Stand Structure

COMPARISON OF ECOLOGICAL CHARACTERISTICS OF THREE REMNANT OLD-GROWTH WOODLOTS IN BELMONT COUNTY, OHIO

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Abstract—Dysart Woods, North and South, and Collins Woods are small remnant old-growth stands with an old-growth cohort that has a significant oak component (> 50 percent) and includes mixed mesophytic species, such as yellow-poplar and white ash. All three stands are transitional to a northern hardwood type (sugar maple/American beech). Collins Woods is bounded on two sides by a surface mine highwall (20-60 feet high), and on another side by a reclaimed surface mine. Dysart Woods's stands are surrounded by second-growth hardwood forest and agricultural fields. We sampled trees larger than 2 inches dbh and measured woody regeneration. In addition, we conducted a 100 percent inventory of all large trees in the old-growth cohort. We found all three stands to be remarkably similar. For example, the basal area of trees at Collins Woods was 123.3 feet square/acre as compared to 101.2 and 102.5 for the South and North Woods at Dysart Woods. The oak component of the old-growth cohort at Collins Woods was 50.3 percent. For Dysart South and North, oak composition was 61.7 percent and 60.7 percent. Yellow-poplar made up 10.3 percent and 9.8 percent of Dysart South and North and 21 percent of the old-growth cohort at Collins Woods. The average dbh of old-growth trees at Collins Woods was 34.4 inches compared to 33.9 inches and 35.1 inches for the Dysart stands. Collins Woods, like Dysart Woods, had virtually no oak regeneration and the overall diameter distribution indicated a reverse J-shaped curve for all three stands with sugar maple predominating in the smaller diameter classes, and oaks and yellow-poplar in the larger classes. The species diversity of Collins Woods was slightly less than that at Dysart Woods, when expressed as Shannon's H', but about the same in species richness. Measures of health and vigor of the stands were very comparable. The estimated overall mortality rate for old-growth trees at Collins Woods was 1.49 percent/year as compared to 1.56 percent and 1.85 percent at the two stands at Dysart. The tree vigor rating, using the USDA, Forest Service vigor codes, (1 as vigorous and 7 as dead), averaged 2.05, 1.94 and 2.37 for Dysart South and North and Collins Woods, respectively.

The degree of similarity among the three stands suggests that they may have been part of a large contiguous forest. In spite of their different histories, the successional changes in these three stands have produced remarkably similar results. These stands represent what many present-day central hardwood forests could look like in about 200 years, if left relatively undisturbed.

INTRODUCTION

Old-growth central hardwood forests are interesting and valuable both from a natural history standpoint as well as examples of the successional process that affects them. The dynamics of these remnant old-growth stands provide clues as to the potential fate of many present-day stands that, like most old-growth remnants, developed from disturbances such as fire. The present study documents the current condition of three remnant old-growth stands in east-central Ohio. The composition of the old-growth cohort (the largest and oldest trees) is suggestive of a disturbance origin, but the gradual replacement of these stands by shade tolerant climax species is an on-going process that is documented in this study. These case studies, in addition to illustrating the process of succession, provide insight into the timing of changes in undisturbed forests.

DESCRIPTION OF THE SITE

The stands at Dysart Woods are old-growth remnants located approximately 5 miles south of St. Clairsville, Ohio, off state Route 9 and are spatially separated by about 1000 feet. The stands at Dysart Woods are surrounded by second-growth hardwoods except for one side of the North Woods, which is an agricultural meadow. Collins Woods is about 13 miles northwest of Dysart Woods, in Belmont County, Ohio, about 3 miles northwest of Morristown. This woodlot is surrounded on 3 sides by former surface mining activity and has highwalls of approximately 60 feet high or higher on the north and east borders. Mining operations that created these highwalls were conducted in the early to mid 1970s. All three woodlots are remnant old-growth stands that are estimated to be in the age range of approximately 300 years. Collins Woods has been purchased by The Nature Conservancy and is preserved as an example of what was most likely an extensive forest cover type about the time of European settlement of eastern Ohio while Dysart Woods is managed by Ohio University. Stands like Collins and Dysart Woods probably owe their origin to disturbance by fire which favors the regeneration of oaks and shade-intolerant species like yellow-poplar (*Liriodendron tulipifera*).

METHODS

The extent of the old-growth forests in the three stands was determined as the area inside the drip line of the area containing large old trees. Dysart North was found to be approximately 15 acres and the South Woods is about 13.5 acres in size while Collins Woods was 8.3 acres.

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A sampling grid was established over each stand in order to locate approximately 16 plots per stand. At each sample location a 0.1-acre circular plot was established. At plot center, a 10 BAF prism was used to estimate the basal area. The plot was classified as to the Society of American Foresters' cover type present (Eyre 1980). In addition, the slope position, aspect and slope percent were determined. All trees 2 inches dbh and larger were measured in the 0.1-acre plots. For each tree, its species, crown class, live crown ratio, USFS vigor rating[2], expected longevity and total height was evaluated and recorded.

In conjunction with the 0.1-acre plots, two 6-foot-radius understory plots were established, one at plot center and another midway between plot center and the perimeter of the 0.1-acre plot on a random azimuth. The percent of the regeneration plot covered by all vegetation (broken down by percent coverage of woody, herbaceous and fern) was estimated for each 6-foot-radius plot. In addition, all tree seedlings (< 2 inches dbh) in the plots were counted by species and size class (< 6 inches, 6 inches-4 feet, > 4 feet).

Finally all large trees in the "old-growth cohort" (27.5 inches dbh and larger) in each stand were measured (100 percent sample). This size limit was selected subjectively because it seemed to include all the large old trees (particularly oaks and yellow-poplar). Each tree was numbered and dbh, total height, live crown ratio, crown radius, vigor class and expected longevity (estimated as < 10 years, 10-20 years or > 20 years) was recorded. In addition to the large live trees, large standing dead trees were also measured by species for dbh and estimated years dead (based on bark and limb condition). All the large trees were located with laser survey equipment to determine their precise location within the stand so that they could be mapped and plotted.

Tree data from 0.1-acre plots and 100 percent samples were combined to produce the diameter distribution by species (number of trees by diameter). For the large trees (> 27.5 inches dbh), only the 100 percent sample data were used.

Seedling data were compiled by species to document the numbers of seedlings by species and size class, which should indicate the regeneration potential of the various species.

Data from the various samples were used to compute importance values of the tree species. Importance value is the sum of relative density, relative frequency and relative dominance. These are obtained as the number of stems of a species relative to the total number of stems, the number of plots containing the species relative to the total number of plots and the basal area of a species relative to the total basal area. This information was compared to importance values reported in previous studies of Dysart Woods.

We used data for total number of species present and total individuals per species to develop measures of diversity in each stand (species richness and Shannon-Weiner index). These measures could be used to compare the diversity of the three stands and to compare them with other forests.

Finally, the data from standing dead trees and estimated longevity of large live trees were used to estimate the rate of mortality (percent per decade). This was done by averaging the class midpoints for estimated longevity for old-growth trees (e.g., 0-10 years = 5 years) and doing the same for estimated years dead for large standing dead trees. Thus, two estimates of rate of mortality were obtained (one based on expected longevity of live old-growth trees and the other based on standing dead trees). These two estimates were then averaged to obtain the value that was presented in subsequent discussions.

RESULTS

Overall

Collins Woods was very similar to the stands at Dysart Woods (Table 1) with an old-growth cohort of oaks and mesophytic hardwoods that is being gradually replaced by northern hardwoods [American beech (*Fagus grandifolia*)/ sugar maple (*Acer saccharum*)]. There were a few large stumps at Collins Woods that indicated limited selective logging had occurred in the past, similar to Dysart Woods, but in general most of the old-growth trees were left. The most unique feature of Collins Woods was the fact that the area had been circumscribed by contour surface mining, and along one side (approximately 800 feet), the highwall remained intact while on another side reclamation by back-filling, recontouring and seeding had been done.

The forested site at Collins Woods was an upper slope, primarily on a west-facing aspect with an average slope inclination of about 18 percent. West-facing aspects and upper slope positions, as occurred at Collins Woods, are typically associated with poorer growing sites (Hicks and Frank 1984). Dysart woods had a wider variety of aspects and slope positions, some of which are associated with better quality sites. The diameter distribution of trees at Collins Woods was a reverse J-shaped distribution, similar to the Dysart Woods stands (Figs. 1-3).

