RESEARCH ARTICLE

Understory Restoration in Longleaf Pine Sandhills

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ABSTRACT: Loss of over 98% of the original extent of longleaf pine (*Pinus palustris* Mill.) systems has resulted in the need for development of understory restoration techniques. In natural longleaf pine systems recruitment of understory dominant species like wiregrass (*Aristida stricta* Michx.) likely occurs following opening of the canopy by fire or other localized disturbances. We investigated site preparation and sowing methods for reestablishing dominant understory species in heavily disturbed xeric sandhills. Wiregrass establishment was significantly higher in burned and irrigated plots than in plots that were only burned or were burned and had soil disturbance. However, without irrigation, burned and disturbed sites showed greater establishment than did either treatment alone. Overall, species richness and cover showed the same patterns when irrigation was present, but were higher in disturbed soils without fire when not irrigated. We recommend sowing native seed mix with a hayblower onto areas with light soil disturbance if irrigation is not possible. Subsequent rolling of seed into soil will increase seedling establishment. Mechanical re-establishment of native groundcover in xeric longleaf pine systems is clearly possible.

Index terms: Aristida stricta direct seeding, groundcover, longleaf pine, restoration, sandhill, site preparation, sowing methods

INTRODUCTION

Historically, much of the upland vegetation throughout the Atlantic Coastal Plain and the xeric sand ridges in Florida was dominated by a longleaf pine (*Pinus palustris* Mill.) overstory with a highly diverse groundcover of grasses and forbs (Myers et al. 1990, Robbins and Myers 1992, Peet and Allard 1993, Outcalt et al. 1999). This xeric longleaf pine community, known as sandhill, was maintained by frequent, low-intensity fire (Christensen 1988, Myers et al. 1990). However, within the last fifty years, fire suppression has been predominant, with many areas managed for timber production or converted to other uses. As the understory community is sensitive to soil disturbance, much of this community component has been lost across the range of longleaf pine systems (Clewell 1989). The result is a loss of species richness and most of the fine fuel that once supported fire.

There is great interest in restoring areas of this once extensive system (Brockway and Outcalt 1998, Gordon and Rice 1998, Hattenbach et al. 1998, Mulligan et al. 2002). Groundcover, especially wiregrass (*Aristida stricta* Michx.) and other native grasses, influenced the fire regime and the plant communities by providing the fuel source for prescribed and natural fires (Outcalt and Lewis 1988, Clewell 1989, Myers et al. 1990). When growing undisturbed, wiregrass is dense and long-lived, but may have low productivity after a decade or two of fire suppression (Clewell 1989). With the return of fire, wiregrass may resume dominance following the removal of woody shrub cover that proliferated without fire (Clewell 1989).

Plant composition is influenced by the fires that spread through the groundcover. In sandhills subject to the historic fire regime of frequent (2-5 year interval), low intensity growing season fires, the groundcover is grass-dominated, with small shrubs and forbs (Christensen 1981). Grasses and forbs tend to disappear with less frequent or longer periods without fire (Glitzenstein et al. 2003), being replaced by woody vegetation, leading to succession to xeric hardwood, or mixed pine communities (Abrahamson 1984, Stout and Marion 1993).

Mechanical disturbance and prolonged fire suppression reduce the natural distribution of wiregrass, which is unlikely to recover when eliminated from the groundcover (Clewell 1989, Myers et al. 1990). Although mechanical chopping, disking and site preparation for commercial forestry or silviculture practices removes wiregrass and other native vegetation that compete with planted pine seedlings, total eradication is not always desirable (Outcalt and Lewis 1988, Clewell 1989). Prescribed fires are needed to control woody species in pine plantations so root competition is reduced during site preparation. Additionally, an understory of wiregrass maintains the soil structure and water holding capacity (Outcalt and Lewis 1988).

Numerous studies have been conducted

to identify methods that will restore sandhill systems (Provencher et al. 1997, Hattenbach et al. 1998, Seamon 1998, Provencher 1999, Brockway and Outcalt 2000, Provencher et al. 2001). Returning longleaf pine and wiregrass to degraded habitats is imperative to returning function to the system (Seamon 1998, Mulligan and Kirkman 2002). In sandhills where wiregrass remains in the habitat, successful restoration has been achieved by fire and combinations of fire and other methods (herbicide application, cutting) to more rapidly reduce hardwoods (Brockway and Lewis 1997, Provencher et al. 1997, Hardesty and Moranz 1998, Brockway and Outcalt 2000). Restoration with wiregrass and other native species has also been investigated on reclaimed mine lands and areas converted to pasture grasses (Bissett et al. 1998, Violi 1999, Gordon et al. 2001, Jenkins et al. 2003).

At The Nature Conservancy's Apalachicola Bluffs and Ravines Preserve (ABRP) (Figure 1), an effort has been underway since the mid-1980s to restore the components and function of a sandhill that was highly disturbed during silvicultural management prior to the Conservancy's ownership. To restore this area, and because fire suppression in the uplands is hypothesized to result in degradation of the ravine community (Schwartz and Hermann 1992), we initiated restoration of longleaf pine and wiregrass to the area and are experimenting with other species. Our goal is to develop techniques for restoration of the diverse understory in longleaf pine sandhills that will work over relatively large landscapes. Thus, we have been experimenting with mechanical seed collection, site preparation and sowing (Hattenbach et al. 1998).

In earlier work, we observed little establishment of herbaceous seedlings when seed was sown on undisturbed soil (Hattenbach et al. 1998). We have been successful in establishing wiregrass, creeping bluestem (*Schizachyrium stoloniferum* [Nash] Hitchc.) and other species by direct seeding onto disturbed soil, particularly if we rolled over the seed to increase contact with the soil (Gordon et al. 2001). However, disturbing the soil is not always desirable. If prescribed burning the site similarly prepared the seedbed, the management costs and potential negative impacts to the site would be lower. As a result, we wanted to compare establishment of species in sites that were burned versus lightly roller chopped. We also observed natural establishment of wiregrass seedlings only in years with unusually wet springs. This led us to hypothesize that: 1) native herb seed will have higher establishment in sites where the soil is disturbed relative to those that are burned; and 2) native herb species are more likely to establish under wet spring conditions. Further, we were interested in whether sowing native seed using different types of equipment would result in differences in seed establishment in burned and chopped sites.

METHODS

Site: Apalachicola Bluffs and Ravines Preserve

The upland portion of ABRP was originally a sandhill community dominated by a longleaf pine canopy and a rich assemblage of grasses and forbs. The soil underlying the sandhill community is a mixture of sands typified by well-drained Quartzipsamments and Paleudults typified by a combination of Lakeland and patchy Troup soils. Water percolates rapidly through the Lakeland deep sands, which has little surface organic material (Means and Grow 1985, Schmidt 1986). The average annual rainfall at the preserve between 1994 and 2002 was 132.6 cm. The highest rainfall occurs in the summer, June through September, and the least rainfall occurs October through November (Leitman et al. 1984).

In the mid-1950s, the uplands at the site were logged and cleared for a slash pine (*Pinus elliottii* Engelm.) plantation and the remaining vegetation along with the topsoil was piled into parallel windrows. The wiregrass that had dominated the understory was largely lost from these windrowed areas. Pines were planted in the cleared inter-windrow areas. Upon The Nature Conservancy's acquisition of the property in the 1980s, the slash pines were harvested and longleaf pine seedlings planted. Groundcover restoration, initiated in the late 1980s, included planting wiregrass and other native seed collected from areas with no windrows (Seamon 1990).

