RESTORATION OF SHORTLEAF PINE (*PINUS ECHINATA* MILL) – BLUESTEM (*ANDROPOGON GERARDII* VITMAN AND *SCHIZACHYRIUM SCOPARIUM* (MICHX.) NASH) COMMUNITIES IN THE SOUTHERN APPALACHIANS

by

AMANDA CARLA NEWMAN

(Under the Direction of Ronald L. Hendrick)

ABSTRACT

Fire suppression and southern pine beetle (*Dendroctonus frontalis* Zimm.) outbreaks have contributed to the decline of native shortleaf pine (*Pinus echinata* Mill.) - bluestem grass (*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities in the southern Appalachians. We evaluated the effects of herbicide application (nursery) and selective felling and prescribed burning (field) on planted shortleaf pine seedling growth and survival and broadcasted bluestem grass seed establishment and cover. Greatest shortleaf pine growth occurred within the fell with burn treatment and the herbicide application treatments. Soil moisture and aspect influenced seedling survival while maximum flame temperature and overstory mortality influenced bluestem grass presence. Greatest big bluestem cover occurred within the shortleaf pine- bluestem grass herbicide treatment and greatest little bluestem cover occurred within the bluestem grass treatment. Herbicide application and felling with prescribed burning may be used to increase shortleaf pine growth rates while promoting the establishment of bluestem grasses.

INDEX WORDS: Shortleaf Pine, *Pinus echinata*, Southern Pine Beetle, Prescribed Burning, Southern Appalachians, Cherokee National Forest, Big Bluestem, *Andropogon gerardii*, Little Bluestem, *Schizachyrium scoparium*, Herbicide, Glyphosate

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DEDICATION

To my grandfather, Carl Newman (1922-2001), and my father, Dan Newman, for their integrity, love, and devotion. Their constant support and steady source of strength have encouraged me to pursue my goals and dreams.

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INTRODUCTION AND LITERATURE REVIEW

BACKGROUND

Fire contributes to forest health by maintaining plant communities and influencing important ecological processes (Bond and van Wilgen, 1996; Hendricks and Boring, 1999). Fire impedes plant succession to maintain fire adapted systems (Pyne *et al.*, 1996). Within the United States, fire adapted communities include southwestern ponderosa pine (*Pinus ponderosa*) forests, Pacific northwestern douglas-fir (*Pinus menziesii*) forests, Rocky Mountain lodgepole pine (*Pinus contorta*) forests, southern California chaparral shrubs, Great Plains tallgrass prairies, and southeastern pine forests (DeBano *et al.*, 1998). The health of these communities is deteriorating (Mutch and Cook, 1996; Edmonds *et al.*, 2000). Fire dependent communities are in decline because of fire suppression practices (Covington and Moore, 1994; Brockway and Outcalt, 2000).

Historically, southern Appalachian forests included mixed pine/hardwood woodlands that were maintained by fire (Komarek, 1965; Vogl, 1972; Delcourt and Delcourt, 1997). The reduction in prescribed burning and suppression of anthropogenic and natural fires have permitted succession from fire dependent, shade intolerant plant species to fire intolerant, shade tolerant species (Hoffman and Anderson, 1945; Smith, 1991; Welch and Waldrop, 2001) . This succession, along with the impact of repeated southern pine beetle attacks, high wildfire potential, and the absence of viable pine and grass seed in the seedbed, are all factors affecting the establishment of shortleaf pine (*Pinus echinata*)- bluestem grass (*Andropogon gerardii* and *Schizachyrium scoparium*) communities within the southern Appalachians (Elliott *et al.*, 1999).

Currently, the shortleaf pine- bluestem grass community is scarce within the southern Appalachians (Elliott and Vose, 2005a). Because of the few locations of this community, land management efforts are needed to restore this system to areas where it once occurred. As part of the USDA Forest Service's efforts to restore pine communities to the southern Appalachian forests, the Coweeta Hydrologic Laboratory and the Cherokee National Forest evaluated the effects of burning and partial felling with burning on shortleaf pine seedling growth and survival and bluestem grass establishment and cover.

FIRE AND THE SOUTHERN APPALACHIANS

The combination of lightning strikes and Native American burning created fire maintained landscapes within the southern Appalachians (Komarek, 1965; van Lear and Waldrop, 1989). Native Americans used fire as a common management tool to clear brush and trees for agricultural practices, hunting, and to maintain early successional plant species for foraging and hunting (Anderson *et al.*, 1970; van Lear and Waldrop, 1989; DeVivo, 1991). These fires created more open areas of mixed pine/hardwood woodlands composed of fire dependent, shade intolerant species including pines, oaks, and grasses (Abrams, 1992). These species included pitch pine (*Pinus rigida*),Virginia pine (*Pinus virginiana*), shortleaf pine (*Pinus echinata*), scarlet oak (*Quercus coccinea*), chestnut oak (*Quercus prinus*), panic grasses (*Panicum* sp.), big bluestem (*Andropogon gerardii*), and little bluestem (*Schizachyrium scoparium*) (Vose *et al.*, 1993; Brose *et al.*, 2001). To perpetuate this pre-settlement landscape cover, periodic high intensity fire disturbance is required (Waldrop *et al.*, 1992; Vose *et al.*, 1999; Clinton and Vose, 2000). Lightning alone does not create large fires that maintain mixed pine/hardwoods with grass understory (Barden and Woods, 1976).

The use of burning has diminished within the southern Appalachians because of the difficulty in managing prescribed burns and limited knowledge of the benefits of burning (van Lear and Waldrop, 1989). With fire exclusion, fire dependent mixed pine/oak woodlands have declined. These communities develop into dense hardwood systems that are fire intolerant and shade tolerant. Common tree species of these communities include red maple (*Acer rubrum*), sourwood (*Oxydendrum arboretum*), blackgum (*Nyssa sylvatica*), and dogwood (*Cornus florida*) (Cain and Shelton, 1995; Harrod *et al.*, 1998; Chapman *et al.*, 2006). Additionally, the riparian shrub species mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron* sp.) have expanded from riparian areas and established in areas of the forest midstory that were once fire maintained (Phillips and Murdy, 1985). These species, along with other fire intolerant species, reach the canopy, produce full shade, and reduce the ability of shade intolerant pines and grasses to recruit and establish (Becton, 1936; Williams and Johnson, 1992; Cain and Shelton, 1994; Welch and Waldrop, 2001). In these later successional communities, viable pine and grass seeds are minimal and may no longer exist within the seedbed.

SOUTHERN PINE BEETLE ATTACKS

The southern pine beetle (*Dendroctonus frontalis* Zimmerman (Coleoptera: Scolytidae)) is a native insect that occurs from Pennsylvania to Texas and from New Mexico to Arizona and Honduras (Thatcher and Barry, 1982). It damages pine forests in 13 southeastern states, Mexico, and Central America (Payne, 1980; Thatcher and Barry, 1982). Southern pine beetles (SPB) attack shortleaf, loblolly (*Pinus taeda*), pitch, and Virginia pines and cause significant tree mortality (USDA Forest Service, 2007). Adult beetles bore into pine bark, feed on the phloem, and lay eggs (Payne, 1980). Attacks increase in drought years when trees are water stressed (USDA Forest Service, 2007). SPB outbreaks have created enormous losses both ecologically and economically. From 1999 to 2003, the beetle damaged more than 1 million acres in the southern states of Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, and Tennessee (USDA Forest Service, 2005). Within these states, the economic timber loss was an estimated $1.5 billion (USDA Forest Service, 2005). Outbreaks impacted approximately 3.1 million acres in 2006, an 11% increase from 2005 (USDA Forest Service, 2007). High tree mortality from SPB outbreaks create 1 hour, 10 hour, 100 hour, and 1000 hour fuel loads and increases in fuel height (Waldrop *et al.*, 2007). Fuel load categories indicate the amount of time dead pine trees could burn, and increases in fuel height create the potential for fuel ladders, which can result in destructive crown fires. Thus, fuel increases produce favorable conditions for wildfires (Vose, 2000).

SPB attacks have caused severe mortality of remaining fire adapted pines and further reduced their presence in the overstory. Attacks have resulted in a loss of pine reproduction or recruitment and further promoted forest succession to fire intolerant, shade tolerant species (Hoffman and Anderson, 1945; Harrington *et al.*, 2000). To counteract SPB attacks, the USDA Forest Service implemented the Southern Pine Beetle Prevention and Restoration Program (USDA Forest Service, 2005). Restoration efforts include lower density planting than current recommendations, thinning, and performing prescribed burns (USDA Forest Service, 2005).

MIXED PINE/HARDWOOD WOODLAND RESTORATION EFFORTS

Less than five percent of the landscape in the southern Appalachians remains in mixed pine/hardwood woodlands because of the loss of fire and repeated southern pine beetle attacks (Vose *et al.*, 1995; Vose *et al.*, 1999). With the absence of fire and succession to fire intolerant, shade tolerant species, a suitable seedbank of fire adapted plant species does not remain in the seedbed (Elliott *et al.*, 1999). To combat fire dependent community declines across the United States, the USDA Forest Service is involved in restoration efforts to return mixed pine/hardwood woodlands to areas of the United States where they once existed (Dey and Hartman, 2005). These efforts include the reintroduction of fire and planting pine seedlings (Mutch, 1994; Elliott *et al.*, 1999). The fell and burn fire treatment is successfully used to prepare sites for pine planting (Abercrombie and Sims, 1986). This fire treatment produces hotter temperatures that effectively reduce hardwood and shrub competition while pine seedlings become established (Swift *et al.*, 1993; Waldrop, 1997; Clinton and Vose, 2000; Elliott *et al.*, 2002).

Managers conduct dormant season burns from September to March and growing season burns from April to August (Guyette and Spetich, 2003). Both dormant and growing season fires increase species richness, diversity, and total forb and legume abundance (Sparks *et al.*, 1998). Growing season burns are more intense and effectively remove hardwoods to promote pine regeneration (Cain and Shelton, 2000). These fires can be dangerous because of high fuel loads and poor weather conditions (Rideout *et al.*, 2003). Late dormant season burns reduce wildfire risk and impede hardwood establishment while effectively reducing small hardwood stems (Sharitz *et al.*, 1992; Sparks *et al.*, 1999).

ECOLOGY OF SHORTLEAF PINE

Shortleaf pine is a native tree species that occurs in 22 states, and it is an important timber species for lumber, plywood, veneer, pulpwood, and barrel production (Lawson, 1990; Little, 2001). The range of shortleaf pine includes southeastern New York and New Jersey; west to Pennsylvania, southern Ohio, Kentucky, southwestern Illinois, and southern Missouri; south to eastern Oklahoma and eastern Texas; east to northern Florida; and northeast through the Atlantic

Coast States to Delaware (Lawson, 1990). It is found on a variety of soil types and grows slowly in the first two years of establishment (Lawson, 1990). Growth varies by site, and slower growth occurs on shallow sandstone while faster growth occurs on deep sandstone, chert, and igneous bedrock soils (Guyette *et al.*, 2007). It is reported that shortleaf pine seedlings and small trees will re-sprout in response to fire or injury (Mattoon, 1915; Cain and Shelton, 2000). Natural regeneration is promoted by fire (Land and Rieske, 2006). Common insect pests of shortleaf pine are the southern pine beetle, black turpentine beetle (*Dendroctonus terebrans*), small southern pine engraver (*Ips avulsus*), pales weevil (*Hylobius pales*), pitch-eating weevil (*Pachylobius picivorus*), pine webworm (*Pococera robustella*), Nantucket pine tip moth (*Rhyacionia frustrana*), and redheaded pine sawfly (*Neodiprion lecontei*) (Lawson, 1990; Guyette *et al.*, 2007). Common forest pathogens of shortleaf pine are annosum root disease (*Heterobasidion annosum*), and littleleaf disease (*Phytophthora cinnamomi*) (Lawson, 1990; Guyette *et al.*, 2007).

Shortleaf pine growth is best on dry to xeric sites because greater competition occurs from hardwoods on mesic sites (Lawson, 1990). The combined use of herbicide applications and burning effectively promote seedling growth by eliminating competition for resources (Nickles *et al.*, 1981; Cain and Shelton, 2002; Amishev and Fox, 2006). Shortleaf pine seeds offer wildlife value because seeds are consumed by birds and small mammals (Lawson, 1990). Older shortleaf pines that are infected with red heart rot (*Phellinus pini*) are used by red-cockaded woodpeckers (*Picoides borealis*) as nesting sites (Lawson, 1990; Masters *et al.*, 1998; Cram *et al.*, 2002).

ECOLOGY OF BLUESTEM GRASS

Little bluestem is a perennial native warm season grass that occurs in prairies, open woods, and dry hills on all soil textures from New York south, to Florida, and west to Arizona and Utah (Stubbendieck *et al.*, 1997). Growth begins in late spring with inflorescences in midsummer and maturing seeds from October to November (Stubbendieck *et al.*, 1997). Big bluestem is a perennial native warm season grass that grows from midspring to early fall from New York, south to Georgia, and west to Arizona and Utah (Stubbendieck *et al.*, 1997). It is planted for meadow or pasture use in areas of abandoned cropland (Dayton, 1948). Typical sites are dry prairies, open woods, and wet overflow areas on all soil textures, but it is most abundant in lowland prairies (Stubbendieck *et al.*, 1997). Little bluestem and big bluestem have similar habitat requirements (Dayton, 1948). Interspecific competition between these species is not significant, but as these species mature, big bluestem may occur in more mesic sites while little bluestem may occur in drier sites (LaGory *et al.*, 1982).

These grasses can occur in high densities, and both species offer fair to excellent forage for wildlife and agricultural animals (Brown, 1979). Little bluestem and big bluestem are considered “bunch grasses” that provide cover for ground nesting birds (Miller and Dickerson, 1999; Yarrow and Yarrow, 1999). These species commonly occur with shortleaf pine and other native grasses (Lawson, 1990). Bluestems are generally drought resistant but can take up to two years to establish (Weaver, 1931; Yarrow and Yarrow, 1999).

Prescribed burning is used to promote little bluestem and big bluestem regeneration (Anderson *et al.*, 1970; Towne and Owensby, 1984; Abrams, 1988; Svejcar and Browning, 1988; Haywood *et al.*, 2001). Burning reduces plant competition for resources (Hulbert, 1988; Engle *et al.*, 1991), and herbicide applications are also used to promote these species (Masters, 1997; Miller and Dickerson, 1999; Barnes, 2007). Seeding following herbicide or burning treatments increases bluestem establishment success (Engle *et al.*, 1991).

SHORTLEAF PINE-BLUESTEM GRASS COMMUNITY RESTORATION

Historically, shortleaf pine and bluestem grasses occurred in mixed pine/oak woodlands (Hubbard *et al.*, 2004). These communities provide grazing and habitat areas for wildlife and agricultural animals as well as open areas for hunting by Native Americans and European settlers (van Lear and Waldrop, 1989). The Ouachita National Forest promotes the restoration of shortleaf pine- bluestem grass communities on 254,000 acres in western Arkansas and eastern Oklahoma (Hedrick *et al.*, 2007). Within this program, most midstory hardwood and overstory and midstory pines under a certain diameter are removed (thin from below), and prescribed dormant or growing season burns are conducted every one to three years (Sparks *et al.*, 2002; Liechty *et al.*, 2005). The use of herbicide applications are being investigated to further the effectiveness of restoration treatments in eliminating hardwood competition (Guldin, 2007; Hedrick *et al.*, 2007).

Within the Ouachita National Forest, white-tailed deer browse, wild turkey forage, and grassland bird communities are more abundant in restored shortleaf pine-bluestem communities compared to non-restored areas (Wilson *et al.*, 1995; Masters *et al.*, 1996; Wood *et al.*, 2004). Bobwhite quail increase in abundance (Cram *et al.*, 2002; Wood *et al.*, 2004), and lepidopteran, reptilian, mammalian, and avian communities are more abundant in these restored areas compared to non-restored areas (Masters *et al.*, 1998; Thill *et al.*, 2004; Rudolph *et al.*, 2006). The USDA Forest Service is effectively establishing red-cockaded woodpecker populations within restored shortleaf pine-bluestem grass communities (Wilson *et al.*, 1995; Guldin *et al.*, 2004).

In the southern Appalachians, there is minimal research on shortleaf pine-bluestem grass community restoration. Many mixed pine/hardwood restoration projects focus on native white pine (*Pinus strobus*), a shade tolerant species (Vose *et al.*, 1993; Vose *et al.*, 1995). White pine is considered a faster growing pine species that is more resistant to SPB attacks (Elliott *et al.*, 2002). However, when white pine reaches the overstory, it produces shade and outcompetes shade intolerant pines, oaks, and grasses (Welch and Waldrop, 2001; Hubbard *et al.*, 2004). Native Americans considered this species to have minimal value to their subsistence compared to fire promoted species that attract wildlife and offer medicinal uses (DeVivo, 1991). White pine is easily removed by burning because of thinner, fire intolerant bark (van Lear and Waldrop, 1989; DeVivo, 1991).

A restoration study conducted in the Conasauga River Watershed of southeastern Tennessee and northern Georgia examined the use of prescribed burning to restore shortleaf pine-bluestem communities (Elliott and Vose, 2005a). Following a single dormant season burn, post burn vegetation was compared to pre- burn vegetation. This study concluded that prescribed burning alone did not facilitate shortleaf pine-bluestem grass regeneration; a more intense fire and planting of shortleaf pine seedlings and bluestem grass seeding would be required to further the restoration efforts of these communities (Elliott and Vose, 2005a).

CHAPTER 2

EVALUATION OF MANAGEMENT PRACTICES FOR RESTORATION OF SHORTLEAF PINE (*PINUS ECHINATA* MILL) – BLUESTEM (*ANDROPOGON GERARDII* VITMAN AND *SCHIZACHYRIUM SCOPARIUM* (MICHX.) NASH) COMMUNITIES IN THE SOUTHERN APPALACHIANS[1]

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ABSTRACT

Fire suppression and southern pine beetle (*Dendroctonus frontalis* Zimm.) outbreaks have contributed to the decline of native shortleaf pine (*Pinus echinata* Mill.) - bluestem grass (*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities in the forests of the southern Appalachians. As part of a larger effort to promote the re-establishment of these communities, we evaluated the effects of burning and partial felling with burning on shortleaf pine seedling growth and survival and bluestem grass establishment in the Cherokee National Forest, Polk County, Tennessee. We applied three experimental treatments in degraded shortleaf pine communities: burn only, partial fell with burn, and no burn. Following these treatments, we planted shortleaf pine seedlings and broadcasted bluestem grass seed. All of the study sites experienced severe drought conditions during the two years of this study. The greatest shortleaf pine growth occurred in the partial fell with burn treatment. This treatment was the most successful in promoting shortleaf pine seedling growth and bluestem grass establishment and cover. The more intense burns achieved by partial felling reduced overstory canopy cover, removed litter and herbaceous-layer cover, and increased nutrient availability during seedling and grass establishment. Soil moisture and aspect influenced seedling survival while maximum flame temperature and overstory mortality influenced bluestem grass presence. Drought conditions most likely limited the success of restoration efforts. If available, forecasted weather conditions should be taken into account prior to treatment application.

INTRODUCTION

Fire contributes to forest health by promoting fire adapted plant communities and influencing important ecological processes (Bond and van Wilgen, 1996; Hendricks and Boring, 1999). Fire impedes plant succession to promote fire adapted systems (Pyne *et al.*, 1996) including shortleaf pine-bluestem grass communities. Prescribed burning benefits shortleaf pine and bluestem grasses by removing plant cover and forest floor litter, increasing light to the forest floor, increasing nutrient availability, and promoting fire adapted species that are dormant in the seedbank (Hodgkins, 1958). In some cases, fire can be used to reduce insect and disease attacks (Parker *et al.*, 2006) and reduce wildfire threat (Fernandes and Botelho, 2003). A survey of USDA Forest Service Forest (USFS) Forest Supervisors and state forestry agencies indicated forest benefits received from prescribed burning are hazard reduction, reforestation, vegetation control, habitat enhancement for nongame wildlife, threatened and endangered species, and game birds and animals, insect and disease protection, more wildlife grazing areas, and reintroduction of fire into the ecosystem (Haines *et al.*, 2001).

Historically, mixed pine/hardwood grass communities have been a common component of the southern Appalachians (van Lear and Waldrop, 1989). These systems were maintained by fire (Komarek, 1965; Vogl, 1972; Delcourt and Delcourt, 1997). The reduction in prescribed burning and suppression of anthropogenic and natural fires have promoted the replacement of fire dependent, shade intolerant plant species by fire intolerant, shade tolerant species (Hoffman and Anderson, 1945; Smith, 1991; Welch and Waldrop, 2001). This succession, along with the impact of repeated southern pine beetle (SPB) (*Dendroctonus frontalis* Zimmerman (Coleoptera: Scolytidae)) attacks and the absence of viable pine and grass seed in the seedbed, have negatively affected the establishment of shortleaf pine (*Pinus echinata* Mill.)- bluestem grass

(*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities within the southern Appalachians (Elliott *et al.*, 1999).

