Snags and Down Wood in Missouri Old-Growth and Mature Second-Growth Forests

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ABSTRACT. *As forest managers in the Midwest focus more attention toward understanding and maintaining ecosystem processes, greater emphasis is being placed on the role of snags and down wood in providing wildlife habitat, cycling nutrients, and maintaining continuity in forest structure following harvest. We measured five remnant old-growth hardwood tracts and six mature, second-growth, hardwood tracts in Missouri and compared findings concerning (1) the volume of down wood and (2) the number and size distribution of snags (i.e., standing dead trees). Volume of down wood ≥ 10 cm in diameter averaged 36 m^3/ha on the old-growth tracts, double the 18 m^3/ha mean volume for the second-growth sites. This difference in volume was concentrated in pieces of down wood with diameters larger than 20 cm; below diameters of 20 cm the number of pieces of down wood by diameter class was similar for the old-growth and second-growth sites. On the old-growth sites, the mean basal area of snags ≥10 cm dbh was 1.9 m^2/ha. This was approximately 1.5 times greater than the mean basal area of snags on the second-growth sites. The number of snags ≥ 10 cm dbh on the old growth sites was approximately 9% of the number of live trees on those sites. The corresponding value for second-growth sites was 8%. On both the old-growth and second-growth sites, the number of snags and the number of live trees by dbh class followed a negative exponential (reverse-J) form. Frequency distributions for the number of snags by dbh class closely followed those for live trees on the same sites. These results provide managers with general guidelines for the quantity of down wood likely to be found in mature second-growth forests and old-growth forests. We also provide some provisional rules of thumb for estimating the density and size distribution of snags from values observed for live trees in the same stand. North. J. Appl. For. 14(4):165–172.*

Snags and fallen logs are important components of forest ecosystems. They cycle nutrients and energy, provide habitat and food, serve as substrate for vascular plants and fungi, and influence rates of soil and water movement. Meyer (1986) identified 23 species of birds, 11 mammals, 12 amphibians, and 8 reptiles common to Missouri forests that are dependent on snags or down logs. Evans and Connor (1979) point out that populations of 36 species of cavity nesting birds occurring in the northeastern United States are greatly influenced by the number and kind of snags. Maser et al. (1979) and Maser and Trappe (1984) offer a thorough discussion of the role of coarse woody debris in the function of forest ecosystems. Although the latter sources use examples from the northwestern United States, the concepts are universal. As forest managers in the Midwest focus more attention toward understanding and maintaining ecosystem processes, they need more information about the various dead wood components of a

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forest and how, like the living components, the amount of dead wood in the forest changes over time.

Detailed information about dead wood in Midwestern forests is limited primarily to studies in remnant old-growth forests where the volumes are relatively high. Reported values for the density, volume, or biomass of snags and down logs vary substantially among sites. Down wood volume estimates reported for old-growth forests in Illinois, Indiana, Iowa, Kentucky, Missouri, and Tennessee range from 32 to 111 m^3/ha; reported biomass of down wood ranges from 14 to 44 Mg/ha (MacMillan 1981, 1988, Muller and Liu 1991, Parker 1989, Richards et al. 1995, Shifley et al. 1995, Spetich 1995). The reported number of snags larger than 10 cm dbh ranges from 19 to 44 per ha with volumes from 12 to 35 m^3/ha (McComb and Muller 1983, Muller and Liu 1991, Parker 1989, Shifley et al. 1995, Spetich 1995).

Because most resource inventories do not routinely measure or summarize information on dead wood, it is difficult to put reported values for old-growth stands into perspective relative to the second-growth forests which dominate the current landscape. Where do reported values for old forests fall relative to second-growth forests? We generally expect old-growth forests to have greater volumes of down or standing dead wood, but how much greater? In one comparison of old-growth and second-growth forests in Kentucky, the mean number of snags ≥ 2.5 cm dbh was greater in a 35-yr-old even-aged second-growth forest (741/ha) than in a nearby old-growth forest (312/ha) (McComb and Muller 1983). However, the number of snags greater than 15 cm did not differ significantly between the second-growth and old-growth sites (14 and 8 snags/ha, respectively).