Regeneration

Like Dysart Woods, Collins Woods showed little or no oak regeneration—no oak seedlings were found in our survey. As with the Dysart stands, Collins Woods had abundant sugar maple, beech and elm (*Ulmus* spp.) regeneration (Figs. 4, 5). Unlike the Dysart stands, elms at Collins Woods have not grown into the small sapling-size class. Perhaps the higher overstory density at Collins Woods, as reflected by higher basal area, is responsible for shading out the elms before they reach sapling size. A variety of other woody regeneration occurred at Collins Woods, including bitternut hickory (*Carya cordiformis*), hophornbeam (*Ostrya virginiana*) and spicebush (*Lindera benzoin*). Seedling numbers at Collins Woods resembled more closely the North Woods at Dysart Woods, although Collins Woods had fewer maples and beech seedlings than

[2] Vigor codes: 1-healthy/vigorous, 2-slight dieback, 3-moderate dieback, 4-slight decline, 6-moderate decline, 6-severe decline, 7-dead.

Table 1—Summary data for Dysart (North and South) and Collins Woods

Variable	Dysart Woods: South Woods	Dysart Woods: North Woods	Collins Woods
Basal area			
(live)(sq. ft./ac.)	101.25	102.50	123.30
SAF cover (pct. of plots)			
Type 54[a]	87.50	81.25	27.80
Type 60	0	12.50	55.50
Type 27	12.50	6.25	16.70
Slope percent (average)	16.75	16.40	17.80
Aspect class (pct. of plots)			
1 (N)	0	25.00	0
2 (NE)	0	0	0
3 (E)	31.25	0	0
4 (SE)	6.25	6.25	0
5 (S)	12.50	25.00	0
6 (SW)	37.50	.625	11.11
7 (W)	12.50	0	83.33
8 (NW)	0	37.50	5.55
Slope position (pct. of plots)			
Ridge	0	6.25	0
Upper slope	31.25	43.75	38.90
Lower slope	37.50	37.50	61.10
Hollow/bottom	31.25	12.50	0

[a] SAF cover type: 54=yellow-poplar; 60=white oak; 27=northern red oak.

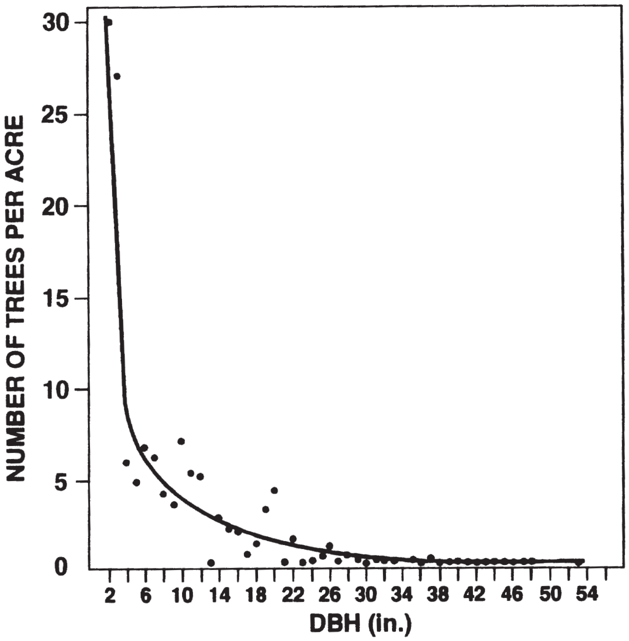

Figure 1—Diameter distribution of all trees > 2 inches dbh, South Woods, Dysart Woods.

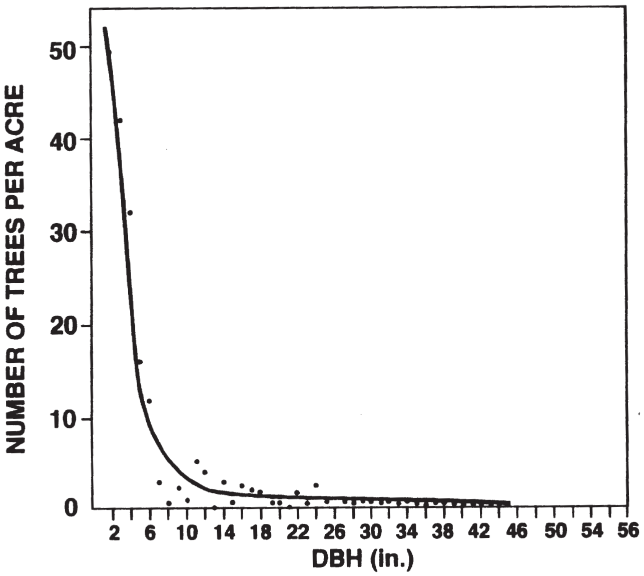

Figure 2—Diameter distribution of all trees > 2 inches dbh, North Woods, Dysart Woods.

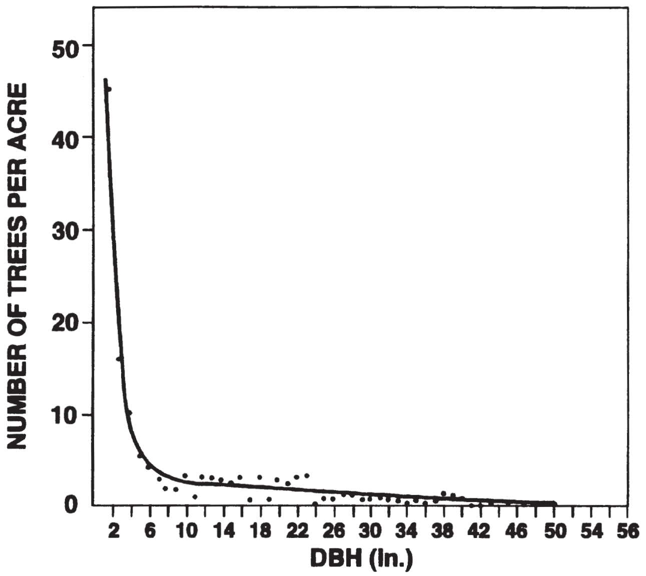

Figure 3—Diameter distribution of all trees > 2 inches dbh, Collins Woods.

either of the Dysart stands. This may reflect the effect of higher basal area and greater shade at Collins Woods or possibly other factors such as a higher deer density.

Overstory

Almost 70 percent of the overstory plots at Collins Woods were classed as northern hardwoods types (beech/maple and sugar maple), whereas the majority of plots at Dysart Woods were classed as mesophytic hardwoods. The large number of beech and sugar maple at Collins Woods that are in the diameter range of 10 to 27 inches is the basis for classifying the Collins Woods plots as northern hardwoods. Of the approximately 35 trees per acre in the 10-27-inch diameter range, 33 of them were beech or maples.

The importance values of species at Collins Woods (relative density + relative dominance + relative abundance) were very similar to those of Dysart stands. For example, sugar maple had an importance value at Collins Woods of 187.5 (Table 2). Its importance values for the South Woods and North Woods at Dysart Woods were 176.6 and 162.9, respectively. The ranking of importance value at Collins Woods was sugar maple, American beech,

Table 2—Relative densities (RD), relative frequencies (RF), relative dominance (RDo) and importance values (IV) for tree species sampled at Dysart and Collins Woods

