Amounts of Down Woody Materials for Mixed-Oak Forests in Kentucky, Virginia, Tennessee, and North Carolina

David C. Chojnacky, *USDA Forest Service, 1115-VMPR, 1400 Independence Avenue, SW, Washington, DC 20250-1115; and* **Thomas M. Schuler,** *USDA Forest Service, Northeastern Research Station, Parsons, WV 26287.*

ABSTRACT: *Fallen or down dead wood is a key element in healthy forest ecosystems. Although the amount of down wood and shrubs can provide critical information to forest resource managers for assessing fire fuel build up, data on biomass of down woody materials (DWM) are not readily accessible using existing databases. We summarized data collected by the USDA Forest Service's Forest Inventory and Analysis (FIA) program into biomass for mixed-oak forest types in Kentucky, Virginia, Tennessee, and North Carolina to obtain a baseline average for Appalachian mixed-oak forests. We sampled a subset of 76 plots from 16 oak forest types and computed biomass for each DWM component, using slightly different equations for each. Biomass of DWM components was summarized using simple statistics. The mean of all DWM components combined was 32 Mg/ha, and the median was 29 Mg/ha. Over half the mean DWM was duff and litter (18 Mg/ha combined); coarse woody material (CWM) was less than 15% of mean DWM; and fine woody material (FWM) (7 Mg/ha) was almost twice CWM. The range of mass for individual components was quite large. These estimates compare favorably to those found in studies for other forest types. South. J. Appl. For. 28(2):113–117.*

Key Words: Deadwood, coarse woody debris, fine woody debris, duff, litter, forest floor, carbon.

Fallen or down dead wood is a key element in healthy forest ecosystems. This sometimes maligned forest component—what we are calling down woody material—provides a nutrient pool for animals and microbes, and it serves as a vital link in the flow of energy and material through its role in carbon sequestration, nutrient cycling, and soil stability (Harmon et al. 1986, Hagan and Grove 1999, Karjalainen and Kuuluvainen 2002). Down woody material also influences fire behavior and ultimately the effects of fire on nutrient cycling (Vose and Swank 1993), wildlife (Hallisey and Wood 1976), and vegetation (Arthur et al. 1998). Consequently, the amount of down wood and shrubs in a forest can provide critical clues to resource managers for assessing fire fuel buildup. Despite its importance, data on the biomass of down woody material are not readily accessible using existing data bases for US forests, and baseline estimates have not been reported for the southern Appalachians, where prescribed fire is increasingly being used to manage mixed-oak forests (Brose et al. 2001).

Down woody material (DWM) consists of five components: (1) coarse woody material (CWM), which is all down and dead pieces 76 mm in diameter and larger; (2) fine woody material (FWM), which includes the smaller-sized woody branch pieces, tallied in three diameter classes; (3) litter, which includes all other dead, detached plant material lying loosely on the forest floor, distinguishable as needles, leaves, cones, bark, rotted wood chunks, or other plant parts; (4) duff, which includes all the partly decayed organic material between litter and the A1 soil horizon that bears little resemblance to original plant structures; and (5) understory shrub and herb cover, which includes all live and dead plants that are still standing upright (down material is included in litter or duff).

These definitions are based roughly on those used by the USDA Forest Service's Forest Inventory and Analysis (FIA) program, which is beginning to measure DWM in its nationwide forest inventories (FIA, http://fia.fs.fed.us/, Jan. 1, 2003). FIA's mission is to collect data from and continually monitor field plots across all forestland ownership in

NOTE: David C. Chojnacky can be reached at (703) 605-5262; Fax: (703) 605-5133; dchajnacky@fs.fed.us. The authors thank Chris Woodall, Brian Cordova, and Barb O'Connell for supplying FIA data used in our analysis; Manchuan Liu for help with data analysis; and Mary Carr and an anonymous reviewer for editorial assistance.

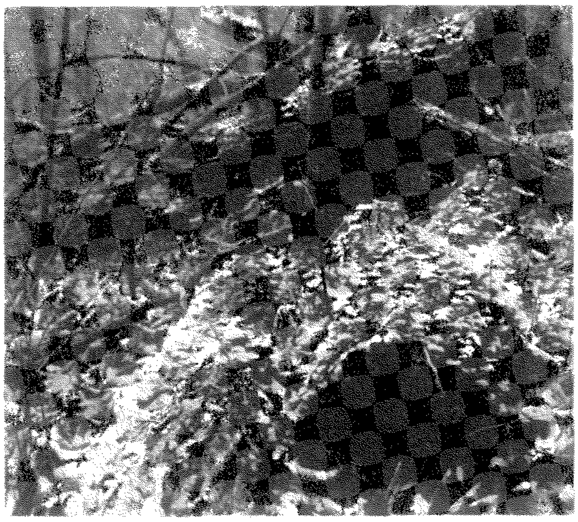

Figure 1. Chestnut oak coarse woody material (>76 mm diameter), fine woody material (<76 mm diameter), and leaf litter, Jefferson National Forest, Virginia.

