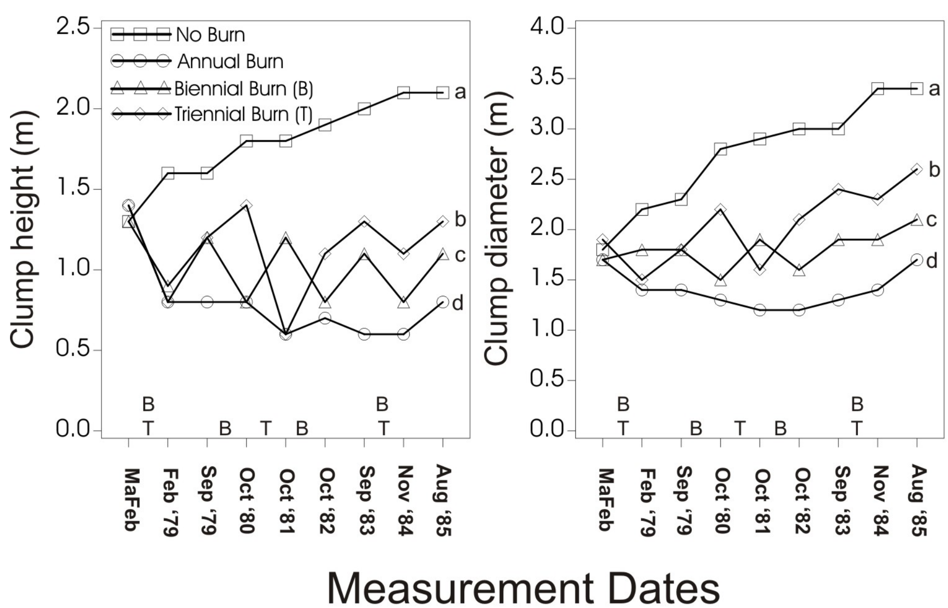


**Figure 1—**Shrub height (left) and clump diameter (right) of *Morella cerifera* in response to prescribed burning (B-biennial and T-triennial) from March 1978 to August 1985; final measurements followed by a different letter are significantly different based on Duncan's Multiple Range Tests (α=0.05) (Haywood and others 2000).

## *Fire Favored Longleaf Pine Regeneration*

It became apparent in these early studies that longleaf pine regeneration tolerated range burning and became the dominant woody plant (Grelen 1975, 1983). This occurred partly because, during its unique grass-stage period, longleaf pine seedlings growing in full sunlight reach sufficient girth to tolerate high temperatures. Large tuffs of needles protect the terminal bud when fire moves quickly through the grass fuels and the highest temperatures are above the seedlings that are no more than 12 cm tall (Lindenmuth and Byram 1948). Once the longleaf pine seedlings emerge from the grass stage, they are more susceptible to heat injury until about 2m tall (Bruce 1951). Nevertheless, the majority of longleaf pine seedlings survive, while the other woody species are top killed by fire.

Grelen (1975) reported that biennial burning in May resulted in larger longleaf pine saplings than biennial burning in either March or July. Grelen (1983) attributed the better growth following May burns to the morphological characteristics of the new shoots, which in March is usually a silvery “candle” that by May has elongated, hardened, and is surrounded by an insulating sheath of needles.

Another factor influencing the seasonality of tree growth might have been differences in root injury even on repeatedly burned sites. Kuehler et al. (2004) reported that fine root production was less on plots repeatedly burned in July compared to plots burned in May and the rate of starch deletion from roots was lower on July-burned plots than on May-burned plots. In addition, foliar Mg concentration was lower on the July-burned plots than on the May-burned plots. Possibly, fire related injury resulted in less metabolic activity in roots following July burns.

Fuel bed conditions may influence the seasonal effect of fire on tree growth. It has been generally argued that there is an accumulation of dead fine fuels in March with few green fuels to lessen fire intensities resulting in more longleaf pine seedling injury. In May, green fuels are present, which lowers the heat of combustion because heat is lost in drying green fuels (Byram 1959). In July, high ambient temperatures and an accumulation of dried fine fuels also mean higher fire intensities than in May.

## *Fire in Older Stands*

The positive relationship between May burning and greater longleaf pine stature in seedling or small pole stands reported by Grelen (1975, 1983) continued through 20 to 37 growing seasons in two separate studies (*tables 1 and 2*) (Haywood and Grelen 2000, Haywood et al. 2001). However, when both longleaf and loblolly pines were considered in these studies, the unburned plots were similar in pine basal area to the average for prescribed burned plots. Thus, burning in direct seeded or natural stands did not influence long-term pine yields but radically changed overall stand structure and species composition, especially in the herbaceous layer. Fire did this by maintaining longleaf pine grasslands (Bruce 1947, Haywood and Grelen 2000, Haywood et al. 2001), in which fires controlled woody vegetation and removed litter allowing sunlight to reach the forest floor, and common grasses and forbs naturally establish in pine grasslands in the West Gulf Coastal Plain (Haywood and others 1998a).