In this paper we present information about the size and volume of snags and down wood at five old-growth sites in Missouri. To put those findings into perspective, we compare our findings with data from six mature, second-growth tracts. Finally, we present some relationships that express the number of snags as a function of the number and size of live trees. We believe this information will be useful to managers who want better information about how the amount of down wood in a forest changes with age and how the size distribution of snags is related to that of live trees.

Methods and Data

We combined three separate data sources for analysis and comparison in this study. Each source is summarized below with a description of sampling procedures at each site. All tracts have oak-dominated overstories. They represent a range of site conditions from xeric oak-hickory forest to mesic forests with a mixture of oaks and sugar maple.

Old-Growth Sites

In 1992 and 1993, we inventoried five remnant old-growth tracts in Missouri for estimates of down wood, standing dead trees, and live trees (Figure 1). At the Big Spring, Dark Hollow, Engelmann Woods, and Roaring River sites, we systematically established thirty 0.1 ha circular plots on a square grid. Plot centers were at least 90m apart, and plots were distributed to cover the entire

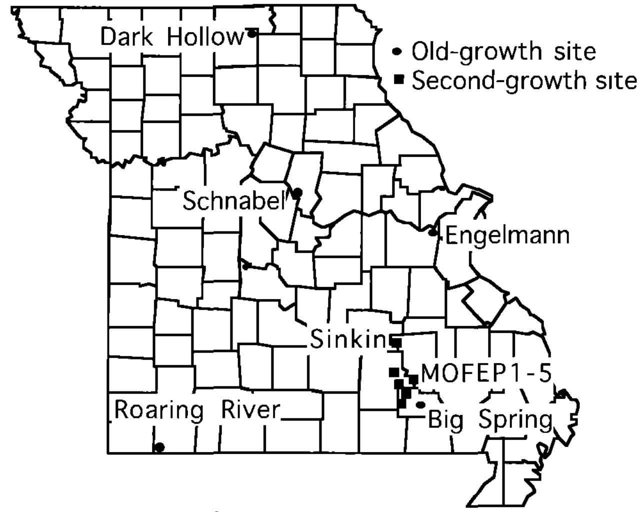

Figure 1. Location of study sites.

tract. On each plot we recorded the number, length, decay class (Table 1), and midpoint diameter of down logs or portions of down logs ≥ 10 cm in diameter. To the extent possible, each down log was measured as a single piece Broken logs, forked logs, and large branches were tallied as multiple pieces, when necessary. Snags and live trees ≥ 10 cm were sampled on the same plots. Heights were recorded for dead trees. At the Schnabel Woods site, the same variables were measured but sampling was restricted to two 0.6 ha plots, one plot with a northeast aspect and the other with a southeast aspect (Richards et al. 1995).

The term "old-growth" applied to a particular Midwestern forest is somewhat subjective and based on a combination of factors including: age of dominant trees; a long history of limited human-caused disturbance; and structural characteristics that include multiple-age cohorts, numerous canopy gaps, full stocking, and the accumulation of snags and down wood from trees in larger size classes (Parker 1989, Martin 1991). The old-growth tracts used in this study had dominant trees that were at least 110 yr old and in some cases exceeded 300 yr. At various times over the last century these tracts have had periodic fires and occasional grazing, events that historically were common statewide. Nevertheless, these tracts are among the best examples of upland remnant old-growth forest in Missouri. The overstories at all sites are dominated by oaks (Table 2).

Table 1. Decay classes used to categorize down wood. Classes based on Maser et al. (1979).

Class	Description
1	Bark intact; twigs present; log intact to partially soft; round; elevated on support points
2	Bark intact; twigs absent; log intact; round shape with soft spots; elevated on support points but sagging slightly
3	Trace of bark; twigs absent; log breaking into large hard pieces; sagging on or near ground
4	Bark absent; twigs absent; round to oval shape decomposing into small, soft, blocky pieces; in full contact with ground
5	Bark absent; twigs absent; log flat and soft; crumbles into powder or small pieces; in full contact with ground.