Currently, shortleaf pine and bluestem grasses are scarce within the southern Appalachians (Elliott and Vose, 2005a) with less than five percent of the landscape remaining in mixed pine/hardwood woodlands (Vose *et al.*, 1995). To combat fire dependent community declines, the USFS is involved in restoration efforts to return mixed pine/hardwood woodland communities to areas of the United States where they once existed (Dey and Hartman, 2005). These efforts include the reintroduction of fire and planting pine seedlings (Mutch, 1994; Elliott *et al.*, 1999). Silvicultural treatments incorporating tree felling and prescribed burning have been successfully used to prepare sites for pine plantings (Abercrombie and Sims, 1986). These treatments produce hotter flame temperatures that effectively decrease hardwood and shrub cover so that pine seedlings can become established (Swift *et al.*, 1993; Waldrop, 1997; Clinton and Vose, 2000; Elliott *et al.*, 2002).

The USFS is promoting the restoration of shortleaf pine- bluestem grass communities on 254,000 acres in the Ouachita National Forest of western Arkansas and eastern Oklahoma (Hedrick *et al.*, 2007). Within this program, midstory hardwood and overstory and midstory pines under a certain diameter are removed (thin from below), and prescribed dormant or growing season burns are conducted every one to three years (Sparks *et al.*, 2002; Liechty *et al.*, 2005). White-tailed deer browse, wild turkey forage, and grassland songbird populations have greater abundance in restored shortleaf pine-bluestem communities compared to non-restored areas (Wilson *et al.*, 1995; Masters *et al.*, 1996; Wood *et al.*, 2004). Bobwhite quail increase in abundance (Cram *et al.*, 2002; Wood *et al.*, 2004) as well as lepidopteran, reptilian, mammalian, and avian populations (Masters *et al.*, 1998; Thill *et al.*, 2004; Rudolph *et al.*, 2006). The USFS is effectively establishing red-cockaded woodpecker populations within restored shortleaf pine-bluestem grass communities (Wilson *et al.*, 1995; Guldin *et al.*, 2004).

There is minimal research on shortleaf pine-bluestem grass community restoration in the southern Appalachians. Many restoration projects have focused on native white pine (*Pinus strobus* L.), a shade tolerant species (Vose *et al.*, 1993; Vose *et al.*, 1995). White pine is a faster growing pine species than shortleaf pine and other yellow pines, and it is more resistant to SPB attacks (Elliott *et al.*, 2002). However, when white pine reaches the overstory, it outcompetes shade intolerant pines, oaks, and grasses (Welch and Waldrop, 2001; Hubbard *et al.*, 2004). Native Americans considered white pine to have minimal value to their subsistence compared to fire promoted species that attract wildlife and offer medicinal uses (DeVivo, 1991). It is easily removed by burning because of thin, fire intolerant bark (van Lear and Waldrop, 1989; DeVivo, 1991).

Because of the few remaining locations of shortleaf pine-bluestem communities, land management efforts are needed to restore these systems to areas where they once occurred in the southern Appalachians. A restoration study conducted in the Conasauga River Watershed of southeastern Tennessee and northern Georgia examined the use of prescribed burning to restore shortleaf pine-bluestem communities (Elliott and Vose, 2005a). Following a single dormant season burn, post burn vegetation was compared to pre- burn vegetation. This study concluded that prescribed burning alone did not facilitate shortleaf pine-bluestem grass regeneration; a more intense burn followed by shortleaf pine seedling planting and bluestem grass seeding was recommended to further restore these communities (Elliott and Vose, 2005a).

As part of the USFS efforts to restore degraded pine communities to the southern Appalachian forests, we evaluated the effects of burning and partial felling with burning on shortleaf pine seedling growth and survival and bluestem grass establishment and cover. The goal of this study was to evaluate management regimes designed to restore shortleaf pine-bluestem grass communities within the Cherokee National Forest of the southern Appalachians. Specifically, we evaluated management practices that may affect the survival and early growth of planted shortleaf pine and bluestem grasses. Our objectives were: 1) determine the growth response of shortleaf pine seedlings and establishment of bluestem grass in relation to fire management regimes (no burn, burn only, and partial felling with burning) and 2) relate pine seedling growth and bluestem grass presence, soil moisture, light, herbaceous-layer cover, woody biomass, and site physiography (aspect, slope, elevation, and soil type). We hypothesized that the silvicultural treatment of partial felling with burning would promote the greatest shortleaf pine seedling growth and bluestem grass establishment while greater soil moisture and light penetration would positively relate to shortleaf pine seedling survival.

METHODS

Site Description

The research sites were located in areas of heavy SPB mortality in the southern Appalachian mixed pine/hardwood forest of the USFS Cherokee National Forest, Polk County, Tennessee (35º00’N, 84º39’W) (Figure 2.1). The overstory was dominated by *Pinus virginiana* Mill., *P. echinata*, *Quercus coccinea* Muenchh., *Q. alba* L., *Acer rubrum* L., *Oxydendrum arboretum* L., and *Nyssa sylvatica* Marsh. The understory was dominated by *Kalmia latifolia* L.and *P. strobus* (Elliott and Vose, 2005b). Mean annual temperature is 14ºC, and mean annual precipitation is 135 cm (Love *et al.*, 2007). Soils are mesic Typic Hapludults (Soil Survey Staff 2008a).

The USFS applied one of three treatments at each site, and we named each site according to the treatment that it received: control (no burn), prescribed burn (burn), and selective cutting of trees followed by prescribed burning (fell with burn). Sites were selected based on aerial photographs and location to Forest Service roads in order to ensure accessibility for treatment application. All sites contained heavy pine mortality from SPB infestations with little to no shortleaf pine regeneration (23-30 m^2 ha^{-1} of basal area).

The no burn treatment was located within an area of 2.86 ha. This area had no recent history of prescribed burning. The soils within the no burn site are in the Brevard (fine-loamy, Parasesquic, mesic Typic Hapludults) and Junaluska (fine-loamy, mixed, subactive, mesic Typic Hapludults) soil series. The Brevard series classification is very deep and well drained on gently sloping to steep high stream terraces, foot slopes, benches, fans and coves of the Southern Appalachian Mountains and mesic areas of the Southern Piedmont (Soil Survey Staff 2008a). It is formed in colluvium and alluvium weathered from a mixture of high-grade metamorphic and igneous rocks. The Junaluska soil series is classified as moderately deep, well drained, moderately permeable soils on ridges and side slopes of the southern Appalachian Mountains. It is formed in residuum that is affected by soil creep in the upper part and is weathered from low grade metasedimentary rocks (phyllite, slate, and low grade, thinly bedded metasandstone) (Soil Survey Staff 2008a). The dominant plant species within the site were *P. strobus*, *Cornus florida* L., and *K. latifolia*.

The burn treatment was located within a treatment area of 4.60 ha. This area was last prescribed burned in 2001 (prior to treatment application). The burn site soils are in the Lostcove (loamy-skeletal, siliceous, active, mesic Typic Hapludults)-Keener (fine-loamy, siliceous, semiactive, mesic Typic Hapludults) complex and McCamy (fine-loamy, siliceous, semiactive, mesic Typic Hapludults) series. The Lostcove-Kenner complex is very stony well-drained, moderately permeable soils on upland footslopes, toeslopes, and the lower side slopes of the Blue Ridge Mountains. The McCamy series is classified as moderately deep and well drained with moderate or moderately rapid permeability. It is formed in residuum affected by soil creep in the upper part that weathered from low-grade metasedimentary rocks (arkose, arkosic sandstone, quartzite, graywacke, metasiltstone, or metasandstone) (Soil Survey Staff 2008a). The dominant plant species within the site were *Q. coccinea* and *Vaccinium corymbosum* L.

The fell with burn treatment was located within a treatment area of 4.92 ha. The area was prescribed burned in 2001 (prior to treatment application). The soils are Junaluska and Junaluska-Brasstown (fine-loamy, mixed, subactive, mesic Typic Hapludults) complex. The Junaluska series is described above. The Junaluska-Brasstown complex is well-drained with moderate permeability and occurs on upland ridges, shoulder slopes, and side slopes in the lower southern Blue Ridge Mountains (Soil Survey Staff 2008a). The dominant plant species within the site were *Q. coccinea*, *V. corymbosum*, and *V. vacillans* Kalm ex Torr.

In August 2005, the USFS Ocoee Ranger District, Cherokee National Forest felled all beetle-killed trees and trees below 25.4 centimeters in diameter at breast height on the fell with burn treatment. In March 2006, they conducted prescribed burns on the burn treatment and the fell with burn treatment within conditions specified in the Prescribed Burning Plan for USFS, Region 8. The fire technique on all sites was a backfire along the upper ridge followed by ignition of a headfire at the bottom of the slope. Following the prescribed burns, the USFS Coweeta Hydrologic Laboratory established four 20 m x 20 m plots within each treatment site with approximately 5-10 m between plots. In April 2006, the USFS Ocoee Ranger District, Cherokee National Forest obtained bare-root shortleaf pine seedlings of similar size from the

Hiawassee River Nursery (Benton, Tennessee) and planted them at an approximate 6.1 m by 6.1 m spacing across all treatment areas. Following the pine seedling planting, we broadcast seeded all sites with big bluestem and little bluestem seed obtained from the Sharp Brothers Seed Company (Clinton, Missouri). We seeded at 9-10 kg ha^{-1}, twice the recommended seeding rate. We chose grass varieties that were suitable to the environmental conditions of our sites: the Rountree variety for big bluestem and the Aldous variety for little bluestem.

Spatial Data Collection

We used ESRI's ArcGIS software (ArcMap v. 9.2) to obtain spatial information for each treatment plot (Environmental Systems Research Institute Inc. (ESRI), 2008). We identified plot locations from GPS coordinates and by viewing the digital orthophoto quarter quadrangles that were obtained from the USFS Forest Supervisor's Office (Cherokee National Forest, Cleveland, Tennessee). We obtained soils information from the Soil Survey Geographic Database (SSURGO) and elevation and slope from the National Elevation Dataset (NED) (Soil Survey Staff 2008b; United States Geological Survey 2008). We used the surface analysis tool (ArcMap v. 9.2) to determine the slope and aspect of each plot, and we used the zonal statistics tool to obtain elevation. The soils layer was intersected with the treatment plots and all variables were exported and used in statistical analyses.

Field Data Collection

We collected soil temperature data during the prescribed burns with 30 cm Type-K thermocouple probes connected to data loggers (Onset Computer Corp., Pocasset, MA). We buried the data loggers 30 cm below the surface for protection from the flames and monitored the air temperature at a 20 cm height above the forest floor (Clinton, unpublished data). One data logger was buried in each plot. For analyses, we used the maximum flame temperature recorded within each plot of the treatment areas. Burn temperature data loggers for plot 4 of the fell with burn treatment were damaged so we averaged the temperatures of plot 2 and 3 for analysis. To calculate overstory mortality, we tagged all live trees before applying the prescribed burn treatments. Following the burns, we calculated percent mortality as [(dead tagged trees/total number of tagged trees)*100] (Elliott and Vose, in review). Overstory mortality on the no burn site indicated mortality that would occur without prescribed burning.

We tagged 10-12 pine seedlings per plot within each treatment area. Some seedlings were located immediately outside the plots because the wide spacing between seedlings did not allow for an adequate sample size within the plots. Plot 1 of the no burn treatment was not planted; therefore we tagged more seedlings located outside of plots 2-4 of this site. We excluded Plot 1 from all analyses. We collected data during the growing seasons (May – October) of 2006 and 2007. We measured basal diameter and height of each tagged seedling to within 0.1 centimeters at the beginning (early May) and end (late October) of each growing season. We calculated relative growth rate (RGR) for shortleaf pine seedling diameter and height for the 2006 and 2007 growing seasons to determine growth rate independent of size (Evans, 1972; Elliott *et al.*, 2002). We calculated RGR of diameter as $RGR_D = (\ln D_2 - \ln D_1) / (t_2 - t_1)$ where D_2 = October 2006 or 2007 diameter, D_1 = May 2006 or 2007 diameter, RGR of height as $RGR_H = (\ln H_2 - \ln H_1) / (t_2 - t_1)$ where H_2 = October 2006 or 2007 height, and H_1 = May 2006 or 2007 height, and t = time in years.

We used a Sunfleck Ceptometer (Decagon Devices, Pullman, WA) to determine light available to each tagged pine seedling. The Sunfleck Ceptometer measures photosynthetic active radiation (PAR), the range of solar light (400-700 nanometers) that plants use in photosynthesis. We obtained biweekly measurements on cloudless days between 1100 and 1500 local solar time to determine the percent of full light reaching the seedling (Pierce and Running, 1988). We measured PAR of full sunlight in adjacent open areas near the seedling plots. We calculated percent full sunlight as PAR measured above the seedling divided by PAR measured in the open areas * 100 (Elliott and Vose, 1995). We recorded two light measurements at a 15 cm height above each seedling to obtain average PAR. PAR measurements were taken on an approximate biweekly schedule depending on full sunlight conditions. Throughout both growing seasons, the Sunfleck Ceptometer would turn off in mid-use and require calibration. Proper recalibration requires full sunlight. However, on many occasions, only partially shaded areas were present during data collection. Calibrating in partial sunlight generates incorrect light measurements. We decided to use the initial light data that we collected during the first sampling date because we were not confident in our other measurements. We recognize that this measurement may have declined over time as vegetation grew.

We measured soil moisture at approximately a 10 cm distance from each seedling with the Hydrosense^{TM} (Campbell Scientific Inc., Logan, UT) and TDR Fieldscout^{TM} 100 (Spectrum Technologies, Inc., Plainfield, IL) volumetric water content measurement systems. Both instruments operate by submitting an electrical impulse through the two probe rods (20 cm length) inserted into the soil. We collected soil moisture near each seedling on an approximate biweekly schedule. For analyses, we averaged the two soil moisture measurements that we obtained from each seedling and used average soil moisture for each seedling over each growing season.

We established 1.0 m diameter circular subplots around each tagged pine seedling to measure herbaceous-layer cover and record bluestem grass presence around the individual pine seedlings. In late July of 2006 and 2007, we identified all plant species within the subplots and visually estimated cover of each species by cover class. The cover classes were: TR (0-1%), 1 (1-3%), 2 (3-10%), 3 (10-20%), 3 (20-30%), 5 (30-40%), 6 (40-50%), 7 (50-60%), 8 (60-70%), 9 (70-80%), and 10 (>80%). To calculate woody biomass, we identified each woody plant within the subplot and measured its height and basal diameter to within 0.1 cm. We used these measurements and species specific and general allometric equations from Boring (1981), Boring (1984), and Elliott and Clinton (1993) to estimate woody biomass. In October 2006 and 2007, we identified each grass species within the subplots and recorded the number of clumps, clump height, and percent cover of each grass species.

To determine grass composition and abundance within each treatment, we established two- 1.0 m by 20 m belt transects within each treatment plot. The two transects were 5 m apart. Each 1.0 m x 1.0 m section along these transects was considered a separate quadrat (40 quadrats per plot). In August of 2006 and 2007, we identified each grass species, visually estimated percent cover, and recorded height.

Statistical Analyses

We recognize that our experimental design constitutes pseudoreplication (Hurlbert, 1984). This lack of replication is common in many fire studies because it is difficult to produce identical fire effects in separate areas (van Mantgem *et al.*, 2001). We made efforts to resolve this limitation in our statistical analyses. We assessed variability among samples by plotting standard deviations around each mean rather than standard error so that we do not infer significance in our results (Hurlbert, 1984; Streiner, 1996; van Mantgem *et al.*, 2001). We realize there may be confounding site effects in our study, and we attempt to simply draw conclusions to these site specific areas of the southern Appalachians (van Mantgem *et al.*, 2001).

To ensure the absence of multicollinearity, we evaluated our environmental variables and removed any correlated variables where $R \geq 0.5$ ($R^2 \geq 0.25$). We performed analysis of covariance (ANCOVA) tests to minimize site differences by accounting for site variability. In pseudoreplicated fire studies, ANCOVA analyses are used in an attempt to ameliorate site differences (van Mantgem *et al.*, 2001). We performed Principal Component Analysis (PCA) of the environmental variables to produce Axis 1 values that we used as a covariate in our ANCOVA analysis. PCA combines many variables into a smaller number of dimensions to remove redundant variables (McCune and Grace, 2002). With the ANCOVA tests, we analyzed the effect of silvicultural treatments on the response variables RGR_D and RGR_H for 2006 and 2007. We used the least squares means separation test to determine significant differences ($\alpha < 0.05$) among treatments.

We used ordination analysis of herbaceous-layer cover within the pine seedling subplots to evaluate plant species and environmental variables and their relationship to community composition (Elliott and Vose, 1995). We used nonmetric multidimensional scaling (NMS) analysis to ordinate the plant species (Kruskal, 1964a, b). This ordination method is used frequently with non-normal, arbitrary, discontinuous, or other questionable datasets because it attempts to locate the number of entities on 1-5 dimensions that will minimize stress, or the differences between the distance between dimensions (McCune and Grace, 2002). We used NMS to determine the plant species association to aspect, elevation, slope, soil series, maximum flame temperature, overstory tree mortality, soil moisture, herbaceous-layer cover, woody biomass, initial light penetration, RGR_D, and RGR_H. We used the autopilot mode and ran 100 iterations (50 runs with real data, 50 runs with randomized data, with a maximum run of 200 iterations).

We performed logistic regression analysis to determine significant ($\alpha < 0.05$) variables influencing bluestem presence. We examined the influence of aspect, herbaceous-layer cover, soil moisture, woody biomass, maximum flame temperature, and overstory mortality to bluestem presence within the subplots of each treatment. Our model selection was backward elimination (sle = 0.1, slr = 0.05), and we calculated the odds ratio for the significant parameters and scaled the results for interpretation. The Hosmer and Lemeshow goodness-of-fit test was used to assess model fit.

We used the known-fates procedure in Program MARK v. 5.0 (White and Burnham, 1999) to model shortleaf seedling survival over the 2-year study period. The known-fates model uses logistic regression to investigate environmental variables influencing survival. We used a two week capture period and lumped the dormant period of 28 weeks (October - March) into a two week sampling period. We modeled survival with uncorrelated variables ($r < 0.3$) and corrected for overdispersion by adding an additional model parameter for this correction. Overdispersion ($\hat{c} > 1$) results from data that contain more variance than expected. We corrected our model for this variance by adding an additional scaling parameter that AIC calculates as an additional model parameter (Burnham and Anderson, 2002; Cooch and White, 2008). We developed 15 models using the variables soil moisture, aspect, overstory mortality, initial seedling diameter, slope, and maximum flame temperature. For model selection, we used Akaike's Information Criterion corrected for overdispersion and adjusted for small sample sizes (QAICc) (Burnham and Anderson, 2002). The lowest QAICc value indicates the best model fit. We calculated the odds ratio for the parameters and scaled the results for interpretation.

Soil Scarification Study

To evaluate effective seasons and methods of bluestem grass restoration in combination with shortleaf pine seedling planting, we established three blocks of five treatments within 5 meter by 5 meter plots located adjacent to the 20 meter by 20 meter plots in the fell with burn treatment. We included a block factor to account for site heterogeneity. We applied this study in September 2006 and March 2007 to incorporate the fall and spring season. The five treatments were 1) reference, 2) fall soil scarification, fall bluestem seeding, spring shortleaf seedling planting, 3) spring bluestem seeding, spring shortleaf seedling planting, 4) spring herbicide treatment, spring bluestem seeding, spring shortleaf seedling planting, and 5) spring soil scarification, spring bluestem seeding, spring shortleaf seedling planting. We obtained bareroot shortleaf pine seedlings from the Georgia Forestry Commission Flint River Nursery (Byromville, GA) and native big bluestem and little bluestem seed of a local seed source from Roundstone Native Seed, LLC (Upton, Kentucky). We planted all seedlings in March of 2007. Within the 5 m plots, we established 1 m diameter circular subplots around each tree seedling to evaluate percent herbaceous-layer cover and bluestem presence. We measured initial seedling height and diameter in March and soil moisture on a biweekly schedule.

Shortleaf pine seedlings suffered high mortality rates by July 2007. We discontinued this study because most of the seedlings within the treatment plots did not survive.

RESULTS

The fell with burn treatment aspects on plots 2-4 were 214º to 291º (Table 2.1). These aspects were different from the other treatments and plot 1 of the fell with burn treatment. All other plots were 83º to102º. Burn treatment plot elevations (621 m to 631 m) were nearly twice that of the other treatments (330 m to 364 m) (Table 2.1). Spatial analyses indicate that the soil series of the first plot on each treatment differed from the other plots of each treatment (Table 2.1). Plot 2 of the no burn treatment was Brevard soils while plots 3-4 of the no burn treatment were Junaluska soils. Plot 1 of the burn treatment was Lostcove-Keener soils while plots 2-4 were McCamy soils. Plot 1 of the fell with burn treatment was Junaluska soils while Plots 2-4 were Junaluska-Brasstown soils. Percent slope was highest on the burn treatment (27%) and lowest on the fell with burn treatment (15%) (Table 2.1). Maximum flame temperatures ranged from 151ºC to 854ºC. Overstory mortality ranged from 3% to 95%. Average soil moisture ranged from 8.1% to 17.6% in the first growing season and 2.9% to 11.5% in the second growing season (Figure 2.2). Average initial light penetration ranged from 13% to 67% (Table 2.2).

