ATTRIBUTES OF DOWN WOODY MATERIALS IN HARDWOOD FORESTS OF THE EASTERN UNITED STATES

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Abstract—The Forest Inventory and Analysis Program (FIA) of the USDA Forest Service conducts a national inventory of down woody materials (DWM) on forestland in the United States. Estimates of DWM for inventory plots occurring in eastern U.S. hardwood forests facilitate large-scale assessment of hardwood forest fuel loadings and wildlife habitat. Therefore, the objectives of this study were (1) to quantify fuel loadings by National Fire Danger Rating System (NFDRS) hour-class for common hardwood forest types of the eastern U.S., (2) to quantify coarse woody debris (CWD) size distributions for common hardwood forest types of the eastern U.S., (3) and to compare the means of CWD and fine woody debris (FWD) by classes of stand live-tree basal area and stand age for hardwood forests of the eastern U.S. using currently available data from FIA. Results indicate appreciable amounts of forest fuels in eastern hardwood forests, particularly in pure and mixed species forests with oak components. Furthermore, size-class distributions of coarse woody pieces indicate a dearth of large-sized coarse woody debris in eastern hardwood forests. Overall, a large-scale assessment of down woody attributes in hardwood forests of the eastern U.S. contributes to understanding this resource's role in the management of fuels and wildlife habitat of the United States.

INTRODUCTION

Down Woody Materials (DWM) are dead organic materials that accumulate in forests as a result of plant mortality and leaf turnover (Woodall and Williams 2005). The Forest Inventory and Analysis Program (FIA) of the USDA Forest Service conducts a national inventory of down woody materials (DWM) on forest land in the United States. FIA inventories numerous DWM components including fine woody debris, coarse woody debris, litter, duff, slash, live/dead shrubs, and live/dead herbs. Fine woody debris (FWD) are small pieces of woody material typically made up of fallen twigs, branches, and upper tree boles. Coarse woody debris (CWD) is often defined as large pieces of woody material that meet minimum size and decay requirements. Coarse and fine woody debris are often the central focus of forest ecosystem analyses because they serve as important indicators of fire hazards, carbon stocks, and wildlife habitat.

The size specifications of fine and coarse woody debris sampled by the FIA program were selected to match the components defined by the National Fire Danger Rating System (NFDRS). This system divides fine and coarse woody debris into size classes that are equivalent to the fuel-hour class system (1-hour, 10-hour, and 100-hour) used by many fire scientists (Deeming and others 1977). In terms of wildlife habitat, coarse woody debris serves as critical habitat for numerous flora and fauna. CWD provides a diversity (stages of decay, size classes, and species) of habitat for fauna ranging from large mammals to invertebrates (Maser and others 1979, Harmon and others 1986, Bull and others 1997, Carey and Harrington 2001, Moseley and others 2004). Flora utilize the microclimate of moisture, shade, and nutrients provided by CWD for regeneration establishment (Harmon and others 1986, Nordén and others 2004). Because of CWD's importance with regard to biodiversity, nutrient cycling, carbon stocks, and fire risk, wood debris is a leading concern for managed forest ecosystems.

Although coarse and fine woody debris serve as an important indicator of numerous forest ecosystem functions, they have been infrequently investigated in hardwood forests of the eastern U.S. Chojnacky and others (2004) presented the most recent efforts to estimate DWM in forests of the east. However, most

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other previous studies have been at smaller spatial scales and/or were directed at more specific forest types or individual wildlife species (for examples see Ulyshen and others 2004, Pyle and Brown 1999, Rubino and McCarthy 2003, Idol and others 2001, McCarthy and Bailey 1994). Therefore, although numerous studies have contributed information regarding DWM, there is a lack of DWM information at scales exceeding individual states and/or single hardwood forest types.

Given the lack of widespread information regarding the down woody resources in hardwood forests of the eastern United States, our objectives were threefold:

1. To quantify fuel loadings by NFDRS hour-class for common hardwood forest types of the eastern U.S.

2. To quantify CWD size class distributions for common hardwood forest types of the eastern U.S.

3. To compare the means of CWD and FWD by classes of stand live tree basal area and stand age in eastern hardwood forests

METHODS

Data

Inventory data from the USDA Forest Service's FIA program were used to estimate coarse and fine woody debris attributes for hardwood forests of the eastern U.S. Data was collected on 860 plots during 2001-2003 in hardwood forests within the following states (number of plots per state in parentheses): AL (71), AR (43), GA (57), IL (16), IN (12), IA (12), KY (55), LA (26), ME (45), MI (74), MN (96), MO (55), NH (6), NY (46), NC (7), OH (23), PA (74), SC (2), TN (81), VA (14), WI (45) (table 1).