Table 2 Characteristics of tracts sampled

Site	Location	Tract size (ha)	No. of plots	Years measured	Dominant tree species	Plot size
Big Spring Natural Area Old-growth	Carter County	65	30	1992	White oak (*Quercus alba* L.) Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) Shortleaf pine (*Pinus echinata* Mill.) Hickory spp. (*Carya* spp.)	0.1 ha for trees ≥ 10 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
Dark Hollow Old-growth	Sullivan County	78	30	1993	N. red oak (*Q. rubra* L.) White oak (*Q. alba* L.) Hickory spp. (*Carya* spp.) Basswood (*Tilia americana* L.)	0.1 ha for trees ≥ 10 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
Engelmann Woods Natural Area Old-growth	Franklin County	55	30	1992	Sugar maple (*Acer saccharum* Marsh.) N. red oak (*Q. rubra* L.) Chinkapin oak (*Q. muehlenbergii* Engelm.) White ash (*Fraxinus americana* L.) Hickory spp. (*Carya* spp.)	0.1 ha for trees ≥ 10 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
Roaring River Natural Area Old-growth	Barry County	49	30	1992	White oak (*Q. alba* L.) Black oak (*Q. velutina* Lam.) N. red oak (*Q. rubra* L.) Hickory spp. (*Carya* spp.)	0.1 ha for trees ≥ 10 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
Schnabel Woods Old-growth	Boone County	32	2	1992	Sugar maple (*A. saccharum* Marsh.) N. red oak (*Q. rubra* L.) Chinkapin oak (*Q. muehlenbergii* Engelm.) Basswood (*T. americana* L.)	0.6 ha for trees ≥ 2 cm and for down wood ≥ 10 cm diameter
Sinkin Experimental Forest Second-growth	Dent and Reynolds Counties	1,659	71	1992, 1993	White oak (*Q. alba* L.) Black oak (*Q. velutina* Lam.) Shortleaf pine (*P. echinata* Mill.) Scarlet oak (*Q. coccinea* Muenchh.)	0.1 ha for trees ≥ 10 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
MOFEP Site 1 (compartments 1& 2) Second-growth	Shannon County	907	146 total, 22 for down wood	1990–1992	Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) White oak (*Q. alba* L.) Hickory spp. (*Carya* spp.) Shortleaf pine (*P. echinata* Mill.)	0.2 ha for trees ≥ 11.4 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
MOFEP Site 2 (compartments 3 & 4) Second-growth	Shannon County	800	146 total, 22 for down wood	1990–1992	Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) White oak (*Q. alba* L.) Hickory spp. (*Carya* spp.) Shortleaf pine (*P. echinata* Mill.)	0.2 ha for trees ≥ 11.4 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
MOFEP Site 3 (compartments 5 & 6) Second-growth	Reynolds and Shannon Counties	708	141 total, 22 for down wood	1990–1992	Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) White oak (*Q. alba* L.) Hickory spp. (*Carya* spp.) Shortleaf pine (*P. echinata* Mill.)	0.2 ha for trees ≥ 11.4 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
MOFEP Site 4 (compartments 7 & 8) Second-growth	Carter County	836	141 total, 22 for down wood	1990–1992	Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) White oak (*Q. alba* L.) Red oak (*Q. rubra* L.) Shortleaf pine (*P. echinata* Mill.)	0.2 ha for trees ≥ 11.4 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter
MOFEP Site 5 (compartment 9) Second-growth	Carter County	473	71 total, 11 for down wood	1990–1992	Black oak (*Q. velutina* Lam.) Scarlet oak (*Q. coccinea* Muenchh.) White oak (*Q. alba* L.) Red oak (*Q. rubra* L.) Hickory spp. (*Carya* spp.)	0.2 ha for trees ≥ 11.4 cm dbh, 0.1 ha for down wood ≥ 10 cm diameter

Sinkin Experimental Forest

We used the 1,600 ha Sinkin Experimental Forest, located in Dent and Reynolds Counties, as a second-growth comparison site (Figure 1). Prior to establishment as an experimental forest in 1950, the tract was treated much like other forests in the area. It was extensively logged between 1900 and 1920; grazing and burning were common in the following years. Since 1950, grazing and wildfire have been excluded from the Sinkin. The majority of the acreage is well-stocked, second-growth, oak–hickory, and oak–pine forest in the 70 to 90 yr age class. Some areas have received experimental silvicultural treatments. Ninety-six 0.1 ha plots were established in 1992–1993 on a systematic grid covering the Sinkin. We limited our analysis to 71 plots that had received no cultural treatments in the prior 40 yr. Sampling procedures were identical to those used for the Big Spring, Dark Hollow, Engelmann, and Roaring River sites. Additional characteristics of the Sinkin site can be found in Table 2.