**Table 1**—*Stand characteristics 6 and 20 years after prescribed burning began to be monitored in a longleaf pine stand in Louisiana that had been direct seeded 4 years earlier (Grelen 1983, Haywood and Grelen 2000)*

| | Fifty best longleaf pine trees per hectare after 6 years | Only longleaf pine trees after 20 years | | | Loblolly and longleaf pine trees after 20 years | | |
|---|---|---|---|---|---|---|---|
| Treatments | Height (m) | Stocking (stems/ha) | Basal area ($m^2$/ha) | Total height (m) | Stocking (stems/ha) | Basal area ($m^2$/ha) | Total height (m) |
| Unburned | 2.7 | 74 | 1.3 | 15.5 | 1829 | 34.2 | 14.1 |
| Biennial March burns* | 4.0 | 1154 | 9.1 | 8.5 | 1154‡ | 9.1 | 8.5 |
| Annual-triennial March burns+ | 1.9 | 1712 | 18.0 | 10.1 | 1712‡ | 18.0 | 10.1 |
| Biennial May burns* | 3.9 | 1278 | 21.4 | 12.5 | 1317 | 23.3 | 12.5 |
| Annual-triennial May burns+ | 4.9 | 1772 | 24.4 | 11.0 | 1796 | 24.6 | 10.7 |

*Monitoring of burns began in 1973 and continued through 1993, for 11 research burns over a 20-yr period.
+Plots were annually prescribe burned from 1973 through 1980, because of a lack of fine fuels, annual burning ceased and triennial burning began in 1983 and continued through 1992, for 12 burns over a 19-yr period.
‡There were no loblolly pines on the plots.

**Table 2**–*Stand characteristics 12 and 37 years after prescribed burning began to be monitored in a natural longleaf pine stand in Louisiana; 20 burns were applied over a 37-yr period from 1962 through 1998 (Grelen 1975, Haywood et al. 2001).*

| | Hundred best longleaf pine trees per hectare after 12 years | Only longleaf pine trees after 37 years | | | Loblolly and longleaf pine trees after 37 years | | |
|---|---|---|---|---|---|---|---|
| Treatments | Height (m) | Stocking (stems/ha) | area ($m^2$/ha) | height (m) | Stocking (stems/ha) | Basal area ($m^2$/ha) | Total height (m) |
| Unburned | 6.5 | 136 | 10.7 | 24.1 | 193 | 18.4 | 24.7 |
| March burns | 8.3 | 519 | 22.3 | 21.3 | 519* | 22.3 | 21.3 |
| May burns | 10.5 | 482 | 30.2 | 24.4 | 482* | 30.2 | 24.4 |
| July burns | 6.9 | 217 | 15.1 | 21.3 | 217* | 15.1 | 21.3 |

.* There were no loblolly pines on the plots.

Without the repeated use of fire, however, the longleaf pine grasslands revert to mixed pine-hardwood cover (Bruce 1947). As shown in *table 3*, forest canopy develops with a basal area divided among longleaf pine (32%), other pine species (52%), and hardwood trees (16%) 20 to 37 years after burning ceases (Bruce 1947, Haywood and Grelen 2000, Haywood et al. 2001). Beneath this canopy is a well-developed understory of woody plants and vines, but the deep shade and accumulation of litter nearly eliminates herbaceous vegetation and pine regeneration.

**Table 3**—*Percentage of basal area among three taxa of vegetation on three ranges in Louisiana in which burning ceased 20 to 37 years earlier (Bruce 1947, Haywood and Grelen 2000, Haywood et al. 2001).*

| | No burning for… | | |
|---|---|---|---|
| | 20 years | 32 years | 37 years |
| Taxa | Haywood & Grelen 2000 (pct) | Bruce 1947 (pct) | Haywood et al. 2001 (pct) |
| Longleaf pine | 3 | 54 | 40 |
| Other pine species | 89 | 38 | 29 |
| Hardwoods | 8 | 8 | 31 |

Another important management technique in longleaf pine grasslands is the control of stand density through thinning. Thinning, initially recommended to stimulate forage production for cattle (Wolters 1982), is now recognized as an important tool in the restoration of herbaceous plant communities (Haywood and Harris 1999). Once longleaf pine stands reach crown closure, usually within 17 years after planting on cutover range, herbage yields are predicted to decrease about 73 to 102 kg/ha with each $m^2$/ha increase in basal area (Wolters 1973, 1982). These predicted values compared favorably with Haywood and Harris' (1999) reported yields for longleaf pine stands in central Louisiana, in which longleaf stands with brushy understories lost herbage more quickly than stands with less woody vegetation in the understory (*table 4*). However, predicted herbage values are conservative partly because they do not account for the above average rainfall that fell during 1995 on Haywood and Harris' (1999) sites. Rainfall influences herbage yields by increasing production by about 10 kg/ha per cm of rainfall during the growing season (Wolters 1982), and gains in yield can range from 7 to 11 kg/ha per cm of rainfall as stand basal area decreases from 23 to 14 $m^2$/ha, respectively (Grelen and Lohrey 1978). In the 1995-growing season, rainfall was 24 cm above average, which could have increased herbage yields by 168 kg/ha for the stands in *table 4*. Regardless, when used together, prescribed burning to remove litter and thinning to reduce overstory basal area can rejuvenate understory herbaceous plant communities that are under stress and in decline (Grelen and Enghardt 1973).