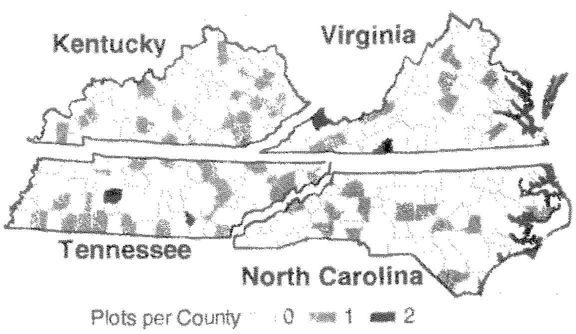

Figure 2. Data included 76 plots in mixed-oak forest types: 21 in Kentucky, 17 in Virginia, 26 in Tennessee, and 12 in North Carolina.

the United States. The program involves three phases: a remote-sensing phase (P1) is used to determine forest area; a grid of 120,000 field plots at 5-km intervals is used to measure trees in a second phase (P2); and a 1/16 subsample of P2 plots is used in a third phase (P3) to collect more detailed forest health information. The P2 plots sample the nation's 302 million ha of forestland with about 1 plot per 2500 ha.

The purpose of this study was to compile FIA P3 measurements on DWM into biomass for mixed-oak forests in Kentucky, Virginia, Tennessee, and North Carolina, to obtain a baseline average for Appalachian mixed-oak forests (Figure 1). Although P2 data on live trees and other forest attributes had been collected for the P3 plots studied, these data were not available for detailed analysis at this time.

Methods

The DWM data were part of larger project that compiled data for 778 P3 plots sampled in the eastern United States in 2001 (Chojnacky et al., in press). We sampled a subset of 76 plots from 16 oak forest types for Kentucky, Virginia, Tennessee, and North Carolina to represent mixed-oak forests in the central and southern Appalachian forests (Figure 2). The forest types had been previously calculated from P2 tree-level data that were unavailable to us or infeasible for further examination.

Computation of biomass for each DWM component was done in a slightly different fashion. For (CWM), we used a simple linear equation that required measurement of log diameter, transect length, and slope correction variables (Brown 1974):

$$\mathrm{CWM} = \sum_{i=1}^{n} \frac{f\,\mathrm{dia}_i^2 \rho d c}{L} \qquad (1)$$

where

CWM = coarse woody material >76 mm diameter (Mg/ha or ton/ac)
n = total pieces of wood sampled on transect
f_m = metric units conversion factor: $\left(\frac{(11.64)(2000)}{(2.2046)(0.404686)(1000)}\right) = 26.09366$
f_E = English units conversion factor: 11.64
dia = log diameter (to nearest inch) at transect intersection of logs >76 mm (small end) for decay classes 1 to 4 and logs >127 mm (small end) for decay class 5; for decay class definitions see FIA website or Chojnacky et al. (in press)
ρ = specific gravity of wood species, from Forest Service, Forest Products Laboratory (L.S. Heath, pers. comm., USDA, FS, NE, 2003)
d = decay class deduction (for conifer: class 1 = 1.0, class 2 = 0.84, class 3 = 0.71, 4 = 0.45, class 5 = 0.35; for hardwood: class 1 = 1.0, class 2 = 0.78, class 3 = 0.45, 4 = 0.42, class 5 = 0.35) (K.L. Waddell, pers. comm., USDA Forest Service, Portland, OR, 2000)
c = $\sqrt{1 + \left(\frac{\text{slope percent}}{100}\right)^2}$ (Brown 1974)
L = transect length (ft).

Because FIA measurements are made in English units, the equation input variables were not converted to the metric system prior to compilation; however, results are easily calculated in either metric or English depending on which f-factor (f_m or f_E) is used.