Missouri Ozark Forest Ecosystem Project

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a large-scale study of the impacts of cultural treatments on a broad range of ecosystem attributes (Brookshire and Hauser 1993). The pretreatment data from that study provide another source of mature, second-growth forest stands for comparison. The MOFEP project includes nine administrative compartments that lie in 5 contiguous tracts in the Missouri Ozarks (Figure 1). Tracts range in size from 473 to 907 ha (Table 2). In 1990–1992, prior to any experimental treatments, a total of 648 sample plots were established in the 5 separate tracts. Plots were distributed to ensure that at least one plot fell within each identified stand. Plot placement within each stand was random These data are representative of mature second-growth upland oak forest in the southeastern Ozarks. Stands originated following the widespread harvesting that occurred in the early 1900s. The sites are generally in the 70 to 90 yr age class and have been subjected to the periodic spring burning and open livestock grazing that were widespread in that region prior to 1950. These tracts have had little human disturbance since 1950.

Live and dead trees ≥ 11.4 cm dbh were sampled on 0.2 ha circular plots. Live trees ≥ 3.8 cm and < 11.4 cm dbh were sampled on four 0.02 ha circular subplots within the main plot. Characteristics recorded for each tree included species, dbh, status, and decay stage. Ninety-nine plots (11 per compartment) were randomly selected for measurement of down wood. Measurement protocols for down wood were identical to those used at the Sinkin Experimental Forest and the old-growth sites.

Analytical Methods

Data from the old-growth, Sinkin, and MOFEP sites were checked for recording errors and summarized to obtain per hectare values for plots and tracts. Volume of each piece of down wood was computed by assuming each had a cylindrical shape with measured length and diameter. Estimates of surface area and ground cover for each piece were based on the same assumptions. Gross volume of the boles of standing dead trees was computed as the frustum of a cone based on measured dbh and height, assuming taper equivalent to form class 78. One-way ANOVA (simple comparison of means) was used to compare tract means for the old-growth sites (n = 5) with those for the second-growth sites (n = 6).

Results and Discussion

Down Wood

The mean volume of down wood on the old-growth sites was 35.9 m^3/ha, double the 17.5 m^3/ha mean volume for the second-growth sites (Table 3). This difference was statistically significant (comparison of means, $P < 0.01$). At both the old-growth and second-growth sites, at least half the total volume of down wood was categorized as decomposition class 3 (Tables 1 and 4). Only about 15% of the volume was in decay classes 1 and 2 combined. The volume of down wood did not differ significantly between the old-growth and second-growth tracts in decomposition classes 1 through 3. Volumes were significantly greater in decomposition classes 4 and 5 on the old-growth sites than on second-growth sites (comparison of means, $P < 0.01$ in both cases).

Surface area of down logs averaged 517 m^2/ha for old-growth sites compared to 318 m^2/ha for second-growth sites (Table 3). This difference was also statistically significant (comparison of means, $P < 0.01$). The percent of the ground surface covered by down wood is proportional to our estimate of surface area. Based on our assumption that each piece of down wood could be represented as a cylinder with known length (m) and known midpoint diameter (cm), the percentage of the ground covered by each piece is equal to the quantity [surface area/(100π)]. We estimated that 1.7% of the ground surface on the old-growth sites was covered by down wood compared to 1.0% for the second-growth sites (Table 3). This difference was also statistically significant (test statistics are identical to those for surface area).

Table 3 Volume and surface area of down logs ≥ 10 cm in diameter.

Site	Volume of down logs (m^3/ha)	Surface area of down logs (m^2/ha)	Area of ground covered by down logs (%)
Old-growth sites			
Big Spring	32.0	472	1.5
Dark Hollow	24.3	443	1.4
Engelmann Woods	49.2	600	2.0
Roaring River	34.6	506	1.6
Schnabel Woods	39.4	563	1.8
Mean of old-growth sites	35.9	517	1.7
Second-growth sites			
Sinkin	16.8	342	1.1
MOFEP Site 1	12.2	240	0.8
MOFEP Site 2	14.3	278	0.9
MOFEP Site 3	20.4	362	1.2
MOFEP Site 4	16.6	343	1.1
MOFEP Site 5	24.9	343	1.1
Mean of second-growth sites	17.5	318	1.0