Field Sample Protocols

The FIA program of the USDA Forest Service conducts a 3-phase inventory of forest attributes of the United States (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into approximate 6,000 acre hexagons with at least one permanent plot established in each hexagon. In phase 1 (P1), the population of interest is stratified and plots are assigned to strata for purposes of increasing the precision of estimates. In phase 2 (P2), tree and site attributes are measured for plots established in the 6,000 acre hexagons. Phase 2 plots consist of four 24-foot fixed-radius subplots on which standing trees are inventoried. Data from the phase 2 used in this study included total standing live tree basal area (square feet) per acre and stand age (years) (for more information see NCRS 2003, Bechtold and Patterson 2005).

In phase 3 (P3), a 1/16th subset of P2 plots are measured for forest health indicators, including down woody materials. Data from P3 plots were utilized in this study to estimate down dead tree information. Coarse and fine woody debris are sampled as part of P3 on 24-foot horizontal distance transects radiating from each FIA subplot center at 30, 150, and 270 degrees (Woodall and Williams 2005). FWD (1-, 10-, and 100-hour fuels) were sampled on the 150 degree transect on each subplot. FWD with transect diameters of 0.01 to 0.24 inches and 0.25 to 0.90 inches (1- and 10-hour, respectively) were tallied separately on a 6 foot slope distance transect (14 to 20 feet on the 150 degree transect). FWD with transect diameters of 1.00 to 2.99 inches (100-hour) were tallied on a 10 foot slope distance transect (14 feet to 24 feet on the 150 degree transect). CWD was defined by the FIA program as down logs with a transect diameter ≥ 3 inches and a length ≥ 3 feet. Transect diameter, length, small-end diameter, large-end diameter, decay class, species, evidence of fire, and presence of cavities was collected for every CWD piece encountered on each of the 3 24-foot transects on every forested FIA subplot. Transect diameter was defined as the diameter of a down woody piece at the point of intersection with a sampling transect.

Analysis

Line intersect model-based estimators were used to determine 1-hour, 10-hour, 100-hour, and 1000-hour per acre fuel loading estimates for each inventory plot (Van Wagner 1964, and Brown 1974). To determine

Table 1—Primary species constituents of forest types and forest-type groups used in this study[a]

Forest type and forest-type group[b]	Number of plots	Predominant constituent tree species
Oak/other pine	48	Oaks (*Quercus* spp. L.), pines (*Pinus* spp. L.)
Oak/loblolly	28	Oaks (*Quercus* spp. L.), loblolly pine (*Pinus taeda* L.)
Post oak/blackjack oak	11	Post oak (*Quercus stellata* Wang.), blackjack oak (*Quercus marylandica* Muenchh.)
Chestnut oak	26	Chestnut oak (*Quercus prinus* L.)
White oak/red oak/ hickory	173	White oak (*Quercus alba* L)., red oak (*Quercus rubra* L.), hickory (*Carya* spp.)
White oak	18	White oak (*Quercus alba* L.)
Northern red oak	13	Northern red oak (*Quercus rubra* L.)
Yellow-poplar/white oak/red oak	25	Yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L)., red oak (*Quercus rubra* L.)
Sweetgum/yellow-poplar	26	Sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.)
Chestnut oak/black oak/scarlet oak	13	Chestnut oak (*Quercus prinus* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.)
Red maple/oak	7	Red maple (*Acer rubrum* L.), oak (*Quercus* spp.)
Mixed upland oaks	63	Upland oaks (*Quercus* spp.)
Sweetgum/nuttall oak/ willow oak	18	Sweetgum (*Liquidambar styraciflua* L.), nuttall oak (*Quercus nuttalli* Palmer), willow oak (*Quercus phellos* L.)
Sweetbay/swamp tupelo/red maple	12	Sweetbay (Magnolia virginiana L.), swamp tupelo (*Nyssa biflora* Walt.), red maple (*Acer rubrum* L.)
Black ash/American elm/red maple	15	Black ash (*Fraxinus nigra* Marsh.), American elm (*Ulmus americana* L.), red maple (*Acer rubrum* L.)
Sugarberry/hackberry/ elm/green ash	20	Sugarberry (*Celtis laevigata* Willd.), hackberry (*Celtis occidentalis* L.), elm (*Ulmus* spp. L.), green ash (*Fraxinus pennsylvanica* Marsh.)
Sugar maple/beech/ yellow birch	138	Sugar maple (*Acer saccharum* Marsh.), beech (*Fagus* spp. L.), yellow birch (Betula alleghaniensis Britt.)
Black cherry	5	Black cherry (*Prunus serotina* Ehrh.)
Hard maple/basswood	16	Hard maple (*Acer* spp. L.), basswood (*Tilia* spp. L.)
Elm/ash/locust	5	Elm (*Ulmus* spp. L.), ash (*Fraxinus* spp. L.), locust (*Gleditsia* spp. L.)
Upland red maple	19	Red maple (*Acer rubrum* L.)
Aspen	67	Aspen (*Populus tremuloides* Michx.)
Paper birch	37	Paper birch (*Betula papyrifera* Marsh.)