Herbaceous-layer Cover

Within the pine seedling subplots, average herbaceous layer cover ranged from 36% to 76% in the first growing season and 39% to 67% in the second growing season (Table 2.2). In the no burn treatment, *Mitchella repens* L. was the most common species with an average cover of 10 in the first growing season and 9 in the second growing season (Table 2.3, Appendix A). In the burn treatment, *V. vacillans* was the most common species in the first growing season with an average cover of 8% while *Sassafras albidum* (Nutt.) Nees was the most common species in the second growing season with an average cover of 12% (Table 2.3, Appendix B). In the fell with burn treatment, *S. albidum* was the most frequent species with an average cover of 19% for both growing seasons (Table 2.3, Appendix C).

Woody Biomass

Average woody biomass within the pine seedling subplots ranged from 40.39 g m^{-2} to 68.90 g m^{-2} in the first growing season and 32.05 g m^{-2} to 200.92 g m^{-2} in the second growing season (Table 2.2). In the no burn treatment, *P. strobus* was the most common woody plant in the first growing season with an average biomass of 1.94 g m^{-2} while *V. vacillans* was the most common woody plant in the second growing season with an average biomass of 2.23 g m^{-2} (Table 2.4, Appendix D). In the burn treatment, *S. albidum* was the most common woody plant with 24.44 g m^{-2} in the first growing season and 21.23 g m^{-2} in the second growing season (Table 2.4, Appendix E). In the fell with burn treatment, *V. vacillans* was the most common woody plant with an average biomass of 1.99 g m^{-2} in the first growing season and 2.05 g m^{-2} in the second growing season (Table 2.4, Appendix F).

NMS Analyses

For the first growing season, the NMS analysis produced a final stress of 19.94 with 3 axes. The proportion of variance explained was 12% for Axis 1, 20.6% for Axis 2, and 21.8% for Axis 3 (cumulative R^2 of 54%). Four environmental variables (elevation, maximum flame temperature, overstory mortality, and percent light penetration) were positively correlated with Axis 2 ($R \geq 0.2$) (Table 2.5). Three environmental variables (slope, soil series, and soil moisture) were negatively correlated with Axis 2 ($R \geq -0.2$). Elevation was positively correlated to Axis 3 while aspect, soil series, maximum flame temperature, overstory mortality, woody biomass and RGR_H were negatively correlated to Axis 3 ($R \geq |0.2|$). *Panicum* species, *S. albidum*, *V. vacillans*, *Rhus copallina* L., *Iris* species, and *Phytolacca americana* L. were positively related to Axis 1 while *Smilax glauca* Walt. was negatively related to Axis 1 ($R \geq |0.2|$) (Figure 2.3, Figure 2.4, Appendix G). *Smilax rotundifolia* L., *V. corymbosum*, *S. albidum*, *S. glauca*, bluestem species, and *Smilax bona-nox* L. were positively related to Axis 2 while *P. strobus*, *A. rubrum*, *M. repens*, *Liriodendron tulipifera* L., and *Q. alba* L. were negatively related to Axis 2 ($R \geq |0.2|$). *Smilax glauca*, *V. vacillans*, *Robinia pseudoacacia* L., and *Solidago odora* Ait. were positively related to Axis 3 while *S. albidum* and *N. sylvatica* were negatively related to Axis 3 ($R \geq |0.2|$).

For the second growing season, the NMS analysis produced a final stress of 20.16 with 3 axes. The proportion of variance explained was 11.9% for Axis 1, 9.8% for Axis 2, and 14.1% for Axis 3 (cumulative R^2 of 35.8%). Slope and soil series were positively correlated with Axis 1 while aspect, maximum flame temperature, overstory mortality, woody biomass, RGR_D, and RGR_H were negatively correlated with Axis 1 ($R \geq |0.2|$) (Table 2.5). Slope, soil series, and soil moisture were positively correlated to Axis 2 while maximum flame temperature, RGR_D, and RGR_H were negatively correlated to Axis 2 ($R \geq |0.2|$). Aspect, slope, and soil series were the site environmental variables that positively correlated to Axis 3 while elevation and RGR_D negatively correlated to Axis 3 ($R \geq |0.2|$). *Mitchella repens* was positively related to Axis 1 while *N. sylvatica*, *V. vacillans*, *Panicum* species, *R. copallina*, and *Hypericum* L. species were negatively related to Axis 1 ($R \geq |0.2|$). *Nyssa sylvatica*, *A. rubrum*, *Ilex ambigua* (Michx.) Torr., *M. repens*, and *P. strobus* were positively related to Axis 2 while *N. sylvatica*, *V. vacillans*, *Panicum* species, and *R. copallina* were negatively related to Axis 2 ($R \geq |0.2|$) (Figure 2.5, Figure 2.6). *Nyssa sylvatica*, *A. rubrum*, *M. repens*, *P. strobus*, and *Q. alba* were positively related to Axis 3 while *Q. coccinea*, *S. rotundifolia*, *S. albidum*, *S. glauca*, and *Vaccinium stamineum* L. were negatively related to Axis 3 ($R \geq |0.2|$) (Figure 2.5, Figure 2.6).

For the first growing season, soil series, slope, average soil moisture, maximum flame temperature, overstory tree mortality, and elevation were important environmental variables with $R \geq |0.20|$ (Figure 2.3, Figure 2.4). For the second growing season, overstory mortality, RGR_H, RGR_D, maximum flame temperature, elevation, slope, and soil series were important environmental variables with $R \geq |0.20|$ (Figure 2.5, Figure 2.6).

Bluestem Cover

The grass species that had the greatest density in the first growing season was *Arundinaria* species in the no burn treatment, *Panicum* species in the burn treatment, and *S. scoparium* in the fell with burn treatment (Table 2.6). In the second growing season, *Carex* species were most common in the no burn treatment and *S. scoparium* was most common in both the burn and fell with burn treatments. In the no burn treatment, *Arundinaria* species had the greatest percent cover with 5% in the first growing season while *Iris* species was the only species present in the second growing season with 1% cover (Table 2.7). *Carex* species produced the greatest cover in the burn treatment with 21% in the first growing season and 15% in the second growing season. In the fell with burn treatment, *S. scoparium* produced the greatest cover with 38% in the first growing season and 78% in the second growing season.

Bluestem Presence Analyses

We performed logistic regression analysis of the variables aspect, herbaceous-layer cover, soil moisture, woody biomass, maximum flame temperature, and overstory mortality to bluestem presence within the subplots. Maximum flame temperature produced a significant positive effect on the first growing season bluestem grass presence (P = 0.0003) (Table 2.8). The Hosmer and Lemeshow goodness of fit test indicated that the maximum flame temperature model was a good fit (P = 0.5245). For the first growing season, the bluestem presence odds ratio indicated that for every 10º increase in maximum flame temperature, the probability of bluestem presence was 1.04 times more likely (Table 2.8). For the second growing season, maximum flame temperature and overstory mortality were significant positive variables for the second growing season bluestem presence (P = 0.0242, 0.0038). The Hosmer and Lemeshow goodness of fit test indicated that both of these variables provided a good fit (P = 0.8664). The bluestem presence odds ratios for the second growing season indicated that for every 10º increase in maximum flame temperature, the probability of bluestem presence was 1.03 times more likely, and for every 10% increase in overstory mortality, the probability of bluestem presence was 1.55 times more likely (Table 2.8).

Seedling Growth Analyses

The first growing season PCA of the variables aspect, elevation, slope, maximum flame temperature, overstory mortality, average soil moisture, herbaceous-layer cover, woody biomass, and initial light penetration yielded an Axis 1 eigenvalue of 2.975 with 33.06% of the variance explained. The second growing season PCA of the variables aspect, elevation, slope, maximum flame temperature, overstory mortality, soil moisture, herbaceous-layer cover, and woody biomass yielded an Axis 1 eigenvalue of 2.916 with 36.45% of the variance explained.

Average shortleaf pine seedling diameter growth ranged from 0.1 cm to 1.0 cm (Figure 2.7) and average shortleaf pine seedling height growth ranged from 9.0 cm to 65.0 cm (Figure 2.8). The PCA Axis 1 covariate was not significant for RGR_D or RGR_H in either growing season (Table 2.9). Therefore, we performed one-way analysis of variance (ANOVA) analyses to evaluate the effects of treatment on pine seedling relative growth rate. For the first growing season, RGR_D was not significantly different among all treatments (Table 2.9). RGR_D was significantly greater in the fell with burn treatment than the no burn treatment (*P* = 0.0059) and the burn treatment (*P* = 0.0279). For the first growing season, RGR_H was not significantly different among treatments. For the second growing season, RGR_D was significantly lower in the no burn treatment than the burn treatment (*P* = 0.0023) and the fell with burn treatment (*P* = < .0001) and RGR_D was significantly greater in the fell with burn treatment than the burn treatment (*P* = 0.0028). For the second growing season, RGR_H was significantly lower in the no burn treatment than the burn treatment (*P* = 0.0005) and the fell with burn treatment (*P* = < .0001). RGRH was significantly greater in the fell with burn treatment than the burn treatment (*P* = 0.0004).

Seedling Survival Analyses

Over the two year study period, seedling survival was 58% on the no burn treatment, 83% on the burn treatment, and 47% on the fell with burn treatment. Modeled seedling survival for all seedlings over the two year period was 61% (95% CI = 51-70%, SE = 4.9%). Grouping was highly correlated with covariates; therefore, we used the covariates instead of groups. The model results for seedling survival indicate that the best model fit was soil moisture and aspect with a QAICc weight = 127.77 (Table 2.10, Table 2.11). This model was 2.4 times more likely to fit the data than the second best model fit of aspect only. The odds ratio scores indicated that for each 5% increase in soil moisture, seedling survival was 2.06 times less likely, and for each 10% increase in aspect, seedling survival was 1.12 times less likely (Table 2.11).

DISCUSSION

Maximum Flame Temperature

Maximum flame temperatures recorded within both the burn and the fell with burn treatments were within the range reported by other burn studies within the southern Appalachians (Swift *et al.*, 1993; Vose *et al.*, 1999; Clinton and Vose, 2007). The greatest maximum flame temperatures occurred on the fell with burn treatment, comparable to the results of Clinton and Vose (2007). Similar to their fell with burn study with heavy fuel loads, the fell with burn treatment in our study produced greater flame temperatures because this site had a greater fuel load from the felling of the dead overstory trees and selected understory.

Soil Moisture

Volumetric soil moisture declined over time in our study. Elliott and Vose (1994) reported similar soil moisture on fell with burn sites in their southern Appalachian study. Soil moisture was 20% for the month of June and declined to 8% for the month of August (Elliott and Vose, 1994). They attributed this decline to a decrease in precipitation through the growing season. For our study, we obtained precipitation records from the National Weather Service Weather Forecast Office (http://www.srh.noaa.gov/mrx/cha/clicha.php). Precipitation was below normal in all months with the exception of August 2006 and July 2007 (Figure 2.9). Drought impacted our treatments, and this impact may result in the decline of soil moisture over our study period.

Light Penetration

The fell with burn treatment produced greater light availability than the other treatments. Greater light may have increased shortleaf pine growth and bluestem grass response. Other studies indicated the importance of light for pine seedling growth. Elliott and Vose (1994) reported that greater light positively correlated to *P. strobus* diameter and height growth. Light availability was an important factor influencing white spruce (*Picea glauca* (Moench) Voss) seedling growth (Lapointe *et al.*, 2006). In addition, high light levels to the soil surface stimulates grass germination and subsequent growth and development (Hulbert, 1988). Light is important for bluestem grass establishment because these species are shade intolerant. Awanda et al. (2003) reported that low light reduced bluestem species photosynthetic rates. In our study, the fell with burn treatment may have positively influenced shortleaf seedling growth and bluestem grass establishment because this treatment produced greater light penetration to the forest floor.

Herbaceous Layer Cover and Woody Biomass

Herbaceous-layer cover and woody biomass were greatest in the fell with burn treatment and lowest in the no burn treatment. In the fell with burn treatment, *Vaccinium* species, *S. albidum*, *Gaylussacia* species, and *N. sylvatica* decreased in frequency from the first growing season to the second growing season but increased in biomass weight, reflecting species growth and development over time. Almost all species in the burn treatment, including *N. sylvatica*, *Vaccinium* species, *S. albidum*, *Gaylussacia* species, *Q. coccinea*, and *Calycanthus floridus* L. greatly increased in frequency from the first growing season to the second growing season. Average herbaceous-layer cover decreased the following year for the no burn and fell with burn treatments while average woody biomass decreased in the no burn treatment.

The burn treatments were more diverse than the no burn treatment, comparable to other southern Appalachian studies. Clinton et al. (1993) reported that prescribed burning produced more plant species diversity than no burning, and Van Lear and Danielovich (1988) concluded that shrub and herbaceous layers in the fell and burn treatment increased in diversity to twice that of unburned plots. The most common plant species on the burn treatments within our study were similar to the results from other southern Appalachian studies (Clinton *et al.*, 1993; Elliott and Vose, 1995; Elliott *et al.*, 1999; Clinton and Vose, 2000). *Pinus strobus* was common in the no burn treatment. The frequency of this species in the no burn treatment is evidence of the encroachment of this species to areas where fire adapted pines once existed prior to SPB attacks and fire exclusion (van Lear and Waldrop, 1989).

NMS Analyses

The results of our ordination revealed plant species locations along the three axes (Elliott and Swank, 2007). For the first growing season, *P. americana*, *Diospyros virginiana* L., *Erechtites hieraciifolia* (L.) Raf. Ex DC., *Panicum* species, bluestem species, *Helianthus* species, *Quercus velutina* Lam., *S. rotundifolia*, *Lysimachia quadrifolia* L., and *S. albidum* were closely associated (Figure 2.3). These species typically occur in post-fire environments because burning stimulates species germination and growth (Bond and van Wilgen, 1996). An increase in maximum flame temperature and overstory tree mortality was associated with *D. virginiana*, *S. rotundifolia*, *P. americana*, and bluestem species while an increase in soil moisture and slope were closely associated with *P. strobus* and *A. rubrum* (Figure 2.4). *Pteridium aquilinum* (L.) Kuhn and *Panicum* species were closely associated with higher elevations. For the second growing season, increases in overstory mortality and RGR_H were associated with *Rubus* L. species, *S. albidum*, *E. hieraciifolia*, *V. corymbosum*, *Gaylussacia baccata* (Wangenh.) K. Koch, and bluestem species, and increases in maximum flame temperature and RGR_D were associated with *Vaccinium arboreum* Marsh (Figure 2.5). Increases in RGR_D and maximum flame temperature were associated with *V. corymbosum* and *Solidago odora* (Figure 2.6). *Acer rubrum* is associated with an increase in slope.

Bluestem Cover

The fell with burn treatment produced more bluestem grass cover compared to the burn and no burn treatment. We observed that the no burn treatment left the forest floor litter intact while the burn treatment left a mosaic of patches on the forest floor. The fell with burn treatment removed most of the litter on the forest floor. The partial removal of litter on the burn treatment and the presence of litter in the no burn treatments may have influenced bluestem grass cover. In another study, surface litter inhibited broadcasted bluestem seed from reaching the soil surface, thus preventing soil contact (Kocher and Studdendieck, 1986). The bluestem grass that we broadcasted on the burn and no burn treatments may not have contacted the soil because of the forest floor plant litter. Maret and Wilson (2005) found that fire removed litter and a follow-up broadcast seed successfully established prairie grasses. The fell with burn treatment removed forest floor litter and may have increased bluestem seed soil contact and produced greater bluestem cover.

Post-treatment density of bluestem grass was greatest in the fell with burn treatment but the density declined from the first growing season to the second growing season. Bluestem presence within the burn treatments and trace amounts or absence in the no burn treatment are comparable to the results of another southern Appalachian study by Elliott et al. (1999). Bluestem was not present before burning but became abundant post-burn. The decrease in grass density in the transects may be influenced by an increase in the herbaceous-layer of other species. In another study, plant cover and biomass inhibited big bluestem and little bluestem establishment (Foster, 1999). The decline in grass density in our study was similar to Sparks et al. (1998). In their study, forest stands in the second growing season after late dormant season burns decreased in species richness, and this decrease was attributed to short-lived benefits of burning and the environmental conditions of the current year. The environmental conditions of prolonged drought in our treatments may have influenced the reduction in bluestem and *Panicum* grasses from the first growing season to the second growing season.

Bluestem Presence

Maximum flame temperature was significantly related to bluestem presence in both growing seasons. Our results are comparable to a prairie grass study by Peet et al. (1975). They found increases in fire temperatures promoted greater big bluestem productivity by allowing nutrients and water to be available in the absence of other plants. In addition to maximum flame temperature within our study, an increase in overstory mortality influenced bluestem presence in the second growing season. Bluestem grasses grow in open or mostly open prairies, woods, and dry hills that receive abundant sunlight (Stubbendieck *et al.*, 1997). Overstory mortality removed shade and increased sunlight penetration to the forest floor. We observed the greatest shade and forest floor litter in the no burn treatment and little to no shade within the fell with burn treatment. The increase in overstory mortality in the fell with burn treatment relates to increases in light penetration to the forest floor. Sparks et al. (1998) concluded that increases in light and reduction in litter stimulated a new herbaceous layer to become established on the forest floor. The fell with burn treatment produced the greatest maximum flame temperatures and overstory mortality. This treatment may have promoted greater bluestem presence because of greater maximum flame temperatures, light, and less litter than the other treatments.

Seedling Growth

Greatest shortleaf seedling growth occurred on the fell with burn treatment, and growth increased in the second growing season. Seedlings were planted in April, later than recommended (Hallgren and Tauer, 1989). According to another study, late seedling plantings can reduce height growth by 10%-30% (Hallgren, 1992). Seedling height growth rates were not significantly different among treatments in the first growing season, but first growing season diameter growth rates were significantly greater in the fell with burn treatment. South and Mexal (1984) suggested that shortleaf pine grows slowly in height after planting. Bongarten and Teskey (1987) found that in drier conditions, pine seedlings may allocate growth to roots rather than stems, but this allocation diminishes over time. In our study, the treatments were impacted by drought in both years, and these drought conditions may have resulted in root allocation rather than height allocation. Allocation of resources to seedling roots may have influenced seedling basal diameters more than seedling height.

The greatest pine seedling height and diameter growth rates occurred in the fell with burn treatment in the second growing season. Seedlings may have recovered from transplant shock (Haase and Rose, 1993) in the first year and focused efforts on growth in the second year. The fell with burn treatment most likely released nutrients into the soil and created more open conditions for light to reach the forest floor. This intense burn killed understory sprouts and effectively removed cover and freed soil nutrients when the seedlings were becoming established and beginning growth (Abercrombie and Sims, 1986). Removal of cover by burning increased overstory mortality resulting in increased seedling height growth in the first 5 years in a study by Liming (1945).

In another southern Appalachian study, low and medium-low intensity fires regenerated stands but did not produced enough overstory mortality to prevent understory shading (Waldrop and Brose, 1999). The results of their study may relate to the greater growth rate of shortleaf pine seedlings within our fell with burn treatment compared to the burn treatment. The medium-high intensity fires of their study were optimum to increase overstory mortality and produce greater understory response. The fell with burn treatment in our study removed more plant litter and cover compared to the other two treatments (Elliott et al., in review). This result is similar to other southern Appalachian studies, in which fell with burn treatments produced hotter temperatures that removed understory hardwood and shrub cover (Swift *et al.*, 1993; Waldrop, 1997; Clinton and Vose, 2000; Elliott *et al.*, 2002). In a table mountain pine (*P. pungens* Lamb.) seedling study during drought conditions, seedlings grew better where duff (Oe+Oa soil layer) was mostly consumed and canopy cover was lower (Williams and Johnson, 1992).

Seedling Survival

Shortleaf pine seedling survival was negatively influenced by an increase in soil moisture and aspect. According to the survival model odds ratio, as aspect increased (approached northern directions) and soil moisture increased, the probability of shortleaf pine seedling survival decreased. Shortleaf seedlings typically occur on southern aspects that are characteristic of xeric sites. Northern aspects are typical of wetter sites with more soil moisture compared to xeric sites. Shortleaf pine grows best on xeric to dry sites because of less competition compared to wetter sites (Lawson, 1990). Shelton and Cain (2000) reported less natural shortleaf and loblolly pine regeneration on wetter sites because of higher levels of plant competition. Murphy et al. (1991) suggested that shortleaf pine regeneration on north-facing slopes is difficult because of greater competition for resources. Other vegetation captures water, nutrients, and other environmental resources before pine seedlings can benefit from the resources. Lower soil moisture and southern aspects may indicate preferential sites of shortleaf pine because of less competition for resources.