The degraded sandhill serves as an ideal location for studying the effects of re-introducing native species using several site treatments and various sowing methods. The experimental area consisted of oligotrophic sandy soil, sparse groundcover with no wiregrass, high percent cover of litter

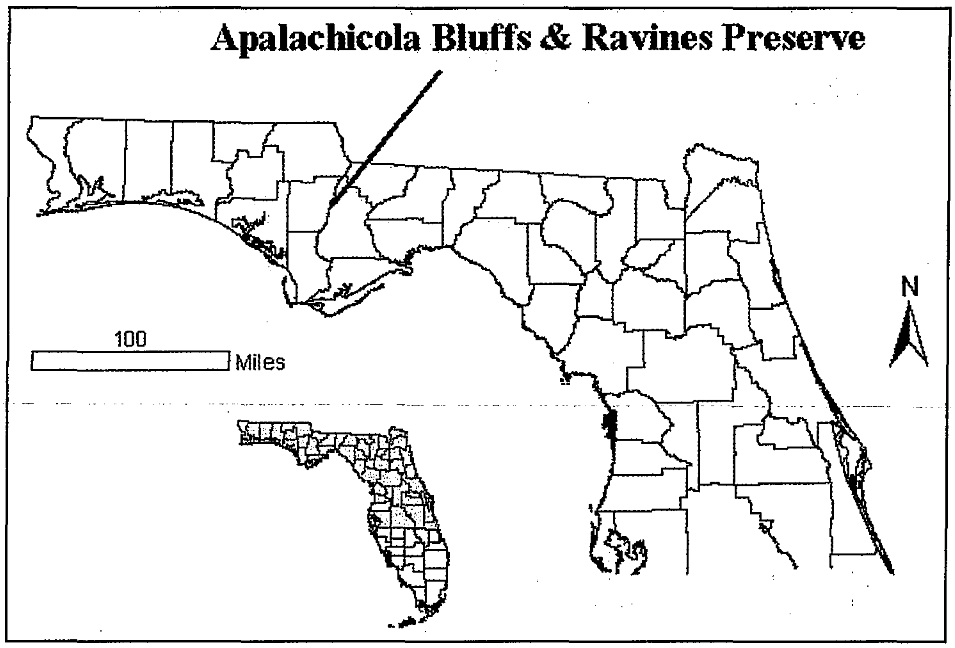

Figure 1. Apalachicola Bluffs and Ravines Preserve in Liberty County, Florida.

and intact windrows. In September 1998, the research plots were located in 30 acres of this degraded sandhill (Figure 2).

Experimental Design

Two experiments were established in 1998 at ABRP to examine the effect of site preparation (Experiment I) and sowing method (Experiment II) on revegetation success. Both experiments shared several of the same site preparation, seed collection, and treatment plots. In Experiment I, we combined site preparation and irrigation in a randomized split plot design, with fire as the main split, and irrigation as the sub-split treatment in the burned area. In Experiment II, we again used the split plot design and two (fire and chop) treatments established for Experiment I. Both experiments also shared control plots.

Six blocks, with ten 15 x 15 m (49 x 49 ft) treatment plots each, were located along the length of 46 m wide areas between intact windrows (Figure 2). A minimum of 10 m separated each plot. As insufficient space was available for all the chopped plots in blocks 5 and 6, these plots were located in a block to the east of the burned blocks. Experiment I utilized four of those plots per block: one each of the site preparation treatments of fire alone, fire and irrigation, fire and roller-chop, and roller-chop alone. All plots in Experiment I were sown using a hayblower, sowing seed from the perimeter of the plots. Experiment II compared the effectiveness of sowing the sandhill seed mix using four different types of machinery: cultipacker, modified fertilizer spreader, hayblower and hydroseeder into either burned or lightly chopped (empty drum roller-chopper) sites. The hayblown plots for both of those site preparation treatments were shared by both experiments. For all treatments, sowing was followed by rolling with a soil aerator for enhanced establishment of sandhill seed as determined by previous research (Hattenbach et al. 1998). The seeds were sown in January and February 1999.

Two types of control plots (15 x 15 m and 10 m or further from the closest experimental plot) were established for each block in the burned and chopped site preparations, but were not subsequently sown (Figure 2). These allowed us to evaluate the contribution of the sown seed to the cover and composition of the unsown plots. We established these control plots in June 1999 after noting differences in species emergence in the site prepared (burned and chopped) and unsown areas compared to surrounding undisturbed sites. Because of space limitations, only three (rather than all six) of the roller-chopped blocks included these additional unsown control plots. Comparisons of these controls need to be evaluated with caution since they were established in summer 1999 and were not randomly located within blocks. As a second control of both sowing and site preparation, we also established one plot per block in the degraded sandhill adjacent to the burn and chopped site preparation units. These provided a comparison of the naturally occurring vegetation with the vegetation in the treatment plots. As a result, we had both site-prepared but not sown controls (nosd), and neither site prepared nor sown controls (cntrl), for a total of 15 control plots.

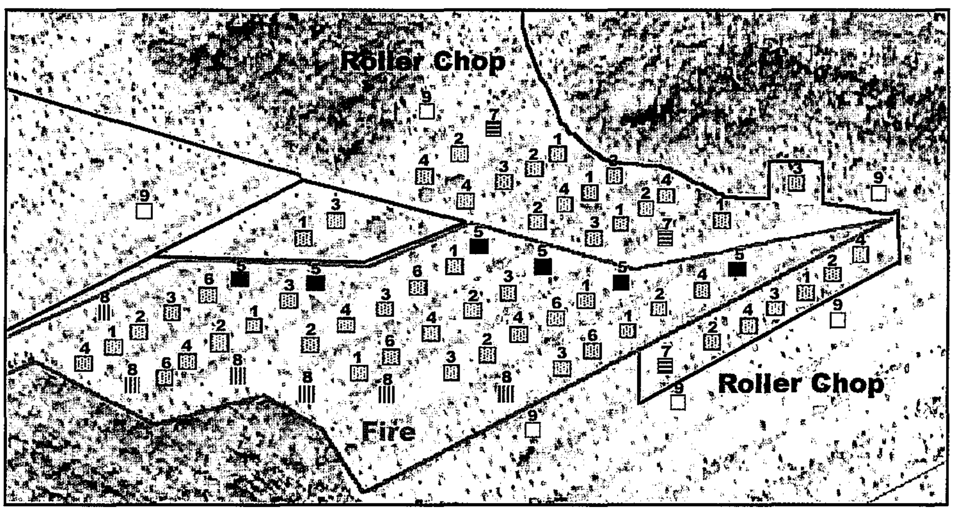

Figure 2. Treatment sites, blocks, and plots at Apalachicola Bluffs and Ravines Preserve. Plots with stipples = treatments, horizontal lines = unsown chopped, vertical lines = unsown burned, open plots = no site preparation, unsown controls. Treatments are as follows: 1 = cultipack (culp); 2 = fertilizer spreader (fesp); 3 = hayblower (habl); 4 = hydroseeder (hydr); 5 = fire, hayblower, irrigate; 6 = fire, hayblower chop; 7 = chop, unsown (cnosd), 8 = fire, unsown (fnosd), 9 = no site preparation, unsown. The last row on the right, designated as roller chop, contains plots 2 & 4 from block 5 and plots 1 through 4 of block 6 because of insufficient space on blocks 5 and 6.