## Current Research

### *Planted Longleaf Pine Seedlings and Fire*

Artificial regeneration is necessary when converting pastures and fallow agricultural fields to longleaf pine or when too few longleaf pine seed trees are present on forest sites. Under these circumstances, the best option for reestablishing longleaf pine is removal of the woody vegetation, site preparation, and planting. A key factor in reforesting longleaf pine has been the development of container planting stock (Barnett et al. 2002), which is recommended over bareroot seedlings to ensure better survival under adverse conditions (Barnett 2002).

**Table 4**—*Influence of woody vegetation on actual and predicted current-year herbaceous plant production on four sites in Louisiana (Haywood and Harris 1999).*

| Stands | Woody plants >10 cm in dbh basal area ($m^2$/ha) | Trees and shrubs <10 cm in dbh: Total (stems/ha) | Trees and shrubs <10 cm in dbh: Height (m) | Canopy cover (pct) | Measured current-year herbage production in 1995 (kg/ha) | Predicted herbage production (kg/ha) |
|---|---|---|---|---|---|---|
| Catahoula RD (Brushy sites) [a] | | | | | | |
| Compartment 71 | 24.4 | 60,146 | 0.8 | 77 | 452 | 358 |
| Compartment 86 | 24.4 | 74,130 | .5 | 57 | 753 | 358 |
| Calcasieu RD (Grassy sites) [b] | | | | | | |
| Compartment 10 | 22.5 | 10,873 | .4 | 56 | 1640 | 1051 |
| Compartment 22 | 28.5 | 35,008 | .4 | 61 | 1160 | 659 |

[a]Formula for predicting herbage production on brushy sites (kg/ha):
$Y = 2853.58 - 102.25 \cdot (m^2/\text{ha of basal area})$ (Wolters 1982).

[b]Formula for predicting herbage production on grassy sites (kg/ha):
$Y = 2520.78 - 65.33 \cdot (m^2/\text{ha of basal area})$ (Wolters 1973).

In current research, longleaf pine stands were established from container stock in either grass-dominated range (the grassy site) or after mature loblolly pine-hardwood forest was clearcut, followed by chop and burn site preparation (the brushy site) (Haywood 2005). One finding has been that container grown longleaf pine emerges more quickly from the grass stage (*fig. 2*) than natural or direct seeded regeneration has in the past, as reported by Harlow and Harrar (1969) and Wahlenberg (1946). Interestingly, emergence was more rapid on the brushy site than on the grassy site (*fig. 2*). Emergence was almost 100 percent after three growing seasons on the brushy site, regardless of how the vegetation was treated. This level of emergence was not reached on the grassy site until after six growing seasons.

Herbaceous plant control significantly increased the growth of longleaf pine regeneration on both sites (*fig. 3*). Although season-long herbaceous plant control was no better than 50 percent on both sites, woody plants were the primary understory vegetation on the brushy site (Haywood 2005). In addition, longleaf pines on the brushy site were as tall after three growing seasons as longleaf pines on the grassy site were after six growing seasons, partly because of more rapid emergence from the grass stage.

I partly attributed the differences in growth rate between the two sites to

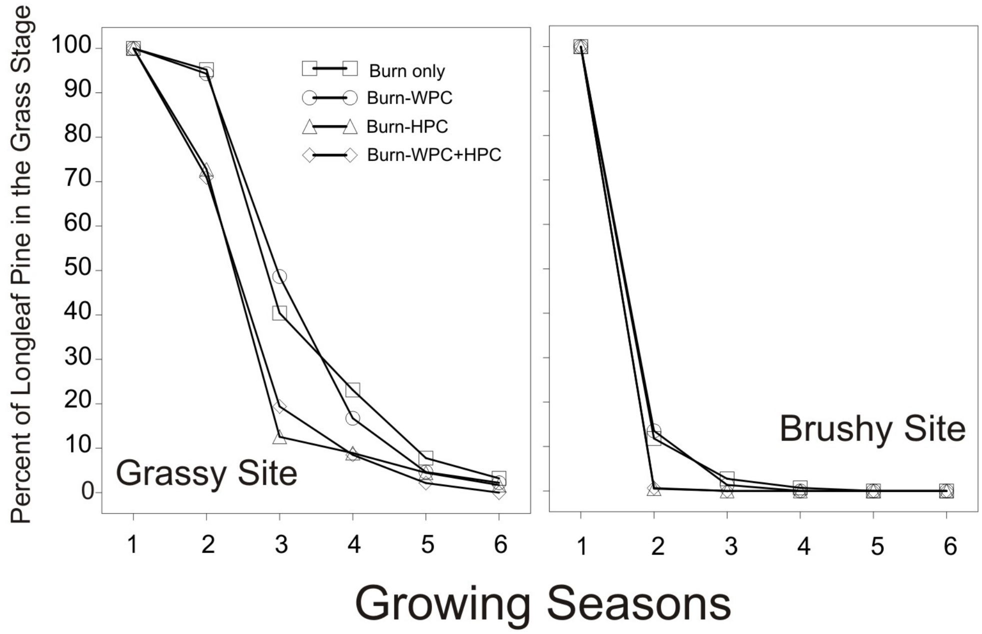


**Figure 2**—Percent of longleaf pine in the grass stage on two sites in central Louisiana by treatment combination: burn only, burn-herbaceous plant control (HPC), burn-woody plant control (WPC), and burn-WPC+HPC (Haywood 2005).