Biomass for fine woody material (FWM) was calculated in a similar fashion, except that diameter class means and piece tallies were used in place of exact diameter measurements:

$$\mathrm{FWM} = \sum_{i=1}^{3} \frac{f T_i d c_i^2 \rho d c a}{L_i} \qquad (2)$$

where

FWM = fine woody material <76 mm diameter (Mg/ha or ton/ac)
i = 3 diameter classes of FWM: 0–6 mm, 6–25 mm, 25–76 mm
T_i = tally of number of pieces in each diameter class
dc_1^2 = 0.0151, mean diameter (in.^{2}) for 0–6 mm small material
dc_2^2 = 0.2890, mean diameter (in.^{2}) for 6–25 mm medium material
dc_3^2 = 2.7600, mean diameter (in.^{2}) for 25–76 mm large material
p = 0.46, median specific gravity of all US tree species
d = 0.9, assumes some decay
a = 1.13, average correction factor to adjust all material as if lying flat on ground.

Litter and duff biomass calculations assumed that the depth measurement represents a uniform cylinder of constant density:

$$\text{Litter or Duff} = fD \tag{3}$$

where

Litter = recognizable plant material on forest floor (Mg/ha or ton/ac)
Duff = unrecognizable plant material below litter and above mineral soil (Mg/ha or ton/ac)
f_m = metric units conversion factor: $\left(\frac{43560}{(2.2046)(0.404686)(1000)}\right) = 48.82473$
f_E = English units conversion factor: $\left(\frac{43560}{2000}\right) = 21.7800$
D = material density (lbs/ft^3); for litter = 0.9, for duff = 2.0 (C.W. Woodall, pers. comm., USDA Forest Service, St. Paul, MN, 2002).

To compute shrub and herb biomass, we applied regression equations developed in the western United States (Mitchell et al. 1987, Brown and Marsden 1976), using the same equations for both live and dead cover:

$$\text{Shrub} = f\left(\frac{109.0 - (2.161\ C_S) + (0.1078\ C_S^2)}{100}\right) \tag{4}$$

where

Shrub = live or dead biomass (Mg/ha or ton/ac)
f_m = metric units conversion factor: 1
f_E = English units conversion factor: $\frac{(2.2046)(0.404686)(1000)}{2000} = 0.44609$
C_S = horizontal projection of live or dead shrub cover above plot surface (%)

$$\text{Herb} = f\left(\frac{13.66 C_H}{1000}\right) \tag{5}$$

where

Herb = live or dead biomass (Mg/ha or ton/ac)
C_H = horizontal projection of live or dead herb cover above plot surface (%).

Biomass of DWM components was summarized using simple statistics including mean, median, minimum, maximum, range, standard deviation, standard error, and coefficient of variation.

The median is probably the most "robust" statistic for assessing DWM; that is, it is relatively insensitive to extreme data values. Although the mean is more influenced by extreme values, it useful for comparison to other studies and includes a probability statement (based on sampling error) on how close it is to the true population mean.

Results

The mean of all DWM components combined was 32 Mg/ha (Table 1), and the median was 29 Mg/ha. Over half the mean DWM was duff and litter (18 Mg/ha combined); CWM was less than 15% of mean DWM (4 Mg/ha); and FWM (7 Mg/ha) was almost twice CWM.

The standard error of all DWM components was 1.5 Mg/ha, which means there is a 19-in-20 chance that the true population mean is between 29 and 35 Mg/ha, or within about ±9% of the sample mean. The range in DWM mass was twice the mean, and the median of each component was generally less than the mean.

The range of mass for individual components—CWM, FWM, litter, and duff—was quite large. Interestingly, none of these components were significantly correlated (at 0.05 probability level) with each other from plot to plot, which means that a low value in one component did not necessarily mean a low value in another, and vice versa. Further explanation of the range in mass among components is likely related to various management practices or other disturbances (such as fire). However, this was not explored because detailed P2 data were lacking for clarifying overall forest condition for each plot.

Discussion

Comparison of our data to that of other studies is difficult because definitions of DWM components are quite variable and few authors report estimates for all components in a single study. However, we do make some rough comparisons.