Site Preparation

Site preparation included burning 8.1 ha of the site in December 1998 and roller chopping 4.05 ha in January 1999 (Figure 2). Fire was applied using a drip-torch mounted on an all-terrain vehicle driven along the length of each windrow. The low intensity fires crept through the dry winter groundcover between windrows over several hours. Fire removed most of the existing groundcover and top-killed some of the hardwoods, though most resprouted. In the chopped plots, a 6.4 m wide light-duty roller chopper with no water in the drum was pulled by a tractor. Because the roller chopper left grooves in the soil, which might result in deeply buried seeds, the chopped plots were rolled with a smooth roller perpendicular to the direction of chopping prior to sowing.

One plot in the burned area in each of the blocks was irrigated from Feb. 1 – June 1, 1999. The plots were watered daily before dawn unless there was natural rainfall. Irrigation amount corresponded to mean average daily rainfall by month for the 10% of months with the highest precipitation recorded from 1968-1997 (National Climatic Data Center). We intended to cease irrigation when the natural rainy season started, but watered through May because rainfall in 1999 was significantly below average. Applied water ranged from 1.13 cm/day in January to 0.38 cm/day in May.

Seed Collection

We collected native sandhill seed in November and December 1998 from several sandhill sites at ABRP with relatively dense stands of wiregrass that had been burned the previous summer. These sites had not been windrowed or planted with off-site pines and were relatively undisturbed by silvicultural practices in the 1950s. Seed was collected both manually and mechanically. Abundant wiregrass seed was hand collected by cutting stalks at the base, then cut into 5 to 8 cm pieces and stored in paper bags. Mechanical collectors included a Woodward Flail-Vac seed stripper (Ag-Renewal, Weatherford, Oklahoma) mounted onto the front of an all-terrain vehicle (ATV) and driven through stands of wiregrass and other plants with mature seed. A rotating brush in the collector pulled the seed from the stalks into a hopper, resulting in a heterogeneous mixture of wiregrass seed, seed stalks, dead oak leaves, small twigs, and seed from other species that also mature in late fall. A Portable Seed Stripper (Prairie Habitats, Argyle, Manitoba, Canada) was also used to collect a mixture of wiregrass seed with some stalks and chaff. Collected material was then stored in paper bags in a temperature and humidity controlled environment.

Direct Seeding

Stored seeds were mixed together (109 kg total) and 60 bags were filled with 2 kg of seed and chaff each. This amounted to approximately 18 kg of material per hectare for seeded plots. Percent of wiregrass seeds was calculated at 24.7 kg per ha based on the average weight of seeds from ten random samples. Seed viability was tested to determine the percent of seeds capable of germinating. The germination rate was 10% for the wiregrass seed used in this study. This rate is within the range (8 to 44%) observed for this species (Hattenbach et al. 1998). The native sandhill seed mix was applied to the plots using the sowing equipment described above.

Data Collection

Species richness across each 225 m^2 plot was censused in July and September 1999 and 2000, and in April 2000. Percent cover of native vegetation, non-native vegetation, bare soil, and litter were ocularly estimated in 9 randomly located 1.0 x 0.5 m quadrats in each plot using Daubenmire cover classes (Bonham 1989). Density of wiregrass was also determined in each quadrat.

Data Analysis

Although monitoring was conducted simultaneously for Experiments I and II, data analyses differed. Experiment I comparisons were made across three site preparation treatment combinations: (1) fire vs. fire and irrigate vs. unsown burned control; and (2) fire and irrigate vs. fire and chop vs. unsown fire; and (3) chop vs. fire vs. fire and chop vs. unsown burned and unsown chopped controls. Differences among treatments in species richness, wiregrass density, and percent cover were analyzed. For Experiment I, Chi-square contingency table analyses were performed for each year to compare treatment effects; treatments could not be compared within an analysis of other treatments because blocks were constrained within the split plot design. ANOVA was then performed on data with treatment removed to examine the effects of year, block and seed sowing. The effects of year were tested using the block within year error term. Richness data were square-root transformed and percent cover and density data were log-transformed to increase consistency with the test assumptions.

For Experiment II, comparisons of burn vs. chop site preparation treatments were again evaluated regardless of sowing method using Chi-square contingency tables for 1999 and 2000. Comparisons of all sowing treatments were then analyzed using ANOVA. We included analysis of interactive effects between the four mechanical sowing methods: cultipack (culp), fertilizer spreader (fesp), hayblower (habl) and hydroseeder (hydr) nested within the two site preparation treatments: roller chopping and prescribed fire. Unsown controls were included in the model. The effects of year were tested using the block within year error term. Data were transformed as described for Experiment I.

RESULTS

Species richness was similar over all treatments and controls (75 plots). We found 163 species, with only six species found in all the plots, consistent with the high species richness of this community. Negligible levels of two non-native species were found in some of the plots and were not included in the analysis. The average number of species ranged from 48.5 to 66.3 species per plot for all site preparation, sowing treatments and controls (Figures 3 and 4). When species richness and composition in the sown plots were compared with the unsown controls, wiregrass was the only species we could demonstrate that we introduced. However, there was a non-significant tendency for higher richness in irrigated plots (Figures 3A and B) than in non-irrigated plots as vegetation cover increased (Figure 3C) and in chopped than in burned plots – even when not sown (Figure 4). This was true across the sowing methods in both experiments.

Experiment I

Chi-square analysis revealed no differences ($p > 0.05$) in wiregrass density in the burned with or without irrigation and the unsown burned control in 1999. Wiregrass density responded significantly to irrigation in 2000 ($\chi^2 = 17.91$, $p < 0.05$; Figure 5A), but not to the burned only site preparation, supporting the original hypotheses that natural seedling establishment occurs in years with wet springs. Wiregrass density was similar in 1999 in the burned treatments that were also either irrigated or chopped (Figure 5B). Again, in 2000, wiregrass density was significantly higher in the irrigated plots ($\chi^2 = 11.29$, $p < 0.05$) with the lowest densities in the unsown burned plots. No differences in wiregrass density were evident in the comparisons of chop versus fire versus fire and chop and the unsown burned control (Figure 5C). We saw no wiregrass in the unsown chopped control (Figure 5C).

For both years, vegetation cover was significantly higher ($\chi^2 = 15.08$ and 6.67, $p < 0.05$) in the irrigated plots than in the

