UNDERSTORY RESTORATION IN LONGLEAF PINE PLANTATIONS: OVERSTORY EFFECTS OF COMPETITION AND NEEDLEFALL

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Abstract—Overstory and midstory vegetation layers strongly limit abundance and species richness of understory herbaceous plants in longleaf pine (Pinus palustris Mill.) plantations. However, the separate effects of overstory competition and needlefall remain unknown and are the subject of this study. Four levels of overstory thinning were applied to 0.10-hectare plots in each of three 13- to 15-year-old plantations at the Savannah River Site, resulting in 0, 25, 50 and 100 percent pine stockings. Four split plots were established within each main plot: trenching (presence or absence) to eliminate pine root competition and needlefall (presence or absence). Containerized seedlings of selected herbs were grown in a greenhouse, planted within each treatment, and their abundance and size were monitored during 1999-2000. Soil surface temperature and availabilities of light, soil water, and soil and foliar nutrients also were measured periodically. Light availability and temperature each decreased with pine stocking, while in specific months, availabilities of soil water and nitrogen were greater in the presence versus absence of trenching. Reductions of seedling performance with increasing pine stocking were less in the presence versus absence of trenching. Certain species demonstrated shade tolerance, while others had optimal growth at 0 percent pine stocking. For several species, cover increased (1999) and then decreased (2000) in response to accumulation of needlefall. Results indicate that plant responses to light availability were strongly regulated by soil water availability and needlefall.

INTRODUCTION

Longleaf pine once dominated one of the most extensive forest ecosystems in North America, but today only 3 percent of its original distribution remains (Landers and others 1995). The primary factors thought to be responsible for the near disappearance of these forests are regenerative failure of longleaf pine, fondness of feral livestock for the seedlings, and fire suppression during the 20th century (Frost 1993).

Natural longleaf pine forests are distinguished by their diverse herb dominated understory communities and associated animal communities (Glitzenstein and others 1993). Fire suppression since 1920 has resulted in the replacement of longleaf pine savannahs with dense, stratified stands of overstory pines, midstory hardwoods, and understory shrubs. In many cases, loblolly pine (*Pinus taeda* L.) has become dominate because its shade tolerance and seed production are superior to those of longleaf pine (Baker and Langdon 1990). In these replacement stands, midstory hardwoods often consist of the turkey oak (*Quercus laevis* Walt.), bluejack oak (*Quercus incana* Bartr.), and blackjack oak (*Quercus marilandica* Muenchh.). Understory vegetation can be large and abundant with species such as sumac (*Rhus spp*.), sparkleberry (*Vaccinium spp*.), and waxmyrtle (*Myrica cerifera* L.). In addition, vine species such as Japanese honeysuckle (*Lonicera japonica* Thunb.), yellow jessamine (*Gelsemium sempervirens* St.Hil.), and greenbriers (*Smilax spp.*) invade the site. These conditions reduce light availability in the understory, and thereby limit diversity of associated plant and animal species (Harrington and Edwards 1999, Johannsen 1998).

To restore longleaf pine communities it is often necessary to plant longleaf pine and to reintroduce understory herbs. However, in order for community restoration to be successful, key factors that limit establishment and maintenance of reintroduced understory herbs must be identified. In fall 1998, research was initiated at the Savannah River Site in plantations of longleaf pine to separate and quantify overstory effects for light, water, and needlefall on a variety of native perennial herbaceous species. Results of this research will be used to aid efforts to restore native longleaf pine communities and to improve our understanding of overstory and understory interactions.

