CHANGES IN DOWN DEAD WOOD VOLUME ACROSS A CHRONOSEQUENCE OF SILVICULTURAL OPENINGS IN SOUTHERN INDIANA FORESTS

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Abstract: The volume and decay stages of down dead wood were evaluated across a chronosequence of 46 silvicultural openings and 10 uncut control stands to determine how down dead wood volume changes with stand development. Openings ranged in age from 8 to 26 years and were divided into three age groups: (1) < 12 years, (2) 12-16 years, and (3) > 16 years. Individual logs were assigned to 5 decay stages ranging from freshly fallen (stage 1) to near total decomposition (stage 5). The volumes of down dead wood in age groups 1 and 2 were greater than that of the control plots (80-100 years old) and decreased with increasing stand age. This trend held true for both large and small diameter material. Down dead wood from decay stages 1 and 5 was scarce in all opening age groups. Age group 1 and 2 plots contained significantly greater volumes of moderately decayed material (decay stages 3 and 4) than the control stands. These findings and those of other researchers suggest that after an initial post-cutting pulse of down dead wood, volume decreases steadily throughout the first 26 years after cutting and levels off at 80 years. Comparison with other research suggests that mid-successional stands, such as the control stands in this study, have greatly reduced down dead volume compared to old growth stands.

INTRODUCTION

Traditional studies of the effects of forest management on stand structure have emphasized vegetative structure, species composition, and species regeneration. The recent emphasis on ecosystem management has focused interest on how forest management affects forest components not traditionally studied, such as down dead wood (DDW) volume. However, studies of the effects of forest management on down dead wood volume in the Central Hardwood Region are lacking.

Research has shown the DDW is important in providing wildlife habitat, creating plant regeneration niches, and releasing nutrients through time. Studies suggest that down dead wood plays an important role the life cycles of numerous forest animals. Among small mammals, the family Soricidae (shrews) use DDW not only as protective cover, but as nesting sites and feeding areas (Harmon and others 1986). Rodents, such as red squirrel (*Tamiasciurus hudsonicus*), eastern gray squirrel (*Sciurus carolinensis*), and eastern chipmunk (*Tamias striatus*) also use woody debris for protective cover by hiding and nesting in hollow logs (Barkalow and Soots 1965, Burt and Grossenheider 1976).

Barnum and others (1992) found that white footed mice (*Peromyscus leucopus*) in a Maryland hardwood forest used logs as a means of traversing their home range. The mice avoided traveling on logs < 5 cm diameter, and preferred logs that were rotten or covered with moss, since large decayed logs may allow mice and other small mammals to make less noise when traveling, thereby reducing their risk of predation. In addition, the loosened bark of decaying logs offers thermal protection and nesting sites for salamanders and other species of amphibians and reptiles (Oliver 1955, Maser and Trappe 1986).

Down dead wood may play an important role in providing safe sites for woody species regeneration, although few if any eastern hardwood plant species are down dead wood obligates (Harmon and others 1986). Palmer (1987) found that while fallen logs and tip-up mounds comprised only 2.1% of forest floor area in a North Carolina old-growth forest, they were sites for 22.3% of tree species regeneration. Buckner and McCracken (1978) found that tip-up

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mounds created by fallen trees provide important regeneration niches for tulip poplar (*Liriodendron tulipifera* L.) in climax forest stands. While decomposing logs generally have lower nutrient levels than surrounding soil (Harmon and others 1986), they can provide regeneration sites free from over-shading by shrubs (Palmer 1987), buffer against extreme temperatures (Harmon et al. 1986), and protect seedlings from material moving down slope (Harmon and others 1986).

Organic material in the form of snags, fallen trees, and decaying logs exert considerable ecological control on a site for decades, or even centuries (Van Lear 1993). This influence results from the relatively slow decay rate of large DDW in hardwood forests. McFee and Stone (1966) observed that yellow birch (*Betula allephaniensis*) DDW persists for a century or more in mature northern forests. In an Indiana old-growth forest, MacMillan (1988) observed that *Quercus* logs decayed at a rate of 1.8% per year. Using this rate of decay, a 3 meter log with a diameter of 30 cm would require 39 years to lose 50% of its mass and 130 years to lose 90% of its mass. As DDW decomposes, nitrogen and other nutrients are sequestered by microorganisms and later become available for plant growth (MacMillan 1981). While the concentration of nutrients stored in woody material is low relative to that in leaves and fine roots, DDW may still be an important component of the biological and biochemical nutrient cycles.