[a] Scientific nomenclature follows the USDA National Plants Data Center.
[b] See North Central Research Station (2002); Miles and others (2001).

the number of CWD pieces per acre, de Vries' (1986) line intersect estimation procedures were used (for application see Waddell 2002). For further information regarding the sample protocol and estimation procedures for the DWM sampled by the FIA program, see Woodall and Williams (2005). Means and standard errors were determined for down woody variables by forest type and by classes of stand live-tree basal area and stand age. Forest type was determined by forest typing algorithms currently utilized by the FIA program to fulfill program reporting requirements (table 1). The forest type algorithm assigns forest type and forest type groups according to the preponderance of stocking by individual species (Bechtold and Patterson 2005). Additionally, significant differences among DWM means by classes were evaluated using ANOVA. Ratios of CWD diameter classes were estimated by dividing the number of CWD pieces per acre for a particular size-class by the total number of CWD pieces per acre.

RESULTS

Mean fuel loading estimates for fuel-hour classes varied considerably by hardwood forest type (table 2). For 1-hour fuels, the northern red oak forest type had the highest fuel loadings, approaching 0.6 tons per acre. By contrast, most other forest types had 1-hour fuel loadings between 0.14 and 0.5 tons per acre. For 10-hour fuels, the elm/ash/locust, oak/loblolly, northern red oak, upland red maple, paper birch, and yellow-poplar/white oak/red oak forest types had the highest fuel loadings meeting or exceeding 1.0 tons per acre. On the contrary, levels in the post oak/blackjack oak, red maple/oak, and black ash/American elm/red maple types were at or below 0.5 tons per acre. For 100-hour fuels, oak/loblolly, yellow-poplar/white oak/red oak, sugar maple/beech/yellow birch, black cherry, paper birch, and upland red maple forest types had the highest fuel loadings nearing or exceeding 3 tons per acre. In contrast, loadings in the post oak/blackjack oak, white oak, black ash/American elm/red maple, and elm/ash/locust types were below 1.5 tons per acre. For 1000-hour fuels, the oak/other pine, white oak/red oak/hickory, and upland red maple forest types had the highest fuel loadings nearing or exceeding 20 tons per acre. By contrast, levels in the sweetgum/yellow-poplar, chestnut oak/black oak/scarlet oak, and sweetbay/swamp tupelo/red maple types were less than 2 tons per acre. Finally, the oak/other pines, white oak/red oak/hickory, and upland red maple forest types had the highest levels of total down woody material with loadings higher than 20 tons per acre.

