VOLUME, MASS, AND NUTRIENTS OF DOWN WOODY DEBRIS FOLLOWING INITIAL SHORTLEAF PINE-BLUESTEM GRASS RESTORATION ACTIVITIES IN THE OUACHITA MOUNTAINS OF ARKANSAS

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Abstract—The Ouachita National Forest is restoring pine-mixed hardwood forests to a shortleaf pine-bluestem grass ecosystem through harvesting, midstory control, and the application of prescribed fire. Mean mass and volume of downed woody debris (DWD) in plots following initial harvesting and midstory-control were respectively 335 percent and 253 percent greater than in plots that had no restoration activities. Harvesting and midstory control also increased the mean DWD contents of C and N by 308 percent and 369 percent, respectively. The initial restoration fire reduced DWD mass in the shortleaf pine-bluestem plots by 27 percent and DWD volume by 28 percent. C and N contents in DWD were also significantly reduced by the initial restoration fire (26 percent and 32 percent) but were still 205 percent and 169 percent greater than in plots without restoration activities.

INTRODUCTION

Downed woody debris (DWD) frequently contains a significant portion of a forest ecosystem's accumulated carbon and nutrients (Hutson 1996, Maser and Trappe 1984, Muller and Liu 1991). Woody debris is especially important as a source of nutrient inputs to soils when other reserves of nutrients, such as forest floor and herbaceous biomass, have been removed by fire (Harmon and others 1986).

Historically, the Ouachita Mountains of Arkansas and Oklahoma were dominated by pine, pine-hardwood, and mixed oak communities with an herbaceous understory (Bukenhofer and Hedrick 1997). The shortleaf pine (*Pinus echinata* Mill.)-bluestem grass (*Andropogon* spp.) ecosystem was an important component of this landscape and consisted primarily of a low-density pine overstory (13.8 to 16.1 m^2 ha^{-1} basal area) with a floristically rich grass and forb understory maintained by fire (Bukenhofer and Hedrick 1997, Masters and others 1995, Spetich and others 2002). Due to fire suppression and commercial harvesting, the Ouachita Mountain landscape today is drastically different. A dense midstory of pine and hardwood trees has encroached, woody vegetation now dominates the understory, and the once prolific grasses are uncommon (Bukenhofer and Hedrick 1997, Bukenhofer and others 1994, Spetich and others 2002).

The Ouachita National Forest (ONF), located in west-central Arkansas and southeastern Oklahoma, plans to restore 62,730 of its 688,000 ha of pine and mixed hardwood forests to a shortleaf pine-bluestem grass ecosystem (Bukenhofer and Hedrick 1997, Bukenhofer and others 1994, Spetich and others 2002). This will be accomplished through overstory thinning, removal of the midstory, and application of moderate intensity fires at a 2- to 5-year interval to maintain the open condition of a shortleaf pine-bluestem community (Spetich and others 2002).

To better understand the impacts of restoration activities on carbon storage and nutrient availability, an intensive study was initiated in two watersheds, one of which is being restored to a shortleaf pine-bluestem community and the other, which is being maintained in its current condition. As part of this larger study, we are evaluating the impacts of the restoration activities on DWD carbon and nutrient pools. In this paper, we evaluate the changes in DWD mass and volume as well as DWD carbon and nitrogen content that occurred following the initial overstory thinning, midstory competition control, and prescribed fire.

METHODS

This study utilized two adjacent sub-watersheds of the Upper Lake Winona Watershed located in the northeastern portion of the Ouachita Mountains in Arkansas (fig. 1). The two sub-watersheds have similar geology, soils, and landform structure. The 908-ha South Alum Creek sub-watershed (control) is a combination of shortleaf pine, pure hardwood, and mixed pine-hardwood stands with a high

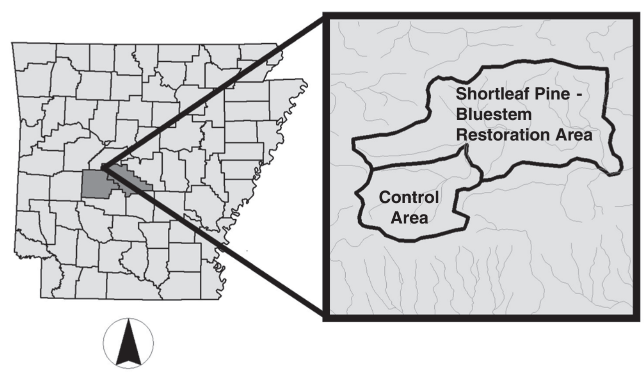

Figure 1—Location of North Alum Creek Sub-Watershed (shortleaf pine-bluestem restoration area) and South Alum Creek Sub-Watershed (control area) in Saline and Garland Counties in west-central Arkansas.