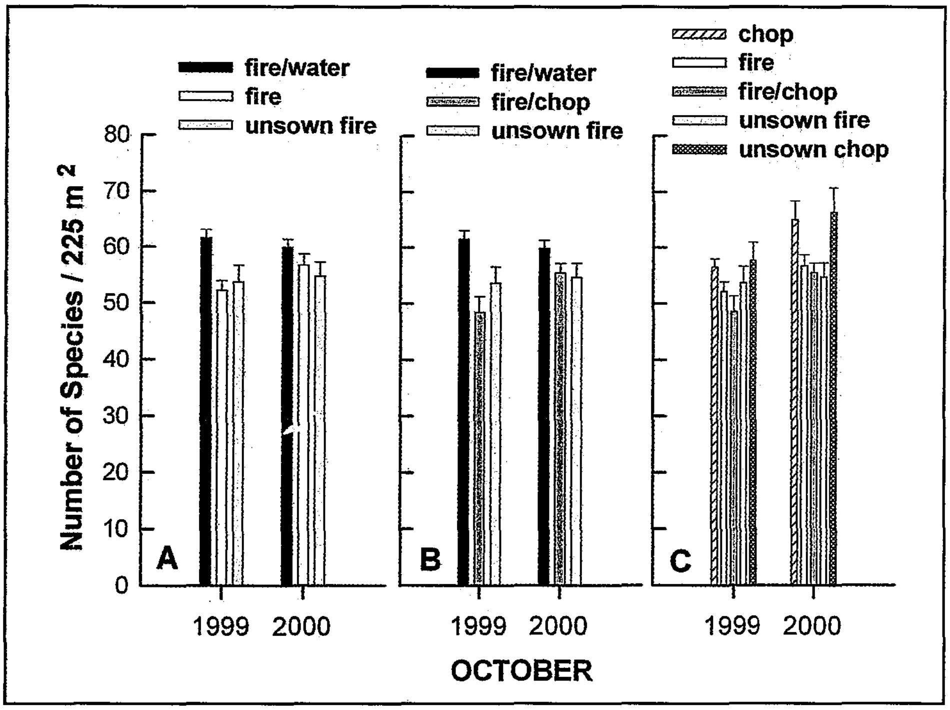

Figure 3. Mean (± 1 SD) species richness in plots by site preparation treatment for Experiment I: (A) fire and irrigation vs. fire treatments; (B) fire and irrigation vs. fire and chopped treatments; and (C) fire vs. chopped vs. fire and chopped treatments in 1999 and 2000.

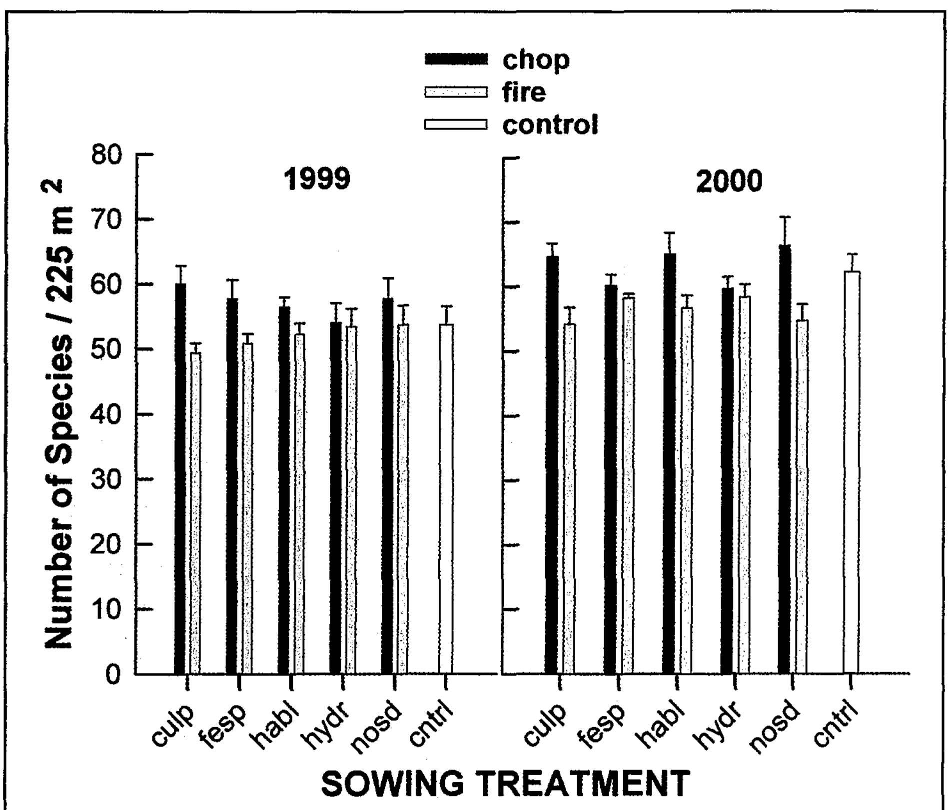

Figure 4. Mean (± 1 SD) species richness in Experiment II plots in October, 1999 and 2000 for the two site preparation treatments chop and fire, and four sowing treatments: cultipack (culp), fertilizer spreader (fesp), hayblower (habl), and hydroseeder (hydr). Un-sown plots (nosd) and control plots (cntrl) are included for comparative purposes; cntrl was not included in the analysis. Sample size was six for all except the chopped but unsown control (nosd), where n=3.

burned and unsown controls (Figure 6A). Vegetation cover was significantly higher (χ^2 = 15.96, $p < 0.05$) in the burned and irrigated plots in 1999 than in the burned and chopped or unsown plots, but was not significantly different in 2000 because of the vegetation cover increase in the other treatments (Figure 6B). In the comparisons of chop versus fire versus fire and chop and the unsown controls (with or without fire), no significant differences in vegetation cover were detected by the Chi-square analysis (Figure 6C).

Bare soil cover was significantly lower (χ^2 = 10.75 and 12.60, $p < 0.05$) in the burned and irrigated than in the burned and sown or unsown controls for both years (Figure 7A). The same pattern was seen when bare soil cover in the burned and irrigated treatment is compared with the burned and chopped treatment and unsown controls χ^2 = 32.74 and 13.77, $p < 0.05$ for 1999 and 2000, respectively) (Figure 7B). Although soil cover significantly differed among the chopped, burned, burned and chopped and the unsown treatments (with or without fire) in 1999 (χ^2 = 24.8, $p < 0.05$), in 2000 differences disappeared as vegetation cover increased.

Litter cover did not vary across the burned and irrigated, burned plots and the unsown controls in 1999 and 2000, although litter cover tended to increase in the burned and irrigated plots in 2000 (data not shown). Litter was significantly lower (χ^2 = 15.96, $p < 0.05$) in the burned and chopped than in the burned and irrigated and the unsown burned controls in 1999, but that difference had diminished by 2000. Litter was also significantly lower in any treatment that included chopping. Significant differences were also detected in 1999 (χ^2 = 19.49, $p < 0.05$), but not 2000, when the chop versus fire versus fire and chop and the unsown controls (with or without fire) were compared.

Examination of the effects of year, block, and seed availability across all treatments (ANOVA) revealed that sowing significantly affected wiregrass density and vegetation and bare soil cover in Experiment I plots except when soil cover in the chop, fire, fire and chop, and unsown controls was compared (Table 1). Although irrigation increased the wiregrass density response, significant differences were not noted between years (Table 1 A, B and C). As discussed above, vegetation and litter cover increased in 2000 from 1999 values while bare soil cover decreased. While response was variable to the main effects of sowing, year, and block, the three-way interaction generally significantly affected wiregrass density and cover of bare soil and litter (Table 1).

Experiment II

Species richness in all treatments increased from 1999 to 2000 (Table 2). Unexpectedly, equivalent species richness was found in the chopped, un-sown plots (66 species) as in sown plots, where overall mean richness was 57 species. As in Experiment I, all the species observed were natives of the north Florida sandhill community. The only species consistently added by the sowing treatments was wiregrass.

Wiregrass density was significantly higher for both years in both the chopped (1999: $\chi^2 = 37.5$ and 2000: $\chi^2 = 34.0$, $p < 0.05$) and burned ($\chi^2 = 15.69$ and 23.08, $p < 0.05$) plots when sown with the fertilizer spreader (Figure 8). Significant differences were not detected between the chop and burn site preparation treatments, however. Interactions of sowing method, block, and year significantly affected the wiregrass density (Table 2).