The size distributions off 1000-hour fuels, otherwise termed CWD in broader ecological contexts, were heterogeneous across hardwood forest types of the eastern US (table 3). The distribution of CWD sizes was dominated by small pieces (3.0 to 7.9 inches in diameter) for most forest types. Ninety percent or more of CWD pieces in the post oak/blackjack oak, chestnut oak/black oak/scarlet oak, sweetgum/yellow-poplar, black cherry, and elm/ash/locust forest types fell within the 3 to 7.9 inch diameter range. In most other forest types, 50 to 85 percent of CWD pieces fell within the 3 to 7.9 inch size class. The sweetbay/swamp tupelo/red maple forest type had an average of thirty-three percent of CWD in the 8 to 12.9 inch CWD diameter size class, while most other types had between 10 and 30 percent. Thirteen to 17.9 inch pieces comprised 5 percent or less of CWD in all forest types, while pieces in the largest size class (18.0 and larger) were absent in most types.

Estimates of mean CWD generally increased by class of stand live basal area until a basal area greater than 120 square feet per acre was attained, although ANOVA results indicated no significant difference between class means ($P = 0.167$) (fig. 1). Estimates of mean FWD essentially remained the same across classes of stand live basal area (fig. 1). Trends in estimates of mean CWD by class of stand age were hardly discernable (fig. 2). Maximum mean CWD was attained at an age class of 75 to 99 years, while the minimum mean was for the 100+ age class. Estimates of mean FWD decreased slightly as stands increased in age, although ANOVA results once again indicated a weak relationship ($P = 0.213$).

DISCUSSION

The results indicate that the majority of hardwood forests in the eastern US contain total down woody fuel loadings below 10 tons per acre. The oak/pine, oak/loblolly, white oak/red oak/hickory, and upland red maple forest types contained the highest mean tons-per-acre of total down woody material of all

Table 2—Mean fuel loadings for hardwood forest types in the Eastern United States

Forest type and forest-type group[a]	1-hour	Standard error	10-hour	Standard error	100-hour	Standard error	1,000-hour	Standard error	Total down woody	Standard error
	tons/ acre		*tons/ acre*		*tons/ acre*		*tons/ acre*		*tons/ acre*	
Oak/other pine	0.19	0.02	0.81	0.12	1.92	0.26	18.45	11.3	21.38	11.37
Oak/loblolly	0.22	0.04	1.02	0.15	3.06	0.88	10.94	6.37	15.24	6.53
Post oak/ blackjack oak	0.14	0.04	0.51	0.11	1.24	0.24	2.13	1.18	4.02	1.26
Chestnut oak	0.18	0.02	0.72	0.09	2.23	0.33	3.28	0.55	6.42	0.76
White oak/red oak/hickory	0.21	0.01	0.64	0.04	1.77	0.12	19.21	6.77	21.84	6.76
White oak	0.22	0.03	0.58	0.06	1.22	0.26	8.69	2.69	10.76	2.69
Northern red oak	0.58	0.35	0.98	0.24	2.11	0.50	7.37	4.37	11.04	4.40
Yellow-poplar/ white oak/red oak	0.22	0.03	1.07	0.16	3.92	0.67	2.71	0.58	7.91	1.10
Sweetgum/ yellow-poplar	0.27	0.05	0.75	0.11	2.22	0.41	1.89	0.54	5.07	0.75
Chestnut oak/ black oak/ scarlet oak	0.36	0.13	0.78	0.13	2.62	0.78	1.49	0.42	5.26	1.00
Red maple/oak	0.16	0.05	0.42	0.08	1.49	0.32	3.73	0.72	5.79	0.67
Mixed upland oaks	0.18	0.02	0.86	0.13	1.89	0.28	7.09	4.57	10.04	4.61
Sweetgum/nuttall oak/willow oak	0.23	0.03	0.78	0.16	2.26	0.55	3.26	1.19	6.53	1.41
Sweetbay/swamp tupelo/red maple	0.14	0.06	0.83	0.27	2.48	1.04	1.55	0.65	5.00	1.33
Black ash/ American elm/ red maple	0.17	0.03	0.42	0.09	1.46	0.28	4.29	0.88	6.34	1.08
Sugarberry/ hackberry/elm/ green ash	0.17	0.04	0.89	0.18	2.09	0.38	3.13	1.14	6.29	1.45
Sugar maple/ beech/yellow birch	0.38	0.03	0.94	0.08	2.89	0.23	5.96	1.04	10.17	1.11
Black cherry	0.33	0.15	0.60	0.19	2.99	1.29	5.85	2.97	9.78	3.34
Hard maple/ basswood	0.29	0.05	0.65	0.20	1.82	0.37	7.49	1.75	10.26	2.18
Elm/ash/locust	0.15	0.04	1.52	0.79	1.34	0.68	2.60	1.47	5.61	1.87
Upland red maple	0.44	0.09	1.24	0.40	4.02	1.10	28.12	24.76	33.81	24.71
Aspen	0.15	0.02	0.73	0.12	2.07	0.35	5.21	0.95	8.16	1.12
Paper birch	0.24	0.07	0.97	0.28	3.16	0.48	6.17	1.05	10.55	1.43

[a] See North Central Research Station (2002); Miles and others (2001).