Our estimate of DWM mass is about 10% of the 211–280 Mg/ha reported for old-growth coniferous forests on the coast of British Columbia (Keenan et al. 1993). Vande Walle et al. (2001) report 3–36 Mg/ha carbon for down woody materials in Belgian deciduous forests, which equates to about 6–72 Mg/ha mass (assuming carbon is 50% mass) and is more comparable to our 32 Mg/ha estimate. Exact definition of DWM is unclear for the estimate

Table 1. **Down woody materials (DWMs) summarized for mixed-oak forest types in Kentucky, Virginia, Tennessee, and North Carolina from 76 FIA plots sampled in 2001. Components include coarse woody material (CWM), fine woody material (FWM), litter, duff, and understory plants.**

Component variable	No. of plots[a]	Mean	Median	Min	Max	Range	SD	SE[b]	CV[c]
			......	......	.(Mg/ha)[d].	......	......	......	%
CWM (>76 mm dia.)	76	4.40	3.12	0	32.81	32.81	5.3	0.61	14
FWM (25–76 mm dia.)	73	5.70	4.28	0	38.75	38.75	5.84	0.68	12
FWM (6–25 mm dia.)	73	1.48	1.13	0	6.84	6.84	1.24	0.15	10
FWM (0–6 mm dia.)	73	0.17	0.13	0.01	0.67	0.66	0.13	0.02	12
Total FWM	73	7.34	5.88	0.39	39.28	38.89	6.49	0.76	10
Litter	75	6.32	6.43	0	21.97	21.97	3.82	0.44	7
Duff	75	11.56	10.73	0	36.59	36.59	8.02	0.93	8
Live shrub	74	1.43	1.03	0	5.21	5.21	1.16	0.14	10
Dead shrub	74	0.38	0.25	0	3.46	3.46	0.54	0.06	16
Live herb	74	0.25	0.14	0	1.05	1.05	0.26	0.03	12
Dead herb	74	0.03	0	0	0.34	0.34	0.06	0.01	33
Total shrub & herb	74	2.09	1.74	0	6.52	6.52	1.48	0.17	8
Total DWMs (includes total shrub & herb)	73	31.97	29.1	3.78	65.34	61.56	12.75	1.49	5

[a] A few components were missing on some plots for various reasons.
[b] Standard error is standard deviation divided by square root of number of plots.
[c] Coefficient of variation is standard error divided by mean and multiplied by 100.
[d] For conversion to tons/ac, multiply by 0.44609.

by Harmon et al. (1995) of 28 Mg/ha mass of forest floor detritus for dry tropical forest sites in Mexico, but their results appear to be comparable to our estimate.

For CWM and FWM combined, our estimate of 12 Mg/ha mass compares favorably to several estimates. For Kentucky old-growth forest, Muller and Liu (1991) report CWM (>20 cm diameter) and some fragments at 17 Mg/ha. Similarly, MacMillan (1988) reports CWM combined with FWM (>5 cm) in old-growth Indiana forests at 18 Mg/ha. On the other hand, Wei et al. (1997) report a larger range of 20–103 Mg/ha mass for CWM and FWM in interior British Columbia pine forests. McCarthy and Bailey (1994) estimate 31 Mg/ha mass for CWM and FWM (>2.5 cm) for Maryland stands of several ages.

Our estimate of litter and duff mass at 18 Mg/ha compares reasonably well with Klopatek's (2002) estimate of 28 Mg/ha for young growth Douglas-fir in Washington. Vose and Swank (1993) estimate litter and duff (with maybe some FWM added) at 34 Mg/ha for mixed pine hardwood in North Carolina. They also reported herb mass at 0.5 Mg/ha, which is similar to our 0.3 Mg/ha estimate.

It should be noted that our estimate of DWM mass was derived from samples from stands of all ages under many different types of management, representing all forestland regardless of tree density. Therefore, we would expect our DWM mean overall stand conditions to be lower than old-growth studies or other ecological studies that examine DWM where it is at least present in sufficient amount for study.

Also, our estimates probably include some nonsampling error that is difficult to assess at this time. Because our data were based on the first-year application of FIA's relatively simple field procedures designed to handle all forest conditions in the United States, our estimates lack the precision and accuracy of studies tailored for specific sites. Our greatest concern is about the auxiliary parameters in the compilation equations (1 to 5), which are not necessarily appropriate for Appalachian mixed-oak forests. Of particular unease are the density parameters and mean diameters of the FWM size classes, which were either extrapolated from sound wood densities (from Forest Products Lab) or based on data from western US forests. However, as future research into these parameters is done, our estimates can be updated accordingly.