No sowing treatment differences were seen for either vegetation or bare soil cover (data not shown). Vegetation cover increased on average in 2000, with mean cover changing from lowest in 1999 in the cultipacker sown plots (25%) to highest in 2000 (58%), leading to significant interaction effects (Table 2). Block effects dominated significant differences in soil cover. Not surprisingly, bare soil tended to be highest in those treatments that caused the greatest disturbance: chopping and cultipacking. All sown plots had less bare ground (40%) than did the no treatment (neither site preparation nor sowing) controls in 2000.

Significant effects were detected in litter cover between chopped and fire site prepa-

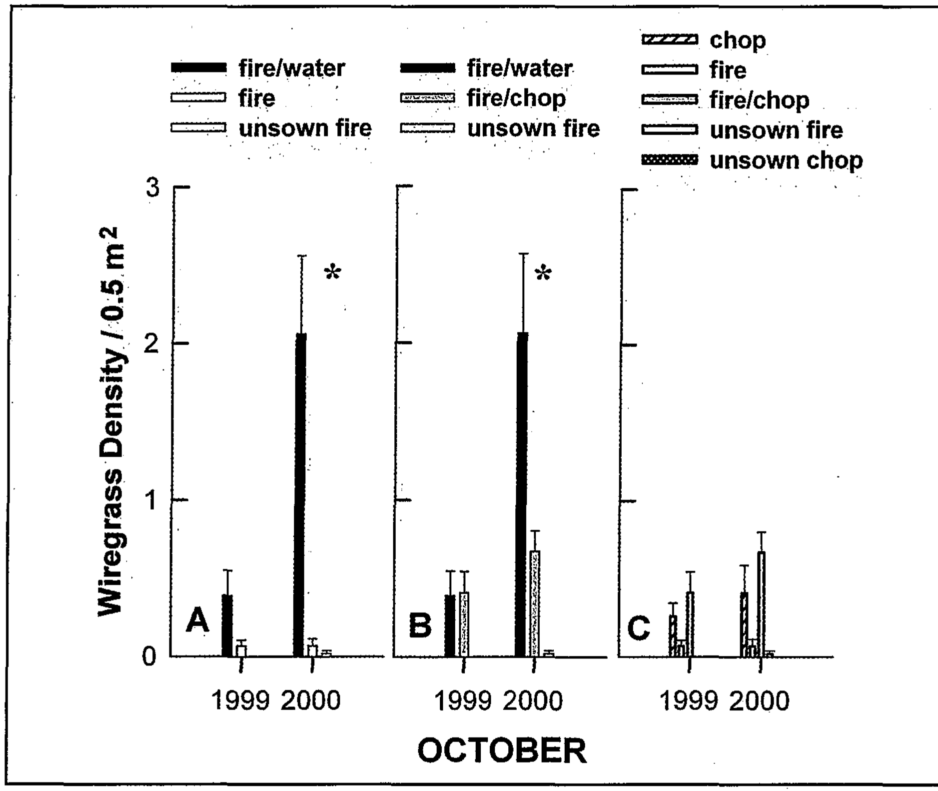

Figure 5. Mean (± 1 SD) density of wiregrass plants/0.5 m^2 in plots by site preparation treatment for Experiment I: (A) fire and irrigation vs. fire treatments; (B) fire and irrigation vs. fire and chopped treatments; and (C) fire vs. chopped vs. fire and chopped treatments in 1999 and 2000. Means accompanied by * (above the bars) are significantly different for site preparation treatments (Chi-square).

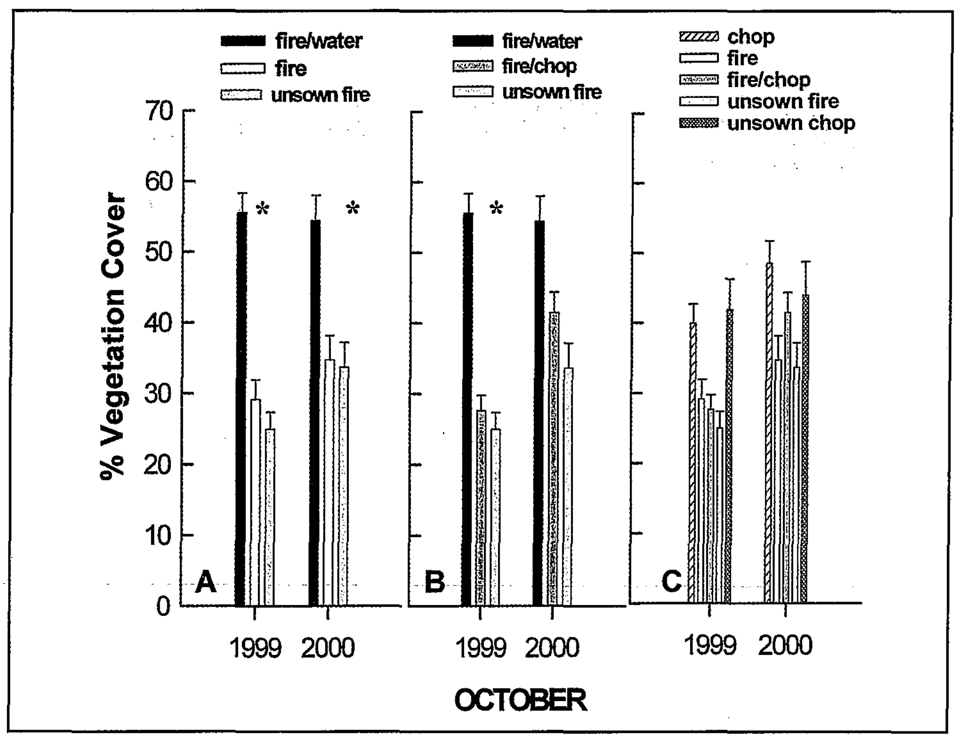

Figure 6. Mean (± 1 SD) percent cover of native vegetation by site preparation treatment for Experiment I: (A) fire and irrigation vs. fire treatments; (B) fire and irrigation vs. fire and chopped treatments; and (C) fire, chopped, and fire and chopped treatments in 1999 and 2000. Means accompanied by * (above the bars) are significantly different for site preparation treatments (Chi-square).