METHODS

The study was initiated within three 13- to 15-year-old longleaf pine plantations at the Savannah River Site, a National Environmental Research Park near Aiken, SC. Soils for the three sites (blocks) consist of Lakeland, Troup, and Blanton sands. In October 1998, basal area of overstory pines was thinned to four stocking levels (0, 25, 50, and 100 percent of the average basal area of unthinned stands) in single 0.1-hectare plots at each site. To remove potential confounding influences from non-pine species, this vegetation was eliminated from the plots by periodic applications of non-soil active herbicides, glyphosate and triclopyr. Within

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each stocking level, four 1.2-meter x 13.7-meter split plots were installed to provide a 2 x 2 factorial arrangement of the presence or absence of trenching or needlefall. In the trenched treatments, a Ditch Witch® was used to excavate linear trenches around each split plot to a depth of approximately 0.5 meters. To prevent future encroachment of pine roots each trench was lined with aluminum flashing and then refilled. In the needlefall treatment, controlled levels of needlefall (presence or absence) were applied monthly at a rate equal to twice that of a fully-stocked stand, where monthly needlefall rates were based on existing data from Harrington and Edwards (1999). Each split plot was divided into eleven quadrats of area one square meter within which a single species was planted. One quadrat remained unplanted throughout the duration of the study and was used to measure soil water content. Each quadrat was kept free of all competing vegetation with monthly hand weeding.

A group of native, perennial, herbaceous species that varied in size and growth form was selected for this study (table 1). Seeds of each species were collected at or near the study sites, germinated via cold stratification and their seedlings were grown for four months within containers. In May 1999 and 2000, populations of 36 seedlings per species were planted within the quadrats with a container dibble. Containerized seedlings of longleaf pine also were planted. A total of thirteen species were planted in each of the split plots (eight in 1999 and five in 2000). To provide room for the three additional species of the 2000 cohort, three species from the 1999 cohort were removed in April 2000.

In combination, the thinning and trenching treatments enabled experimental separation of interference from the overstory pines into above- and below-ground components. Likewise, the needlefall treatment was applied independent of pine stocking level, and thus its effects can be quantified separately. Measurements of environmental conditions (crown closure via vertical densitometer, soil water content via time domain reflectometry, available soil nitrogen via KCL extractions, and foliar nitrogen, potassium, and phosphorus content) and soil surface temperature were taken periodically during each growing season. Performance of planted species (survival, cover, height, and biomass) also was monitored during each growing season.

RESULTS

Environmental Conditions

The long-term average growing season (May-October) precipitation for Aiken SC is 66 centimeters (weather.com). Precipitation for the 1999 and 2000 growing season was 56 and 48 centimeters, respectively (Savannah River Forest Station 2000). Although both years were drier than normal, precipitation was sufficient in 1999 at the time of planting. In contrast, rainfall for May 2000 was less than 1.3 centimeters, which negatively impacted survival of seedlings planted in that year. Soil surface temperature declined linearly with pine stocking and the difference between 0 and 100 percent stockings averaged 3.2 degrees Centigrade.

In the two growing seasons since thinning of pines, basal area has increased by 15, 28, and 32 percent in the 100, 50, and 25 percent stocking levels, respectively. In contrast, crown closure has increased at a much slower rate, particularly in the 25 and 50 percent stocking levels where little change occurred from 1999 to 2000. The thinning and trenching treatments had no visually detectable influence on pine vigor except for mortality of two trees that died from unknown causes.

In the absence of trenching, soil water declined consistently as pine stocking increased from 50 to 100 percent. However, in the presence of trenching, soil water availability was influenced very little by pine stocking. These responses indicate that the trenching treatment was successful in partitioning competition from pine into above- and below-ground components. During several periods in the 1999 and 2000 growing seasons, soil water in non-trenched split plots dropped below 6 percent, the assumed permanent wilting point for these soils.

In three of the five months of monitoring, available nitrogen differed significantly among treatments. In June, available nitrogen was greater in the presence versus absence trenching. Available nitrogen in August was less in the presence versus absence of needlefall, while the opposite trend occurred in September.