Summary

We summarized data collected by the USDA Forest Service's FIA program into biomass for mixed-oak forest types in Kentucky, Virginia, Tennessee, and North Carolina to obtain a baseline average for Appalachian mixed-oak forests. We sampled a subset of 76 plots from 16 oak forest types, calculating biomass using different equations for the various components of DWM. Our analysis provides an estimate of 32 Mg/ha DWM biomass (mean) for mixed-oak forests in the four states. Over half the DWM was duff and litter (18 Mg/ha combined); less than 15% was coarse wood; fine wood was almost twice coarse wood. These estimates compare favorably to those found in studies for other forest types, given the varying locations, assumptions, and conditions of other studies.

Literature Cited

Arthur, M.A., R.D. Paratley, and B.A. Blankenship. 1998. Single and repeated fires affect survival and regeneration of woody and herbaceous species in an oak-pine forest. J. Torrey Bot. Soc. 125(3):225–236.

Brose, P., T. Schuler, D. Van Lear, and J. Berst. 2001. Bringing fire back: The changing regimes of the Appalachian mixed-oak forests. J. For. 99(11):30–35.

Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. GTR INT-16. 34 p.

Brown, J.K., and M.A. Marsden. 1976. Estimating fuel weights of grasses, forbs, and small woody plants. USDA For. Serv. Res. Note. INT-210. 11 p.

Chojnacky, D.C., R.A. Mickler, L.S. Heath, and C.W. Woodall. [in press]. Estimates of down woody materials in eastern U.S. forests. Submitted to Environ. Manage.

HAGAN, J.M., AND S.L. GROVE. 1999. Coarse woody debris. J. For. 97(1):6–11.

HALLISEY, D.M., AND G.W. WOOD. 1976. Prescribed fire in scrub oak habitat in central Pennsylvania. J. Wildl. Manage. 40(3):507–516.

HARMON, M.E., J.F. FRANKLIN, F.J. SWANSON, P. SOLLINS, S.V. GREGORY, J.D. LATTIN, N.H. ANDERSON, S.P. CLINE, N.G. AUMEN, J.R. SEDELL, G.W. LIENKAEMPER, K. CROMACK, JR., AND K.W. CUMMINS. 1986. Ecology of coarse woody debris in temperate ecosystems. P. 133–302 *in* Advances in ecological research, volume 15, Macfadyen, A., and D.E. Ford (eds.) Academic Press, New York.

HARMON, M.E., D.F. WHIGHAM, J. SEXGON, AND I. OLMSTEAD. 1995. Decomposition and mass of woody detritus in dry tropical forest of the northeastern Yucatan Peninsula, Mexico. Biotropica 70(3):305–316.

KARJALAINEN, L., AND T. KUULUVAINEN. 2002. Amount and diversity of coarse woody debris within a boreal forest landscape dominated by *Pinus sylvestris* in Vienansalo wilderness, eastern Fennoscandia. Silva Fennica 36(1):147–167.

KEENAN, R.J., C.E. PRESCOTT, AND J.P. KIMMINS. 1993. Mass and nutrient content of woody debris and forest floor in western red cedar and western hemlock forests on northern Vancouver Island. Can. J. For. Res. 23(6):1052–1059.

KLOPATEK, J.M. 2002. Belowground carbon pools and processes in different age stands of Douglas-fir. Tree Physiol. 22(2–3):197–204.

MACMILLAN, P.C. 1988. Decomposition of coarse woody debris in an old-growth Indiana forest. Can. J. For. Res. 18(11):1353–1362.

MCCARTHY, B.C., AND R.R. BAILEY. 1994. Distribution and abundance of coarse woody debris in a managed forest landscape of the central Appalachians. Can. J. For. Res. 24(7):1317–1329.

MITCHELL, J.E., P.N.S. BARTLING, AND R.O. O'BRIEN. 1987. Understory cover-biomass relationships in the Front Range ponderosa pine zone. USDA For. Serv. Res. Note RM-471. 5 p.

MULLER, R.N., AND Y. LIU. 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Can. J. For. Res. 21(11):1567–1572.

VANDE WALLE, I., S. MUSSCHE, R. SAMSON, N. LUST, AND R. LEMEUR. 2001. The above- and belowground carbon pools of two mixed deciduous forest stands located in East Flanders (Belgium). Ann. For. Sci. 58(5):507–517.

VOSE, J.M., AND W.T. SWANK. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: Aboveground biomass, forest floor mass, and nitrogen and carbon pools. Can. J. For. Res. 23(10):2255–2262.

WEI, X., J.P. KIMMINS, K. PEEL, AND O. STEEN. 1997. Mass and nutrients in woody debris in harvested and wildfire-killed lodgepole pine forests in the central interior of British Columbia. Can. J. For. Res. 27(2):148–155.