	Dysart Woods														
	South Woods					North Woods					Collins Woods				
Species	RD	RF	RDo	IV	Rank	RD	RF	RDo	IV	Rank	RD	RF	RDo	IV	Rank
Sugar maple	46.95	100	29.63	176.58	1	55.04	90	17.89	162.93	1	69	100	18.5	187.5	1
American beech	14.24	70	23.04	107.28	2	13.51	80	29.27	122.78	2	15	67	15.1	85.6	2
Elms	17.37	50	3.29	70.66	3	6.65	40	3.25	49.90	4	2	22	3.6	27.6	5
Black cherry	6.37	40	0	46.51	4	4.11	40	0	44.11	6	1	11	0.1	12.1	13
White oak	3.06	20	19.75	42.81	5	1.72	40	26.02	67.74	3	1	17	15.6	33.6	4
White ash	3.24	30	1.65	34.89	6	1.61	20	3.25	24.86	9	1	11	3.5	15.5	10
Blackgum	2.24	20	4.94	27.18	7	1.87	20	1.63	23.50	10	1	11	0.4	12.4	12
Yellow-poplar	1.20	20	3.29	24.49	8	2.08	10	4.88	16.96	13	3	17	2.5	22.5	7
Northern red oak	1.78	10	1.64	13.42	9	1.61	20	4.88	26.49	8	2	39	25.0	66.0	3
Shagbark/shell Bark/bitternut Hickory	1.16	10	1.65	12.81	10	1.51	20	1.63	23.14	11	2	11	1.3	14.3	11
Flowering dogwood	0.72	10	0	10.72	11	4.26	30	0	34.26	7	1	6	0.1	7.1	15
Red maple	1.27	0	6.58	7.85	12	1.72	40	3.25	44.97	5	2	17	3.3	22.3	8
Black walnut	<0.01	0	0	<0.01	13	—-	—	—-	—-		—	—-	—-	—-	
Blue beech/ Hophornbeam	—-	—-	—-	—-		3.12	20	0	23.12	12	1	22	0.2	23.2	6
Serviceberry	—-	—-	—-	—-		0.32	10	0	10.32	15	—	—-	—-	—-	
Sourwood	—-	—-	—-	—-		—-	—	—-	—-		—	—-	—-	—-	
Hackberry	—-	—-	—-	—-		0.32	10	0	10.32	15	—	—-	—-	—-	
Basswood	—-	—-	—-	—-		0.52	10	0	10.52	14	—	—-	—-	—-	
Black oak	—-	—-	—-	—-		—-	—	—-	—-		2	11	6.0	19.0	9
Sassafras	—-	—-	—-	—-		—-	—	—-	—-		1	6	1.1	8.1	14

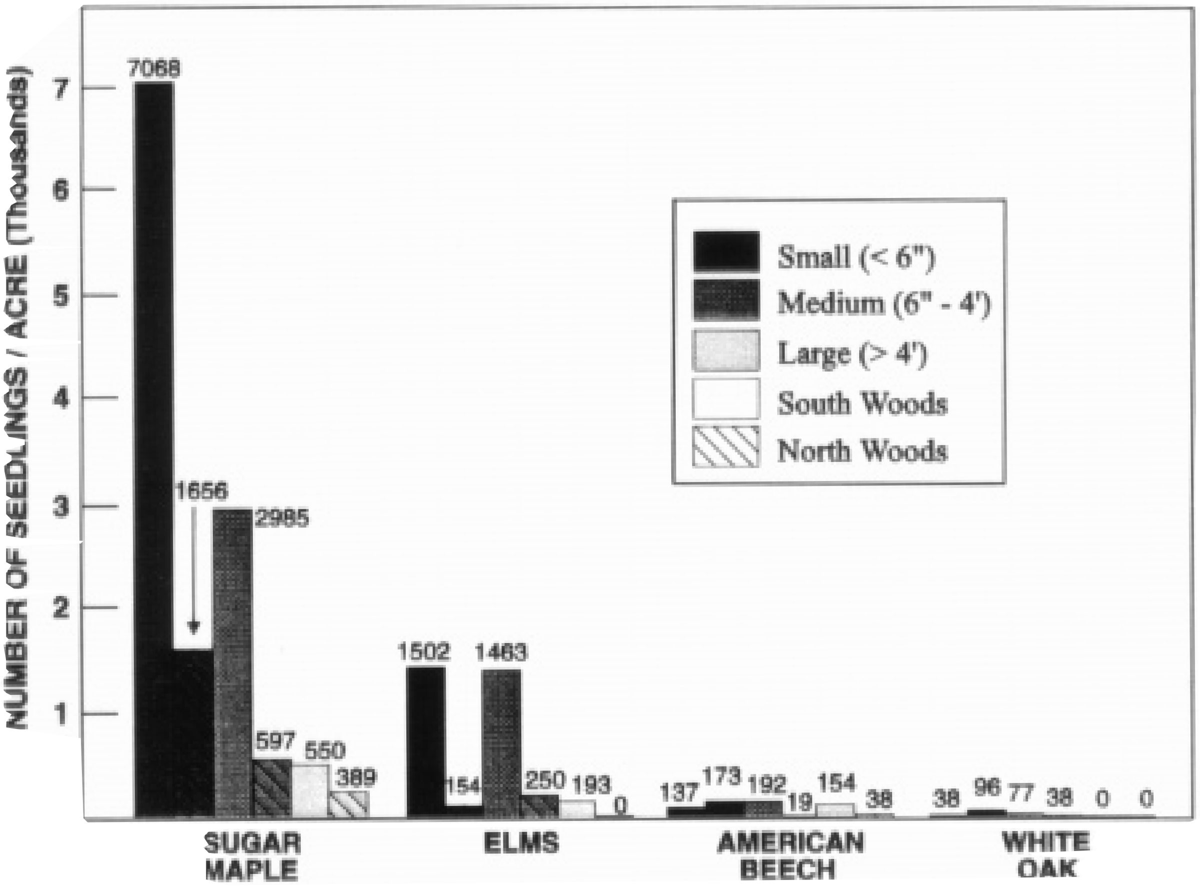

Figure 4—Number of seedlings per acre by species and height class for the North and South Woods, Dysart Woods.

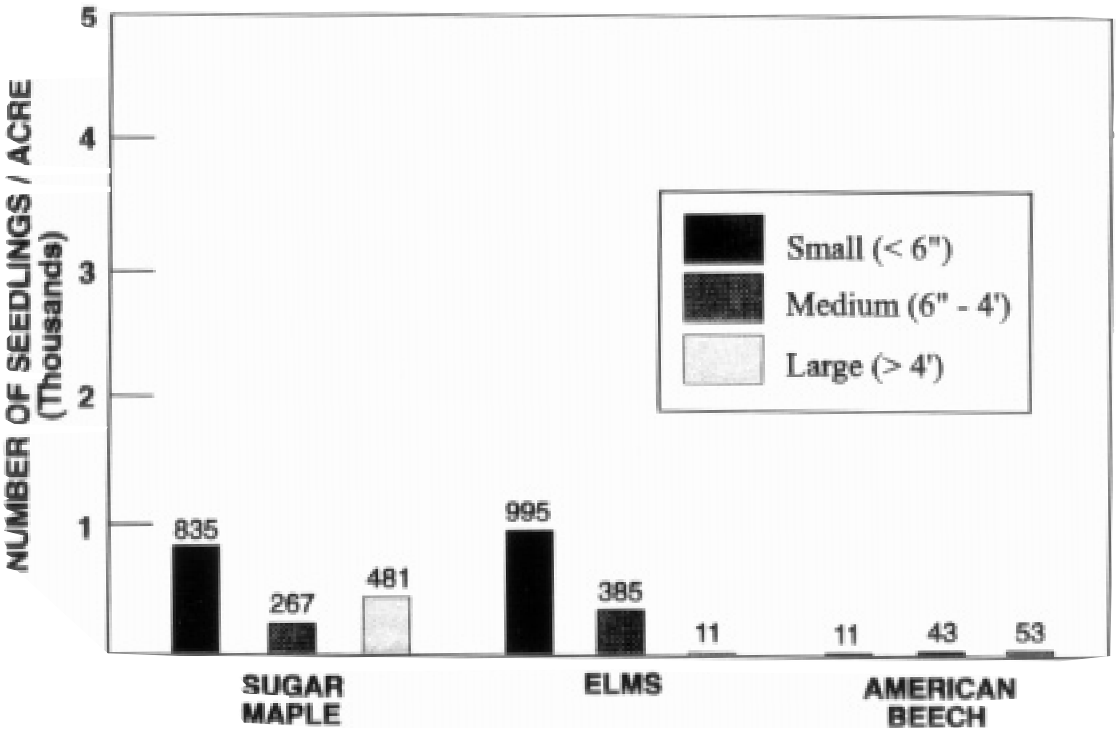

Figure 5—Number of seedlings per acre by species and height class for Collins Woods.

northern red oak (*Quercus rubra*), white oak (*Quercus alba*) and elm, whereas 4 of the top 5 species at Dysart North and South were the same, and sugar maple and American beech were the first- and second-ranked species at all these stands.

Previous studies performed at Dysart Woods (Benner 1971, Lafer 1968, Smith 1979) reported importance values. Figures 6 and 7 show the change over time of the relative ranking of species by importance values. In general, sugar maples and beech were ranked 1 and 2, while oak declined and elms increased. The species diversity at Collins Woods, as measured by Shannon's H' was lower than that of Dysart Woods (Table 3). But diversity based on species richness was very similar among the three stands.