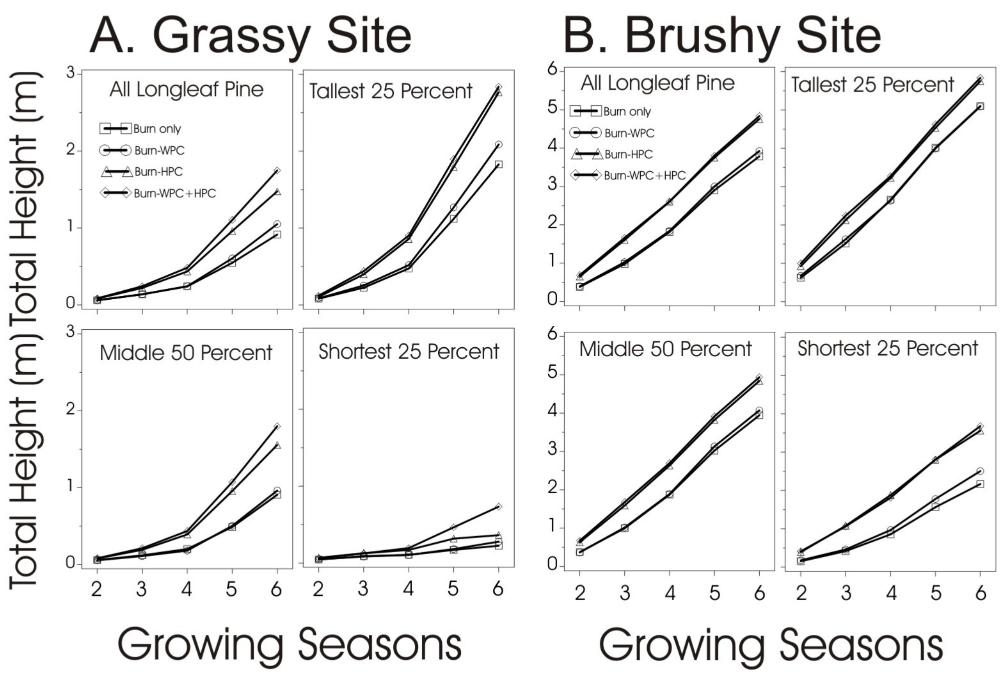


**Figure 3**—On two sites in central Louisiana, total height of all longleaf pine trees and total height of the tallest 25%, middle 50%, and shortest 25% of the trees by treatment combination: burn only, burn-woody plant control (WPC), burn-herbaceous plant control (HPC), and burn-WPC+HPC (Haywood 2005).

differences in the degree of herbaceous competition, with the grassy site having the most herbaceous vegetation and the least longleaf pine growth. In other work, Brockway and Outcalt (2000) increased development of longleaf pine seedlings by applying herbicide to prescribed burned and grass-dominated cover in Florida, and Haywood (2000) also increased height growth of longleaf pine seedlings with no more than 50 percent herbaceous plant control.

Differences in inherent site quality probably influence growth rate differences between the two sites (*fig. 3*). However, differences in intensity of the prescribed burns may be more important. Grass-dominated fuels carry intense prescribed burns in young longleaf pine stands, which can adversely affect seedling and sapling growth (Haywood 2002). At the brushy site, there was less grass and more erect forbs than at the grassy site, and this non-uniform, sparse, vertical fuel bed kept fire intensities low (Haywood 2005).

Another factor has been a low incidence of brown-spot needle blight. This disease can keep longleaf pine seedlings in the grass stage and nullify benefits from vegetation management treatments (Derr 1957). A low incidence of disease is likely contributed to the timely initiation of height growth (Kais et al. 1986), and the positive response of trees to herbaceous plant control (Derr 1957).

Woody plant control did not affect longleaf pine growth on either site (*fig. 3*). On the grassy site, fires were intense and the combination of burning and herbaceous plant competition may have kept the woody vegetation in check (Haywood 2005). On the brushy site, fires were less intense but woody plant control still did not benefit longleaf pine seedlings.

Some land managers may be willing to allow brush encroachment on sites where intense prescribed burns are not achieved during stand establishment with the opinion that by the time canopy closure is reached needle cast will improve fuel bed conditions and more intense fires will be possible. After stand closure, repeated burning coupled with a chemical or mechanical hardwood release can be used to create open stand conditions. Less intensive management is especially appealing if land managers focus on the tallest 25 percent of the longleaf pine trees and not on the whole population of trees (*fig. 3*). Nevertheless, where vegetation components have shifted away from grassland to brush, an aggressive burning program applied over several decades will eventually be necessary to decrease the number and stature of competing woody plants and favor herbaceous vegetation (Waldrop et al. 1992).