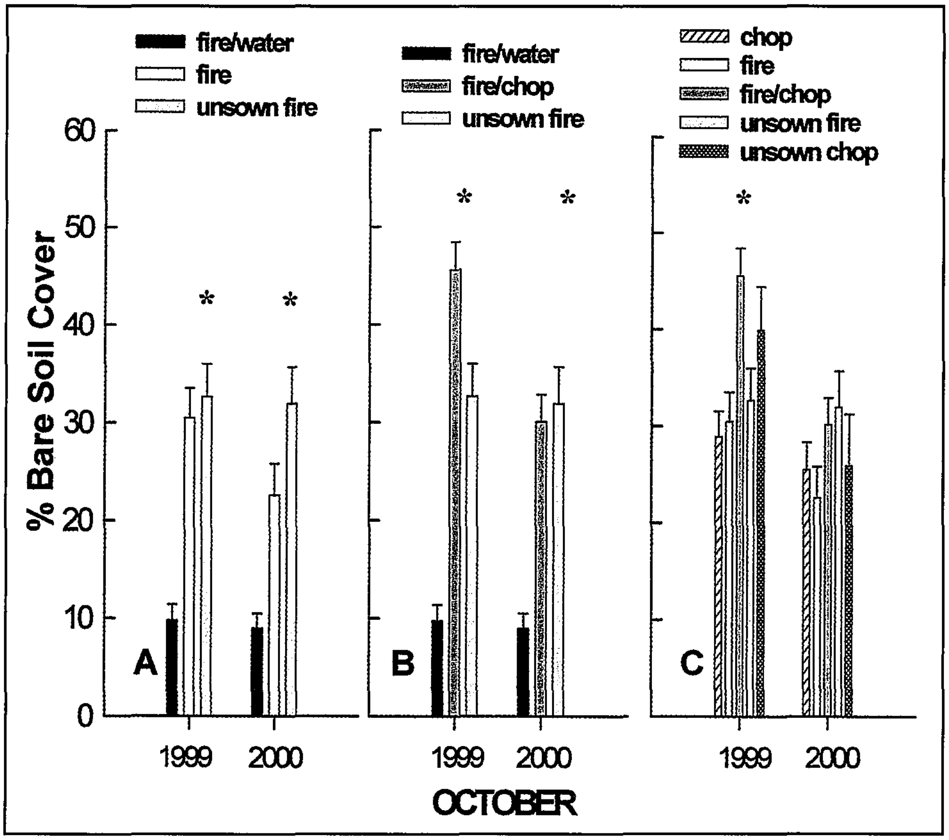

Figure 7. Mean (± 1 SD) percent cover of bare soil in plots by site preparation treatment for Experiment I: (A) fire and irrigation vs. fire treatments; (B) fire and irrigation vs. fire and chopped treatments; and (C) fire, chopped, and fire and chopped treatments in 1999 and 2000. Means accompanied by * (above the bars) are significantly different for site preparation treatments (Chi-square).

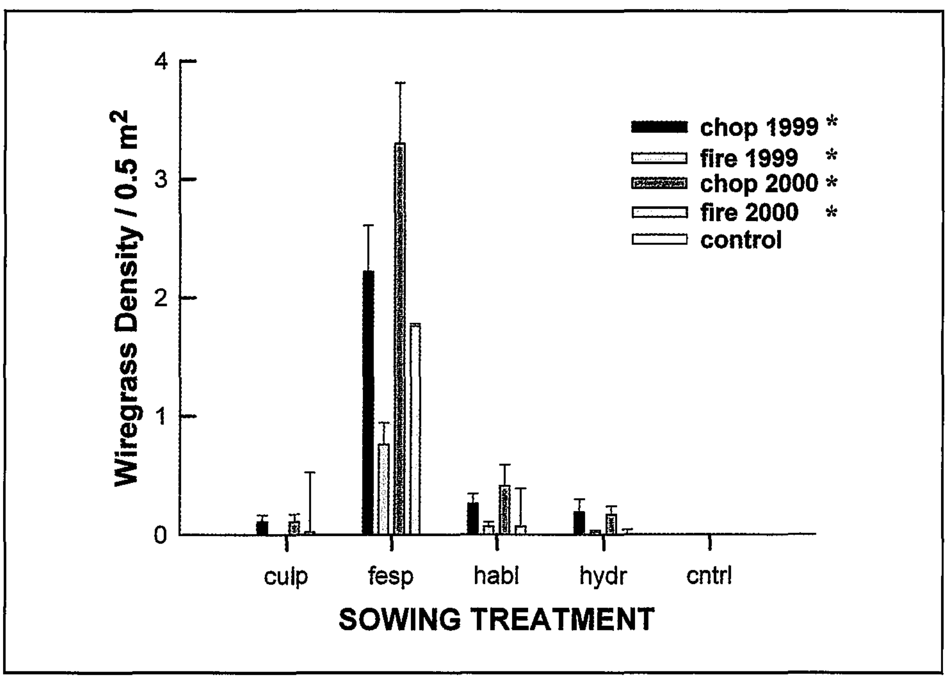

Figure 8. Mean (± 1 SD) density of wiregrass plants/0.5 m^2 sampling plots for October 1999 and 2000 by site preparation treatments (chop and burn) and four sowing treatments: cultipack (culp), fertilizer spreader (fesp), hayblower (habl), and hydroseeder (hydr). Control plots (cntrl) are included for comparative purposes and were not included in the analysis. Significant differences between years are indicated by * in the legend (Chi-square).

ration treatments for 1999 ($\chi^2 = 5.79$, p = 0.05). As in Experiment I, percent litter was higher in the burned (44%) than in the chopped site (30) in 1999. Conversely, species richness, wiregrass density, and other cover measurements all tended to be higher in the chopped than in the burned treatment. As for the other cover variables, interactions involving sowing method and block influenced litter cover (Table 2).

DISCUSSION

Site preparation

Site preparation for sowing native seed in disturbed sandhills appears to depend on the degree of site disturbance. In degraded sandhills with undisturbed soil, mechanically sown seeds can establish if the vegetation is burned and then irrigated early in the growing season. If irrigation or fire is not possible, lightly roller-chopping the site should allow good establishment of species like wiregrass, though not as successfully as the fire and irrigation management. Burning prior to chopping appears unnecessary. Fire alone will not result in good establishment unless precipitation levels are high.

Species richness

Consistent with the results of previous restoration research in this system (Hattenbach et al. 1998), sowing seed had little effect on species richness aside from adding in species like wiregrass that appear not to disperse into the plots naturally under the conditions tested. The first year after sowing, species richness was highest in the irrigated plots compared with all treatments and controls, showing early benefits of watering to seed germination. Two years after sowing, species richness remained higher in all chopped treatments than in the un-irrigated burned treatments indicating that soil disturbance may also stimulate seed germination by breaking up the crust and aerating the soil. Seed germination would be enhanced not only for the seeds sown by direct seeding methods but also from adjacent areas or from the seedbank present in the soil.

Wiregrass

Regardless of site preparation, the best establishment of wiregrass occurred in plots sown with the fertilizer spreader, suggesting a contribution from a mechanical treatment. In this sowing method, the seed mix was manually pushed through the machine before being rolled into the soil. A wooden dowel was used to force the seed through the fertilizer spreader, which may have stripped awns or bristles from some of the seeds, allowing the closer seed/soil contact. The addition of vermiculite may also have improved soil quality for germinating seedlings. However, the higher density likely resulted from repeated driving through the plots as seed were sown vertically, rather than being applied into the plots from the edges. This impact would have the same effect as repeated rolling of seed into the soil. The second highest establishment was in the hayblown plots, and that approach remains our recommendation because no modifications are needed and it is fast and easy to use. Multiple passes with a roller or soil aerator might mimic the greater establishment in the plot when the fertilizer spreader was used.

Wiregrass densities increased significantly the second year of the study. However, wiregrass densities overall were still lower (0.86 ± 2.18 clumps/0.5 m^2) in this study than in the second year (4.38 ± 4.40 clumps/0.5 m^2) of the previous study (Hattenbach et al. 1998). Germination experiments showed that the 10% germination of wiregrass collected in 1998 was considerably lower than the 45% germination in the 1997 study. The highest density in the fertilizer spreader plots of approximately 5 plants/m^2 is consistent with densities found in native sandhills of 5.3 plants/m^2 as recorded by Clewell (1989). Interestingly, the significant increases in wiregrass densities the second year of this study support other observations that wiregrass seeds may remain dormant beyond one growing season (Seamon 1998, Mulligan and Kirkman 2002).