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basal area (25.3 to 27.6 m^2 ha^{-1}) and a dense midstory. The 1,364-ha North Alum Creek sub-watershed is being managed to create a shortleaf pine- bluestem ecosystem (pine-bluestem restoration area). This is accomplished through the felling of overstory hardwoods and pines (reducing the total basal area by approximately 50 percent), followed by the felling of midstory trees and brush, and the application of prescribed fires on a 2- to 5-year interval. Due to poor local hardwood markets, only pine timber was merchandised. Hardwood timber and midstory vegetation were left where they fell. The harvesting and midstory control activities took place in late fall of 2000 through spring of 2001. The initial prescribed fire occurred in February 2002. No restoration or management activities occurred in the control area during this time period.

Six 0.08-ha plots that received the entire suite of restoration activities in the shortleaf pine-bluestem area and five 0.08-ha plots in the control area were studied. To quantify the amount and nutrient content of fine DWD (< 7.6 cm in diameter) and coarse DWD (≥ 7.6 cm in diameter) in these plots, the volume of DWD was inventoried and samples were collected for specific gravity, C concentration, and N concentration determination. Inventory and sampling occurred in the fall of 2001 after harvesting and midstory competition control and again in the spring and summer of 2002 following the initial prescribed fire. DWD less than 10.1 cm in diameter was inventoried on each plot using the planar intersect method described in Brown (1974). Pieces of debris less than 10.1 cm in diameter that intersected one of four 16.1-m transects, arranged 90° to one another, were tallied and used to calculate volume. Because four transects were established on each plot, the length of the transect used to inventory fine DWD was staggered to prevent all fine debris from being inventoried from the center of the plot. The 16.1-m transects were extended 15.2 m off plot for specific gravity and nutrient sample collection. Volume was calculated using an equation modified from Van Wagner (1964). For DWD greater than 10.1 cm in diameter, the mid-length diameter and length of every piece on a plot was measured using methods described in Spetich and others (2002). The cylindrical volume of each piece was then calculated. The mass of all DWD was determined using specific gravity measurements and the volume inventories. C and N were quantified by combustion using a LECO C/N analyzer. The mass was used in conjunction with the nutrient analyses to determine the C and N content of the DWD. The temperature of the restoration fire was determined on the shortleaf pine-bluestem plots using tiles painted with temperature-indicating liquids, which liquefy and evaporate at specific indication temperatures. The median temperature of the prescribed fire was 202 °C at the soil surface and 138 °C approximately 30 cm above the soil surface.

Welch's t-tests ($\alpha = 0.05$) were used to quantify the effects of the harvesting and thinning operations on the treatment area and to document initial differences between the shortleaf pine-bluestem restoration area and the control. Paired t-tests ($\alpha = 0.05$) were used to determine significant differences due to the initial restoration fire. The assumption of normality for each t-test was confirmed using the Shapiro-Wilk test.

RESULTS AND DISCUSSION

Harvesting and Midstory Control

Total DWD volumes after the initial overstory harvest and midstory removal were 253 percent greater in the shortleaf pine-bluestem plots (122.9 m^3 ha^{-1}) than in the control plots (34.8 m^3 ha^{-1}) (table 1). In the control plots, mean volumes of fine (17.2 m^3 ha^{-1}) and coarse DWD (17.6 m^3 ha^{-1}) were similar. However, there was 32 percent more coarse DWD than fine DWD volume in the shortleaf pine-bluestem plots. Within the control plots, pine comprised the majority of the DWD (64 percent), but in the shortleaf pine-bluestem plots, pine accounted for only 41 percent of the total DWD. The higher levels of DWD in the shortleaf pine-bluestem plots are likely a result of overstory harvesting and midstory control activities. The relatively greater volumes of hardwood DWD compared to pine DWD were related to the lack of local commercial markets for hardwoods resulting in midstory trees and hardwoods being left on the site. Harvesting and removal of merchantable pine boles resulted in a lack of any significant increase in coarse pine DWD within the shortleaf pine-bluestem plots. This resulted in an increase in the ratio of hardwood to pine DWD in the shortleaf pine-bluestem plots.