Diverse plant communities developed on both sites. On the grassy site, there was a well-established grassland community before planting the longleaf pines. Eighty-five herbaceous species and 19 woody species were commonly found. Sixteen of these (*table 5*) were indicators of a well-developed understory in longleaf pine forests in Louisiana, as described by Turner et al. (1999). On the brushy site, many plants common in the original mature loblolly pine-hardwood forest were still common after harvesting, site preparation, and longleaf pine establishment. By the fourth growing season after planting, 101 herbaceous species and 34 woody species were widespread on the brushy site. Twenty of these were indicators of a well-developed understory in a longleaf pine forest (*table 5*).

Apparently, the brushy site had a more diverse plant community than the grassy site. Based on visual observation of site conditions, this was surprising. Usually, loblolly pine-hardwood stands established on longleaf pine sites are thought to be degraded, requiring great effort to restore to longleaf pine grasslands. However,

**Table 5**—*Understory plants inventoried in two sapling size longleaf pine plantations that are indicators of well-established longleaf pine understory in Louisiana (Turner et al. 1999).*

| Common names | Scientific names | Common names | Scientific names |
|---|---|---|---|
| Herbaceous plants | | | |
| *Grassy site* | | *Brushy site* | |
| big bluestem | *Andropogon gerardii* Vitman | broomsedge bluestem | |
| broomsedge bluestem | *Andropogon virginicus* L. | arrowfeather threeawn | |
| arrowfeather threeawn | *Aristida purpurascens* Poir. | calico aster | *Symphyotrichum lateriflorum* (L.) A. & D. Löve var. *lateriflorum* |
| needleleaf rosette grass | *Dichanthelium aciculare* [Desv. ex Poir.] Gould & C.A. Clark | Nuttall's wild indigo | *Baptisia nuttalliana* Small |
| tapered rosette grass | *Dichanthelium acuminatum* [Sw.] Gould & C.A. Clark | spurred butterfly pea | *Centrosema virginianum* (L.) Benth. |
| flowering spurge | *Euphorbia corollata* L. | needleleaf rosette grass | |
| bushy goldentop | *Euthamia leptocephala* (Torr. & Gray) Greene | tapered rosette grass | |
| | | flowering spurge | *Euphorbia corollata* |
| sharp blazing star | *Liatris acidota* Engelm. & Gray | erect milkpea | *Galactia erecta* (Walt.) Vail |
| beaked panicgrass | *Panicum anceps* Michx. | | |
| blackeyed susan | *Rudbeckia hirta* L. | littleleaf sensitive-briar | *Mimosa microphylla* Dry |
| little bluestem | *Schizachyrium scoparium* [Michx.] Nash var. *divergens* [Hack.] Gould | dollarleaf | *Rhynchosia reniformis* DC. |
| slender rosinweed | *Silphium gracile* Gray | blackeyed susan | |
| sidebeak pencilflower | *Stylosanthes biflora* (L.) B.S.P. | little bluestem | |
| multibloom hoarypea | *Tephrosia onobrychoides* Nutt. | anisescented goldenrod | *Solidago odora* Ait. |
| | | sidebeak pencilflower | *Stylosanthes biflora* (L.) B.S.P. |
| | | Virginia tephrosia | *Tephrosia virginiana* (L.) Pers. |
| | | Small's noseburn | *Tragia smallii* Shinners |
| | | nettleleaf noseburn | *Tragia urticifolia* Michx. |
| Woody plants | | | |
| blackjack oak | *Quercus marilandica* Muenchh. | saw greenbrier | *Smilax bona-nox* L. |
| farkleberry | *Vaccinium arboreum* Marsh. | farkleberry | *Vaccinium arboreum* |

Haywood et al. (1998a) found that common native herbaceous plants naturally establish on forestlands if proper management practices, such as prescribed burning, create the open conditions necessary for colonization. Therefore, restoring diverse understory plant communities of common plants may be less difficult than originally believed in the West Gulf Coastal Plain and elsewhere (Smith et al. 2002). However, ecosystem restoration goes beyond re-vegetating forestlands (Covington et al. 1998), and the restoration of rare plants within unique habitats may require more than basic silvicultural practices.