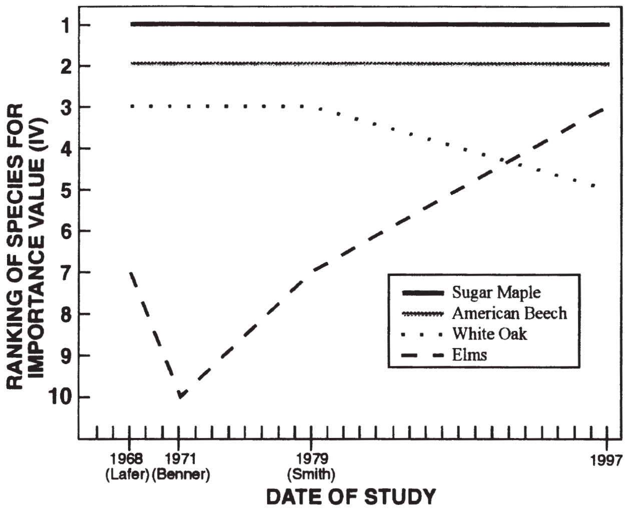

Figure 6—Relative ranking of species by importance values over 31 years for the South Woods, Dysart Woods.

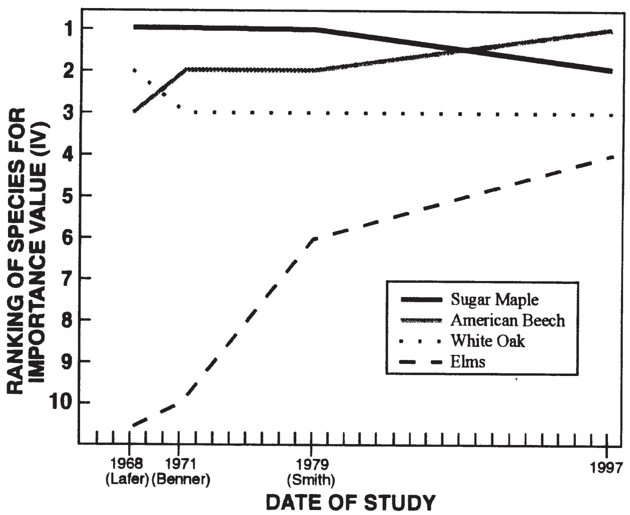

Figure 7—Relative ranking of species by importance values over 31 years for the North Woods, Dysart Woods.

Old-Growth

There was an average of 9.7 large trees per acre at Collins Woods as compared to 7.9 and 8.0 at Dysart South and North (Table 4). The average dbh of old-growth trees was very similar among all three stands but trees at Dysart Woods were, on average, about 15-20 feet taller, probably indicating an inherently better overall growing site at Dysart Woods. This difference in height is not related to any effect of mining over the past 30 years since old-growth trees, even on the best of sites, grow very little in height. For example, growth curves for yellow-poplar presented by Carmean and others (1989) indicate that trees on average sites grow about two feet per year. By age 100, yellow-poplar trees on these sites typically grow less than one foot per year, and by 250-300 years of age, trees have virtually ceased height growth due to the natural slowing with age. Thus the greater height at Dysart Woods most likely resulted from a steeper growth curve during the first 100 years of life rather than any occurrences in recent years. Collins Woods had a higher proportion of northern red oak and yellow-poplar and a lower proportion of white oak.

Comparing measures of forest health and vigor for the three stands, we found that they were very comparable. The overall rate of mortality (percent per year) for the large trees at Collins Woods was estimated to be 1.49 percent, whereas Dysart South and North were estimated to be 1.85 percent and 1.56 percent, respectively. The USDA, Forest Service vigor code averaged 2.37 (1 being most vigorous and 7 being dead) for Collins Woods (Table 5). The two stands at Dysart Woods averaged 1.94 and 2.05.

DISCUSSION AND CONCLUSIONS

The old-growth component of the forest at Collins and Dysart Woods regenerated in the late 17th or early 18th century. Many authors have linked oak regeneration to fire (Abrams 1992). It is acknowledged by a number of writers (Curtis 1959, Pallardy and others 1988) that presettlement fires, either caused by lightning or set by native people, were an important disturbance that led to the regeneration of oaks over vast areas. Native American populations were decimated by disease that was introduced by early European explorers which led to a lower incidence of fire. In the absence of fire, oaks regenerate poorly, mostly because they are unable to compete in the understory of established stands (Norwacki and others 1990).

Dysart and Collins Woods are old-growth "islands" that have persisted in spite of landscape changes, such as reduced fire, land clearing, subsistence farming and logging, that occurred throughout the central hardwood region.

The diameter distribution and structure of the stands gives important clues as to the origin of the various cohorts present. For example, the white oaks have a diameter distribution typical of an even-age stand in spite of the fact that the aggregate distribution of all species has the reverse J-shaped distribution typical of all-age stands. Stout (1991) observed a similar phenomenon on a much wider scale that characterizes so-called "transition" stands, currently covering a large area in the Allegheny Plateau of

Table 3—Species diversity [species richness and Shannon-Weiner Index (H')] for Collins Woods, Dysart Woods and other old-growth central hardwood forests

Forest	Shannon-Weiner H' $(H'=-1\sum_{i=1}^{n} pi \ln pi)$	Species richness No./0.1 ac.	Species richness Total no.	Reference
Collins Woods	1.25	—-	15	Present study
Dysart, South	1.69	4.0	13	Present study
Dysart, North	1.72	5.8	18	DeSelm and Sherman (1982)
Savage Gulf (TN)	3.70	—-	22	Monk (1967)
Beech-white oak	2.77	—-	—	Bryant (1987)
Ault Park (OH)	2.83	—-	21	Bryant (1987)
California Woods (OH)	3.11	—-	20	Bryant (1987)
Caldwell Park (OH)	3.35	—-	21	Bryant (1987)
Winton Woods (OH)	2.18	—-	15	Bryant (1987)
Bowles Woods (OH)	1.94	—-	15	Bryant (1987)
Melborne Forest (OH)	3.07	—-	17	Bryant (1987)
Davis-Purdue (IN)	2.50	—-	30	Ward and Parker (1987)

Table 4—Summary data for attributes of live large trees (> 27.5 inches d.b.h.) for Dysart Woods (South and North) and Collins Woods

	Dysart Woods[a]											
	South Woods				North Woods				Collins Woods[a]			
Species	Total no. trees	RD[b]	D.b.h.	Ht.	Total no. trees	RD[b]	D.b.h.	Ht.	Total no. trees	RD[b]	D.b.h.	Ht.
			In.	Ft.			In.	Ft.			In.	Ft.
White oak	55	51.4	35.3	120.9	59	48.4	37.5	121.4	18	22.2	36.9	100.8
Northern red oak	11	10.3	36.2	123.5	13	10.6	38.1	122.6	20	24.8	37.3	108.6
Black oak	0	0	—	—	2	1.7	29.0	117.0	3	3.7	31.7	102.0
Sugar maple	8	7.5	29.8	121.3	3	2.5	32.3	116.7	7	8.6	29.6	104.6
Red maple	1	0.9	32.0	121.3	1	0.8	32.0	88.0	0	0	—	—
American beech	18	16.8	30.9	101.0	17	13.9	30.0	106.0	12	14.8	29.9	98.9
Yellow-poplar	11	10.3	31.2	115.0	12	9.8	34.2	134.7	17	21.0	34.7	110.7
White ash	3	2.8	34.7	136.4	12	9.8	31.9	123.1	1	1.2	29.0	110.0
Blackgum	0	0	—	—	1	0.8	28.0	120.0	0	0	—	—
Shagbark hickory	0	0	—	—	2	1.7	30.5	128.0	0	0	—	—
Elm	0	0	—	—	0	0	—	—	3	3.7	32.7	108.3
Total/overall	107[c]	100	33.9	122.3	122[c]	100	35.1	120.5	81[c]	100	34.4	105.1

[a] All figures are averages.
[b] Relative density (percent).
[c] Number of large trees per acre—South Woods @ 13.43 ac. = 7.97 large trees/ac., North Woods @ 15.18 ac. = 8.04 large trees/ac., and Collins Woods @ 8.36 ac. = 9.69 large trees/ac.