Plant Responses

Survival of the 1999 cohort was high, averaging greater than 80 percent for the eight species. In contrast, survival of the 2000 cohort was low probably because of the severe spring drought, averaging less than 10 percent for the five species. However, first-year survival of each cohort was greater in the presence versus absence of trenching. During the second growing season, survival of the 1999 cohort was greater in the presence of trenching and absence of needlefall.

The species of the 1999 cohort varied in their patterns of response to the pine stocking, trenching, and needlefall treatments; however, the highest performance was observed when pine stocking was 0 percent. In addition, most species had superior performance in the presence versus absence of trenching. Cover, height, and biomass responses of the 2000 cohort plant could not be analyzed because of poor survival.

Anthaenantia villosa, *Pinus palustris*, *Liatris elegans*, and *Sorghastrum secundum* demonstrated an interactive response pattern. They exhibited excellent performance even under 100 percent stocking of longleaf pine, as long as availability of below-ground resources did not severely limit their growth (i.e., in trenched split plots). However, if below-ground resources were in growth-limiting supplies (i.e., in non-trenched split plots), performance declined considerably as pine stocking increased and associated availability of light decreased. These species also exhibited superior performance in the presence versus absence of needlefall, except at full stocking in non-trenched split plots where needlefall negatively affected species' performance.

Solidago odora, *Pityopsis graminifolia*, and *Lespedeza hirta* demonstrated an additive response pattern to the

Table 1—Species planted in the longleaf pine study at the Savannah River Site

Scientific name	Characteristics
Anthaenantia villosa (Michx.) Beauvois[a]	Ascending perennial grass; short rhizomes
Lespedeza hirta (L.) Hornemann[a]	Erect perennial forb; nitrogen fixer
Liatris elegans (Walt.) Michx.[a,c]	Erect perennial forb; corms
Pinus palustris Mill.[a]	Tree
Pityopsis graminfolia (Michx.) Nutt.[a,c]	Erect perennial forb; rhizomes
Solidago odora Aiton[a,c]	Erect perennial forb; short rhizomes
Sorghastrum secundum (Ell.) Nash[a]	Ascending, tufted perennial grass; short rhizomes
Sporobolus junceus (Michx.) Kunth[a]	Erect to sprawling perennial grass
Andropogon ternarius (Michx.)[b]	Erect perennial grass; short rhizomes
Carphephorus bellidifolius (Michx.) T.& G.[b]	Ascending perennial forb
Chrysopsis gossypina (Michx.) Ell.[b]	Erect, decumbent, or ascending perennial forb
Desmodium ciliare (Muhl. Ex Willd.) DC.[b]	Erect perennial forb
Eragrostis spectabilis (Pursh) Steudel[b]	Erect perennial grass; short rhizomes

[a]May 1999 planting;
[b]May 2000 planting;
[c]Removed

treatments. Species' performance increased as pine stocking decreased and in the presence of trenching; however, the two factors did not interact.

Foliar nitrogen of *Sporobolus junceus* was greater in the presence versus absence of needlefall, indicating a "fertilizer" effect. Per-plant amounts of nitrogen, phosphorous, and potassium increased as pine stocking decreased, a direct result of increases in plant biomass.

CONCLUSIONS

This research has increased our understanding of the complexity by which overstory pines affect understory vegetation through resource competition and needlefall. Performance of most species was increased when availability of below-ground resources was elevated, regardless of pine stocking. In addition, effects of trenching and needlefall interacted with pine stocking level for certain species, indicating that limiting effects of shade can be either moderated or exacerbated by variation in below-ground resources or presence of needlefall. The two response patterns, interactive and additive, provide a means of classifying herbaceous species according to their potential performance in longleaf pine community restoration, given specific overstory, understory, and needlefall conditions of longleaf pine plantations.

Research results indicate that containerized reproduction can be a successful method for restoring herbaceous species if rainfall is adequate at the time of planting. Optimal performance of planted species is likely to occur in large canopy openings with minimal root competition from associated woody and herbaceous species.

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