## *Fire is not a Panacea*

Intense fires can reduce the growth rate of longleaf pine saplings, although most of the trees survive (Haywood 2002). For example, a series of prescribed burns initiated after the longleaf saplings were about 2m tall adversely affected height growth (*fig. 4*) because the successive biennial burns were very intense and always scorched most of the pine foliage (*table 6*). The three burns in March and July averaged 630 and 650 kJ/s/m in intensity, respectively, which was nearly four times

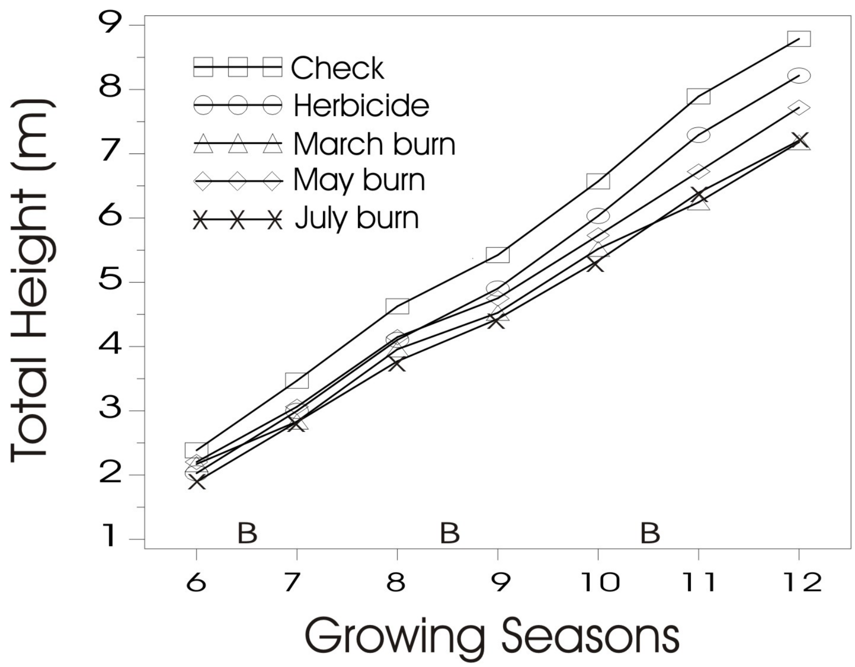


**Figure 4**—Height growth of longleaf pine saplings from the 6 through 12 growing seasons; either the plots were prescribed burned (B) in March, May, or July in the 7, 9, and 11 growing seasons or the woody vegetation was treated with herbicides (Haywood 2002).

the intensity of an average winter backfire (Haywood 1995). Burns in May averaged 551 kJ/s/m. Fire intensity might have been related to subsequent height growth because total height of the longleaf pine trees was less on the March- and July-burned plots than on the May-burned plots after three burns over a 6-year period.

Regardless, the differences in fire intensity, although always severe and resulting in high percentages of needle scorch, seem to support the argument that the accumulation of dead fine fuels in March, with little green fuel, results in fast rates of fire spread and high fire intensities (*table 6*). Overall, May fires were the least intense, as predicted.

Severe needle scorch can result in growth loss among even large 65-year-old longleaf pine trees in pine grasslands (Haywood et al. 2004b). The diameter at breast height (dbh) growth of longleaf pine was significantly less for scorched trees (0.34 cm/year) than for unscorched trees (0.46 cm/year) over a 5-year period. Likewise, longleaf pine root sucrose and starch concentrations were significantly reduced in response to crown scorch, and, therefore, there were fewer carbohydrates available for pine root metabolism (Sword and Haywood 1999).

Despite high fire intensities, fine fuel loads do not necessarily decrease. For example, repeated burnings in seedling and sapling longleaf pine grasslands maintain conditions for good grass development and continued high fuel loads. As shown in *table 6*, the first burns in 1999 were in a 6-year-old grass rough and the fuel loads averaged 4700 kg/ha. Four years later, fuel loads averaged 5900 kg/ha.

Under forest canopy, most of the fine fuels are litter and the recovery of fuels after prescribed burning may be different from pine grasslands. For example, operational prescribed burns were done in fully stocked loblolly pine (22.9 $m^2$/ha of basal area) and two mixed pine (23.4 $m^2$/ha of basal area) stands (Haywood et al.

**Table 6**—*Fuel loads and fire intensities for prescribed burns conducted on a pine-grassland site in 1999 through 2003.*

| Years and treatments | Burning date | Oven-dried fuel load (kg/ha) | Rate of spread (m/s) | Range in fire intensity (kJ/s/m) | Average fire intensity (kJ/s/m) * |
|---|---|---|---|---|---|
| 1999 | | | | | |
| March burn | March 2 | 3702 | 0.06 | 319 – 429 | 385 |
| May burn | May 14 | 6003 | .03 | 290 – 378 | 341 |
| July burn | July 8 | 4377 | .08 | 400 – 688 | 590 |
| 2001 | | | | | |
| March burn | March 13 | 5287 | .06 | 522 – 561 | 544 |
| May burn | April 30 | 6171 | .06 | 548 – 827 | 734 |
| July burn | July 31 | 6323 | .08 | 871 – 1026 | 943 |
| 2003 | | | | | |
| March burn | March 11 | 6240 | .08 | 905 – 1035 | 962 |
| May burn | May 6 | 6543 | .05 | 504 – 662 | 579 |
| July burn | July 22 | 4863 | .05 | 334 – 534 | 417 |

*A low intensity winter backfire would be between 0 and 173 kJ/s/m.