Table 5—Health/vigor indices for Dysart and Collins Woods

Health/vigor indices	Dysart, North	Dysart, South	Collins Woods
Estimated tree mortality[a] (pct./yr.)	1.56	1.85	1.49
Average[b] USFS vigor rating	2.05	1.94	2.37

[a] Based on all trees in the old-growth cohort.
[b] Vigor assessed on a scale of 1-7, where 1=healthy and 7=dead.

Pennsylvania. These stands contain representatives of oak-hickory as well as northern hardwood types, and the oak component is generally in the larger diameter classes and possesses a normal or bell-shaped distribution.

The diameter distribution of the American beech component of the stands in Dysart Woods provides some interesting questions. In both stands, beech displays a reverse J-shaped distribution, typical of shade-tolerant species, but with a wave of larger diameter trees. This suggests that a cohort of beech ingrowth responded to a disturbance that produced fairly substantial canopy gaps about 75-150 years ago. Disturbances, such as drought, insect or disease attacks, ice or wind damage, could trigger such a phenomenon. Beech is representative of so-called “role-2” species (Shugart 1987) and is shade tolerant enough to regenerate in dense shade (Harcombe and others 1982) and capable of responding to canopy gaps as they develop.

The diameter distribution of sugar maple in all stands was typical of the reverse J-shaped distribution expected of shade-tolerant species in an all-age stand. However, the larger number of overtopped saplings in the Dysart North Woods compared to the South Woods seems to suggest that the regeneration of sugar maple in the two stands has become dissynchronous, and this relates to some fairly recent disturbance events that are not common to both stands. A ground fire would be a likely explanation but no charcoal or fire scars on trees was evident to point to such an occurrence and no reports of fires were found in published accounts of the history of Dysart Woods. An alternative explanation might be a different woodland grazing regime for the two stands.

The regeneration inventory of the stands reinforces our conclusions regarding the occurrence of a gradual shift from oaks to a maple-beech forest. This is a process that is on-going throughout the central hardwood region. Loftis (1989) indicates that the process is best described by combining the concepts of “initial floristics composition” and “vital ecological attributes” of species. That is to say that propagules of all the species present today were present when the stands first developed, but the shifts in dominance over time reflect a change in conditions that favor some species over others. Currently, the balance has shifted toward sugar maple and American beech and away from oaks and yellow-poplar. This transition from oaks to maples and other northern or mesophytic hardwoods is a trend that is well documented in old-growth forests throughout the central hardwood region (Downs and Abrams 1991, Schlesinger 1989). The interesting phenomenon relating to greater overall abundance of regeneration (especially sugar maple) in the Dysart South Woods may be part of the same process that has caused the reverse to be true of trees in the sapling size class (2 inches-6 inches dbh). In-other-words, the dense low shade created by the cohort of maples and beech in the sapling size class may be preventing regeneration, even of shade-tolerant species, in the North Woods. The high shade from canopy-level trees in the South Woods has allowed better seedling establishment there. Elms are apparently producing more seedlings and saplings now than were reported in past studies of Dysart Woods, but due to their intermediate status in shade tolerance and their susceptibility to disease, they will probably not become significant contributors to any future overstory.

The remarkable similarity between the old-growth components of the three stands indicates that strong forces are at work driving the ecosystem changes that have taken place. These stands were probably historically part of a single large stand but even so, in spite of differences in average aspect and soils (Lafer 1968) the resulting old-growth cohorts have maintained a high degree of similarity. The dissynchrony in regeneration between the two Dysart stands, however, indicates that it is the intrinsic characteristics of the system rather than particular disturbance events that drive the process.

Regarding species diversity, Dysart and Collins Woods is on the low end of the scale for old-growth forests with values for the Shannon-Weiner index of 1.69 and 1.72. There are two reasons for the mathematically low values. First, these stands have relatively low woody species richness compared to other old-growth forests reported in the central hardwood region (Table 3) and secondly, as Loucks (1970) proposes, northern hardwood types become dominated by sugar maple which reduces their diversity.

The process of oak replacement by maple and beech can be illustrated by plotting the change in ranking of importance values of species over the past 30 years (Figs. 6 and 7). As can be seen on these two figures, white oak is generally declining in rank whereas sugar maple is either increasing or maintaining. In both stands, sugar maple is now the top ranked species and American beech is in second position. An interesting rise in the importance value ranking of elms is primarily related to a large influx of sapling-sized trees—many of which are presently showing symptoms of declining vigor.

The future of these stands, barring a major disturbance event, is likely to continue on a course where large senescent oaks and yellow-poplars are replaced by sugar maple and American beech trees presently in subordinate canopy positions. Stresses, such as drought, air pollution/acid deposition, insects [gypsy moth (*Lymantria* *dispar*), etc.] and diseases (beech bark disease, Dutch elm disease, dogwood anthracnose, etc.) will play a role in the future of Collins and Dysart Woods, and these factors, although unpredictable, will probably alter the course of events by affecting the balance in competitive advantage among species.

Perhaps one of the greatest values of these remnant old-growth stands is the fact that they offer a glimpse into the future. The central hardwood region, following logging, fires and agricultural abandonment since the turn of the century, has rebounded with millions of acres of second-growth forests dominated by oaks and mesophytic hardwood species (MacCleery 1992). Stands like Collins and Dysart Woods give a good indication of what these forests will look like in 200 years with minimal disturbance (fire exclusion and limited cutting). They also, when viewed in the context of a collective whole of remnant deciduous forests, illustrate that some rather consistent processes (vital ecological attributes) are moving these stands in the same direction and these same forces will probably shape today's second-growth forests in a similar way.

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CHARACTERIZATION OF COARSE WOODY DEBRIS ACROSS A 100 YEAR CHRONOSEQUENCE OF UPLAND OAK-HICKORY FORESTS

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Abstract—Coarse woody debris is an important component influencing forest nutrient cycling and contributes to long-term soil productivity. The common practice of classifying coarse woody debris into different decomposition classes has seldom been related to the chemistry/biochemistry of the litter, which is the long term objective of our research. The objective of this preliminary study was to measure the volume, mass and nutrient content of the different decay classes of the down dead wood (DDW) component of coarse woody debris in upland hardwood stands of different ages. Three oak-hickory stands in southern Indiana: aged 1, 31, and 80-100 years since harvest were chosen for this study. Volume, mass, and C, N, S, and P content were determined on DDW from each decay stage in each stand. Results show that there is a large decrease in DDW volume and mass from recently harvested stands to more mature stands. The dominant decay stage shifts from Class II in the 1 year-old stand to Class III in the 31 year-old stand. The decay stages also have significantly different DDW density and C:N ratios, but only if outer and inner woody material are separated. The decomposition classes used to distinguish DDW correspond to distinguishable stages of DDW decay, as indicated by different C:N ratios and wood densities. The outer woody material seems to decay more quickly than the inner material, which is likely due to lower initial C:element ratios. Further work is needed in order to relate these patterns of coarse woody debris decay to nutrient mineralization and immobilization patterns.

INTRODUCTION

Maintaining the long-term productivity of managed forest soils is essential for the conservation of our forest resources. Finding ways to prevent soil erosion and soil compaction and to maintain soil structure and soil organic matter content are some of the goals of long-term soil productivity research. These indicators of soil quality are relatively easy to measure and quantify, but one aspect of soil quality that is not so easily assessed is nutrient cycling.

Some aspects of nutrient cycling in temperate forests have been well studied in the past. Nutrient availability (Powers 1990, Roy and Singh 1995), nutrient uptake rates and nutrient partioning (Habib and others 1993, Robinson 1986), nutrient leaching (Jordan and others 1993, Yin and others 1993), and returns of nutrients from leaf (Gholz and others 1985, Taylor and others 1989) and fine root turnover (Joslin and Henderson 1987, McClaugherty and others 1982) have been studied by numerous researchers. A topic that has received less attention in nutrient cycling studies is the contribution of coarse woody debris (CWD). Coarse woody debris is generally defined as dead woody material with a diameter of 10 centimeters or greater. This includes a range of woody debris from fallen logs and branches to standing dead trees and stumps. As a subset of this material, down dead wood (DDW) is considered to be those branches, logs, and stumps that are in contact with the soil. Many studies have determined the amount and relative state of decay of either CWD or DDW in both managed and old-growth forests of the Central Hardwoods Region (Jenkins and Parker 1997, McCarthy and Bailey 1994, Muller and Liu 1991, Richards and others 1995, Shifley and others 1995), but fewer have attempted to characterize the nutrient content or decay rate of this material (Abbott and Crossley, Jr. 1982, MacMillan 1988). This information is important for our understanding of the role of large dead woody material in forest nutrient cycling and forest soil productivity.