The drought impacts during our study may have adversely influenced seedling mortality. Drought conditions influence survival because transplant shock is mainly attributed to water stress that limits root growth and photosynthesis (Burdett, 1990). Williams and Johnson (1992) found that table mountain pine seedlings suffered high mortality rates that they attributed to drought. In their study, soil moisture was 40% lower than normal for that region during the important May-August development period. The drought conditions during our study may have limited water availability to our seedlings, resulting in high mortality due to great water stress.

The planting date of our seedlings may have influenced seedling mortality. Our seedlings were planted in April, later than recommended. In a study with a similar planting date and drought conditions, Hallgreen and Tauer (1989) planted their shortleaf seedlings in April. These seedlings suffered greater mortality than other seedlings planted in December-March because the trees planted earlier were more established before the effects of the drought began. An earlier planting date may have increased seedling survival within our study. South and Barnett (1986) found greater survival in March plantings rather than May plantings. Their results indicated that soil moisture at time of planting accounted for 45% of the variation in survival while survival was attributed to sufficient soil moisture, quality seedlings, and careful handling and planting. Moisture fell below 10% in May, and survival decreased to below 90%. In June, moisture declined to 5%, and survival fell to 22%. The results of their study may relate to the mortality within our study. The late planting date of our seedlings combined with a decrease in soil moisture may have influenced seedling mortality within our treatments.

According to South and Mexal (1984), planting success is influenced by seedling handling, prolonged exposure to environmental conditions before planting, planting depth, j-rooting, and root twirling. The seedling survival within our treatments may be partially attributed to poor planting conditions. Brissette and Barnett (1989) suggest that proper planting increases seedling survival. Within our study, the fell with burn treatment was planted last. This treatment was not readily accessible, and the bare-root seedlings were contained in burlap bags exposed to environmental conditions until they were hand-planted. Girard et al. (1997) reported that prolonged exposure to environmental conditions created stress in pine seedlings and resulted in high mortality. The seedlings planted within the fell with burn treatments may have suffered prolonged conditions such as warm temperatures, water stress, and other environmental conditions that most likely negatively impacted seedling survival.

CONCLUSION

Shortleaf pine and bluestem grasses are fire adapted, shade intolerant species that grow best in open canopies with little competition for resources (Lawson, 1990). More intense fires achieved by felling overstory and understory species before prescribed burning can benefit shortleaf pine-bluestem communities by opening the canopy, reducing understory competition, and partially removing the forest floor layer. All of these factors can increase shortleaf pine growth rates and bluestem grass establishment. Greater seedling growth occurred within the fell with burn treatment, and bluestem grass establishment was influenced by high intensity fire (i.e., maximum flame temperature) and subsequent overstory mortality.

Restoration of shortleaf pine-bluestem grass communities where they once existed throughout the southern Appalachians will take time and forest management efforts. These communities provide wildlife habitat for small mammals, threatened or endangered species, and game species. Restoration of these communities increases native groundcover, returns the natural disturbance pattern of burning to forest systems, decreases the risk of wildfire, impedes forest succession towards dominance of mountain laurel and rhododendron, and increases plant and animal diversity. The results of this study can be used to further the restoration efforts of these communities.

The silvicultural treatment of partial felling with burning followed by shortleaf pine seedling planting and bluestem grass broadcast seeding produced the greatest shortleaf pine growth rates and bluestem grass cover. High intensity fire can remove more forest floor litter, canopy and herbaceous-layer cover, and stimulate greater bluestem grass establishment and shortleaf pine diameter and height growth. Proper planting technique, site selection (southern aspects), and adequate precipitation are also important considerations to restoration treatments for these communities. Drought conditions may limit restoration success. If available, forecasted weather conditions should be taken into account prior to treatment application.

Table 2.1. Characteristics for each treatment research plot. All plots located within the Cherokee National Forest, Tennessee.

	Latitude	Longitude	Area (ha)	Plot	Maximum Flame Temperature (ºC)	Post-Treatment Overstory Mortality (%)	Aspect (degrees)	Elevation (m)	Slope (%)	Soil Series
No Burn Treatment	35º 5' 3″	84º 35' 18″	2.86	2	---	3	183	330	14	Brevard
				3	---	6	152	338	20	Junaluska
				4	---	4	108	336	21	Junaluska
Burn Only Treatment	35º 9' 13″	84º 36' 32″	4.60	1	259	47	123	622	27	Lostcove-Keener
				2	333	13	114	631	20	McCamy
				3	338	8	104	627	19	McCamy
				4	151	12	102	621	17	McCamy
Fell with Burn Treatment	35º 5' 41″	84º 35' 1″	4.92	1	530	95	151	350	16	Junaluska
				2	851	52	291	356	16	Junaluska-Brasstown
				3	854	15	237	364	15	Junaluska-Brasstown
				4	852	43	214	357	15	Junaluska-Brasstown

Table 2.2. Light penetration, herbaceous-layer cover, and woody biomass by treatment. Light penetration calculated as {[(PAR measured above the seedling) / (PAR measured in the open areas)] * 100}. Yearly measurements are averages and standard deviations of all measurements are included in parentheses.

	Light Penetration	**Percent Herbaceous-Layer Cover (m^{-2})**	**Woody Biomass ($g\ m^{-2}$)**
2006			
No Burn Treatment	13 ± (17)	59 ± (32)	54.16 ± (108.56)
Burn Treatment	38 ± (26)	36 ± (23)	40.37 ± (44.87)
Fell With Burn Treatment	67 ± (26)	76 ± (29)	68.89 ± (85.51)
2007			
No Burn Treatment	---	39 ± (22)	32.05 ± (40.93)
Burn Treatment	---	47 ± (28)	58.29 ± (62.04)
Fell With Burn Treatment	---	67 ± (36)	200.89 ± (347.28)

Table 2.3. Plant species, frequency, and percent cover of the five most common species within treatment subplots.

2006	**Species**	**Frequency (# subplots)**	**Average % Cover**
No Burn Treatment	*Mitchella repens*	24	10
	Pinus strobus	17	15
	Acer rubrum	14	8
	Vaccinium vacillans	11	8
	Nyssa sylvatica	8	10
Burn Treatment	*Vaccinium vacillans*	20	8
	Sassafras albidum	18	13
	Smilax glauca	16	2
	Nyssa sylvatica	8	9
	Quercus coccinea	8	8
Fell With Burn Treatment	*Sassafras albidum*	21	19
	Vaccinium vacillans	15	19
	Nyssa sylvatica	12	17
	Bluestem species	12	2
	Panicum species	7	2
2007			
No Burn Treatment	*Mitchella repens*	21	9
	Pinus strobus	14	13
	Acer rubrum	10	6
	Vaccinium vacillans	7	11
	Sassafras albidum	5	3
Burn Treatment	*Sassafras albidum*	17	12
	Smilax glauca	15	3
	Vaccinium vacillans	14	16
	Smilax rotundifolia	10	14
	Quercus coccinea	10	14
Fell With Burn Treatment	*Sassafras albidum*	14	19
	Nyssa sylvatica	11	20
	Vaccinium vacillans	11	19
	Bluestem species	9	8
	Vaccinium corymbosum	6	18

Table 2.4. Plant species, density, and biomass of the five most common woody species within treatment subplots.

2006	**Plant Species**	**Density (stems m $^{-2}$)**	**Average Biomass (g m $^{-2}$)**
No Burn Treatment	*Pinus strobus*	36	1.94
	Vaccinium vacillans	29	2.10
	Acer rubrum	20	27.58
	Gaylussacia ursina	19	0.09
	Nyssa sylvatica	15	16.46
Burn Treatment	*Sassafras albidum*	34	24.43
	Vaccinium vacillans	20	1.95
	Nyssa sylvatica	15	9.82
	Quercus coccinea	11	12.64
	Calycanthus floridus	11	0.04
Fell With Burn Treatment	*Vaccinium vacillans*	125	1.99
	Sassafras albidum	64	27.67
	Gaylussacia baccata	62	0.04
	Gaylussacia ursina	39	0.10
	Nyssa sylvatica	24	20.03
2007			
No Burn Treatment	*Vaccinium vacillans*	38	2.22
	Pinus strobus	25	2.70
	Acer rubrum	19	8.33
	Gaylussacia ursina	19	0.06
	Sassafras albidum	8	6.01
Burn Treatment	*Vaccinium vacillans*	99	1.97
	Sassafras albidum	56	21.22
	Gaylussacia ursina	34	0.06
	Quercus coccinea	31	12.58
	Calycanthus floridus	15	0.08
Fell With Burn Treatment	*Vaccinium vacillans*	89	2.05
	Sassafras albidum	39	109.70
	Nyssa sylvatica	36	29.07
	Gaylussacia baccata	24	0.05
	Gaylussacia ursina	24	0.04

Table 2.5. Nonmetric multidimensional scaling of environmental variables with R values. R values are listed for the 3 axes coordinates for 2006 and 2007. Values of R ≥ |0.20| are bold.

		2006			**2007**	
Environmental Variable	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Aspect	0.180	-0.126	**-0.353**	**-0.324**	-0.170	**0.317**
Elevation	-0.134	**0.537**	**0.375**	0.005	-0.065	**-0.617**
Initial Light Penetration	0.144	**0.392**	0.089	---	---	---
Maximum Flame Temperature	0.157	**0.478**	**-0.237**	**-0.622**	**-0.474**	-0.155
Overstory Mortality	0.153	**0.491**	**-0.304**	**-0.594**	-0.131	-0.163
RGR_D	0.111	0.193	-0.163	**-0.450**	**-0.370**	**-0.210**
RGR_H	0.005	0.161	**-0.269**	**-0.436**	**-0.256**	-0.182
Slope	-0.080	**-0.662**	-0.152	**0.257**	**0.252**	**0.579**
Soil Moisture	-0.016	**-0.490**	-0.114	0.177	**0.255**	0.095
Soil Series	0.056	**-0.725**	**-0.250**	**0.318**	**0.290**	**0.645**
Woody Biomass	0.104	0.086	**-0.247**	**-0.291**	-0.183	-0.039

Table 2.6. Treatment transect data by grass species, density, average percent cover, and average height.

	Species	**Density (clumps m $^{-2}$)**	**Average % Cover (m $^{-2}$)**	**Average Height (cm)**
2006				
No Burn Treatment	*Arundinaria* species	6	6	33
	Schizachyrium scoparium	3	< 1	< 20
Burn Treatment	*Panicum* species	66	3	29.83
	Schizachyrium scoparium	53	1	52.00
	Andropogon gerardii	43	1	34.20
	Carex species	4	4	26.00
Fell with Burn Treatment	*Schizachyrium scoparium*	452	3	29.98
	Andropogon gerardii	230	4	40.63
	Panicum species	116	5	24.15
	Poa species	3	13	27.00
2007				
No Burn Treatment	*Carex* species	4	4	27.50
	Arundinaria species	3	19	25.50
	Panicum species	1	5	< 20
Burn Treatment	*Schizachyrium scoparium*	24	3	40.18
	Carex species	22	5	35
	Panicum species	18	1	< 20
	Poa species	11	4	33.50
	Andropogon gerardii	6	10	73.75
Fell with Burn Treatment	*Schizachyrium scoparium*	357	9	44.99
	Andropogon gerardii	109	8	55.51
	Panicum species	80	9	31.21
	Carex species	15	5	44.30
	Poa species	3	8	< 20

Table 2.7. Average percent cover of grass species located within treatment subplots. Bluestem grasses *S. scoparium* and *A. gerardii* could not be differentiated in their early development.

Treatment	**Species**	**Average Cover (%)** **2006**	 **2007**
No Burn	*Arundinaria* species	5	---
	Iris species	---	1
Burn	*Carex* species	4	7
	Bluestem species	2	1
	Panicum species	1	---
Fell with Burn	*Panicum* species	3	8
	Poa species	---	10
	Bluestem species	5	9
	Carex species	3	1

Table 2.8. Logistic regression analyses of bluestem grass presence. Included are degrees of freedom (DF), parameter estimates, standard error, p-values, odds ratios (the odds of encountering bluestem grass; values >1 indicate a positive relationship), scale (a unit factor more common to that specific parameter), scaled odds ratios (the odds ratio by scale), and Tau-a (model fit p-values).

Model	Parameter	DF	Parameter Estimate	Standard Error	Pr > ChiSq	Odds Ratio	Scale	Scaled Odds Ratio	Tau-a
2006 Bluestem Presence									0.17
	Intercept	1	-3.5174	0.7379	< .0001				
	Maximum Flame Temperature	1	0.00403	0.00111	0.0003	1.004	10	1.04	
2007 Bluestem Presence									
	Intercept	1	-4.3955	1.0107	< .0001				
	Maximum Flame Temperature	1	0.00301	0.00134	0.0242	1.003	10	1.03	0.23
	Overstory Mortality	1	0.043	0.0149	0.0038	1.044	10	1.55	

Table 2.9. Partial ANOVA table of seedling growth analyses.

Model	**Source**	**DF**	**Mean Square**	**F**	**Pr > F**
2006 RGR_D	PCA Value	1	0.0271	0.16	0.6918
	Treatment	2	3.4207	19.94	< .0001
2006 RGR_H	PCA Value	1	0.0052	0.04	0.8493
	Treatment	2	0.8247	5.75	0.0047
2007 RGR_D	PCA Value	1	0.0254	1.32	0.2553
	Treatment	2	0.5023	25.95	< .0001
2007 RGR_H	PCA Value	1	0.0202	0.59	0.4439
	Treatment	2	1.5775	46.18	< .0001

Table 2.10. Seedling survival models. Models for the 2-year study period included soil moisture (SM), aspect (ASP), overstory mortality (TMORT), initial seedling diameter (DIAM), slope (SLOPE), and maximum flame temperature (TEMP). Lower QAICc values (adjusted for overdispersion) indicate better model fit of data. Delta QAICc is the difference between the current QAICc and the best model QAICc. QAICc Weights is the support of the model for the data compared to the other models; QAICc weights of all models must equal 1. Model Likelihood is the likelihood that the model fits the data best out of all of the other models. K is the number of model parameters. QDeviance is the -2 log Likelihood difference between the current model and the full model with all parameters.

Model	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	K	QDeviance
{INT + SM + ASP }	127.77	0	0.32	1	4	119.75
{INT + ASP }	129.56	1.79	0.13	0.41	3	123.55
{INT + SM}	130.39	2.62	0.09	0.27	3	124.38
{INT + TMORT + ASP }	130.94	3.17	0.07	0.20	4	122.92
{INT + DIAM + ASP }	131.17	3.40	0.06	0.18	4	123.15
{INT + ASP + SLOPE}	131.19	3.42	0.06	0.18	4	123.17
{INT + TMORT }	131.64	3.867	0.05	0.14	3	125.63
{INT + TEMP }	131.95	4.18	0.04	0.12	3	125.94
{INT + SM + DIAM + TMORT + ASP + SLOPE}	132.03	4.25	0.04	0.12	7	117.97
{INT + SLOPE}	132.16	4.39	0.04	0.11	3	126.15
{INT + DIAM + TMORT + ASP }	132.38	4.60	0.03	0.10	5	122.34
{INT + SM + DIAM }	132.40	4.63	0.03	0.10	4	124.38
{INT + DIAM }	132.73	4.95	0.03	0.08	3	126.71
{INT + DIAM + TMORT + ASP + SLOPE}	134.06	6.29	0.01	0.04	6	122.03

Table 2.11. Seedling survival estimates of the top seedling survival model. Beta estimates for the top model of soil moisture (SM) and aspect (ASP) (INT + SM + ASP). SE= standard error, LCI = lower confidence interval, UCI = upper confidence interval, Odds Ratio = the odds of encountering a live shortleaf seedling (values < 1 indicate a negative relationship), Interpretation = likelihood of bluestem presence, Scale = a unit factor more common to that specific parameter, Scaled Odds Ratio = the odds ratio by scale.

Factor	Beta Estimate	SE	LCI	UCI	Odds Ratio	Interpretation	Scale	Scaled Odds Ratio	Interpretation
INT	7.6985	1.4418	4.8726	10.5245					
SM	-0.1449	0.0679	-0.2781	-0.0118	0.8651	1.1560	5	0.4845	2.0641
ASP	-0.0117	0.0053	-0.0221	-0.0012	0.9884	1.0117	10	0.8900	1.1236

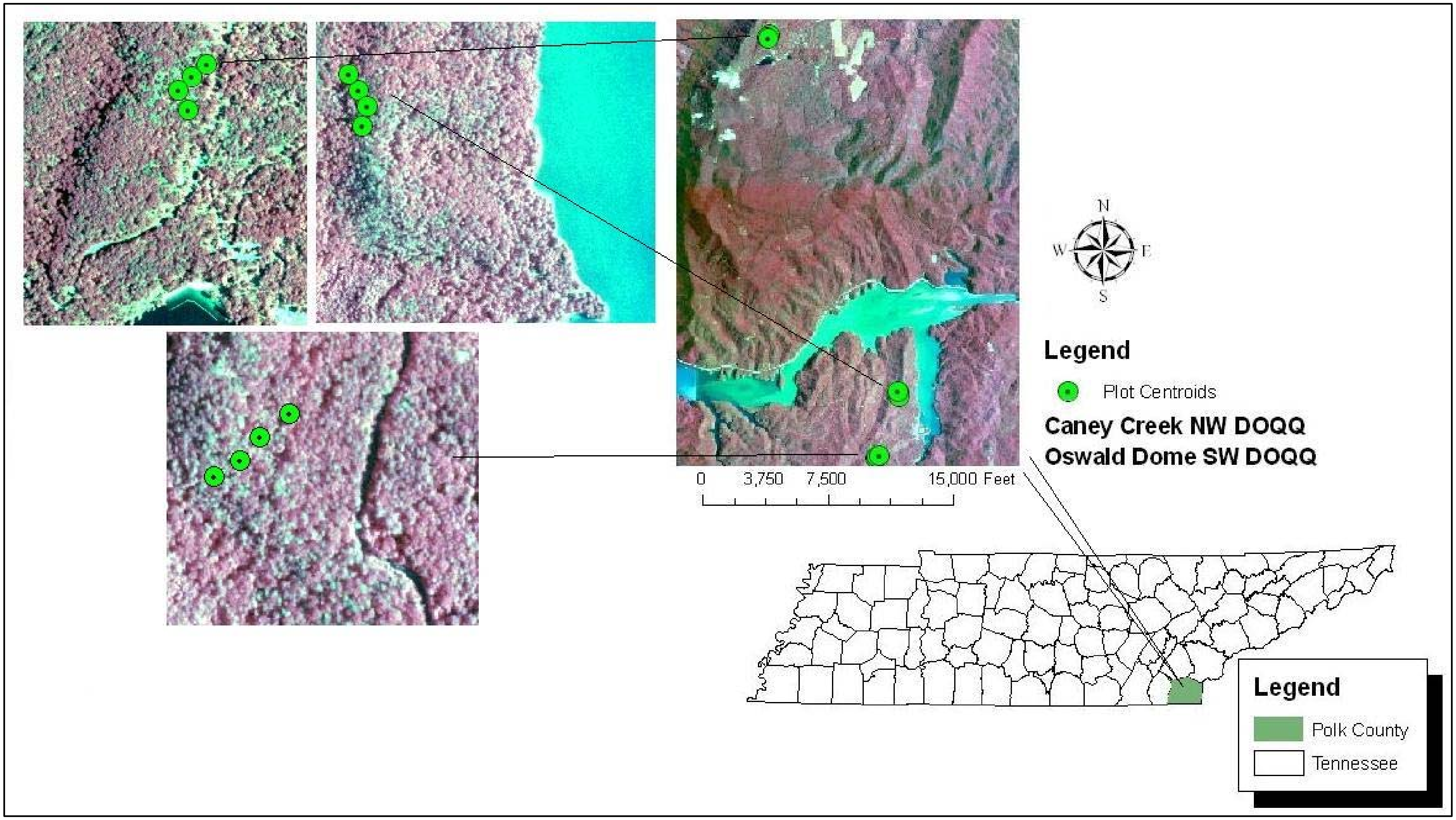

Figure 2.1. Map of treatment sites located within the Cherokee National Forest, Polk County, Tennessee.