Percent Cover

Percent cover of native species increased from 1999 to 2000 with the addition of

Table 1. Effects of sowing, year, and block on vegetation and cover in the Experiment I plots: site preparation treatments A, B and C comparisons (Figures 3, 5-7). Year effects were tested using the block within year error term. Significant p-values are bolded.

Factor	Seed		Year		Block (Year)		Seed * Year		Seed * Year * Block	
df	1		1		5		1		11	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Site Preparation Treatments										
A. fire/water vs fire vs unsown fire										
Species richness	3.32	0.094	3.05	0.14	0.19	0.96	0.01	0.92	1.87	0.15
Wiregrass density	23.01	**0.0001**	3.25	0.13	3.68	**0.003**	4.94	**0.027**	2.2	**0.012**
Vegetation cover	22.82	**0.0001**	6.69	**0.049**	0.17	0.97	0.82	0.36	1.27	0.24
Bare soil cover	30.5	**0.0001**	4.82	0.079	0.62	0.68	0.32	0.57	1.83	**0.048**
Litter cover	1.29	0.25	1.67	0.25	1.27	0.27	1.84	0.17	2.96	**0.001**
B. fire/water vs fire/chop vs unsown fire										
Species richness	0.59	0.46	4.66	0.083	0.16	0.97	0.11	0.75	0.9	0.56
Wiregrass density	46.14	**0.0001**	5.12	0.073	3.77	**0.003**	8.44	**0.004**	2.2	**0.014**
Vegetation cover	38.3	**0.0001**	16.08	**0.01**	0.36	0.88	0.02	0.89	1.06	0.39
Bare soil cover	9.6	**0.002**	32.55	**0.002**	0.14	0.99	0.76	0.38	2.11	**0.019**
Litter cover	3.32	0.07	11.94	**0.018**	1.59	0.16	11.65	**0.0007**	4.11	**0.0001**
C. chop vs fire vs fire/chop vs unsown fire vs unsown chop										
Species richness	0.26	0.61	25.29	**0.004**	0.33	0.89	0.62	0.44	1.1	0.4
Wiregrass density	32.56	**0.0001**	0.97	0.37	2.64	**0.023**	0.81	0.37	0.98	0.47
Vegetation cover	3.94	**0.048**	29.33	**0.003**	0.41	0.84	0.63	0.42	1.83	**0.048**
Bare soil cover	0.07	0.78	13.88	**0.014**	1.24	0.29	0.16	0.69	2.22	**0.013**
Litter cover	2.9	0.089	9.73	**0.026**	0.67	0.65	0.24	0.63	3.06	**0.0006**

Table 2. Effects of sowing, year, and block on vegetation and cover in the Experiment II plots (Figures 4 and 8). Seed indicates sowing treatment (cultipacker, fertilizer spreader, hayblower and hydroseeder). Year effects were tested regardless of site preparation treatments (chop or fire) using the block within year error term. Significant p-values are bolded.

Factor	Seed		Year		Block (Year)		Seed * Year		Seed * Year * Block		Block		Seed * Block		Block * Year	
	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value
df	3		1		5		3		33		5		15		5	
Species richness	0.15	0.93	15.43	**0.011**	1.06	0	0.07	0.98	0.54	0.97	1.98	0.1	0.8	0.67	1.06	0.4
Wiregrass density	129.96	**<0.0001**	2.75	0.16	2.32	**0.042**	5.32	**0**	1.84	**0**	2.75	**0.018**	1.44	0.12	2.31	**0.042**
Vegetation cover	0.33	0.81	37.8	**0**	1.78	0.11	4.08	**0.007**	2.4	**<0.0001**	1.11	0.35	4.06	**<0.0001**	1.78	0.11
Bare soil cover	1.73	0.16	3.89	0.11	5.38	**<0.0001**	1.68	0.17	1.23	0.18	5.69	**<0.0001**	1.73	**0.041**	5.38	**<0.0001**
Litter cover	1.04	0.37	0.17	0.7	3.25	**0.007**	0.38	0.77	1.58	**0.021**	1.04	0.4	2.28	0	3.25	**0.007**

native sandhill seed mix. Not surprisingly, cover of bare ground showed the inverse pattern to that of vegetation and species richness. Mean percent bare soil of 28% and 25% was consistent with the 10% to 30% range previously noted by The Nature Conservancy (1997). These values are low, compared with the 50% to 61% cover in a previous study (Gordon et al. 2000); however, that research was conducted on bulldozed windrows, and this research was established between windrows with significantly less soil disturbance. Litter cover was intermediate between vegetation and bare ground and more variable. Cover of non-native species in the plots was negligible, however.

Management Implications

Because this study was conducted in only one location, our conclusions and recommendations can only be tentative. However, the results allow us to hypothesize likely management implications: if the restoration site is disturbed, but likely to have a seedbank of native vegetation present, native vegetation will become established following prescribed fire and light disturbance of the soil surface prior to sowing. Even if the site has some cover of natives, light chopping with an empty roller drum seemed not to negatively impact cover over non-chopped sites, and appeared to more effectively prepare the site for seed than did burning alone.

Further, we cautiously recommend that seed be sown using the hayblower unless a fertilizer spreader could be modified to disperse long-awned seed easily. Seeds should be rolled at least once, and perhaps multiple times post sowing. The use of available machinery is advised rather than modifying or using equipment that is designed for another purpose. Other restoration efforts now are using a Grasslander No-Til Seeder® (Hennessey, Oklahoma 73742), which appears to effectively both sow and roll simultaneously, but is difficult to use where existing native vegetation impedes vehicle movement.

If native vegetation is present on the sandhill site but the soil will be completely disturbed during the construction or revegetation process, perhaps the most important factor for successful colonization by natives is maintenance of the topsoil on the site. Native species appear to establish well on disturbed soils from both the sown material and the soil seedbank. Microtopographic features left from disking or bulldozing should be smoothed as much as possible to restore soil compaction and prevent seed from washing into depressions. Irrigation appears unnecessary for species establishment in a non-drought year, when average rainfall is recorded.

In this study, we did not see an increase in non-native species because the research site was relatively free of non-native grasses and weedy native species and native soils were present, although disturbed. However, if soils have been modified for road construction or pasture or the site is covered with non-native species like bahiagrass, roller chopping may not be desirable as weedy and invasive species are more likely to colonize modified soils (Greenberg et al. 1997, Harper-Lore 1998).

Prescribed fire and irrigation, particularly during drought years, might be the best site preparation if native vegetation is already present and irrigation is possible. If irrigation is not possible, light roller chopping prior to sowing appears appropriate. The sowing equipment tested is all commercially available and fairly simple to operate. In all cases, we recommend using a roller to press seed into the ground following sowing. The straightforward use and the minimal amount of seed preparation allow for easy seed sowing and establishment. Seed availability and soil quality on highly disturbed sites may be the largest impediments to revegetation with natives.

The most encouraging result from this study, similar work elsewhere at ABRP (Hattenbach et al. 1998), and work in bahiagrass pastures in central Florida (Gordon et al. 2001, Jenkins 2003) is the presence of a rich native seedbank that responds to site preparation treatments. Further investigation is necessary to identify the generality of these results. However, where that seedbank remains, restoration of longleaf pine systems is vastly simplified.

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LITERATURE CITED

Abrahamson, W.G. 1984. Post-fire recovery of Florida Lake Wales Ridge vegetation. American Journal of Botany 71:9-21.