Past studies in northern (Gore and Patterson 1986) and southern (McCarthy and Bailey 1994) Appalachian hardwood forests have examined DDW biomass in clearcuts, mature stands, and old-growth forests. These studies found that DDW biomass is highest in recent clearcuts, declines in mature forest, and increases in old-growth forests. Changes in total DDW volume, volume by decay stage, and volume by diameter class as a response to forest management have not been examined in the Central Hardwood Region.

We will address three main questions in this paper. First, how does total DDW volume vary with stand succession stage? Second, how does the DDW volume of different decay stages vary with stand age? Finally, how does the diameter of down dead wood vary with successional stage? We will examine how these parameters vary in 8-26 year-old silvicultural openings and 80-100 year-old mature stands. We will also compare the results of our study to those of an old-growth study also conducted in southern Indiana.

METHODS

Between 1994 and 1996 we sampled 46 silvicultural openings (commercial group selections and clearcuts) and 10 uncut control stands on the Pleasant Run Unit of Hoosier National Forest, Morgan-Monroe State Forest, and Yellowwood State Forest in southern Indiana. To remove site induced variation, all plots were located on *Fagus-Acer saccharum/Arisaema* mesic slopes as delineated by Van Kley and others (1994). We sampled three silvicultural opening age groups; (1) < 12 years, (2) 12-16 years; and (3) > 16 years. All totaled, we sampled 16 age group 1 plots, 19 age group 2 plots, 11 age group 3 plots, and 10 control plots (age group 4). Openings ranged from 8 to 26 years in age and from 0.1 to 11 ha in size. Due to public pressure, there has been no major cutting on the Hoosier National Forest since 1986. Therefore, our study did not include any openings less than 8 years in age. Control plots were all 80-100 years old.

Field Sampling

We estimated DDW volume within a 500m^2 plot placed within the silvicultural opening and control stand plots. We placed the plot within the center of smaller openings and randomly along the mesic slope in larger openings and control stands. Within each plot, we measured the midpoint diameter and length of all down dead wood 10 cm or greater in diameter.

Each DDW segment was visually classified into one of five decay stages (Thomas 1979). Decay stages ranged from 1 (freshly fallen) to 5 (near complete decomposition). If a piece of down dead wood contained more than one decay stage, we measured it as separate segments by decay stage.

Data preparation and analysis: Volume was determined in m^3 with the following equation for the volume of a cylinder:

$$[(\text{Midpoint diamter}/2)^2\pi] * \text{Segment length}$$

The mean DDW volume of each group class was calculated. Within each age group, volume was further subdivided by decay class and diameter class for comparison. Four diameter classes were compared: (1) 10-20 cm, (2) 21-30 cm, (3) 31-40 cm, and (4) > 40. All values were converted to a per hectare basis and compared between age groups using one-way Analysis of Variance and the Tukey test for pair-wise multiple comparisons. Changes in DDW volume through time was analyzed with regression analysis.

RESULTS

Our results show distinct differences in the total DDW volume of the silvicultural openings and control plots (Figure 1, Table 1). The two youngest age groups (1 and 2) contained greater volumes of down dead wood than the older groups 3 and 4. Plots located in openings (age groups 1-3) contained significantly greater volumes of DDW than the uncut control plots (group 4, Table 1). Age group 2 plots contained the greatest amount of stage 4 down dead wood, suggesting that at least 12-16 years were required for logs to decay to this stage. Since we lacked preharvest DDW data, the preharvest DDW volume of these plots is unknown. However, our age class 4 data suggest that the DDW volume in precut stands was probably relatively low. Therefore, most of the DDW observed in our plots was probably post-harvest in origin. The volume of decay stage 4 DDW was greatly reduced in age group 3 plots and further reduced in age group 4 (control) plots. Decay stage 3 comprised the vast majority of DDW volume across all age groups. This suggests that decay stage 3 may need to be subdivided into several smaller stages to better assess down dead wood dynamics. Decay stage 5 DDW was nearly absent from plots of all four age groups, and decay stage 1 was absent from all four age groups.