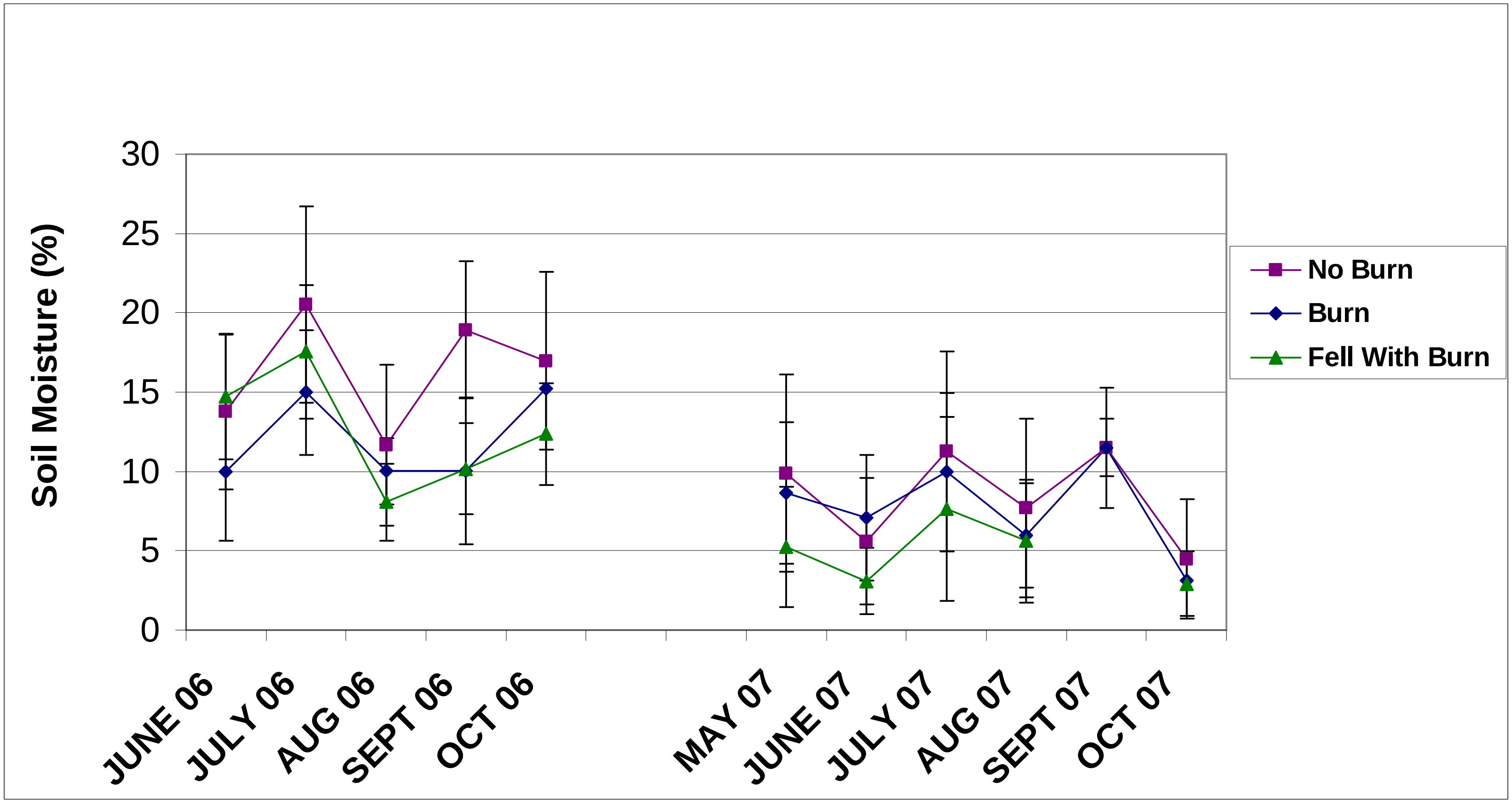

Figure 2.2. Average volumetric water content with standard deviations by treatment for each month of the 2-year study period.

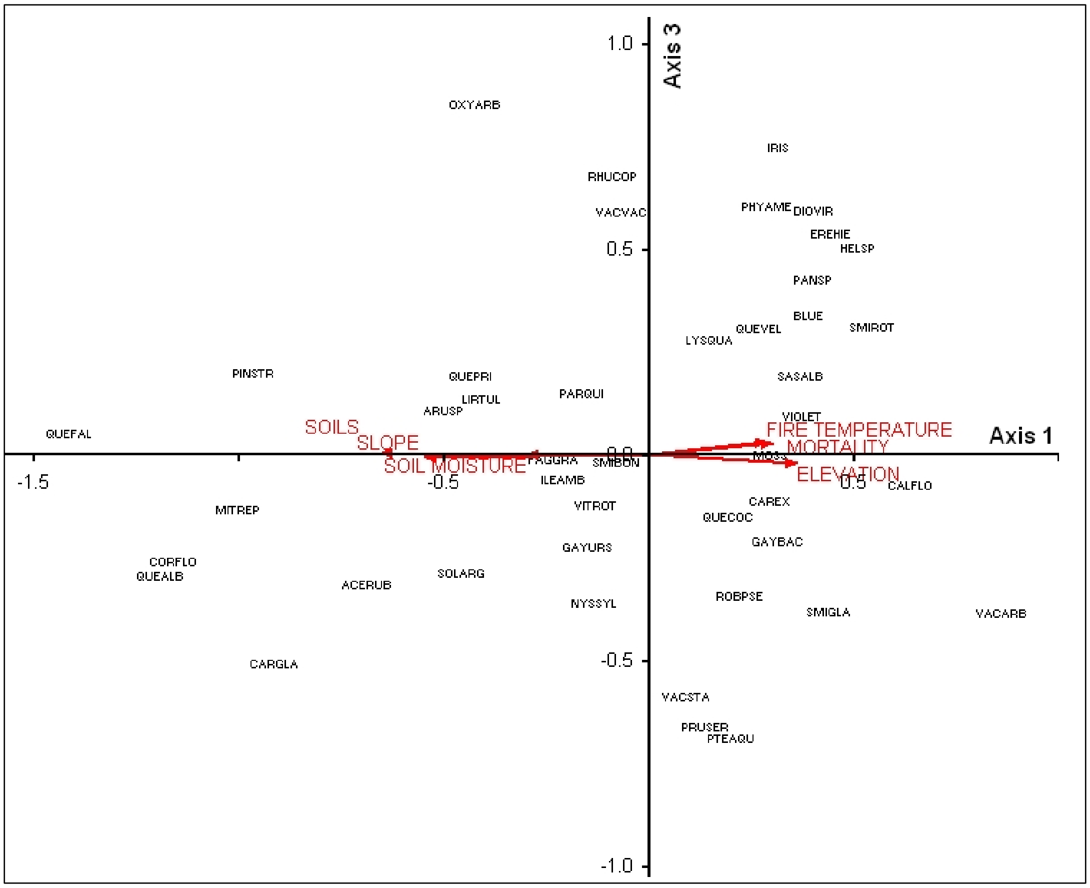

Figure 2.3. 2006 NMS ordination graph of Axis 1 and Axis 3 with important line vectors. Vectors include soil series (SOILS), slope (SLOPE), soil moisture (SOILMOISTURE), maximum flame temperature (FIRETEMPERATURE), overstory mortality (MORTALITY), and elevation (ELEVATION). Only environmental variables with $R^2 \geq 0.2$ are included. Species codes: ACERUB= *Acer rubrum*; ARUSP= *Arundinaria* species; BLUE= bluestem grass species; CALFLO= *Calycanthus floridus*; CAREX= *Carex* species; CARGLA= *Carya glabra*;; CORFLO= *Cornus florida*; DIOVIR= *Diospyros virginiana*; EREHIE= *Erechtites hieraciifolia*; FAGGRA= *Fagus grandifolia*; GAYBAC= *Gaylussacia baccata*; GAYURS= *Gaylussacia ursina*; HELSP= *Helianthus* species; ILEAMB= *Ilex ambigua*; IRIS= *Iris* species; LIRTUL= *Liriodendron tulipifera*; LYSQUA= *Lysimachia quadrifolia*; MITREP= *Mitchella repens*; NYSSYL= *Nyssa sylvatica*; OXYARB= *Oxydendrum arboreum*; PANSP= *Panicum* species; PARQUI= *Parthenocissus quinquefolia*; PHYAME= *Phytolacca americana*; PINSTR= *Pinus strobus*; PRUSER= *Prunus serotina*; PTEAQU= *Pteridium aquilinum*; QUEALB= *Quercus alba*; QUECOC= *Quercus coccinea*; QUEFAL= *Quercus falcata*; QUEPRI= *Quercis prinus*; QUEVEL= *Quercus velutina*; RHUCOP = *Rhus copallina*; ROBPSE= *Robinia pseudocacia*; SASALB= *Sassafras albidum;* SMIBON= *Smilax bona-nox*; SMIGLA= *Smilax glauca*; SMIROT= *Smilax rotundifolia*; SOLARG= *Solidago odora*; VACARB= *Vaccinium arboreum*; VACSTA= *Vaccinium stamineum*; VACVAC = *Vaccinium vacillans*; VIOLET= *Viola* species; VITROT= *Vitis rotundifolia*.

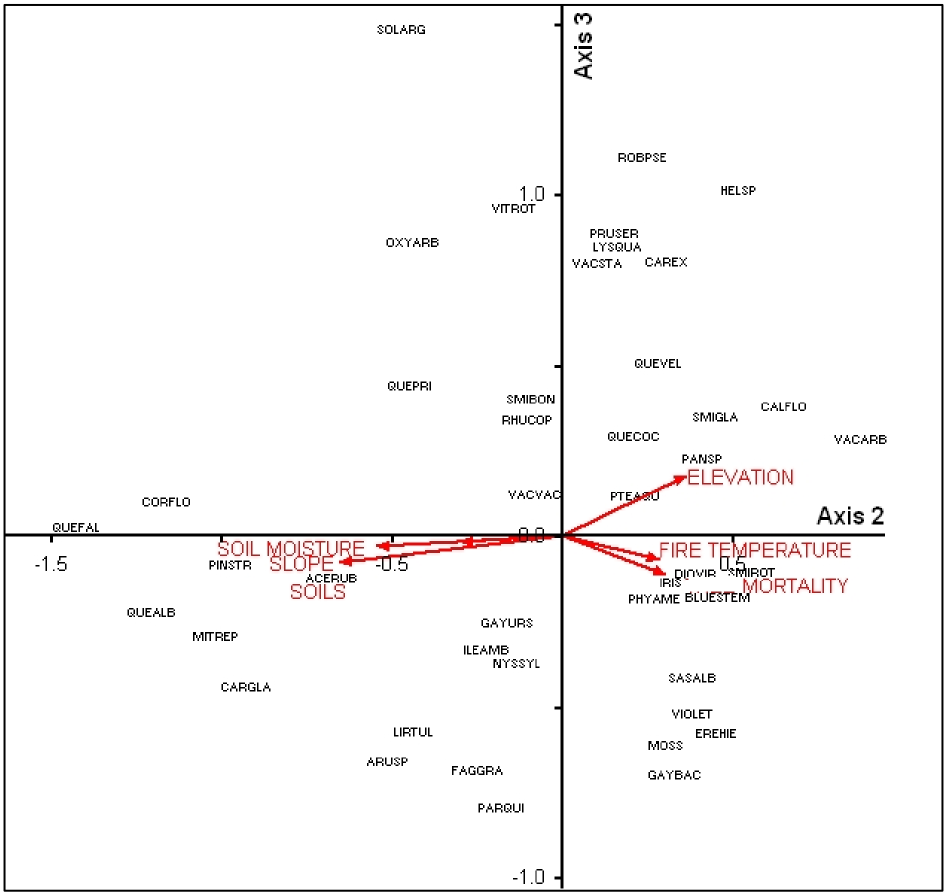

Figure 2.4. 2006 NMS ordination graph of Axis 2 and Axis 3 with important line vectors. Vectors include soil moisture (SOILMOISTURE), slope (SLOPE), soil series (SOILS), Elevation (ELEVATION), maximum flame temperature (FIRETEMPERATURE), and overstory mortality (MORTALITY). Only environmental variables with $R^2 \geq 0.2$ are included. Species codes: ACERUB= *Acer rubrum*; ARUSP= *Arundinaria* species; BLUE= bluestem grass species; CALFLO= *Calycanthus floridus*; CAREX= *Carex* species; CARGLA= *Carya glabra*;; CORFLO= *Cornus florida*; DIOVIR= *Diospyros virginiana*; EREHIE= *Erechtites hieraciifolia*; FAGGRA= *Fagus grandifolia*; GAYBAC= *Gaylussacia baccata*; GAYURS= *Gaylussacia ursina*; HELSP= *Helianthus* species; ILEAMB= *Ilex ambigua*; IRIS= *Iris* species; LIRTUL= *Liriodendron tulipifera*; LYSQUA= *Lysimachia quadrifolia*; MITREP= *Mitchella repens*; NYSSYL= *Nyssa sylvatica*; OXYARB= *Oxydendrum arboreum*; PANSP= *Panicum* species; PARQUI= *Parthenocissus quinquefolia*; PHYAME= *Phytolacca americana*; PINSTR= *Pinus strobus*; PRUSER= *Prunus serotina*; PTEAQU= *Pteridium aquilinum*; QUEALB= *Quercus alba*; QUECOC= *Quercus coccinea*; QUEFAL= *Quercus falcata*; QUEPRI= *Quercis prinus*; QUEVEL= *Quercus velutina*; RHUCOP = *Rhus copallina*; ROBPSE= *Robinia pseudocacia*; SASALB= *Sassafras albidum;* SMIBON= *Smilax bona-nox*; SMIGLA= *Smilax glauca*; SMIROT= *Smilax rotundifolia*; SOLARG= *Solidago odora*; VACARB= *Vaccinium arboreum*; VACSTA= *Vaccinium stamineum*; VACVAC = *Vaccinium vacillans*; VIOLET= *Viola* species; VITROT= *Vitis rotundifolia*.

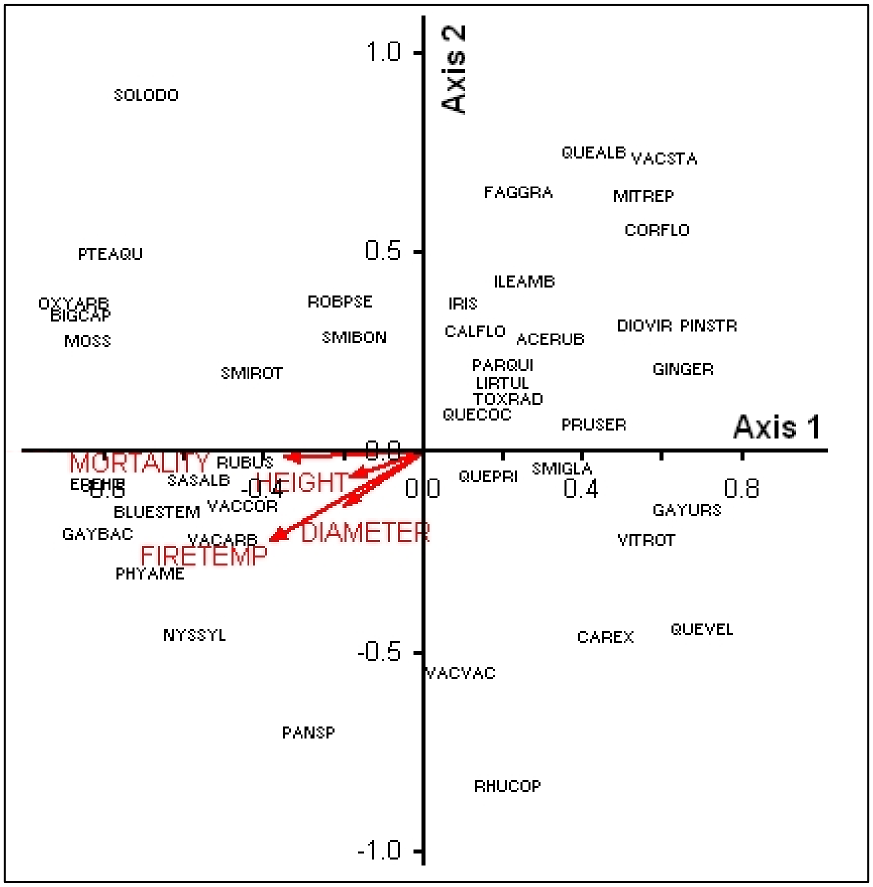

Figure 2.5. 2007 NMS ordination graph of Axis 1 and Axis 2 with important line vectors. Vectors include overstory mortality (MORTALITY), RGR_H (HEIGHT), RGR_D (DIAMETER), and maximum flame temperature (FIRETEMP). Only environmental variables with $R^2 \geq 0.2$ are included. Species codes: ACERUB= *Acer rubrum*; ARUSP= *Arundinaria* species; BLUE= bluestem grass species; CALFLO= *Calycanthus floridus*; CAREX= *Carex* species; CARGLA= *Carya glabra*;; CORFLO= *Cornus florida*; DIOVIR= *Diospyros virginiana*; EREHIE= *Erechtites hieraciifolia*; FAGGRA= *Fagus grandifolia*; GAYBAC= *Gaylussacia baccata*; GAYURS= *Gaylussacia ursina*; HELSP= *Helianthus* species; ILEAMB= *Ilex ambigua*; IRIS= *Iris* species; LIRTUL= *Liriodendron tulipifera*; LYSQUA= *Lysimachia quadrifolia*; MITREP= *Mitchella repens*; NYSSYL= *Nyssa sylvatica*; OXYARB= *Oxydendrum arboreum*; PANSP= *Panicum* species; PARQUI= *Parthenocissus quinquefolia*; PHYAME= *Phytolacca americana*; PINSTR= *Pinus strobus*; PRUSER= *Prunus serotina*; PTEAQU= *Pteridium aquilinum*; QUEALB= *Quercus alba*; QUECOC= *Quercus coccinea*; QUEFAL= *Quercus falcata*; QUEPRI= *Quercis prinus*; QUEVEL= *Quercus velutina*; RHUCOP = *Rhus copallina*; ROBPSE= *Robinia pseudocacia*; SASALB= *Sassafras albidum;* SMIBON= *Smilax bona-nox*; SMIGLA= *Smilax glauca*; SMIROT= *Smilax rotundifolia*; SOLARG= *Solidago odora*; VACARB= *Vaccinium arboreum*; VACSTA= *Vaccinium stamineum*; VACVAC = *Vaccinium vacillans*; VIOLET= *Viola* species; VITROT= *Vitis rotundifolia*.

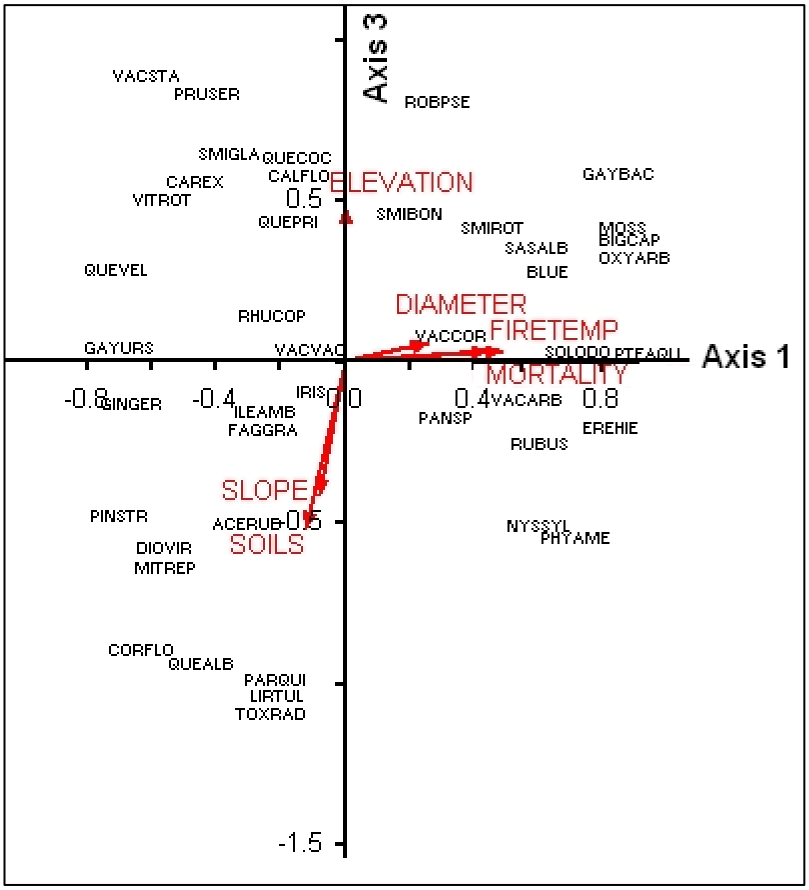

Figure 2.6. 2007 NMS ordination graph of Axis 1 and Axis 3 with important line vectors. Vectors include slope (SLOPE), soil series (SOILS), elevation (ELEVATION), RGR_D (DIAMETER), maximum flame temperature (FIRETEMP), and overstory mortality (OVERSTORY). Only environmental variables with $R^2 \geq 0.2$ are included. Species codes: ACERUB= *Acer rubrum*; ARUSP= *Arundinaria* species; BLUE= bluestem grass species; CALFLO= *Calycanthus floridus*; CAREX= *Carex* species; CARGLA= *Carya glabra*;; CORFLO= *Cornus florida*; DIOVIR= *Diospyros virginiana*; EREHIE= *Erechtites hieraciifolia*; FAGGRA= *Fagus grandifolia*; GAYBAC= *Gaylussacia baccata*; GAYURS= *Gaylussacia ursina*; HELSP= *Helianthus* species; ILEAMB= *Ilex ambigua*; IRIS= *Iris* species; LIRTUL= *Liriodendron tulipifera*; LYSQUA= *Lysimachia quadrifolia*; MITREP= *Mitchella repens*; NYSSYL= *Nyssa sylvatica*; OXYARB= *Oxydendrum arboreum*; PANSP= *Panicum* species; PARQUI= *Parthenocissus quinquefolia*; PHYAME= *Phytolacca americana*; PINSTR= *Pinus strobus*; PRUSER= *Prunus serotina*; PTEAQU= *Pteridium aquilinum*; QUEALB= *Quercus alba*; QUECOC= *Quercus coccinea*; QUEFAL= *Quercus falcata*; QUEPRI= *Quercis prinus*; QUEVEL= *Quercus velutina*; RHUCOP = *Rhus copallina*; ROBPSE= *Robinia pseudocacia*; SASALB= *Sassafras albidum;* SMIBON= *Smilax bona-nox*; SMIGLA= *Smilax glauca*; SMIROT= *Smilax rotundifolia*; SOLARG= *Solidago odora*; VACARB= *Vaccinium arboreum*; VACSTA= *Vaccinium stamineum*; VACVAC = *Vaccinium vacillans*; VIOLET= *Viola* species; VITROT= *Vitis rotundifolia*.