Although there is relatively little information regarding the nutrient content and decay rate of CWD, there are visual evaluations of the state of decay of CWD that are used by both university researchers (Muller and Liu 1991, Jenkins and Parker, 1997) and U.S. Forest Service personnel (Shifley and others 1995). These evaluations are based upon many visual cues, including bark slippage, penetration of visible decay into the core of the log, the number and size of branches remaining on the log, the shape of the log, the physical integrity of the log, and the degree of burial in the soil for DDW. Although these visual classification systems are useful, they are qualitative assessments and are subject to interpretation by the investigator. There is also the possibility that changes with increasing decay in certain CWD characteristics differ by species. Quantitative information about the elemental and biochemical nature of CWD at the different decay stages is necessary in order to assess the role of CWD in forest nutrient budgets and nutrient cycling.

Finally, most coarse woody debris studies have been conducted in either mature or old growth forest stands. Few have attempted to characterize the changes in CWD

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at different stages of stand development (Jenkins and Parker 1997, McCarthy and Bailey 1994). These studies have shown that there are significant and important differences in the volume, biomass, and distribution of CWD into the different decay classes with stand age. Understanding the dynamics of CWD as a stand develops from recently-harvested to mature or old growth stages is important if we are to accurately assess the role of CWD in forest regeneration and development.

We decided to restrict our study of coarse woody debris to down dead wood (DDW), i.e., fallen dead logs and branches in contact with the soil and tree stumps less than one meter high. This material is greatly influenced by the biotic and abiotic soil environment and in turn should directly influence biological and chemical processes in the soil. Therefore, our designation of down dead wood differs from the general definition of coarse woody debris in that our study does not include standing dead trees or broken treetops touching the ground that are still attached to the trunk. The two objectives for our research were: 1) to assess the volume and mass of DDW in upland oak-hickory forests of different age; and 2) to determine the nutrient content of DDW from the different decomposition classes as used by Thomas (1979).

MATERIALS AND METHODS

Study Site Descriptions

This study was implemented at the Southern Indiana Purdue Agricultural Center in Dubois County, Indiana. The soils in this area are different families within the family of fine-silty, mixed mesic Ultic Hapludalfs. The mean annual temperature is 12 degrees Celcius, and the mean annual precipitation is 1150 millimeters. The ecological land-type phase of these stands is classified as a Quercus alba-Acer saccharum Parthenocissus dry mesic ridge (USDA 1995). Three historically oak-hickory dominated stands were chosen for this study. The first was selectively harvested in 1996 (Site 1) with a post-harvest herbicide of undesirable trees and coppicing of desirable trees during the same year; thus we consider this stand to have undergone clearcutting. The second stand was clearcut harvested in 1966 (Site 2). The third is a mature stand dominated by white oak (*Quercus alba*) in the overstory and has not been harvested for the last 80-100 years (Site 3). The vegetation, climatic, and soil data for the three stands is given in Table 1. For the stand harvested in 1996, pre-harvest vegetation data is listed.

Field Sampling

Down dead wood was sampled according to the protocol of Thomas (1979) as used by Jenkins and Parker (1997). Three circular plots measuring 500 square meters were established in Sites 1 and 3, the mature and recently-harvested stands. In order to sample from locations with similar physiographic and soil characteristics, we had to restrict our sampling to two plots in Site 2, the stand harvested in 1966. The length and mid-point diameter of all DDW at least 10 centimeters in diameter were sampled. If a log or branch tapered to a diameter of less than 10 centimeters, only that portion of the DDW at least 10 centimeters in diameter was included. Lateral branches greater than 10 centimeters in diameter on down logs were also measured. Where a piece of DDW crossed the boundary of the circular plot, only that portion within the plot was measured. Each piece of DDW was evaluated and was assigned a decomposition class. The criteria for this classification scheme are listed in Table 2. The length and mid-point diameter of the DDW were used to calculate DDW volume, using the equation for the volume of a cylinder.

Table 1—Vegetation inventory for upland hardwood forests in southern Indiana. Overstory trees are all 10 cm or greater dbh. Understory trees are all 2.5 to 9.9 cm dbh

		Saplings		Overstory		
Age	N	Species		Species		
			Stems/ha		*Stems/ha*	(m^2/*ha*)
1	3	*Acer saccharum*	2370	*Acer saccharum*	123	(5.6)
		Nyssa sylvatica	554	*Quercus alba*	71	(15.9)
				Quercus rubra	40	(12.6)
				Carya glabra	40	(4.7)
		All species	3780	All species	384	(47.9)
31	2	*Acer saccharum*	741	*Acer saccharum*	515	
		Asimina triloba	546	*Prunus serotina*	300	
				Sassafras albidum	143	
		All species	1950	All species	1430	
100	3	*Acer saccharum*	740	*Acer saccharum*	253	(3.9)
				Quercus alba	103	(19.0)
		All species	770	All species	445	(27.4)

Table 2—Classification scheme for down dead wood decomposition stage, taken from Thomas (1979)

Character	Class I	Class II	Class III	Class IV	Class V
Bark	Intact	Mostly intact	Mostly absent	Absent	Absent
Structural integrity	Sound	Sapwood rotting	Heartwood sound	Heartwood rotten	None
Branches	All twigs present	Larger twigs present	Larger branches present	Branch stubs present	Absent

Laboratory Methods

In order to estimate biomass and nutrient content of the down dead wood, two cross sections from one log per decomposition class were taken. For Class II and III material, we chose logs that were approximately 20-30 centimeters in diameter. We were only able to locate a single piece of Class I material, found in Site 3. Two cross-sections from this Class I log, each approximately 10-15 centimeters in diameter, were taken for analysis. For Classes IV and V DDW, there were no intact cylinders from which to take a cross-section; therefore, various irregularly shaped pieces of material from these classes were taken for analysis. This sampling was done within each stand so that differences in DDW characteristics by stand age as well as by decomposition class could be assessed.

Each cross section or piece of DDW was cut into smaller pieces and dried at 65 degrees Celsius to constant weight (approximately 1 week). Because differences may exist in DDW characteristics between the inner and outer wood of Class I, II, and III material, within each cross-section we separated the outer 2-3 centimeters of wood from the inner wood. The outer wood consisted mainly of the bark and sapwood; the inner wood consisted mainly of the heartwood.

To determine the biomass of down dead wood, the density of the material at the different decomposition stages was determined using the soil clod bulk density method (Blake and Hartge 1986). Pieces of oven-dried DDW material were weighed, dipped in liquid Saran resin, dried overnight at 105 degrees Celsius, and the dry weight and displacement volume measured. Becaue the outer wood diameter varied between 2 and 3 centimeters, we used a diameter of 2.5 centimeters to calculate the mass of entire logs.

To determine the nutrient content of down dead wood, pieces of each cross section were ground in a Wiley mill until the material passed through a 1 millimeter diameter mesh screen. The ground DDW was re-dried at 65 degrees Celsius for at least 24 hours. Total C, N, and S content were determined using a LECO CNS 2000 elemental analyzer. Total P content was determined using the phospho-molybdate blue colorimetric procedure (Olsen and Sommers 1982) after digestion of the material in perchloric acid and hydrogen peroxide. Nutrient concentrations (micrograms per gram of tissue) were then multiplied by the estimated biomass in order to determine the total nutrient content of DDW within each of the stands.

Statistics

Our initial hypotheses were: 1) The volume, mass, and nutrient content of DDW will decrease with increasing stand age; 2) the dominant decay stage of DDW will also increase with stand age; and 3) the density, C:N, C:S, and C:P ratios of DDW will decrease with increasing decay stage.

All statistical analyses were carried out using the ANOVA procedure in SAS (SAS Institute, Inc. 1989) with an alpha-level of 0.05. Where a significant difference was indicated by the ANOVA, Duncan's multiple range test with an alpha-level of 0.05 was used as the means separation test. Because this study does not include true replication of stand age, the true error associated with differences in DDW characteristics by stand age cannot be known. We used plot within stand as the replication for stand age. The error term associated with this type of analysis may be biased, but without true replication of stand age, we cannot determine the degree of bias, if any.