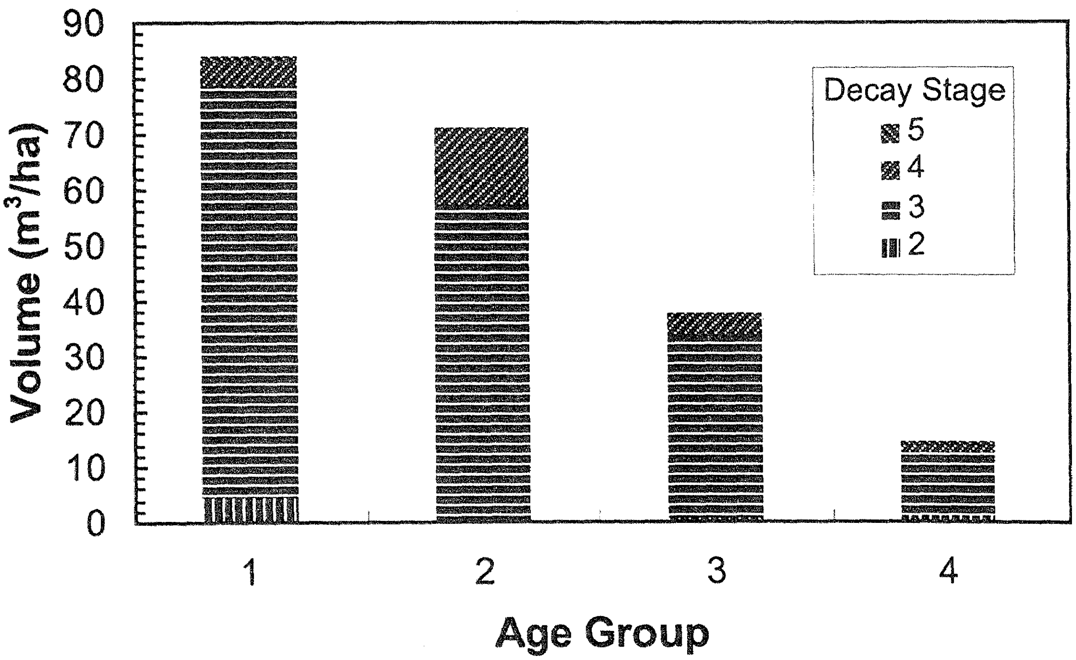

Figure 1. Down dead wood volume of all age groups by decay stage. Age group (1) < 12 years, (2) 12-16 years, (3) >16 years and (4) 80-100 years (control plots). Decay stage 1 is the least decayed and decay stage 5 is the most decayed. No decay stage 1 logs were found on the study plots.

Table 1. Comparison of mean volume (m^3/ha) by decay stage for all age groups. Age group (1) < 12 years, age group (2) 12-16 years, (3) >16 years, and (4) 80-100 year old control stands. Decay stage 1 is the least decayed and decay stage 5 is the most decayed. No decay stage 1 logs were found on the study plots. Means within a row not superscripted with the same letter are significantly different ($P < 0.05$).