Mean DWD mass was significantly greater in the shortleaf pine-bluestem plots than in the control plots. Generally these differences in mass were similar to differences observed in DWD volumes. However, differences in DWD mass between the shortleaf-pine bluestem and control plots were greater than those observed for volume due to differences in specific gravity between pine and hardwood DWD, along with high specific gravity of the fresh undecomposed hardwood DWD that was left following harvesting and midstory control. Total mass of DWD was 335 percent greater whereas total volume of DWD was only 253 percent greater in the shortleaf pine-bluestem plots compared to control plots. Hardwood DWD mass was 678 percent greater in the shortleaf pine-bluestem plots (43.1 Mg ha^{-1}) than in the control plots (5.5 Mg ha^{-1}) (table 1). Hardwood DWD mass accounted for 64 percent of the total DWD mass in the shortleaf pine-bluestem plots but only 36 percent in the control plots. Harvesting and midstory control activities in the shortleaf pine-bluestem plots appeared to have dramatically increased the ratio of hardwood to pine DWD mass in the restoration area as well as the total mass of DWD.

As a result of the higher levels of DWD, mean C and N contents were also greater in the shortleaf pine-bluestem plots (30.9 Mg ha^{-1} and 139.4 kg ha^{-1}) than in the control plots (7.6 Mg ha^{-1} and 29.7 kg ha^{-1}) (table 1). Fine DWD contained 41 percent of the total DWD C in the control and shortleaf pine-bluestem plots. This was similar to the overall contribution of fine DWD to the total DWD mass. However, 53 percent of the N in DWD was contained in fine DWD. This was due to the higher N concentration in the fine DWD (0.26 percent) than in the coarse DWD (0.16 percent). Concentrations of C in fine (46 percent) and coarse DWD (47 percent) were similar. Overall N concentrations of fine hardwood DWD (0.49 percent) were much higher than fine pine DWD (0.19 percent), coarse hardwood DWD (0.21 percent), or coarse pine DWD (0.10 percent). The particular restoration harvesting and midstory control activities utilized in the shortleaf pine-bluestem plots increased the

Table 1—Mean volume, mass, C content, and N content of pine and hardwood downed woody debris before the initial shortleaf pine-bluestem restoration fire on the control and shortleaf pine-bluestem restoration area

	Fine DWD			Coarse DWD			Total DWD		
Treatment	Pine	HWD	Total	Pine	HWD	Total	Pine	HWD	Total
	volume (m^3 ha^{-1})								
Control	8.2a[a]	9.0a	17.2a	14.1a	3.5a	17.6a	22.3a	12.5a	34.8a
SP-B	22.7b	30.3b	53.0b	28.0a	41.9b	69.9b	50.7a	72.3b	122.9b
	mass (Mg ha^{-1})								
Control	3.3a	4.1a	7.4a	6.7a	1.5a	8.2a	10.0a	5.5a	15.5a
SP-B	9.9b	17.1b	26.9b	14.3a	26.0b	40.4b	24.2a	43.1b	67.3b
	carbon content (Mg ha^{-1})								
Control	1.5a	1.8a	3.4a	3.6a	0.6a	4.2a	5.1a	2.5a	7.6a
SP-B	4.6b	7.6b	12.2b	7.1a	11.6b	18.7b	11.7a	19.2b	30.9b
	nitrogen content (kg ha^{-1})								
Control	8.3a	12.3a	20.6a	6.5a	2.7a	9.2a	14.7a	15.0a	29.7a
SP-B	17.3b	51.6b	68.9b	14.1a	56.4b	70.5b	31.4b	108.0b	139.4b

SP-B = shortleaf pine-bluestem; DWD = downed woody debris; HWD = hardwood.

[a] Means for control and SP-B areas with the same letter for a given DWD component and parameter do not significantly differ at $\alpha = 0.05$.

contents of C and N by increasing the mass of DWD. These practices also altered the species composition and ratio of fine to coarse DWD following initial restoration activities. These alterations appear to change the C:N ratio in the DWD of the shortleaf pine-bluestem areas as well.

Initial Restoration Fire

The initial restoration fire reduced mean DWD volumes in the shortleaf pine-bluestem plots by 28 percent (from 122.9 to 88.5 m^3 ha^{-1}) (table 2). Fine DWD accounted for the majority (60 percent) of this reduction in DWD volume because fine fuels ignite and are consumed more readily than coarse DWD. There was not a statistically significant loss of coarse DWD volume when both pine and hardwoods were included in the analysis. However, the mean volume of coarse hardwood DWD was significantly reduced from 41.9 to 35.6 m^3 ha^{-1} whereas fine hardwood DWD volume was reduced from 30.3 to 17.5 m^3 ha^{-1} (42 percent). Reductions in the fine pine DWD were not significant. We suspect that the high variability in pine DWD among plots was responsible for the lack of statistically significant reductions in pine DWD. DWD volumes measured in the control plots before and after the initial restoration fire in the shortleaf pine-bluestem area generally differed by less than 0.5 m^3 ha^{-1}, indicating little or no change in DWD volumes in these watersheds as a result of severe climatic conditions or mortality.