Table 3—Mean ratios of diameter classes of coarse woody debris for hardwood forest types in the Eastern United States

Forest type and forest-type group[a]	3.0 – 7.9	Standard error	8.0 – 12.9	Standard error	13.0 – 17.9	Standard error	18.0 +	Standard error
	inches		*inches*		*inches*		*inches*	
Oak/other pine	0.85	0.04	0.11	0.03	0.01	0	0.03	0.02
Oak/loblolly	0.74	0.07	0.13	0.05	0	0	0.13	0.07
Post oak/ blackjack oak	0.93	0.03	0.07	0.03	0	0	0	0
Chestnut oak	0.82	0.03	0.11	0.03	0.05	0.02	0	0
White oak/red oak/ hickory	0.83	0.02	0.10	0.01	0.02	0	0.05	0.02
White oak	0.68	0.09	0.18	0.07	0.02	0.01	0.12	0.08
Northern red oak	0.73	0.08	0.18	0.05	0	0	0.08	0.08
Yellow-poplar/ white oak/red oak	0.83	0.05	0.13	0.05	0.04	0.02	0	0
Sweetgum/ yellow-poplar	0.89	0.04	0.09	0.04	0.01	0.01	0	0
Chestnut oak/black oak/scarlet oak	0.94	0.03	0.04	0.03	0	0	0.01	0.01
Red maple/oak	0.87	0.05	0.12	0.05	0.01	0.01	0	0
Mixed upland oaks	0.85	0.04	0.08	0.03	0.02	0.01	0.04	0.03
Sweetgum/nuttall oak/willow oak	0.73	0.10	0.10	0.04	0.04	0.03	0.14	0.08
Sweetbay/swamp tupelo/red maple	0.66	0.14	0.33	0.15	0	0	0.05	0.03
Black ash/ American elm/red maple	0.83	0.04	0.16	0.04	0	0	0	0
Sugarberry/ hackberry/elm/ green ash	0.83	0.04	0.15	0.04	0.01	0.001	0	0
Sugar maple/ beech/yellow birch	0.81	0.02	0.15	0.02	0.03	0.01	0.02	0.01
Black cherry	0.94	0.04	0.06	0.04	0	0	0	0
Hard maple/ basswood	0.86	0.03	0.07	0.02	0.03	0.02	0.04	0.03
Elm/ash/locust	0.91	0.01	0.09	0.01	0	0	0	0
Upland red maple	0.83	0.06	0.11	0.04	0.01	0	0.06	0.06
Aspen	0.84	0.02	0.13	0.02	0.01	0.01	0.01	0.01
Paper birch	0.84	0.03	0.14	0.03	0.02	0.01	0	0

Due to rounding, not all ratios will add up to 1 for individual forest types.
[a] See North Central Research Station (2002); Miles and others (2001).