	Age Group 1		Age Group 2		Age Group 3		Age Group 4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Decay Stage 2	4.08[a]	12.47	0.04[a]	0.11	0.50[a]	1.21	0.75[a]	1.59
Decay Stage 3	74.27[a]	39.69	57.25[ab]	39.77	33.37[bc]	24.40	11.60[c]	11.80
Decay Stage 4	4.62[b]	4.54	13.44[a]	8.99	3.93[b]	3.51	2.06[b]	2.70
Decay Stage 5	0.67[a]	1.88	0.05[a]	0.14	0.00[a]	0.00	0.27[a]	0.86
Total	83.64[a]	33.61	70.77[ab]	42.40	37.80[b]	24.71	14.71[c]	11.29

Our results also suggest that the rate of change in down dead wood volume is not constant across age classes (Figure 2). Regression analysis with a negative exponential model suggested that volume decreased rapidly with increasing stand age, and leveled off in 80-100 year stands. Following harvest, smaller diameter slash decays quickly, resulting in a rapid decrease in DDW volume. Our study contained only 8-26 year old openings and 80-100 year stands. Additional sampling of 0-8 year old and 30-70 year old stands is needed to help clarify changes in DDW volume in these forests.

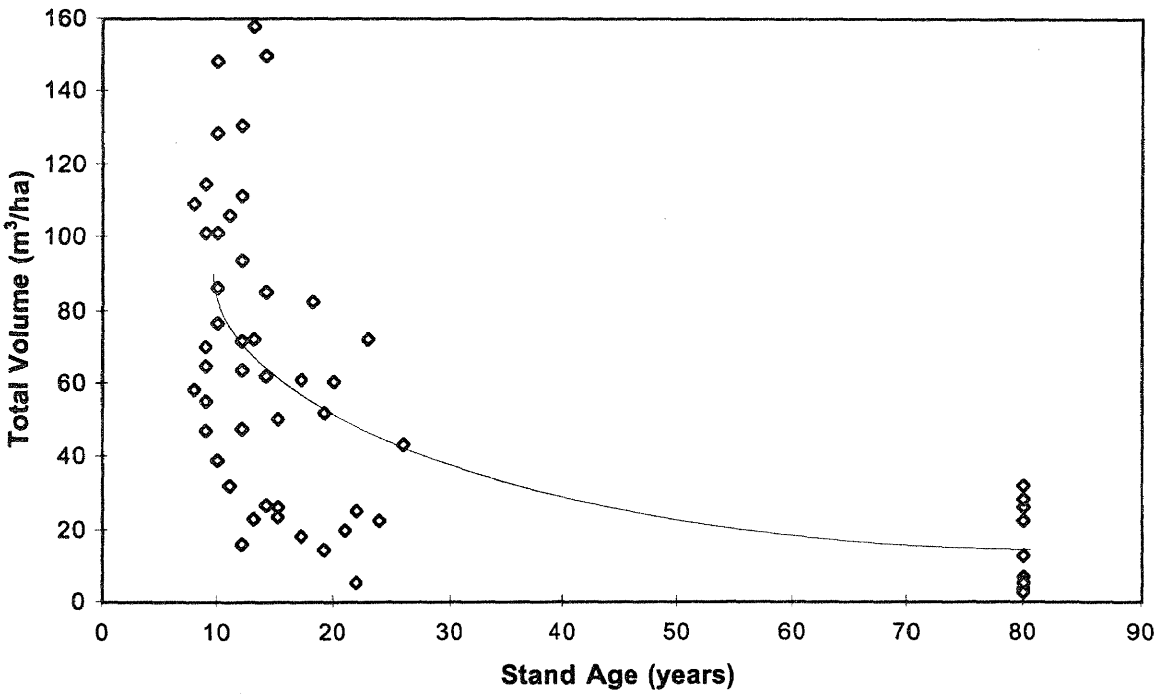

Figure 2. Negative exponential model of stand age vs. total down dead wood volume. Total volume = $146.62e^{0.06Age}$. $R^2 = 0.67$, Adjusted $R^2 = 0.45$, $P < 0.001$.

The volume of DDW across the four age groups varied by diameter class (Figure 3). The older age groups (3 and 4) had much lower volumes of DDW for all 4 diameter classes. Age group 1 plots contained significantly greater volumes of all four diameter classes of DDW than age group 4 plots (Table 2). Generally, the volume of DDW from all four diameter classes decreased with increasing stand age. The control plots (age group 4) were almost entirely lacking in larger diameter DDW, suggesting that most DDW on the sites was from smaller diameter fallen branches, instead of whole fallen trees.