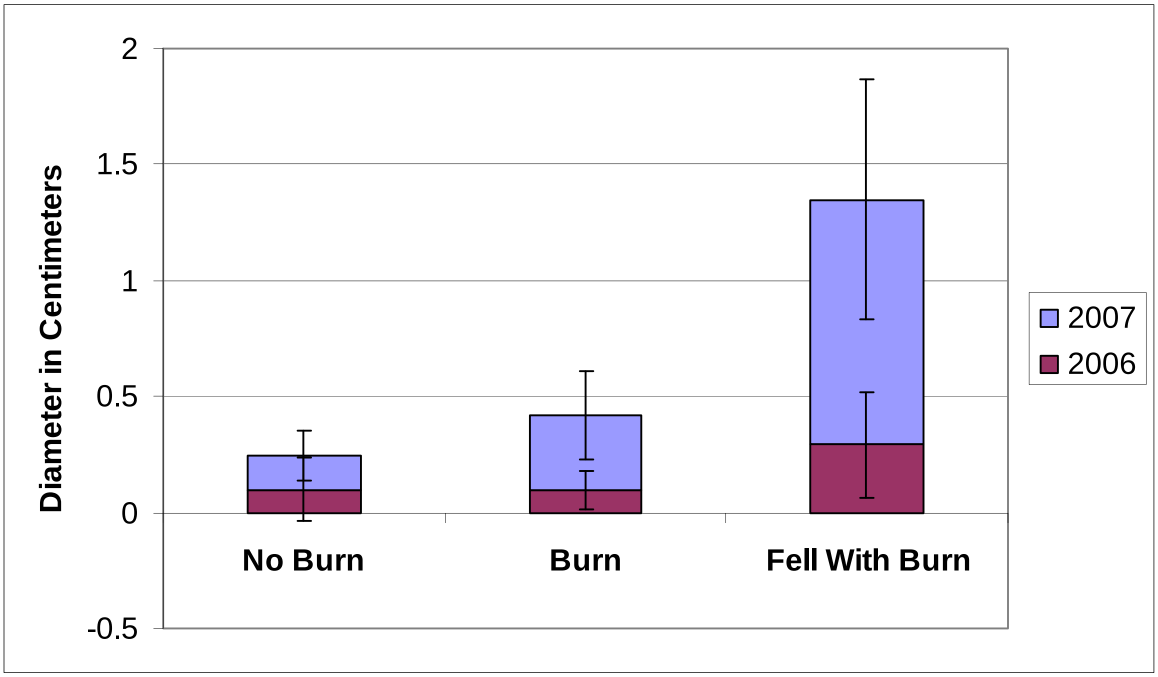

Figure 2.7. Average shortleaf pine seedling diameter growth with standard deviations by treatment.

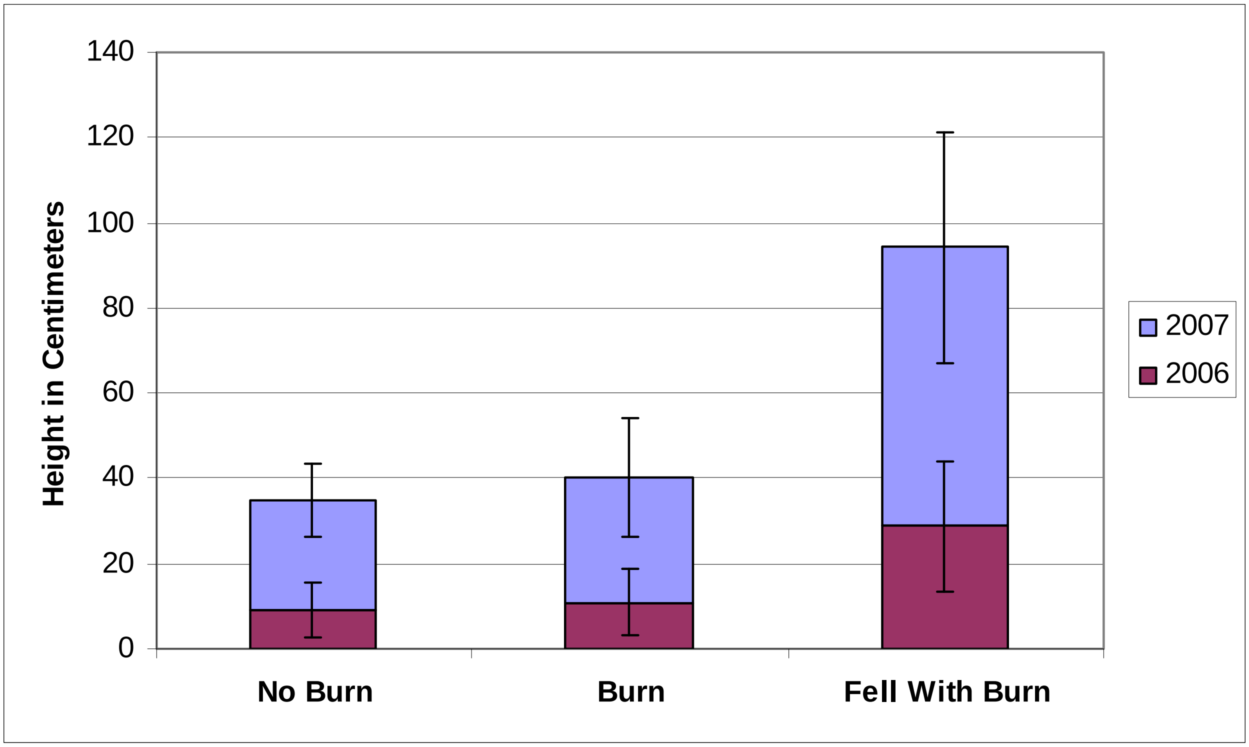

Figure 2.8. Average shortleaf pine seedling height growth with standard deviations by treatment.

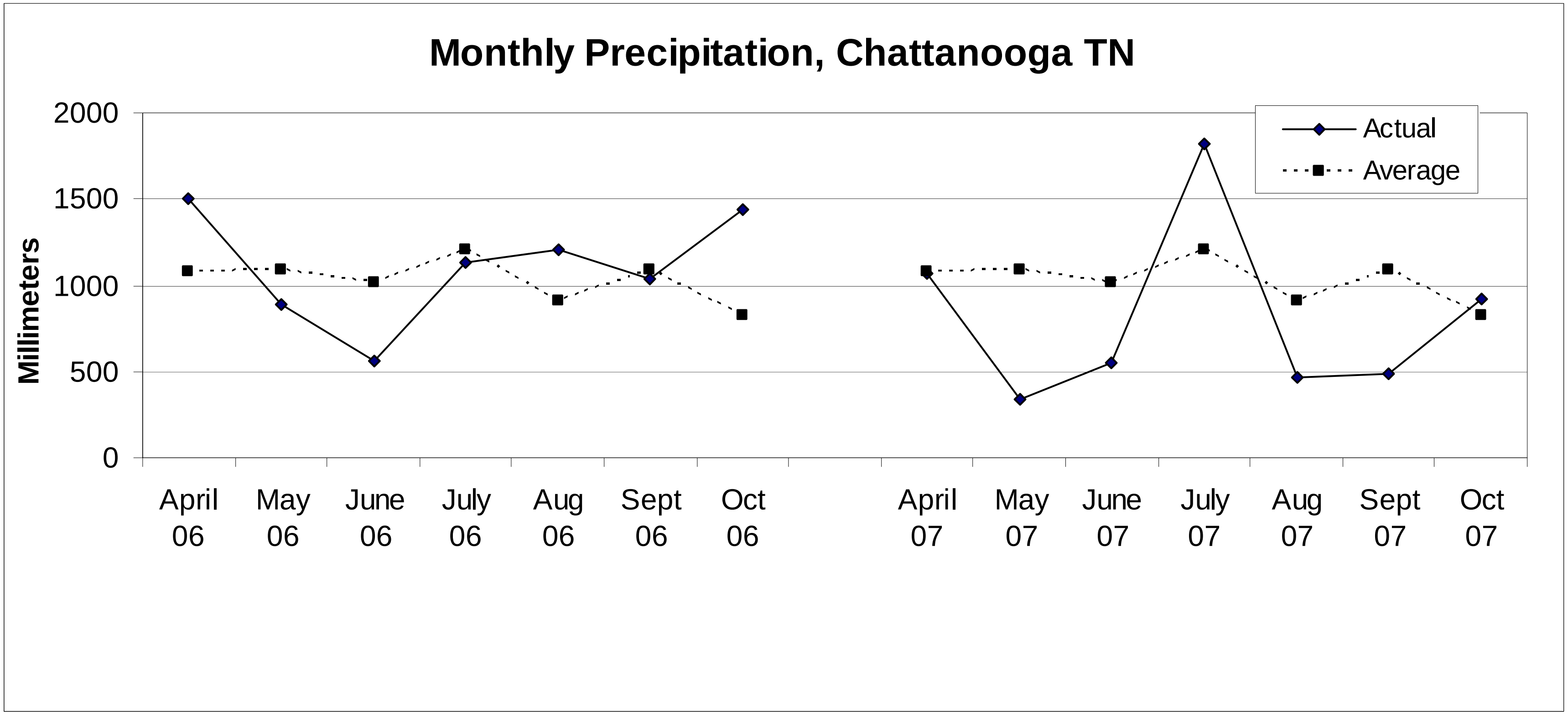

Figure 2.9. Local average precipitation and actual precipitation in millimeters. Data obtained from the National Weather Service Forecast Office, Morristown, Tennessee.

CHAPTER 3

SHORTLEAF PINE (*PINUS ECHINATA* MILL.) AND BLUESTEM GRASS (*ANDROPOGON GERARDII* VITMAN AND *SCHIZACHYRIUM SCOPARIUM* (MICHX.) NASH) RESPONSE TO HERBICIDE APPLICATION[1]

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[1] Newman, A.C. and R.L. Hendrick. To be submitted to *Southern Journal of Applied Forestry*.

ABSTRACT

Shortleaf pine (*Pinus echinata* Mill.) - bluestem grass (*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities are in decline because of plant succession, repeated southern pine beetle attacks, and the absence of viable seed in the seedbed. In restoration studies, herbicide applications are successfully used to further the effectiveness of restoration treatments. We investigated the use of six treatments: broadcast seeding bluestem grass (with and without herbicide), planting shortleaf pine (with and without herbicide), and planting shortleaf pine and broadcast seeding bluestem grass (with and without herbicide). We measured the relative growth rate of shortleaf pine seedling height and diameter and estimated bluestem grass cover by species. Greatest diameter and height growth rates occurred within the herbicide application treatments with no significant differences between shortleaf pine herbicide and shortleaf pine and bluestem grass herbicide treatments. Greatest *A. gerardii* cover occurred within the shortleaf pine and bluestem grass herbicide treatment while greatest *S. scoparium* cover occurred within the bluestem grass treatment. These differences may be attributed to the dominance of *A. gerardii* over *S. scoparium* when less competition and more resources are available. Herbicide applications can be used to increase shortleaf pine growth rates while promoting the establishment of bluestem grasses (within our study, *A. gerardii*). The use of broadleaf herbicides should be investigated to further restoration success. Selective herbicide use can facilitate greater shortleaf pine growth and bluestem grass cover.

INTRODUCTION

Historically, shortleaf pine and bluestem grasses occurred in mixed pine/oak woodlands of the southern Appalachians (Hubbard *et al.*, 2004). These communities supported grazing and habitat areas for wildlife and agricultural animals as well as open areas for hunting (van Lear and Waldrop, 1989). Ecological succession, along with the impact of repeated southern pine beetle attacks (*Dendroctonus frontalis* Zimmerman (Coleoptera: Scolytidae)) and the absence of viable pine and grass seed in the seedbed have negatively affected the establishment of shortleaf pine (*Pinus echinata* Mill.)- bluestem grass (*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities within the southern Appalachians (Elliott *et al.*, 1999). Because of the few remaining locations of these communities, land management efforts are needed to restore this system to areas where they once occurred.

The USDA Forest Service (USFS) promotes the restoration of shortleaf pine- bluestem grass communities on 254,000 acres in the Ouachita National Forest of western Arkansas and eastern Oklahoma (Hedrick *et al.*, 2007). Within this program, midstory hardwood and overstory and midstory pines under a certain diameter are removed (thin from below), and prescribed dormant or growing season burns are conducted every one to three years (Sparks *et al.*, 2002; Liechty *et al.*, 2005). Bobwhite quail increase in abundance (Cram *et al.*, 2002; Wood *et al.*, 2004), and lepidopteran, reptilian, mammalian, and avian communities are more abundant in these restored areas compared to non-restored areas (Masters *et al.*, 1998; Thill *et al.*, 2004; Rudolph *et al.*, 2006). The USFS is effectively establishing red-cockaded woodpecker populations within restored shortleaf pine-bluestem grass communities (Wilson *et al.*, 1995; Guldin *et al.*, 2004).

The USFS is investigating the use of herbicides to further the effectiveness of shortleaf pine-bluestem grass restoration treatments by eliminating hardwood competition (Guldin, 2007; Hedrick *et al.*, 2007). Herbicide applications promote shortleaf pine growth and establishment within natural stands and plantations (Shelton and Cain, 2000; Amishev and Fox, 2006). *Andropogon gerardii* and *S. scoparium* commonly occur with shortleaf pine and other native grasses (Lawson, 1990). Herbicide applications successfully promote the establishment and growth of these grass species by eliminating or reducing competition for resources (Masters, 1997; Miller and Dickerson, 1999; Barnes, 2007).

As part of the USFS effort to restore degraded pine communities to the southern Appalachian forests, we evaluated the effects of herbicide application on shortleaf pine seedling growth rates and bluestem grass cover. The main objective was to determine the influence of herbicide application on the growth response of shortleaf pine seedlings and establishment of bluestem grass. More specifically, we examine which treatment produces the greatest shortleaf pine growth rate and bluestem grass cover. We hypothesized that planting shortleaf pine seedlings and applying herbicide would produce the greatest shortleaf pine growth rate while broadcast seeding bluestem grass and applying herbicide would produce the greatest bluestem cover.

METHODS

Site Description

We conducted this study at the Whitehall Forest Nursery in Athens, GA (33° 92' N latitude, -83° 36' longitude). The nursery was established in 1980 with underground drainage. In April 2007, the nursery was subsoiled at a 0.6 meter width to a depth of 61 centimeters and rototilled to a 36 centimeter depth. Bare ground was maintained by spraying a 2% solution of

Roundup Ready® (glyphosate). We installed three irrigation lines with six sprinklers on each line. The irrigation lines were spaced 12.2 meters apart with sprinklers spaced 12.2 meters apart at a height of 2.3 meters. The sprinklers sprayed water up to a 12.2 meter distance. We achieved a minimum of 15% volumetric water content by watering 3 days per week in the 2007 growing season and 2 days per week in the 2008 growing season. Plots received approximately 15.5 centimeters of irrigated water per week in 2007 and 5 centimeters of irrigated water per week in 2008 (in addition to actual rainfall). Nursery soils are derived from the Madison soil series. The Madison series consists of well drained, moderately permeable soils that formed in residuum weathered from felsic or intermediate, high-grade metamorphic or igneous rocks great in mica content (Soil Survey Staff 2008a).

Experimental Design

We applied a randomized complete block design with three blocks of six treatments. We blocked our treatments to account for site heterogeneity that may exist within the nursery. The six treatments were 1) bluestem grass (BG), 2) bluestem grass with herbicide (BG+H), 3) shortleaf pine (SP), 4) shortleaf pine with herbicide (SP+H), 5) shortleaf pine and bluestem grass (SP/BG), and 6) shortleaf pine and bluestem grass with herbicide (SP/BG+H) (Figure 3.1). We established these treatments in 5 m x 5 m plots with 2 m buffers between plots, and we blocked by location. We obtained big bluestem and little bluestem grass seed native to Kentucky and Tennessee from Roundstone Native Seed, LLC (Upton, KY) and broadcasted the seed at 9-10 kilograms per hectare, twice the recommended rate. We obtained shortleaf pine bare-root seedlings of similar size from the Georgia Forestry Commission Flint River Nursery (Byromville, GA). In May 2007, we hand planted the seedlings within the designated treatment plots on a 1.5 meter by 1.5 meter spacing (9 seedlings per plot). We treated *Solenopsis invicta* (imported fire ants) with Orthene (acephate) insecticide powder when they were detected. For the treatments that incorporated herbicide, we used a back-pack sprayer with a shielded wand and applied Roundup Ready® (glyphosate). The SP/BG+H and BG+H treatments received spot herbicide application until July of each growing season to remove cover of other plant species while bluestem species were establishing. The SP+H treatment received herbicide applications throughout the study period to maintain bare ground.

Data Collection

We obtained soil samples with Oakfield Soil Sampler soil probes (Oakfield, WI) to investigate soil differences among the three blocks. From each plot, we collected 5 soil samples evenly spaced within each plot, combined the samples, and selected a subsample of the mixture. We submitted each plot sample to the University of Georgia (UGA) Soil Testing and Plant Analysis Laboratory (Athens, GA) to determine lime buffer capacity, pH, equivalent water pH, organic matter, and content of calcium, potassium, magnesium, manganese, nitrate, phosphorus, and zinc. We tested for soil differences within each block to ensure there were no major differences among soil properties that would influence seedling growth or bluestem grass response.

We measured basal seedling diameter and height to within 0.1 centimeters each month during May-October 2007 and March-September 2008 and calculated relative growth rate (RGR) for each year. We used RGR to determine the seedling growth rate independent of size (Evans, 1972; Elliott *et al.*, 2002). We calculated RGR_D as $RGR_D = (\ln D_2 - \ln D_1) / (t_2 - t_1)$ where D_2 = final growing season diameter, D_1 = initial growing season diameter, and RGR_H as $RGR_H = (\ln H_2 - \ln H_1) / (t_2 - t_1)$ where H_2 = final growing season height and H_1 = initial growing season height, and t = time in years.

We measured monthly volumetric water content (soil moisture) every two weeks during May-October 2007 and March-September 2008. We collected readings approximately 10 centimeters from each seedling with the TDR Fieldscout^{TM} 100 (Spectrum Technologies, Inc., Plainfield, IL) volumetric water content measurement system. The Fieldscout^{TM} instrument operates by submitting an electrical impulse through the two probe rods (20 centimeters in length) inserted into the soil. We averaged two soil moisture measurements that we collected from each seedling. In October 2007 and September 2008, we established 1.0 m diameter circular subplots around each seedling and identified the bluestem species, bluestem clumps, and bluestem clump heights. For plots that did not contain shortleaf seedlings, we collected bluestem cover by establishing the same circular plots at the same spacing where seedlings would have been planted. We visually estimated bluestem percent cover by cover class. The cover classes were: TR (0-1%), 1 (1-3%), 2 (3-10%), 3 (10-20%), 3 (20-30%), 5 (30-40%), 6 (40-50%), 7 (50-60%), 8 (60-70%), 9 (70-80%), and 10 (>80%).

Statistical Analysis

For RGR_D and RGR_H, we used linear mixed-effects models (Littell *et al.*, 2006) in consultation with the UGA Statistical Consulting Center (Athens, GA). We used repeated measures analysis of variance (ANOVA) and analysis of covariance (ANCOVA) models to analyze significant differences of RGR_D and RGR_H between years (2007 and 2008). Dependent variables were RGR_D and RGR_H in 2007 and 2008, and the independent variables were plot treatment and year. For ANCOVA models, our covariate was the yearly average growing season soil moisture that we obtained near each seedling. We modeled treatment effects with random effects to allow for correlation among trees within each plot. We chose the unstructured serial correlation structure because we only collected two repeated measures per seedling. This structure allowed no assumptions to be placed on the variance-covariance matrix structure. We calculated the denominator degrees of freedom using the Kenward-Rogers approximation (Littell *et al.*, 2006).