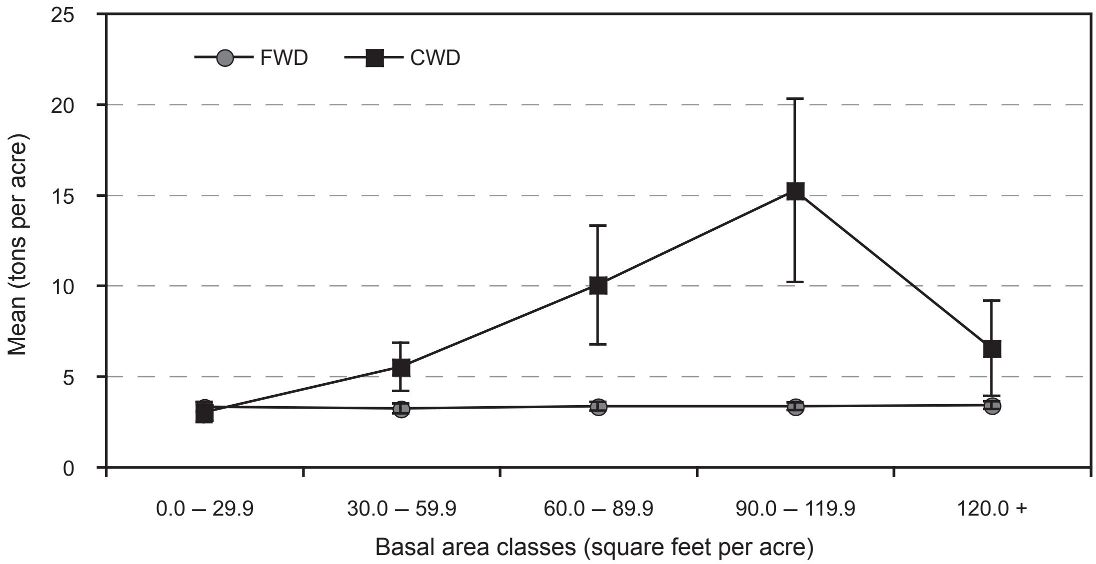

Figure 1—Means and associated standard errors of fine woody debris (FWD) and coarse woody debris (CWD) in hardwood forests across the Eastern U.S. by standing live tree basal area class.

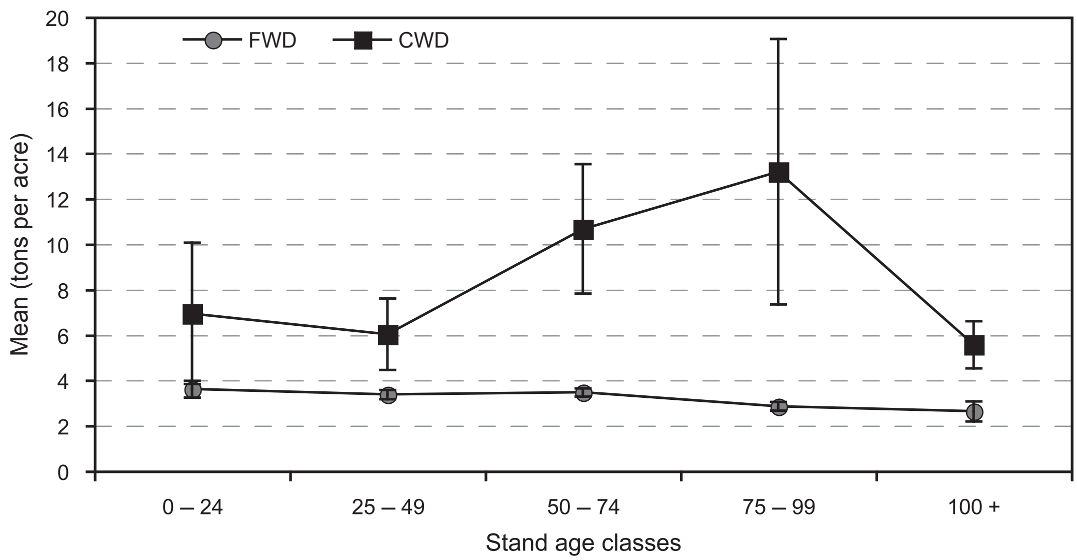

Figure 2—Means and associated standard errors for fine woody debris (FWD) and course woody debris (CWD) by stand age classes (years).

forest type groupings and had larger ratios of CWD to FWD than most other forest types. These forest types are prevalent in the hardwood forests of much of the eastern U.S. Within the context of fuel loadings in forests across the nation, the fire dangers in eastern hardwood forests should be considered low due to the mesic environments and relatively low mean fuel loadings. However, fire dangers might be exceedingly high for local areas due to high fuel loadings (> 50 tons per acre) in isolated areas and regional droughts.