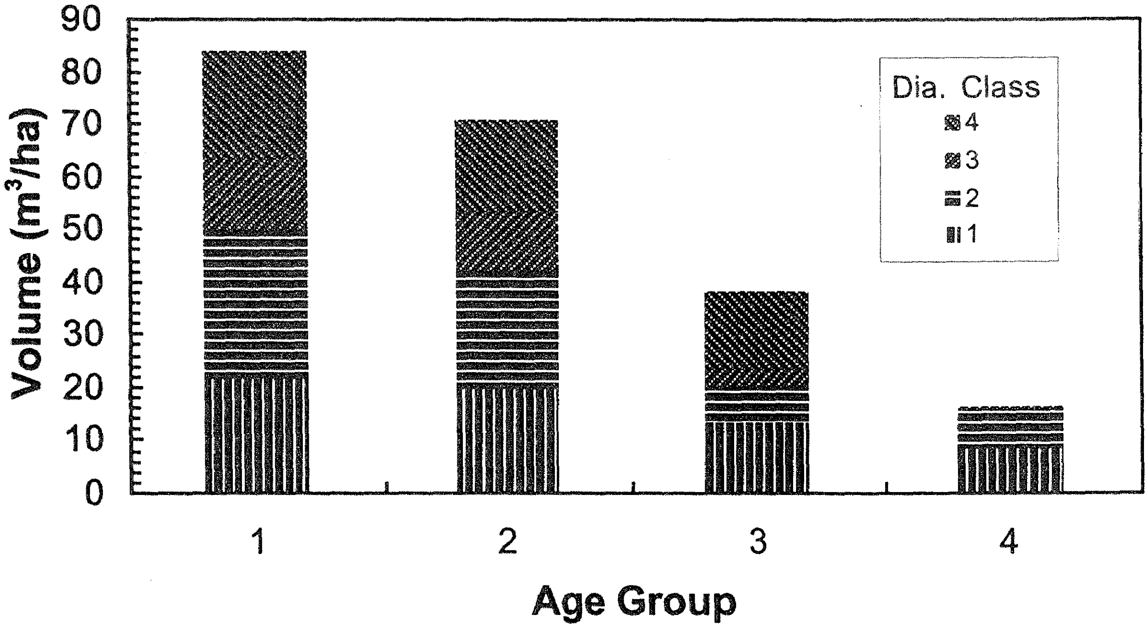

Figure 3. Down dead wood volume of all age groups by diameter class. Age group (1) < 12 years, age group (2) 12-16 years, and (3) >16 years. Diameter class (1) 10-20 cm, (2) 21-30 cm, (3) 31-40 cm, and (4) > 40cm.

Table 2. Comparison of mean volume (m^3/ha) by diameter class for all age groups. Age group (1) < 12 years, (2) 12-16 years, (3) >16 years, and (4) 80-100 year old control stands. Diameter class (1) 10-20 cm, (2) 21-30 cm, (3) 31-40 cm, and (4) > 40cm. Means within a row not superscripted with the same letter are significantly different ($P < 0.05$).

	Age Group 1		Age Group 2		Age Group 3		Age Group 4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Diameter Class 1	21.40^{a}	11.32	19.58^{a}	13.15	12.92^{ab}	10.93	7.05^{b}	4.44
Diameter Class 2	28.02^{a}	20.25	22.30^{ab}	18.43	7.05^{b}	8.17	7.20^{b}	8.05
Diameter Class 3	13.86^{a}	14.64	10.95^{ab}	14.51	3.54^{ab}	6.18	0.46^{b}	0.86
Diameter Class 4	20.35^{a}	23.18	17.94^{a}	19.18	14.29^{a}	22.41	0.00^{a}	0.00