The losses in DWD mass due to the prescribed fire in the shortleaf-pine bluestem plots were similar to the volume losses. The overall mass of DWD was reduced 27 percent, from a mean of 67.3 to 48.9 Mg ha^{-1}, whereas the volume was reduced 28 percent (table 2). Fine DWD accounted for 57 percent of the overall loss. Although the reduction of mass was statistically significant, the DWD mass in the shortleaf pine-bluestem plots (48.9 Mg ha^{-1}) following the fire was still 218 percent greater than in the control plots (15.4 Mg ha^{-1}). The prescribed fire did not alter the ratio of hardwood to pine DWD. Hardwoods made up 64 percent and 65 percent, respectively, of the total DWD mass before and after the initial restoration fire. The restoration fire amplified the difference between the coarse to fine DWD ratios in the shortleaf-pine bluestem plots. Coarse DWD made up 60 percent of the total DWD mass in the shortleaf pine-bluestem plots prior to the initial prescribed fire but made up 67 percent after the fire. Only 44 percent of DWD in the control plots was in the coarse size class.

Carbon losses in the shortleaf pine-bluestem were, as expected, similar to losses of DWD mass. Mean C content was reduced from 30.9 to 22.9 Mg ha^{-1}, a loss of 26 percent. Mean N DWD content in the shortleaf pine-bluestem plots was reduced by 32 percent, from 139.4 to 95.2 kg ha^{-1} (table 2). Even with these losses, C and N contents following the prescribed fire were respectively 205 and 169 percent greater in the shortleaf pine-bluestem plots than in the control plots. The reduction of N in DWD does not mean that this nutrient was lost from the ecosystem. Our sampling methods did not measure any ash additions to the forest floor/mineral soils or whether N was volatilized, oxidized, or redistributed off site through convection.

The fire had little impact on C or N concentrations. Mean C concentrations were unchanged (47 percent) in coarse DWD and only increased from 46 percent to 47 percent in fine DWD. Mean N concentrations before and after the fire were also similar in both the coarse DWD (0.26 percent to 0.27 percent) and fine DWD (0.16 percent to 0.15 percent). The fire did slightly alter the C:N ratio in the shortleaf pine-bluestem from 222:1 prior to the fire to 240:1 after the fire.

Table 2—Mean volume, mass, C content, and N content of pine and hardwood downed woody debris in the shortleaf pine-bluestem restoration area before and after the initial restoration fire

	Fine DWD			Coarse DWD			Total DWD		
Treatment	Pine	HWD	Total	Pine	HWD	Total	Pine	HWD	Total
					volume (m³ ha⁻¹)				
Before	22.7a[a]	30.3a	53.0a	28.0a	41.9a	69.9a	50.7a	72.3a	122.9a
After	15.1a	17.5b	32.6b	20.3a	35.6b	55.9a	35.5a	53.0b	88.5b
					mass (Mg ha⁻¹)				
Before	9.9a	17.1a	26.9a	14.3a	26.0a	40.4a	24.2a	43.1a	67.3a
After	6.6a	9.8b	16.4b	10.8a	21.8b	32.5b	17.3b	31.6b	48.9b
					carbon content (Mg ha⁻¹)				
Before	4.6a	7.6a	12.2a	7.1a	11.6a	18.7a	11.7	19.2a	30.9a
After	3.1a	4.6b	7.7b	5.3a	9.9b	15.2b	8.4	14.4b	22.9b
					nitrogen content (kg ha⁻¹)				
Before	17.3a	51.6a	68.9a	14.1a	56.4a	70.5a	31.4a	108.0a	139.4a
After	11.2a	33.3b	44.4b	13.1a	37.7b	50.8b	24.2a	71.0b	95.2a

DWD = downed woody debris; HWD = hardwood.

[a] Means before and after the fire with the same letter for a given DWD component and parameter do not significantly differ at $\alpha = 0.05$.

This was most likely due to decreases in fine DWD, which had lower C:N ratios than did coarse DWD.

CONCLUSIONS

The initial restoration activities of overstory harvesting and midstory control added significant amounts of DWD and associated N and C content to the restoration area. Had hardwood timber been marketed, the additions of coarse DWD and hardwood DWD would probably have been less. The initial restoration fire removed a significant amount of DWD as well as C and N contained in the DWD. However, even after the initial restoration fire, there was still significantly more DWD and associated N and C on the shortleaf pine-bluestem plots than on the control. Due to the spatial heterogeneity in harvesting and fire that occurs in an area being restored to a shortleaf pine-bluestem ecosystem and because of our selection of only shortleaf pine-bluestem plots that received the full complement of restoration activities, changes of DWD in this study most likely overestimate the true changes that occurred over the 1,364-ha watershed.

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