We selected the best fitting model based upon the lowest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values. These values estimate how generated models fit our data. These two information criterion approaches differ in the calculation of *k* (number of model parameters). AIC uses 2 as a constant to calculate *k* and BIC uses ln (*N*) to calculate *k* (N = sample size) (Burnham and Anderson, 2002). Smaller AIC and BIC values indicate better model fit. Different models produced lower AIC and BIC values. The differences of these values indicated that each method produced a model that fit the data better than the other selection method. To account for model selection differences, we chose the model that resulted in the lowest value of one method and close to the lowest value with the other method.

For bluestem grass, we used ANOVA models in a randomized block design, where *A. gerardii* and *S. scoparium* percent cover in 2007 and 2008 were dependent variables and block and treatment were independent variables. For all analyses, our significance level was $\alpha = 0.05$, and we performed Least Square Means multiple comparisons using Tukey-Kramer Adjustment post-hoc test for the mixed models and Tukey's test for all other analysis.

RESULTS

Five seedlings died during the study, and we replanted these seedlings with reserves to ensure equal spacing among the seedlings. In May 2008, six seedlings were attacked by red-headed pine sawflies (*Neodiprion lecontei*). We sprayed Orthene (acephate) insecticide to remove the sawflies and protect the seedlings. The seedlings that were attacked by the sawflies, suffered mortality, or were replanted were excluded from all statistical analyses. The

Hydrosense^{TM} instrument failed to record measurements in May 2008. This instrument was repaired by July 2008. During May-August, we borrowed the USFS Coweeta Hydrologic Laboratory Hydrosense^{TM}. From May 2008 until the end of the study (September 2008), we collected soil moisture on a monthly basis at the same time as seedling heights and diameters. The mixed models indicated variability among the blocks, but this variability was accounted for as a random effect and not considered an important factor in RGR_D or RGR_H. Blocking was not significant for *A. gerardii* or *S. scoparium* cover.

We did not observe either bluestem species in the first growing season. Both species were present in the second growing season (Table 3.1). Average cover of *A. gerardii* ranged from 0% to 13%, and average cover of *S. scoparium* ranged from 1% to 14%. Average bluestem clumps ranged from 1 to 3, and average clump height ranged from 116.6 cm to 202.5 cm. In the ANOVA analysis, blocking was not significant for either species, but treatment was significant for both species (Table 3.2). For *A. gerardii* cover, the SP/BG+H treatment contained the greatest average cover (13%) and was significantly different from all other treatments. The greatest average *S. scoparium* cover occurred within the BG treatment (14%) and was significantly different from the SP/BG+H, BG+H, SP+H, and SP treatments. *Andropogon gerardii* did not occur within the SP and SP+H treatments. However, *S. scoparium* did occur within the SP treatment (1%) even though we did not broadcast seed in this treatment. *Schizachyrium scoparium* did not occur in the SP+H treatment. The presence of *S. scoparium* in the SP treatment may be explained by wind carrying seed into the treatment area.

Average diameter growth ranged from 0.3 cm to 1.0 cm in the first growing season and 1.4 cm to 2.6 cm in the second growing season (Figure 3.2). For RGR_D analysis, we developed models with varying fixed and random effects and added soil moisture as a covariate. Year (*F*

=15.38, *P* =0.0002), treatment (*F* =19.15, *P* <.0001), year*treatment (*F* =20.63, p <.0001), and soil moisture* year (*F* =11.87, *P* <.0001) were significant. We developed a total of 22 models (Table 3.3). The best model fit for RGR_D was year*soil moisture. RGR_D was significantly greater within the SP+H and SP/BG+H treatments. Both the SP+H treatment (*P* <0.0001) and SP/BG+H treatment (*P* <0.0001) RGR_D means were 1.06 while the mean RGR_D for the SP treatment (*P* <0.0001) was 0.84 and the SP/BG treatment (*P* <0.0001) was 0.79. There were no significant differences between the SP+H and SP/BG+H treatments (*P* =1.000) or the SP/BG and SP treatments (*P* =0.6218).

Average height growth ranged from 16.3 cm to 32.7 cm in the first growing season and 53.0 cm to 89.4 cm in the second growing season (Figure 3.3). For RGR_H analyses, we developed 24 models with varying fixed and random effects and added soil moisture as a covariate (Table 3.4). The best model fit for RGR_H was year and treatment. Both year (*F* =14.55, *P* =0.0002) and treatment (*F* =4.95, *P* =0.0031) were significant. The SP+H treatment and the SP/BG+H treatment had significantly greater RGR_H than the SP and SP/BG treatments. Mean RGR_H for the SP+H treatment (*P* <0.0001) and SP/BG+H treatment (*P* <0.0001) were 0.77 and 0.79, respectively, while the mean RGR_H for the SP treatment (*P* <0.0001) is 0.68 and the SP/BG treatment (*P* <0.0001) was 0.60. There was no significant difference between the SP+H and SP/BG+H treatments (*P* =0.9700) or the SP/BG and SP treatments (*P*=0.4800).

DISCUSSION

Neither bluestem species were present in the first growing season, but it can take up to two years for these species to establish (Weaver, 1931; Yarrow and Yarrow, 1999). We broadcasted seed in May, later than the recommended seeding time of early spring. In native warm season grasses, later planting dates may result in delayed seed germination (Miller and

Dickerson, 1999). We broadcast seeded at this late date because we initially applied this study in the southern Appalachians. However, drought impacted seedling survival and bluestem establishment. Most seedlings suffered mortality and bluestem grass was not present within any treatment. Thus, we were not surprised that bluestem grass species were not present in the first growing season since these species generally require two years for establishment, and we seeded the grass late.

Andropogon gerardii and *S. scoparium* responded differently to herbicide application in the second growing season. Greater *A. gerardii* cover occurred in the SP/BG+H treatment while greater *S. scoparium* cover occurred in the BG treatment. Contrary to our hypothesis, greater bluestem cover did not occur in the BG+H treatment compared to the other treatments. Campbell and Swain (1973) attributed losses of perennial pasture species to moisture stress, ant theft, soil fauna damage, residual herbicides, and plant competition. In our study, residual herbicide remaining after spot application treatments, ant theft, and wind transport of seed outside of treatment areas could have negatively affected the bluestem seedling success, but we did not measure those parameters. Shortleaf pine seedlings may have facilitated bluestem cover because care was taken in herbicide application around each seedling.

Greater *A. gerardii* cover with herbicide application is similar to the results of Beran et al. (2000) who observed greater establishment of *A. gerardii* with the use of herbicides. We expected greater *S. scoparium* cover within herbicide treatments, similar to other studies (Choi and Pavlovic, 1998). The difference between *A. gerardii* and *S. scoparium* response to treatment may be explained by the interspecific competition between these species, which can result in a niche shift of *S. scoparium* in the presence of *A. gerardii* (LaGory *et al.*, 1982). *Andropogon gerardii* may have inhibited *S. scoparium* by shading this species, and *S. scoparium* may have produced more cover in the presence of other herbaceous cover when *A. gerardii* could not compete against other plants.

The soil moisture*year interaction was the best fitting model for RGR_D. Soil moisture was a significant covariate, and year was a significant factor. Yeiser and Barnett (1991) reported greater soil moisture on herbicide plots than non-herbicide plots. They suggested competition for soil moisture influenced shortleaf pine seedling growth. However, we did not detect differences in soil moisture among the treatments in our study. Shortleaf pine seedling RGR_D and RGR_H were greater in the second growing season than the first growing season, which may have been influenced by the late planting date. South and Barnett (1986) reported greater proportional growth of pine seedlings planted in March than those planted in May. In our study, planting pine seedlings earlier in the spring may have increased shortleaf pine seedling growth during the first year.

Treatment was a second significant factor in the RGR_H model. Our results are similar to those of Creighton et al. (1987). They planted loblolly (*Pinus taeda* L.), longleaf (*P. palustris* Miller), and slash pine (*P. elliottii* Engelm.) and applied herbicide for two years. A significant positive response in pine growth resulted from their herbicide applications. In another study, herbicide applications effectively removed competition and allowed for early establishment rates and greater height and diameter growth among loblolly pine and shortleaf pine seedlings (Cain, 1996). In our study, greater RGR_D and RGR_H occurred within the SP/BG+H and SP+H treatments. Yeiser and Barnett (1991) used Roundup® herbicide applications to remove competition, and significantly greater height and diameter growth occurred in the herbicide treatments in both the first and second years. Miller et al. (1991) found greater height and diameter growth of loblolly pine in herbicide treatments.

CONCLUSION

Greater diameter growth rates occurred within the SP+H and SP/BG+H treatments. These two treatments may have removed other plant cover and allowed more resources to be available to shortleaf seedlings (Cain, 1991). Within our study, no significant height or diameter growth rate differences occurred between the SP/BG+H and SP+H treatments, indicating that bluestem grasses did not inhibit shortleaf seedling RGR_D or RGR_H. The bluestem species responded differently to herbicide treatments. *Andropogon gerardii* produced greater cover in the SP/BG+H treatment, and *S. scoparium* produced greater cover in the BG treatment. Difference in cover by treatment may be attributed to the shading of *A. gerardii* over *S. scoparium*.

Herbicide applications may increase shortleaf pine growth rates while promoting the establishment of bluestem grasses (in this study, *A. gerardii*). However, the use of glyphosate herbicides will result in the mortality of shortleaf pine and bluestem grasses along with the plant species that prevent the restoration of these communities. For restoration efforts, the use of broadleaf herbicides may potentially be used to remove competition within the southern Appalachians. We could not use these herbicides in our study because we did not have broadleaf weeds within the nursery. We observed common nursery weeds similar in growth and form to bluestem grasses. Broad application of herbicides that would remove the nursery weeds would have also removed the bluestem grasses. In the southern Appalachians, the nursery weeds within our study would be infrequent, and broadleaf herbicide may be more easily applied and effective in promoting bluestem grasses because of the presence of broadleaf species in the field.

Shortleaf pine-bluestem grass communities provide wildlife habitat for small mammals, threatened or endangered species, game species, and others. Restoration of these communities increases plant and animal diversity and native groundcover while inhibiting ecological succession. Application of restoration treatments should account for forecasted drought conditions, if available. The failure of our field study within the southern Appalachians demonstrates the importance of precipitation and related soil moisture for successful seedling and bluestem grass establishment. We achieved adequate soil moisture with the use of irrigation within the nursery and successfully applied herbicide treatments and achieved pine seedling and grass establishment. Removal of competing plants by applying a broadleaf herbicide may facilitate greater bluestem grass establishment and cover. The USFS forest management policies currently limit the use of herbicide applications within National Forests. However, herbicide use can facilitate greater shortleaf pine growth and bluestem grass cover and should be considered as a tool to increase the restoration success of this community (Hedrick *et al.*, 2007).

Table 3.1. Average percent cover, average number of clumps, and average clump height of *A. gerardii* and *S. scoparium* by treatment type. Data obtained during the second growing season (2008) within the 1.0 m diameter subplots of the Whitehall Forest Nursery, Athens, GA.

Treatment	**Bluestem Species**	**Average Percent Cover**	**Average Number of Clumps**	**Average Clump Height**
BG+H				
	A. gerardii	1	1	202.5
	S. scoparium	3	1	128.6
BG				
	A. gerardii	4	1	170.6
	S. scoparium	14	3	116.6
SP				
	A. gerardii	0	0	0
	S. scoparium	1	2	135.0
SP/BG				
	A. gerardii	1	1	156.2
	S. scoparium	9	3	119.3
SP/BG+H				
	A. gerardii	13	1	183.9
	S. scoparium	5	1	130.5
SP+H				
	A. gerardii	0	0	0
	S. scoparium	0	0	0

Table 3.2. Partial ANOVA table for *A. gerardii* and *S. scoparium* cover. Data obtained during the second growing season (2008).

	Source	**DF**	**SS**	**MS**	**F-value**	**Pr > F**
A. gerardii cover						
	Treatment	5	4259.92	851.98	8.00	<.0001
	Block	2	3.50	1.75	0.02	0.98
S. scoparium cover						
	Treatment	5	4097.69	819.54	6.49	<.0001
	Block	2	247.81	123.91	0.98	0.38

Table 3.3. Mixed effects models developed for RGR_D. Lower AIC and BIC values indicate better model fit. Bolded model indicates best fit to data based upon lowest comparative AIC and BIC values.

Fixed effects	**Random effect(s)**	**AIC**	**BIC**
Year*SM	No random effects	13.2	21.2
Year*SM	Plot	13.4	25.3
Year*SM	**Block**	**13.7**	**10.1**
Year*SM	Block, plot	15.3	10.8
Year, Treatment, Year*Treatment	Block, plot	19.5	21.4
Year, Treatment, Year*Treatment	Plot	19.5	21.4
Year, Treatment, Year*Treatment	No random effects	21	29
SM	No random effects	21.6	29.6
SM	Block	22	18.4
SM	Plot	22.3	24.2
Year, Treatment, Year*Treatment	Block	23	19.4
SM	Block, plot	24	19.5
Year*treatment*SM	No random effects	30.5	38.5
Year*treatment*SM	Block, plot	31.1	27.5
Year*treatment*SM	Plot	31.1	30
Year*treatment*SM	Block	31.7	28.1
Treatment*SM	No random effects	33	40.9
Treatment*SM	Block	34.2	30.6
Treatment*SM	Block, plot	34.2	30.6
Treatment*SM	Plot	34.4	36.4
Year, Treatment	Plot	71.9	73.9
Year, Treatment	Block	76.2	72.6

Table 3.4. Mixed effects models developed for RGR_H. Bolded model indicates best fit to data based upon lowest comparative AIC and BIC values.

Fixed effects	Random effect(s)	AIC	BIC
Year, Treatment	No random effects	75.1	83.1
Year, Treatment	**Block**	**76.5**	**72.9**
Year, Treatment	Plot	76.7	78.6
Year, Treatment, Year*Treatment	No random effects	77.3	85.3
Year*SM	Block	78.2	75.5
Year*SM	No random effects	78.2	86.2
Year, Treatment	Block, plot	78.4	80.9
SM	Block	78.6	75.9
SM	No random effects	78.6	86.6
Year, Treatment, Year*Treatment	Block	78.7	75.1
Year, Treatment, Year*Treatment	Plot	78.8	80.8
Year*SM	Block, plot	80.2	76.6
Year*SM	Plot	80.2	82.2
SM	Block, plot	80.6	77
SM	Plot	80.6	82.5
Year, Treatment, Year*Treatment	Block, plot	80.6	83
Treatment*SM	Block	89.8	87.1
Treatment*SM	Block, plot	89.8	87.1
Treatment*SM	Plot	89.8	91.2
Treatment*SM	No random effects	89.8	97.7
Year*treatment*SM	Block	110.8	108.1
Year*treatment*SM	Block, plot	110.8	108.1
Year*treatment*SM	Plot	110.8	112.3
Year*treatment*SM	No random effects	110.8	118.8

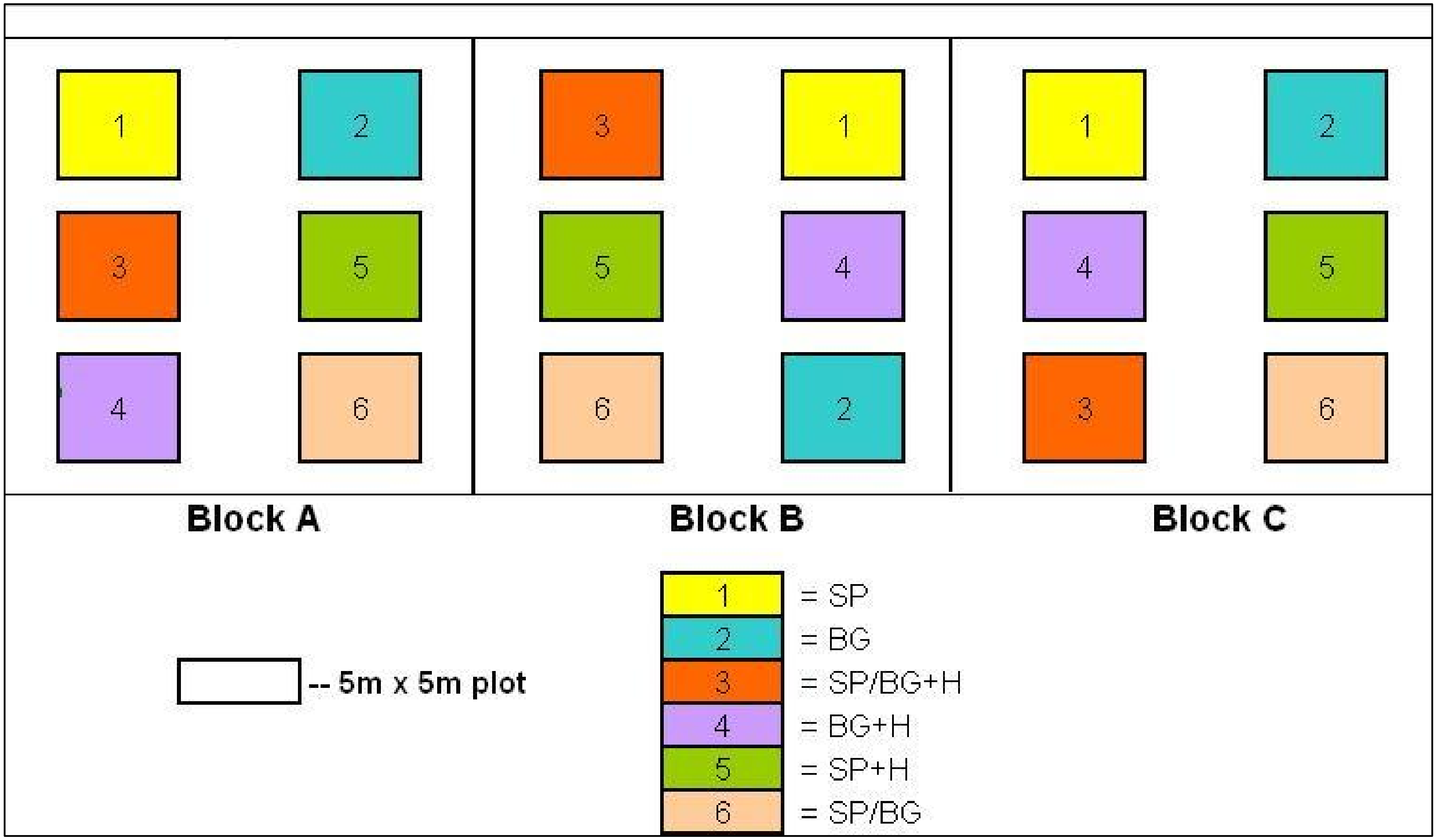

Figure 3.1. Experimental design for Whitehall nursery treatment plots.

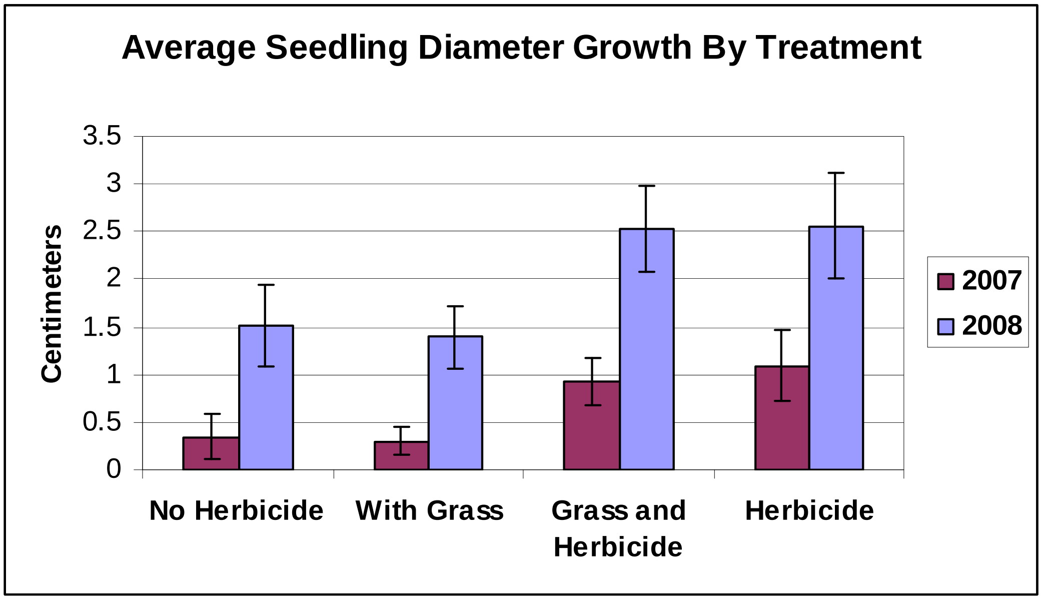

Figure 3.2. Average seedling diameter growth with standard deviations by treatment.