DISCUSSION

The results of our study exhibit trends similar to studies conducted in other parts of the eastern hardwood forest. Gore and Patterson (1986) also observed sharp decreases in down dead wood following harvest in New Hampshire hardwood forests and McCarthy and Bailey (1994) observed similar results in southern Appalachian forests. Gore and Patterson (1986) observed much lower down dead wood volumes in 50 year stands. The high volume of DDW present in recent silvicultural openings results from the addition of post-harvest slash and stumps. While our study lacked data from openings 1-8 years in age, these younger openings tend to contain even greater volumes of less-decayed post-harvest slash (McCarthy and Bailey 1994). The majority of this input is of relatively small diameter and has a large surface area that leads to rapid decomposition. Once the majority of this small diameter material decays, a lag period occurs because the small volume of down dead wood input from the developing stand is less than the loss from decomposition (Figure 2). We observed little input of DDW from young freshly fallen trees in age classes 1-3. While mortality does occur in these developing stands, most dead trees are less than 10 cm diameter and therefore were not measured in this study. This volume of DDW is probably negligible compared to the volume of post-harvest slash.

The 80-100 year old stands (age group 4) are in the understory reinitiation stage as defined by Oliver (1981). At this stage of stand development, there is little overstory mortality, and therefore little input of DDW in the form of dead trees. Age class 4 plots (80-100 years old) had a low mean relative density of dead trees greater than 30 cm dbh (relative density = 3.5, standard error = 1.87). This low mortality explains the generally low overall down dead wood volume in these stands and the low volume of highly decayed and large diameter dead wood. We expect that canopy trees will begin to die as these stands develop over time (McGee 1984).

Comparison of our data to those collected from an Indiana old-growth forest revealed several important trends. Spetich (1995) found a total down dead wood volume of 74.2 m^3/ha in Donaldson's Woods, an old-growth forest remnant in southern Indiana. Age group 1 plots in our study contained a greater volume of down dead wood (83.6 m^3/ha) than Donaldson's Woods. However, Donaldson's Woods exhibited a greater volume of DDW than either age group 2 (70.8 m^3/ha) or age group 3 (37.8 m^3/ha) plots. In addition, the down dead wood volume of Donaldson's Woods was approximately three times greater than that of our age group 4 (control) plots (15.8 m^3/ha).

The openings and control stands sampled in this study generally exhibited lower volumes of logs by decay stage than Donaldson's Woods. Decay stage 5 down dead wood volume was much greater in Donaldson's Woods (6.5 m^3/ha) than in any of the ages classes sampled in this study (maximum = 0.7 m^3/ha for age class 1). Donaldson's Woods also exhibited a greater volume of decay stage 4 down dead material (11.4 m^3/ha) than age groups 1, 3, and 4 (4.6 m^3/ha, 3.9 m^3/ha, and 1.9 m^3/ha, respectively). Age group 2 plots contained a greater volume of decay stage 4 down dead wood (13.4 m^3/ha) than Donaldson's Woods. This greater value was probably because of the decaying of post-harvest slash. In our study, decay stage 4 material had all but disappeared in age group 3 openings. This decay stage 4 material did not appear in these openings as decay stage 5 material. A possible explanation for the lack of decay stage 5 material is that the large volume of post-harvest slash may have decayed so quickly that it was not detected as decay stage 5 material. Spetich (1995) also observed a much greater volume of diameter class 4 (> 40 cm diameter) down dead wood. Age group 1 openings contained 20.4 m^3/ha of diameter class 4 down dead wood, compared to 43.5 m^3/ha for Donaldson's Woods. Age group 4 (control) plots contained no logs over 40 cm in diameter.

The large volume of highly decayed large diameter DDW has been offered as a characteristic of old-growth forests (Parker 1989, Spetich 1995). While old-growth forests in southern Indiana consist of small scattered fragments, the existance of forests across the landscape that contain some old-growth characteristics may be important in managing biodiversity. In addition, highly decayed down wood of large diameter has been found to be very important habitat for numerous animal species (Oliver 1955, Harmon and others 1986, Maser and Trappe 1986, Barnum and others 1992). In light of these studies, it appears that the mature 80-100 year forest matrix of southern Indiana may not provide optimum habitat for these species. More research is needed in the more recently cut stands, which provide greater volumes of larger diameter DDW, to determine their suitability for these species. If continued research supports the importance of down dead wood in the Central Hardwood Forest Region, management techniques may need to be modified to better allow for this forest component.

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