The diameter distribution of pieces of down wood followed a negative-exponential (reverse-J) shape for both the old-growth and second-growth tracts (Figure 2). This diameter distribution is a good indicator of the relative size of the material present. Between 10 and 20 cm, there is virtually no difference in the distribution of pieces of down wood at the old-growth and second-growth sites. On both the old-growth and the second-growth sites, 70 to 80% of the pieces of down wood had a midpoint diameter no larger than 20 cm in diameter. At midpoint diameter classes in excess of 20 cm, however, the old-growth tracts consistently had more pieces of down wood per hectare. Although small in absolute number, these large-diameter down logs have comparatively large volumes per piece and account for the significant difference in observed volume of down wood between the old-growth and second-growth sites.

Forest managers can think of "yields" of down wood in much the same manner that they customarily view yields of standing timber. At our study sites the greatest accumulation of down wood occurred in old-growth forests at ages that were well beyond typical ages for timber production This is not surprising when one considers that the source

Table 4. Percent of down wood volume by decomposition class Class 1 is newly fallen, Class 5 is heavily decomposed. Additional detail on class definitions is given in Table 1.

Decomp class	Down wood volume (%) Old-growth	Down wood volume (%) Second-growth	P-values for comparisons by class
Class 1	2	8	0.71
Class 2	11	9	0.22
Class 3	52	71	0.42
Class 4	26	11	< 0.01
Class 5	9	1	< 0.01

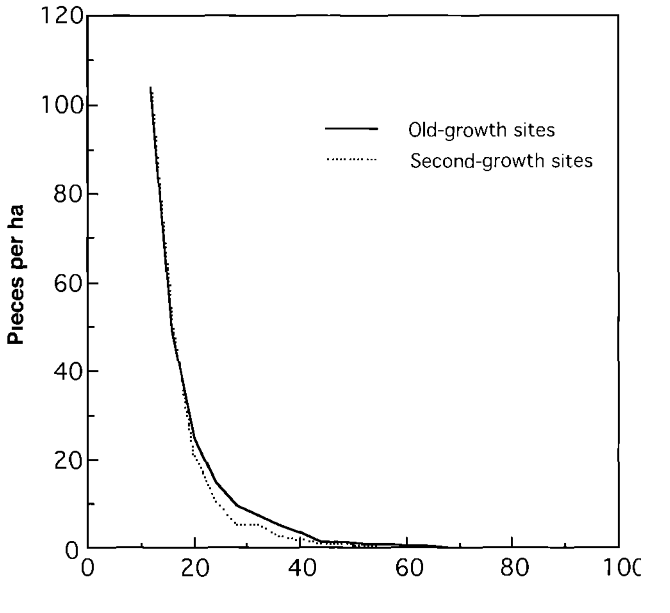

Figure 2. Mean number of pieces of down wood per ha by piece midpoint diameter for old-growth and second-growth sites. Between 10 and 20 cm diameter, the size distribution of pieces observed at the old-growth sites was virtually identical to that of the second-growth sites. The old-growth tracts consistently had more pieces of down wood at larger diameters.

of down wood is trees that had previously been part of the standing live volume. Timber harvesting is typically timed to prevent major additions of merchantable volume to the forest floor. We expect the relationship between merchantable volume growth and accumulation of down wood to generally be inverse but somewhat indirect because down wood includes unmerchantable trees and tree parts as well as merchantable volume. Moreover, many dead trees remain standing for years before they move to the forest floor. Consequently we would expect the accumulation of down wood on the forest floor to lag behind the accumulation of standing volume. The relatively large volumes of down wood associated with old-growth tracts support this assertion. Large volumes of down wood will not be associated with maximization of timber production. But on the other hand, older forests with large volumes of down wood provide a type of structural diversity on the forest floor that is rare in the current landscape and is obviously not provided by second-growth forests in the 70 to 90 yr age class.

Snags

The number of snags or standing dead trees on the old-growth sites averaged 35 per ha compared to 31 per ha for the second-growth sites (difference not statistically significant, $P = 0.52$) (Table 5). Because the minimum dbh of dead trees tallied at the 5 MOFEP tracts was 11.4 cm (rather than 10 cm dbh as at the other sites) the number of snags on the second-growth sites was slightly underestimated. Inclusions of trees between 10 and 11.4 cm at the MOFEP sites would simply further reduce the difference in the mean number of snags between the old-growth and second-growth sites.