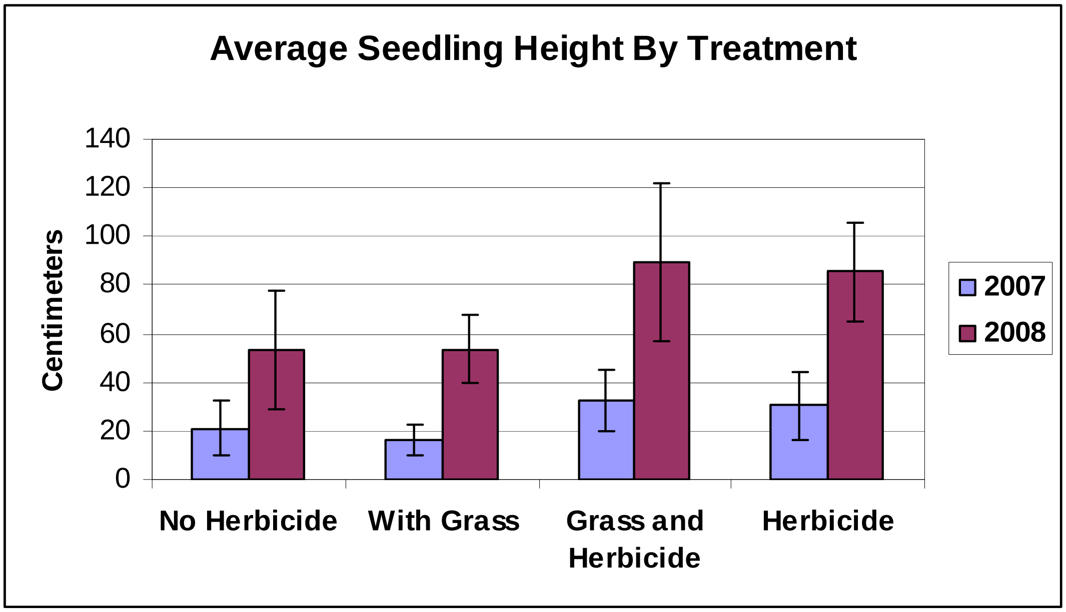

Figure 3.3. Average seedling height growth with standard deviations by treatment.

CHAPTER 4

SUMMARY AND CONCLUSION

Historically, at lower elevations, the southern Appalachians included mixed pine/hardwood woodlands that were maintained by fire. The reduction in prescribed burning and suppression of anthropogenic and natural fires have promoted the replacement of fire dependent, shade intolerant plant species to fire intolerant, shade tolerant species. This succession, along with the impact of repeated southern pine beetle attacks, high wildfire potential, and the absence of viable mixed pine/hardwood and grass seed in the seedbed, are all factors affecting the establishment of shortleaf pine (*Pinus echinata* Mill.)- bluestem grass (*Andropogon gerardii* Vitman and *Schizachyrium scoparium* (Michx.) Nash) communities within the southern Appalachians. Currently, shortleaf pine and bluestem grasses are scarce within the southern Appalachians. Because of the remaining few locations of these ecologically valuable communities, land management efforts are needed to restore these species to areas where they once occurred in the southern Appalachians.

Objective 1 was to determine the growth response of shortleaf pine seedlings and presence of bluestem grass in relation to fire management regimes (no burn, burn only, and partial felling with burning) within a field setting. More specifically, our objective was to relate seedling microclimate conditions of light penetration to the seedling, volumetric water content (soil moisture), plant competition, woody biomass, aspect, slope, elevation, maximum flame temperature, overstory mortality, and soil series to shortleaf seedling growth and bluestem presence. We hypothesized that the silvicultural treatment of partial felling with burning would promote the greatest seedling growth and bluestem response while greater values of soil moisture and light penetration would positively correlate to seedling survival and growth.

The silvicultural treatment of partial felling with burning followed by shortleaf pine seedling planting and bluestem grass broadcast seeding produced the greatest shortleaf pine growth rates and bluestem grass abundance. Prescribed burning removed herbaceous-layer cover along with overstory canopy cover. Removal of the canopy and herbaceous-layer during shortleaf seedling establishment allowed more light and nutrients to be readily available to the shortleaf pine seedlings. Greater maximum flame temperature during the prescribed burns and the subsequent overstory mortality influenced bluestem grass presence. Shortleaf pine does not compete for resources as well as other plant species, and greater soil moisture and northern aspects may indicate greater plant competition. Intense fires achieved by felling overstory and understory species benefit shortleaf pine-bluestem communities by increasing shortleaf pine growth rates and bluestem grass presence. Proper planting technique, site selection (southern aspects), and adequate precipitation are important components to restoration treatments for these communities. Drought conditions may limit restoration success. If available, forecasted weather conditions should be taken into account prior to treatment application.

Objective 2 was to identify the treatment that produced the greatest shortleaf pine growth rate and bluestem grass cover in relation to herbicide applications within a nursery setting. We hypothesized that planting shortleaf pine seedlings and applying herbicide would produce the greatest shortleaf pine growth rate, and broadcast seeding bluestem grass seed and applying herbicide would produce the greatest bluestem cover. Greater shortleaf seedling diameter and height growth rates occurred within the herbicide treatments. No significant differences of height or diameter growth rates occurred between the shortleaf seedling and bluestem grass herbicide treatment and the shortleaf seedling herbicide treatment, indicating that bluestem grasses did not inhibit shortleaf seedling diameter or height growth rates. Bluestem species responded differently to herbicide treatments. Big bluestem produced greater cover in the shortleaf seedling and bluestem grass herbicide treatment, and little bluestem produced greater cover in the bluestem seeding treatment. Residual herbicide, ant theft, or wind may explain less cover within the bluestem seeding herbicide treatment. Also, difference in cover by treatment may be attributed to the shading of big bluestem over little bluestem.

Herbicide applications may increase shortleaf pine growth rates while promoting the establishment of bluestem grasses (in this study, big bluestem). However, the use of glyphosate herbicides will result in the mortality of shortleaf pine and bluestem grasses along with the plant species that prevent the establishment of these communities. For restoration efforts, the use of broadleaf herbicides may potentially be used to remove plant competition within the southern Appalachians. We could not use these herbicides in our study because we did not have broadleaf weeds within the nursery. We observed common nursery weeds similar in growth and form to bluestem grasses. Broad application of herbicides that would remove the nursery weeds would have also removed the bluestem grasses. In the southern Appalachians, the nursery weeds within our study would be infrequent, and broadleaf herbicides may be more easily applied and effective in promoting bluestem grasses because of the presence of broadleaf species in the field.

Application of restoration treatments should account for forecasted drought conditions, if available. The failure of our soil scarification field study within the southern Appalachians demonstrates the importance of precipitation and related volumetric water content for seedling and bluestem grass establishment. We achieved adequate soil moisture with the use of irrigation within the nursery and applied the herbicide treatments within this setting.

Shortleaf pine-bluestem grass communities provide wildlife habitat for small mammals, threatened or endangered species, game species, and others. Restoration of these communities increases plant and animal diversity and native groundcover while inhibiting ecological succession. The results of this study indicate that prescribed burning, herbicide applications, bluestem grass seeding, and shortleaf pine planting can be used to increase restoration efforts of shortleaf pine-bluestem grass communities.

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APPENDIX A
NO BURN TREATMENT PLANT SPECIES, FREQUENCY, AND AVERAGE PERCENT COVER WITHIN SUBPLOTS.

No Burn Treatment 2006 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Mitchella repens	24	10
Pinus strobus	17	15
Acer rubrum	14	8
Vaccinium vacillans	11	8
Nyssa sylvatica	8	10
Sassafras albidum	8	10
Liriodendron tulipifera	6	7
Gaylussacia ursina	5	13
Smilax glauca	3	2
Cornus florida	2	30
Quercus alba	2	7
Oxydendrum arboreum	1	50
Arundinaria species	1	20
Smilax bona-nox	1	15
Smilax rotundifolia	1	10
Carya glabra	1	5
Quercus prinus	1	5
Fagus grandifolia	1	3
Quercus velutina	1	3
Ilex ambigua	1	2
Parthenocissus quinquefolia	1	2
Quercus coccinea	1	1
Rhus copallina	1	1
Panicum species	1	trace

No Burn Treatment 2007 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Mitchella repens	21	9
Pinus strobus	14	13
Acer rubrum	10	6
Vaccinium vacillans	7	11
Sassafras albidum	5	3
Gaylussacia ursina	4	4
Ilex ambigua	4	2
Diospyros virginiana	3	16
Smilax glauca	3	2
Quercus coccinea	3	1
Quercus alba	2	7
Liriodendron tulipifera	2	5
Cornus florida	1	15
Smilax rotundifolia	1	5
Fagus grandifolia	1	3
Iris species	1	3
Nyssa sylvatica	1	2
Parthenocissus quinquefolia	1	2
Quercus velutina	1	2
Hexastylis arifolia	1	1
Toxicodendron radicans	1	1

APPENDIX B

BURN TREATMENT PLANT SPECIES, FREQUENCY, AND AVERAGE PERCENT COVER WITHIN SUBPLOTS.

Burn Treatment 2006 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Vaccinium vacillans	20	8
Sassafras albidum	18	13
Smilax glauca	16	2
Nyssa sylvatica	8	9
Quercus coccinea	8	8
Smilax rotundifolia	8	7
Carex species	5	6
Quercus velutina	5	5
Smilax bona-nox	5	3
Panicum species	4	2
Solidago odora	3	14
Vaccinium corymbosum	3	9
Vaccinium stamineum	3	5
Robinia pseudocacia	3	4
Pinus species	3	Trace
Vitis rotundifolia	2	23
Calycanthus floridus	2	18
Acer rubrum	2	8
Quercus prinus	2	3
Lysimachia quadrifolia	2	2
Bluestem species	2	1
Helianthus species	1	1
Erechtites hieraciifolia	1	Trace
Iris species	1	Trace

Burn Treatment 2007 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Sassafras albidum	17	12
Smilax glauca	15	3
Vaccinium vacillans	14	16
Smilax rotundifolia	10	14
Quercus coccinea	10	14
Nyssa sylvatica	6	13
Carex species	4	5
Smilax bona-nox	4	1
Solidago odora	3	15
Quercus prinus	3	7
Pinus species	3	trace
Vitis rotundifolia	2	35
Calycanthus floridus	2	25
Vaccinium stamineum	2	13
Robinia pseudocacia	2	8
Vaccinium corymbosum	2	8
Prunus serotina	2	4
Quercus velutina	2	4
Gaylussacia ursina	1	40
Acer rubrum	1	30
Rubus species	1	5
Iris species	1	1
Rhus copallina	1	1
Poa species	1	trace
Vaccinium species	1	trace

APPENDIX C

FELL WITH BURN TREATMENT PLANT SPECIES, FREQUENCY, AND AVERAGE PERCENT COVER WITHIN SUBPLOTS.

Fell With Burn Treatment 2006 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Sassafras albidum	21	19
Vaccinium vacillans	15	19
Nyssa sylvatica	12	17
Bluestem species	12	2
Panicum species	7	2
Gaylussacia ursina	6	13
Gaylussacia baccata	5	24
Phytolacca americana	5	22
Smilax glauca	4	3
Iris species	4	1
Erechtites hieraciifolia	3	27
Smilax rotundifolia	2	23
Pinus species	2	1
Viola species	2	trace
Acer rubrum	1	10
Smilax bona-nox	1	10
Pteridium aquilinum	1	5
Vaccinium corymbosum	1	4
Quercus coccinea	1	3
Rhus copallina	1	3
Diospyros virginiana	1	2
Vitis rotundifolia	1	trace

Fell With Burn Treatment 2007 Plant Species	**Frequency (# subplots)**	**Average Cover (%)**
Sassafras albidum	14	19
Nyssa sylvatica	11	20
Vaccinium vacillans	11	19
Bluestem species	9	8
Vaccinium corymbosum	6	18
Panicum species	6	8
Erechtites hieraciifolia	6	2
Phytolacca americana	5	6
Gaylussacia baccata	4	18
Smilax rotundifolia	3	17
Smilax glauca	3	2
Gaylussacia ursina	2	16
Vaccinium corymbosum	2	14
Pteridium aquilinum	2	5
Rhus copallina	2	3
Pinus species	2	2
Rubus species	1	10
Acer rubrum	1	5
Diospyros virginiana	1	5
Ilex ambigua	1	5
Bignonia capreolata	1	1
Hexastylis arifolia	1	trace
Hypericum species	1	trace

APPENDIX D
NO BURN TREATMENT SPECIES, DENSITY, AND AVERAGE BIOMASS OF WOODY PLANTS WITHIN SUBPLOTS.

No Burn Treatment 2006 Plant Species	Density (stems m^{-2})	Average Biomass (g m^{-2})
Pinus strobus	36	1.94
Vaccinium vacillans	29	2.10
Acer rubrum	20	27.58
Gaylussacia ursina	19	0.09
Nyssa sylvatica	15	16.46
Sassafras albidum	13	23.35
Gaylussacia baccata	5	0.08
Quercus alba	4	7.14
Cornus florida	3	19.51
Fagus grandifolia	3	0.15
Oxydendrum arboreum	1	505.08
Liriodendron tulipifera	1	20.04
Carya glabra	1	3.34
Quercus velutina	1	1.92
Vaccinium stamineum	1	1.87
Prunus serotina	1	0.24

No Burn Treatment 2007 Plant Species	Density (stems m^{-2})	Average Biomass (g m^{-2})
Vaccinium vacillans	38	2.22
Pinus strobus	25	2.70
Acer rubrum	19	8.33
Gaylussacia ursina	19	0.06
Sassafras albidum	8	6.01
Ilex ambigua	6	7.37
Cornus florida	6	6.67
Diospyros virginiana	4	78.53
Quercus alba	4	16.11
Quercus coccinea	3	9.80
Liriodendron tulipifera	3	7.79
Quercus velutina	1	1.38
Fagus grandifolia	1	0.11

APPENDIX E
BURN TREATMENT SPECIES, DENSITY, AND AVERAGE BIOMASS OF WOODY PLANTS WITHIN SUBPLOTS.

Burn Treatment 2006 Plant Species	**Density (stems m^{-2})**	**Average Biomass (g m^{-2})**
Sassafras albidum	34	24.43
Vaccinium vacillans	20	1.95
Nyssa sylvatica	15	9.82
Quercus coccinea	11	12.64
Calycanthus floridus	11	0.04
Vaccinium stamineum	5	1.83
Quercus velutina	4	34.52
Robinia pseudoacacia	3	2.93
Vaccinium corymbosum	3	0.15
Prunus serotina	3	0.03
Acer rubrum	1	48.69
Quercus prinus	1	1.45

Burn Treatment 2007 Plant Species	**Density (stems m^{-2})**	**Average Biomass (g m^{-2})**
Vaccinium vacillans	99	1.97
Sassafras albidum	56	21.22
Gaylussacia ursina	34	0.06
Quercus coccinea	31	12.58
Calycanthus floridus	15	0.08
Nyssa sylvatica	11	12.99
Vaccinium stamineum	10	1.91
Quercus prinus	8	7.00
Vaccinium corymbosum	6	0.17
Robinia pseudoacacia	4	2.64
Acer rubrum	3	44.61
Quercus velutina	3	10.87
Prunus serotina	3	0.10
Ilex ambigua	1	3.73

APPENDIX F
FELL WITH BURN TREATMENT SPECIES, DENSITY, AND AVERAGE BIOMASS OF WOODY PLANTS WITHIN SUBPLOTS.

Fell With Burn Treatment 2006 Plant Species	**Density (stems m^{-2})**	**Average Biomass (g m^{-2})**
Vaccinium vacillans	125	1.99
Sassafras albidum	64	27.67
Gaylussacia baccata	62	0.04
Gaylussacia ursina	39	0.10
Nyssa sylvatica	24	20.03
Acer rubrum	5	4.98
Quercus prinus	4	16.73
Ilex ambigua	3	9.68
Diospyros virginiana	3	7.49

Fell With Burn Treatment 2007 Plant Species	**Density (stems m^{-2})**	**Average Biomass (g m^{-2})**
Vaccinium vacillans	89	2.05
Sassafras albidum	39	109.70
Nyssa sylvatica	36	29.07
Gaylussacia baccata	24	0.05
Gaylussacia ursina	24	0.04
Vaccinium arboreum	20	0.24
Vaccinium corymbosum	4	0.45
Acer rubrum	3	12.16
Ilex ambigua	3	4.70
Diospyros virginiana	1	2.05
Quercus velutina	1	109.70
Rhus copallina	1	29.07

APPENDIX G

NONMETRIC MULTIDIMENSIONAL SCALING OF PLANT SPECIES WITH R VALUES. 3 AXES COORDINATES FOR 2006 AND 2007. R ≥ |0.20| IN BOLD.

Species	**2006**			**2007**		
	Axis 1	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Acer rubrum	-0.164	**-0.274**	-0.062	0.091	0.125	**0.268**
Arundinaria species	0.018	-0.085	-0.138	---	---	---
Bignonia capreolata	---	---	---	-0.161	0.067	-0.072
Bluestem species	0.154	0.151	-0.087	**-0.237**	-0.095	-0.105
Calycanthus floridus	-0.028	0.152	0.100	0.014	0.081	-0.147
Carex species	-0.045	0.074	**0.260**	0.142	-0.191	-0.183
Carya glabra	-0.110	-0.159	-0.095	---	---	---
Cornus florida	-0.074	**-0.239**	0.018	0.103	0.112	**0.205**
Diospyros virginiana	0.122	0.061	-0.027	0.152	0.095	0.199
Erechtites hieraciifolia	0.154	0.107	-0.179	**-0.322**	-0.047	0.108
Fagus grandifolia	-0.006	-0.032	-0.144	0.031	0.132	0.052
Gaylussacia baccata	-0.080	0.077	**-0.245**	-0.174	-0.058	-0.132
Gaylussacia ursina	-0.141	-0.046	-0.157	**0.215**	-0.054	0.009
Hexastylis arifolia	---	---	---	0.128	0.042	0.039
Helianthus species	0.100	0.086	**0.200**	---	---	---
Hypericum species	---	---	---	-0.001	**-0.209**	0.027
Ilex ambigua	-0.024	-0.042	-0.103	0.080	0.191	0.106
Iris species	**0.246**	0.087	-0.053	0.016	0.093	0.034
Liriodendron tulipifera	0.028	-0.095	-0.164	0.027	0.031	**0.227**
Lysimachia quadrifolia	0.073	0.022	**0.224**	---	---	---
Mitchella repens	-0.086	-0.477	-0.173	**0.255**	**0.342**	**0.352**
Nyssa sylvatica	**-0.294**	-0.056	-0.27	**-0.326**	**-0.332**	**0.364**
Oxydendrum arboreum	0.174	-0.067	0.169	-0.161	0.067	-0.072
Panicum species	**0.265**	**0.202**	0.126	-0.082	**-0.281**	0.079
Parthenocissus quinquefolia	0.027	-0.021	-0.166	0.026	0.031	**0.226**
Phytolacca americana	**0.255**	0.088	-0.091	-0.209	-0.120	**0.207**
Pinus species	-0.196	0.085	0.175	-0.087	0.094	-0.090
Pinus strobus	0.104	-0.475	-0.061	**0.336**	0.165	**0.288**
Poa species	---	---	---	0.088	-0.150	-0.067
Prunus serotina	-0.180	0.018	**0.221**	0.092	0.011	**-0.225**
Pteridium aquilinum	-0.148	0.026	0.018	**-0.204**	0.141	0.004
Quercus alaba	-0.081	**-0.263**	-0.063	0.089	0.192	**0.255**

	2006			**2007**		
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Quercis prinus	0.059	-0.117	0.137	0.024	-0.026	-0.113
Quercus velutina	0.093	0.061	0.151	**0.201**	-0.159	-0.082
Rhus copallina	**0.208**	-0.009	0.097	0.035	**-0.248**	-0.030
Robinia pseudocacia	-0.125	0.049	**0.361**	-0.036	0.100	**-0.211**
Rubus species	---	---	---	-0.142	-0.015	0.082
Sassafras albidum	**0.212**	**0.345**	**-0.530**	**-0.471**	-0.098	**-0.309**
Smilax bona-nox	-0.016	-0.009	0.153	-0.037	0.107	-0.192
Smilax glauca	-0.330	**0.281**	**0.258**	**0.211**	-0.038	**-0.485**
Smilax rotundifolia	0.159	**0.239**	-0.070	-0.186	0.092	-0.171
Solidago odora	-0.069	-0.080	**0.317**	-0.139	**0.203**	0.002
Toxicodendron radicans	---	---	---	0.026	0.031	**0.226**
Vaccinium arboreum	---	---	---	-0.197	-0.102	0.071
Vaccinium corymbosum	-0.122	**0.213**	0.075	-0.094	-0.040	-0.001
Vaccinium stamineum	-0.170	0.007	**0.209**	0.129	0.184	**-0.215**
Vaccinium vacillans	0.644	-0.006	0.103	0.002	**-0.624**	0.000
Viola species	0.022	0.085	-0.157	---	---	---
Vitis rotundifolia	-0.041	-0.020	**0.263**	0.129	-0.07	-0.127