In our initial analysis, DDW density and concentrations of C, N, S, and P were the dependent variables and the outer or inner DDW portion of each decomposition class within each stand age was the independent variable. For Class IV and V DDW no distinction between inner or outer wood was made. Although the density and element concentration of DDW in different classes differed significantly, there was no difference by stand age within a decomposition class. Therefore the values within a decomposition class across stand ages were combined and the average used to calculate DDW mass and element content for the individual decomposition classes and the location within a decomposition class.

In order to test hypothesis 1, we compared the total volume, mass, and C, N, S, and P content of all classes of DDW combined within each stand. The high degree of plot to plot variability coupled with low degrees of freedom for the error term (based on number of plots) led to our finding no significant differences by stand age. Therefore, we decided to compare DDW within each decomposition class within each stand to other classes of DDW within the same stand and across all stands. In this analysis, DDW volume, mass, and element content (C, N, S, P) were the dependent variables and decomposition class by stand age was the independent variable. This analysis was also used to test hypothesis 2.

Because the inner and outer wood of DDW may have different chemical characteristics, we repeated the above analysis, subdividing Classes I, II, and III DDW into inner and outer material. In order to test the third hypothesis, this classification of DDW was used to compare DDW density and DDW C:N, C:S, and C:P ratios. Comparisons of DDW classes and the location within a class were made with this analysis. No comparison of stand ages was made with respect to these variables; rather, the average values across the stands were used.

RESULTS

Although there is a striking difference between the total amount of DDW in the 1 year-old stand and the 31 and 80-100 year-old stands (table 3), the high degree of variability among the plots masked any statistical differences by stand age. We compared our results to those of Jenkins and Parker (1997), who estimated the volume of DDW in numerous hardwood forest stands in southern Indiana (fig. 1). The total volume of DDW in our study agrees with their results; however, differences are evident in the distribution of DDW between the two studies. In this study the mass and volume of Class II material was greater in the 1 year-old stand and Class IV material was greater in all stands (age 1, 31, and 80-100 years) of our study than in their study.

The dominant decay class differed somewhat by stand age (table 3). The volume and mass of Class II DDW in the 1

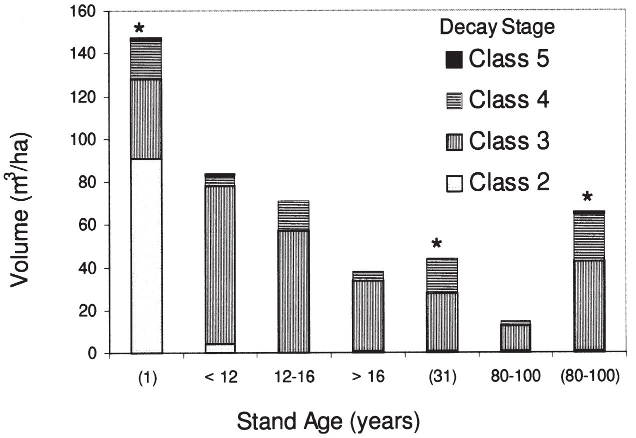

Figure 1—Down dead wood volume by decay stage across a chronosequence of upland hardwood forests in southern Indiana. (*) indicates stands measured in this study. All others taken from Jenkins and Parker (1997).

Table 3—Total volume, mass, and nutrient content of down dead wood by decay class across a 100-year chronosequence of upland oak-hickory forests in southern Indiana

Age	Decay class	N	Volume	Mass	C	N	S	P
Yrs			*m^3/ha*	-------*Mg/ha*-------		-----------------*Kg/ha*-----------------		
1	II	3	90.8a	85.2a	42.8a	80.0a	26.4a	4.7abc
1	III	3	38.3bc	35.3b	18.2bc	42.4abc	17.5ab	1.8bc
1	IV	3	17.8bc	15.7b	7.5bc	27.9abc	14.6abc	4.9ab
1	V	3	1.2c	1.0b	0.5c	5.5c	7.4bcd	4.6abc
Total			148.1	137.2	69.0	155.8	66.0	16.0
31	II	3	0.6c	0.6b	0.3c	1.4c	0.2d	0.1c
31	III	3	27.1bc	24.8b	12.7bc	60.9ab	8.9bcd	1.7bc
31	IV	3	15.9bc	14.0b	6.7bc	51.7abc	7.3bcd	4.6abc
31	V	3	0.5c	0.4b	0.2c	5.1c	0.6cd	0.3bc
Total			44.2	39.8	19.9	119.1	17.0	6.7
100	II	3	0.7c	0.7b	0.3c	1.6c	0.2d	0.1c
100	III	3	41.7b	37.9b	19.5b	72.8a	11.7bcd	1.7bc
100	IV	3	22.3bc	19.6b	9.4bc	72.5a	10.3bcd	6.5a
100	V	3	1.0c	0.8b	0.4c	9.7bc	1.1cd	0.5bc
Total			65.7	59.0	29.7	156.5	23.3	8.8

Columns followed by the same letters do not differ significantly using Duncan's multiple range test with alpha = 0.05. All values are based on plot averages; thus "N" refers to the number of plots sampled in each stand.

year-old stand was significantly greater than any other class within that stand and across all stands. In the 80-100 year-old stand, the volume of Class III DDW was significantly greater than the volume of Class II or Class V DDW, but there was no significant difference in DDW mass by decomposition class in either the 31 or 80-100 year-old stands.

The C, N, S, and P content of the down dead wood followed a somewhat different trend than the distribution of DDW volume and mass. Although the mass and C content of Class III material is greater than Class IV material in all three stands, the amount (kilograms per hectare) of N, S, and P held in these two classes of DDW is similar. Lower C:element ratios (table 4) in Class IV material account for the similarity in the amount of nutrients held in DDW of these two classes despite the difference in DDW mass. Class V DDW had the least mass (megagrams per hectare) and nutrient content (kilograms per hectare). Class II material was also a very small component of the DDW mass and nutrient content in the 31 and 80-100 year-old stands. The amount of down dead wood mass (metric tons per hectare) and nutrients generally did not differ significantly by location within a log (table 5).

The bulk density and C:N ratio of down dead wood, however, did show significant trends by decay stage and location (table 4). The density of outer sapwood and bark of Class I, II, and III DDW is significantly greater than Class IV and V DDW. The density of the inner heartwood of Class I and II material is also significantly greater than Class IV and V material. The C:N ratio of inner heartwood decreased significantly from Class I to III DDW and was significantly greater than Class IV and V material. Outer sapwood and bark C:N ratios of Classes I, II, and III were significantly lower than the inner heartwood C:N ratios of Class I, II, and III material.

DISCUSSION

The mass and distribution of down dead wood (DDW) in this study was consistent with that found in other studies in the Central Hardwood Region. The trend of decreasing DDW mass with increasing stand age is supported by the work of Jenkins and Parker (1997), which was also conducted in southern Indiana hardwood forests. They found that Class III DDW dominated the volume of total DDW in stands of different ages. Although the number of pieces of Class IV and V DDW may be expected to increase with stand age, the volume and mass of DDW may still be dominated by Class III logs, which retain much more of their original mass and volume than DDW in later decay stages.

Although our study was of stands in the same geographical region as those of Jenkins and Parker (1997), our results suggest a greater volume and mass of Class II DDW in recently-harvested stands and a greater volume and mass of Class IV DDW in all age stands. Part of this discrepancy is probably due to the limited nature of our study. We investigated only one stand per age class, whereas Jenkins and Parker (1997) studied many stands per age class. However, part of this discrepancy may be due to the fact that different stand ages were investigated in the two studies. Our study included stands aged 1, 31, and 80-100 years since harvest. Jenkins and Parker (1997) investigated stands 8-12, 12-16, and 80-100 years of age. Although they did not study stands younger than 8 years after harvest, they hypothesized that Class III material would dominate stands less than 12 years of age. McCarthy and Bailey (1994) assessed the coarse woody

Table 4—Indicators of down dead wood decay across a 100-year chronosequence of upland oak-hickory forests in southern Indiana

Decay class	In/out	N	Density	C:N	C:P
			Mg/m^3		
I	Out	3	0.930ab	220:1c	2903:1c
II	Out	3	0.938ab	172:1c	2533:1c
III	Out	3	0.932ab	144:1c	2893:1c
I	In	3	0.921ab	839:1a	20622:1bc
II	In	3	0.950a	861:1a	35533:1ab
III	In	3	0.901bc	419:1b	48400:1a
IV	—	3	0.878c	130:1c	1550:1c
V	—	3	0.816c	42:1c	854:1c

Values within a column followed by the same letter do not differ significantly using Duncan’s multiple range test with alpha = 0.05.
All values are based on the average across all three stands; thus “N” refers to the number of stands sampled.
“In” refers to the inner heartwood of a log cross-section, more than 2.5 cm from the outer edge of the log. “Out” refers to the outer 2.5 cm of a log cross-section, including the bark and sapwood.