2004a). Springtime prescribed burns destroyed most of the live foliage in the understory on these three sites, but the effect was short term and understory vegetation recovered between burns (*fig. 5*). Burning reduced the amount of 1-hour time-lag dead fuels, but the 1-hour fuels accumulated between burns. The 10-hours fuels were significantly reduced by burning. Interestingly, dead fuel loads decreased on unburned plots as well, although the same personnel collected all of the fuel samples. Whither this is a long-term or short-term trend is uncertain.

Southern pine beetle (*Dendroctonus frontalis*) and Ips engraver beetle (*Ips* spp.) are the most destructive insects in the pine forests of the southern United States. Bark beetle abundance often increases following prescribed burning (Haywood et al. 2004a). Additionally, ambrosia beetles (*Platypodidae*) are attracted to fire-stressed stands and are vectors of known and suspected root pathogens. In the mixed pine and loblolly pine stands, prescribed burning resulted in increased numbers of beetles (*fig. 6*). Principally, the beetles trapped were in three guilds--ambrosia beetles, bark beetles (*D. terebrans, Hylastes tenuis* and *salebrosus*, *Ips grandicollis* and *arulsus*), and weevils (*Cossonus corticola*, *Hylobius pales*, and *Pachylobius picivorus*). No southern pine beetles were trapped, but the majority of weevils trapped were *C. corticola*, which may be an associate of the southern pine beetle (Goyer et al. 1980). Too few ambrosia beetles were trapped to determine response trends.

Another adverse effect from prescribed burning could be an increase in soil bulk density caused by exposure of the mineral soil to rainfall, with consequent dispersal of aggregates that can clog soil pores (Boyer and Miller 1994). Boyer and Miller (1994) observed this negative effect on soil bulk density after 12 years of repeated burning; bulk density of the surface 15 cm of mineral soil was 1.22 g/cm$^3$ on the unburned plots and 1.26 g/cm$^3$ on the burned plots. In a study in Louisiana, however, I did not find a significant difference between burning (1.28 g/cm$^3$) and no burning

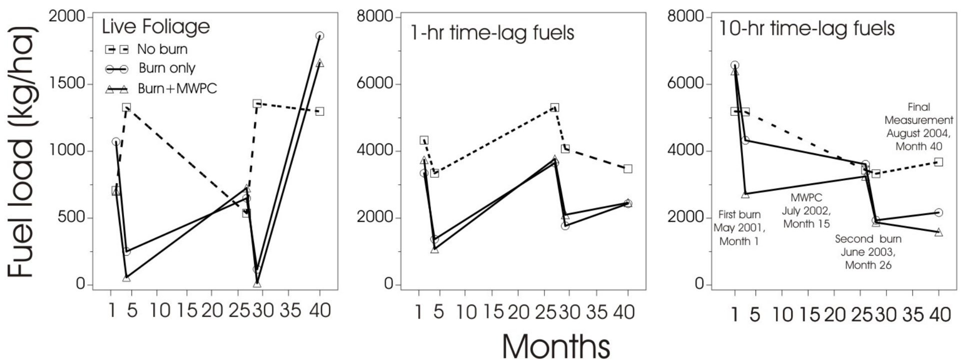


**Figure 5**—Fuel load changes after two prescribed burns and mechanical woody plant control (MWPC) in three fuel classes (live foliage, 1-hr time-lag dead fuels, and 10-hr time-lag dead fuels) on three sites in central Louisiana; the burns were in May 2001 and June 2003 and the mechanical treatment was in July 2002.