For most hardwood forests, CWD constituted the majority of the total down woody fuel loading. With the exception of upland red maple forest types, forests that had oak species mixtures often had the highest mean CWD. Four out of the top five forest types in terms of highest CWD amounts were oak forest types (oak/other pine, oak/loblolly, white oak/red oak/hickory, white oak) accounting for almost a third of study observations. Eyre (1980) also found unusually high levels of CWD in some eastern oak stands. There may be a number of reasons why mixed species oak forests have higher levels of CWD. First, across much of New England and New York beech bark disease (BBD) mortality has added unnaturally high amounts of CWD to many stands (Gore and Patterson 1986). McGee (1998) estimated that BBD-induced mortality may have increased CWD volumes by as much as 25 percent. Second, forests in the southern U.S. are periodically infested with southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) in varying degrees of severity (Coulson and others 1999). The SPB causes mortality in all pine species often devastating entire softwood stands and resulting in large amounts of down woody material. CWD is particularly prevalent when an SPB attack is followed by windthrow events and a lack of active management (e.g., salvage logging) (Hanula 1993). In the southern states of Georgia, Alabama, Arkansas, and Lousiana where hardwood forests are interspersed and commingled with yellow pine species, SPB could account for much of the accumulation of down woody material. Bragg (2004) noted that in pine-hardwood stands in southern Arkansas, pines contributed more DWM (60 percent) than hardwood species, even though softwoods contributed less than 20 percent of the overstory stem count. Third, high levels of CWD in oak forests may indicate widespread oak tree mortality. Thomas and Boza (1984) and Kessler (1989) suggest that oak forests are in a state of decline highlighted by observed oak forest declines in regions of the south-central US. The high level of CWD in oak forests may be another indicator of their decline. In addition to oak decline, extensive gypsy moth defoliation has caused oak mortality for more than a century in eastern and and north-central forests of North America (Davidson and others 1999).

In terms of wildlife habitat, CWD appears to be prevalent across most hardwood forests in this study. However, we found that most hardwood forests have less than 10 tons per acre of CWD in sizes below 8 inches (transect diameter). Further, very few hardwood forests on average had any CWD pieces greater than 13 inches, a finding supported by McCarthy and Bailey (1994). These results indicate that CWD hardwood forest habitat may provide adequate structural diversity and ecological niches for smaller fauna. Further, the moderate stages of CWD decay indicate no recent widespread mortality events and no immediate loss of CWD habitat. However, the lack of large CWD pieces provides little habitat for larger-sized fauna and may reflect decades of utilization and natural negative exponential stand size-class distributions common (Spetich and others 1999) in eastern hardwood forests.

Relationships between standing tree attributes, such as stand age and density, and total down woody fuel loadings refines understanding of stand dynamics and its role in DWM accumulation. For FWD, we found no relationship with stand age or stand basal area. However, we found increasing CWD amounts with increasing stand age and basal area (except for the highest classes of independent variables). Our findings are similar to Spetich and Guldin (1999) with regards to the accumulation of DWM in southern Arkansas and Northern Louisiana, and the increase of DWM with increasing basal area. Spetich and Guldin (1999) found that accumulation of dead trees was highest in southeast Arkansas, and that increasing volumes corresponded with increasing site productivity—a function of increased biomass corresponding with increased dead wood volume over time. However, Nordén and others (2004) found no correlation between DWM volume and basal area in temperate broadleaved forests in Europe, and suggested that stand age and management, which also affect basal area, may preclude the use of basal area as a predictive variable. Although we found possible relationships between CWD and stand age/density, future studies may need to incorporate variables relating to ownership, climate, physiography, and stand history to further elucidate CWD differences across large-scales.

CONCLUSIONS

We present results of one of the first regional assessments of DWM in hardwood forests of the eastern US. Our estimates of DWM suggest that fuel loadings are not exceedingly high in most hardwood forests and may only pose a fire danger in isolated areas of high fuel loadings in times of drought. Beyond obvious fire danger assessment, our study also suggests: (1) the lack of large CWD pieces indicates a lack of habitat for large fauna, (2) the prevalence of CWD in oak forests may indicate widespread impacts of forest pests and oak decline, (3) weak correlation between total woody fuels and stand age/density indicate the difficulty in predicting DWM attributes for any given hardwood stand, (4) and climatic attributes of temperature and moisture may influence the accumulation of CWD across the diverse hardwood ecosystems of the eastern US. Although DWM may serve as an indicator of fire dangers and habitat, it may also indicate the impacts of forest pests and resulting health of hardwood forests.

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