Bissett, N.J., P.N. Gray, and S. A. Hedges. 1998. Direct seeding of wiregrass and associated species on reclaimed land. Unpublished Manuscript.

Bonham, C.D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, N.Y. 338 p.

Brockway, D.G., and C.E. Lewis. 1997. Long-term effects of dormant-season prescribed fire on plant community diversity, structure and productivity in a longleaf pine wiregrass ecosystem. Forest Ecology and Management 96:167-183.

Brockway, D.G., and K.W. Outcalt. 1998. Gap-phase regeneration in longleaf pine wiregrass ecosystems. Forest Ecology and Management 106:125-139.

Brockway, D.G., and K.W. Outcalt. 2000. Restoring longleaf pine wiregrass ecosystems: Hexazinone application enhances effects of prescribed fire. Forest Ecology and Management 137:121-138.

Christensen, N.L. 1981. Fire regimes in southeastern ecosystems. Pp. 112-136 *in* H.A. Mooney, T.M. Bonnickson, N.L. Christensen, J.E. Lotan, and W.A. Reiners, eds. Fire regimes and ecosystem properties. U.S. Department of Agriculture, Forest Service. General Technical Report no. WO-26.

Christensen, N.L. 1988. Vegetation of the coastal plain of the southeastern United States. Pages 317-363 *in* M.G. Barbour and W.D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, N.Y.

Clewell, A.F. 1989. Natural History of Wiregrass (*Aristida stricta* Michx., Gramineae). Natural Areas Journal 9:223-233.

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

Gordon, D.R., A.C. Cox, G.S. Seamon, J.L. Slapcinsky, and D.A. Jones. 2001. Native sandhill species revegetation techniques. Final Report to the Florida Department of Transportation BB-937, University of Florida, Gainesville. 98 pp.

Gordon, D.R., and K.J. Rice. 1998. Patterns of differentiation in wiregrass (*Aristida beyrichiana*): implications for restoration efforts. Restoration Ecology 6:166-174.

Greenberg, C. H., S.H. Crownover, and D.R. Gordon. 1997. Roadside soils: a corridor for invasion of xeric scrub by nonindigenous plants. Natural Areas Journal 17:99-109.

Hardesty, J.L., and R.A. Moranz. 1998. Longleaf pine ecosystem restoration in Northwest Florida sandhills: issues and recommendations. Summary of the Workshop held at Eglin Air Force Gase, November 4-6, 1998. The Nature Conservancy, Gainesville, Fla. Harper-Lore, B. L. 1998. Do native grasslands have a place on roadsides? Pp. 29-31 *in* Land and Water.

Hattenbach, M.J., D. Gordon, G. Seamon, and R.G. Studenmund. 1998. Development of direct seeding techniques to restore native groundcover in a sandhill ecosystem. Pp. 64-67 *in* Proceedings of The Longleaf Pine Ecosystem Restoration Symposium, Conference Proceedings, Ft. Lauderdale, Fla.

Jenkins, A.M., D.R. Gordon, and M.T. Renda. 2003. Native alternatives for non-native turfgrasses in central Florida: germination and responses to cultural treatments. Restoration Ecology. In press.

Jenkins, A.M. 2003. Seed banking and vesicular-arbuscular mycorrhizae in pasture restoration in central Florida. M.S. Thesis. University of Florida, Gainesville. 2003.

Leitman, H.M., J.A. Sohm, and M. A. Franklin. 1984. Wetland hydrology, tree distribution, Apalachicola River flood plain. Water-Supply Paper 2196-A. U.S. Geological Survey. 52 pp.

Means, D.B., and G. Grow. 1985. The endangered longleaf pine community. Enfo 85:1-12.

Mulligan, M.K., and L.K. Kirkman. 2002. Burning influences on wiregrass (*Aristida beyrichiana*) restoration plantings: natural seedling recruitment and survival. Restoration Ecology 10:334-339.

Mulligan, M.K., L.K. Kirkman, and R.J. Mitchell. 2002. *Aristida beyrichiana* (wiregrass) establishment and recruitment: implications for restoration. Restoration Ecology 10:68-76.

Myers, R., P. Seamon, and G. Seamon. 1990. Wiregrass regeneration and community restoration. Research summary/proposal.

Outcalt, K.W., and C.E. Lewis. 1988. Response of wiregrass (*Aristida stricta*) to mechanical site preparation. KBN Engineering and Applied Sciences Inc, Valdosta State College, Valdosta, Ga. 12 pp.

Outcalt, K.W., M.E. Williams, and O. Onokpise. 1999. Restoring *Aristida stricta* to Pinus palustris ecosystems on the Atlantic Coastal Plain, USA. Restoration Ecology 7:262-270.

Peet, R.K., and D.J. Allard. 1993. Longleaf pine vegetation of the Southern Atlantic and Eastern Gulf Coast regions: a preliminary classification. Pages 45-82 *in* Proceedings Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, FL.

Provencher, L., A.R. Litt, D.R. Gordon, J.L. Hardesty, N.M. Gobros. K.E.M. Galley, G.W. Tanner, L.A. Brennan, S.J. McAdoo, J.P. McAdoo, and B.J. Herring. 1999. Restoration of fire-suppressed longleaf pine sandhills at Eglin Air Force Base, Florida: a summary of key findings. Produced by the Longleaf Pine Restoration Project for the Natural Resources Management Division of Eglin Air Force Base. 12 pp.

Provencher, L., B.J. Herring, D.R. Gordon, H.L. Rodgers, K.E.M. Galley, G.W. Tanner, J.L. Hardesty, and L.A. Brennan. 2001. Effects of hardwood reduction techniques on longleaf pine sandhill vegetation in northwest Florida. Restoration Ecology 9:12-27.

Provencher, L., H.L. Rodgers, K.E.M. Galley, J.L. Hardesty, G.W. Tanner, D.R. Gordon, J.P. McAdoo, J. Sheehan, and L.A. Brennan. 1997. Initial post-treatment analysis of restoration effects on plants, invertebrates, and birds in sandhill systems at Eglin Air Force Base. Annual Report to Natural Resources Division, Eglin Air Force Base: 94 pp. + appendices.

Robbins, L.E., and R.L. Myers. 1992. Seasonal effects of prescribed burning in Florida: a review. Misc. Publication 8, Tall Timbers Research Station, Inc., Tallahassee, Fla. 118 pp.

Schmidt, W. 1986. Alum Bluff, Liberty County, Florida. America Centennial Guide - SE Section. Geological Society. Pp. 355-357.

Schwartz, M.W., and S.M. Hermann. 1992. The population biology of *Torreya taxifolia*: Habitat evaluation, fire ecology, and genetic variability. Final report. 108 pp.

Seamon, G. 1990. Putting the puzzle together: Restoring the longleaf pine/wiregrass ecosystem. The Nature Conservancy. Pp. 1-2.

Seamon, G. 1998. A longleaf pine sandhill restoration in northwest Florida. Restoration & Management Notes 16:46-50.

Stout, I.J., and W.R. Marion. 1993. Pine flatwoods and xeric pine forests of the southern coastal plain. Pages 373-446 *in* W.H. Martin, S.G. Boyce, and A.C. Echternacht, editors. Biodiversity of the Southeastern United States: Lowland terrestrial communities. John Wiley and Sons, New York, N.Y.

Violi, H. 1999. Evaluation of restoration techniques in an abandoned bahiagrass pasture. University of California, Riverside, Calif. 86 pp.