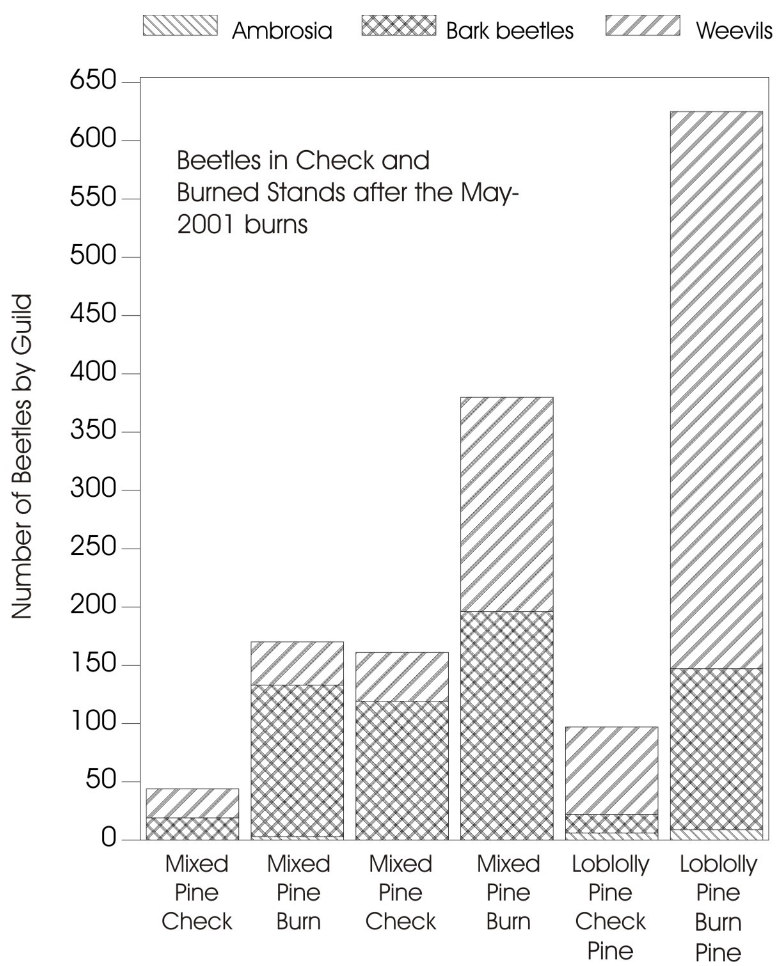


**Figure 6**—Number of beetles captured by guild after prescribed burning in May 2001 (Haywood and others 2004a).

(1.24 g/cm$^3$) on soil bulk density in the surface 10 cm of mineral soil, although four prescribed burns were applied over a 12-year period.

### *Other Brush Control Options*

Other brush control treatments besides prescribed burning are available. However, the chemical treatment of brush can be associated with some sublethal injury that stunts longleaf pine growth for several years, although the injured longleaf pine trees appear to recover and begin growing at a rate similar to untreated trees (*fig. 4*). In addition, Patterson et al. (2004) found that the chemical control of woody vegetation resulted in greater soil bulk densities in seedling longleaf pine plantations; untreated plots averaged 1.48 g/cm$^3$ compared to 1.62 g/cm$^3$ on woody plant control plots. They attributed the increase in soil bulk density to less root system proliferation and soil agitation.

The mechanical harvesting of pine straw controlled understory vegetation and increased soil bulk densities (Haywood et al. 1998b). Nine mechanical treatments over an 11-year period left the mineral soil exposed to natural weathering processes and raised soil bulk density to 1.44 g/cm$^3$ in the surface 10 cm of mineral soil, compared to 1.26 g/cm on the untreated plots. At a soil depth of 10 to 20 cm, bulk density was 1.55 g/cm$^3$ and 1.51 g/cm$^3$ on the treated and untreated plots, respectively.

For felling brush and midstory vegetation, the Kisatchie National Forest currently uses machine-mounted horizontal-shaft drum shredders (described by Haywood et al. 2004a). However, mechanical treatments are expensive, and in 2004, the cost was nearly $370/ha. In addition, mechanical felling of brush was no more effective at reducing available fine fuels than burning alone (*fig. 5*). Mechanical treatments may control large midstory vegetation, but unless prescribed burning follows mechanical woody plant control, the effectiveness of mechanical treatments will not last long because brush recovers rapidly in the West Gulf Coastal Plain.

## Conclusion

Fire research on the Kisatchie National Forest originally focused on improving herbage quality for cattle, and how prescribed burning coupled with control of stand stocking through thinning could increase herbage productivity. However, from a resource perspective, the most important long-term benefit from prescribed burning was the establishment of longleaf pine-grassland forests with rich herbaceous plant communities and the continued maintenance of these pine grasslands by the repeated application of fire. Through the 1990s, the fire research program provided crucial information on how fire influenced forest stand structure and species diversity in the West Gulf Coastal Plain.

Under current funding levels and with the available technologies, a timely fire regime is the only vegetation management practice that is generally applicable over many thousands of acres to reduce fuel loads and control hardwood trees and shrubs. Fire should be applied when woody stems start to become reestablished in the understory. Frequency of burns is dependent upon site productivity and the desired or existing plant community.

The development and use of container stock has been a major advance in the artificial regeneration of longleaf pine. Container stock provides better survival under adverse conditions and more rapid emergence from the grass stage than if either bare-root planting stock or direct seeding is used. A low incidence of brown-spot needle blight, a disease that keeps seedlings from initiating height growth and responding to vegetation management practices, may be as important as planting containers.

Emergence from the grass stage is faster and growth greater on brushy sites than on grassy sites for several reasons: (1) herbaceous plants are more competitive with longleaf seedlings than small woody plants, (2) brushy sites may be inherently more fertile than grassy sites, and (3) prescribed fire intensities are greater on grassy sites than on brushy sites. Although controlling woody plants was not beneficial in terms of longleaf pine seedling development, woody vegetation cannot be allowed to grow unchecked in longleaf pine plantations. Without woody plant control, a mixed pine-hardwood forest will develop, because loblolly pine and hardwood brush will outgrow many of the longleaf pine seedlings. At some point, woody vegetation has to be controlled by fire or other means to establish longleaf pine grasslands.

A long-term burning program successfully started when the longleaf pines are still seedlings can maintain pine grasslands on the Kisatchie National Forest, but often the understory herbaceous plant community is no longer productive once the stands reach 60 percent canopy closure. However, a lack of productivity does not equate to a lack of species richness. Thinning of overstocked stands of longleaf pine and continued burning can maintain productive and rich understory plant communities.

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