Table 5—Volume, mass, and nutrient content of down dead wood by decay stage and location across a 100-year chronosequence of upland oak-hickory forests in southern Indiana

Age	Decay class	In/out	N	Volume	Mass	C	N	S	P
Yrs				*m^3/ha*	-----------*Mg/ha*----------		-------------------*Kg/ha*-----------------		
1	II	In	3	49.3a	46.9a	23.9a	20.6bcd	4.2bc	0.1c
1	II	Out	3	41.5ab	38.3ab	18.9ab	59.4ab	22.2a	4.7ab
31	II	In	2	0.2d	0.2d	0.1d	0.2e	0.0c	<0.0c
31	II	Out	2	0.4d	0.4d	0.2d	1.3de	0.2c	0.1c
100	II	In	3	0.2d	0.2d	0.1d	0.2e	0.0c	<0.0c
100	II	Out	3	0.5d	0.4d	0.2d	1.4de	0.2c	0.1c
1	III	In	3	22.0bcd	20.1bcd	10.4bcd	13.2cde	3.2c	0.1c
1	III	Out	3	16.3bcd	15.2bcd	7.7bcd	29.2bcde	14.3ab	1.8bc
31	III	In	2	14.5bcd	13.1bcd	6.8bcd	16.5cde	3.2c	0.2c
31	III	Out	2	12.6cd	11.7cd	6.0bcd	44.3abcd	5.7bc	1.5bc
100	III	In	3	31.1abc	28.0abc	14.5abc	35.5abcde	6.9bc	0.4c
100	III	Out	3	10.6cd	9.9cd	5.0cd	37.3abcde	4.8bc	1.2bc
1	IV	—-	3	17.8bcd	15.7bcd	7.5bcd	27.9bcde	14.6ab	4.9ab
31	IV	—-	2	15.9bcd	14.0bcd	6.7bcd	51.7abc	7.3bc	4.6ab
100	IV	—-	3	22.3bcd	19.6bcd	9.4bcd	72.5a	10.3bc	6.5a
1	V	—-	3	1.2d	1.0d	0.5d	5.5de	7.4bc	4.6ab
31	V	—-	2	0.5d	0.4d	0.2d	5.1de	0.6c	0.3c
100	V	—-	3	1.0d	0.8d	0.4d	9.7cde	1.1c	0.5c

Values within a column followed by the same letters do not differ significantly using Duncan's multiple range test with alpha = 0.05.
All values are plot averages; thus "N" refers to the number of plots sampled within each stand.
"In" refers to the inner heartwood of a log cross-section, more than 2.5 cm from the outer edge of the log. "Out" refers to the outer 2.5 cm of a log cross-section, including the bark and sapwood.

debris volume and mass of forest stands in the Central Appalachians that ranged in age from clearcut to old-growth. As in our study, they found that Class II CWD dominated the clearcut stand. They also found that Class IV and V material was more abundant in older forest stands than is suggested by Jenkins and Parker (1997), also similar to the results of our study.

The differences we found with respect to DDW density and C:N ratios among the different classes, I-V, lends chemical support to the class distinctions of coarse woody debris made in the field. If these class distinctions are to have any meaning with respect to patterns of nutrient cycling, one would expect there to be significant differences with respect to C:element ratios. The differences between the bark plus sapwood and heartwood C:N ratios, however, illustrate the importance of distinguishing these two components of DDW. The initial chemical composition of these two substrates is different, and this may affect their decay dynamics. By the time DDW reaches Class III, the bark and sapwood are porous, loose or absent, indicating that there is substantial decay of this material. However, the inner heartwood is often still intact. This visual evaluation is supported by the lower C:element ratios of outer woody material versus inner woody material in Classes I and II. Although tree species may differ with respect to outer wood and inner wood decay rates, higher C:N ratios in outer wood than inner wood is to be expected among most live woody plants.

It is generally thought that a C:N ratio of 15:1 to 30:1 is necessary for net mineralization of nitrogen from organic residues in soil systems (Foth, 1978). The C:N ratios of DDW of all decomposition classes in this study were greater than 40:1. However, there is no experimental evidence to substantiate claims concerning the critical C:element ratios for net mineralization of N, P, or S from coarse woody debris. There have been studies in a variety of forest types that have investigated mass loss and nutrient concentrations in CWD at different stages of decomposition (Macmillan 1988, Abbott and Crossley 1982, Lang and Forman 1978). None of these, however, have investigated N, P, or S mineralization and immobilization patterns directly. Laboratory and field studies on the decomposition and nutrient mineralization of leaf, forest floor, and fine root litter are abundant, but studies with CWD are surprisingly absent from the literature.

Although nutrient mineralization and immobilization patterns of decaying DDW are difficult to assess at present, there is evidence that suggests DDW decay rates are related to C:N ratios. Macmillan (1988) found that DDW density was highly correlated with the DDW C:N ratio for oak (*Quercus*), hickory (*Carya*), maple (*Acer*), and beech (*Fagus*) DDW. We also found a significant relationship between density of different decomposition classes and the C:N ratio, but only when inner heartwood was examined (data not shown).

One of the visual cues that distinguishes Class II from Class III DDW is the onset of significant bark slippage and the absence of most smaller limbs. Because the bark and outer woody tissues are higher in N, S, and P, they would be expected to decay at a rate much faster than the inner heartwood material. This more rapid decay means that Class II DDW quickly progresses into Class III DDW. A major difference between Class III and Class IV DDW is the integrity of the inner woody material. Because this material has a much lower N, S, and P content initially, it decays much more slowly than the sapwood and bark. Therefore, the transition between Class III and Class IV is more gradual and lengthy than the transition from Class II to Class III. Given this set of circumstances, it is easy to understand why DDW in most stands is dominated by Class III material. Future research on DDW decay and nutrient dynamics should focus on direct examinations of nutrient mineralization and immobilization patterns so that critical C:element ratios can be established. Also, Van Lear (1993) has pointed out that we know almost nothing about the amount and decay of coarse root systems after a harvest or canopy tree death. Studying this type of coarse woody debris presents methodological challenges, but we will not have a full picture of forest nutrient cycling until this gap in our knowledge is filled.

CONCLUSIONS

Our first hypothesis stated that we expected the volume and mass of down dead wood in the recently clearcut stand to be significantly greater than in the 31 and 80-100 year-old stands. Although there is a large difference in the volume and mass between the recently clearcut and the other stands, we did not find a significant difference. This is most likely due to the high degree of variation between plots within a stand and the low number of plots (2 or 3) in each stand used to estimate volume and mass of DDW. However, our results did follow the same general trend that Jenkins and Parker (1997) and McCarthy and Bailey (1994) found for other Central Hardwood forest stands.

Our second hypothesis stated that the most abundant down dead wood class in the 1 year-old stand would be Class II; whereas, decomposition classes III and IV would be the most abundant DDW classes in the 31 and 80-100 year-old stands. This hypothesis was supported by our results. This is somewhat different than what was found by Jenkins and Parker (1997), but it agrees well with the findings of McCarthy and Bailey (1994). The rapid decomposition of the sapwood and bark and the slow decomposition of the inner heartwood are probably the main reasons Class III DDW is so abundant in forest stands of all ages. Our final hypothesis stated that we expected the density and C:element ratios to decrease with increasing decomposition class. This hypothesis is true for density and the C:N ratios of inner heartwood DDW. There was a significant decrease in the C:N ratio from Classes I and II to Class III and from Class III to Classes IV and V for the inner heartwood material. These differences in density and C:N ratio between decomposition classes lend direct chemical support for the classification schemes used to distinguish the different decomposition stages of coarse woody debris. However, they also illustrate the heterogeneous nature of material within a piece of DDW and the need to study different fractions within a log as well as different decay classes of whole logs.

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