Both the snag basal area and the live basal area were significantly greater on the old-growth sites than on the second-growth sites ($P = 0.04$ and $P < 0.01$ for comparison of snag and live basal area, respectively) (Table 5). Mean basal area of snags on the old-growth tracts was 1.9m^2/ha, nearly 1.5 times the mean value observed on the second-growth sites. Even when we made allowances for the differences in field procedures for sampling trees below 11.4 cm dbh, the mean basal area of snags at the old-growth sites was still greater than observed at the second-growth sites ($P = 0.06$).

The gross volume of snags on the old-growth sites was 10m^3/ha. This is roughly equivalent to 30% of the volume of down wood on these sites. For the second-growth sites, a comparable estimate of snag volume was available only for the Sinkin site. At 11 m^3/ha, the volume of snags on the Sinkin site was slightly higher than the mean for the old-growth sites, but well within the 95% confidence interval of the mean of the old-growth sites.

Table 5. Characteristics of live and standing-dead trees by site and type. Values are for all trees ≥ 10 cm dbh except MOFEP sites which include only trees ≥ 11.4 cm dbh.

Site	Live trees (n/ha)	Snags (n/ha)	Live tree basal area (m^2/ha)	Snag basal area (m^2/ha)	Ratio of snags/live trees (%)	Ratio of snag/live basal area (%)	Snag volume (m^3/ha)	Combined snag + down wood volume (m^3/ha)
Old-growth sites								
Big Spring	467	39	21.6	1.7	8	8	9.4	41.4
Dark Hollow	331	36	22.8	1.7	11	8	9.4	33.7
Engelmann	398	31	22.3	1.5	8	7	8.5	57.7
Roaring River	442	41	21.8	2.4	9	11	13.9	48.5
Schnabel Woods	367	27	27.1	2.0	7	8	10.2	49.6
Old-growth mean	401	35	23.1	1.9	9	8	10.3	46.2
Second-growth sites								
Sinkin	475	47	20.5	1.6	10	8	11.4	28.2
MOFEP Site 1	445	26	18.6	0.9	6	5	N/A	N/A
MOFEP Site 2	414	23	19.2	0.9	5	5	N/A	N/A
MOFEP Site 3	396	27	19.6	1.3	7	7	N/A	N/A
MOFEP Site 4	337	46	18.9	2.0	14	10	N/A	N/A
MOFEP Site 5	311	14	16.7	0.9	5	5	N/A	N/A
Second-growth mean	396	31	18.9	1.3	8	7	N/A	N/A

Within a given tract, the relationship between the number of snags and the number of live trees by dbh class was remarkably consistent. Because of differences in scale, this relationship is most readily seen when the number of snags by dbh class is multiplied by a factor of 10 and plotted simultaneously with the number of live trees (Figure 3, panels A and B). For trees larger than 28 cm dbh, the sample size is small for each diameter class. This results in jaggedness in the lines for snags at large diameters. However, the overall shape of the snag diameter distribution follows that of the live trees for both old-growth and mature second-growth tracts. When diameter distributions for old-growth and second-growth tracts are compared, there is substantial similarity in the number of live trees and snags by dbh class (Figure 3, panels C and D). However, below 40 cm dbh the number of live trees and snags is generally greater on the second-growth sites. Above 40 cm dbh, the old-growth tracts averaged 6 snags per ha compared to 2 per ha for the second-growth sites Although small in absolute number, these few large-diameter snags have large volumes and are the trees most likely to contain cavities (Allen and Corn 1990).

At the old-growth sites, the mean number of snags per ha ranged from 7 to 11% of the number of live trees per hectare. The average across all 5 old-growth tracts was 8%. Values for second growth sites ranged from 5 to 14% and on average were 1% lower than the old-growth tracts (Table 5). Standing dead basal area as a percentage of live basal area was 8% for old-growth tracts and 7% for the second-growth sites. This difference was not statistically significant [comparison of means, $P = 0.21$, percent (p) transformed as arcsin ($p^{0.5}$)].

Knowledge of the relationships between the number of live trees and snags is potentially quite useful, particularly

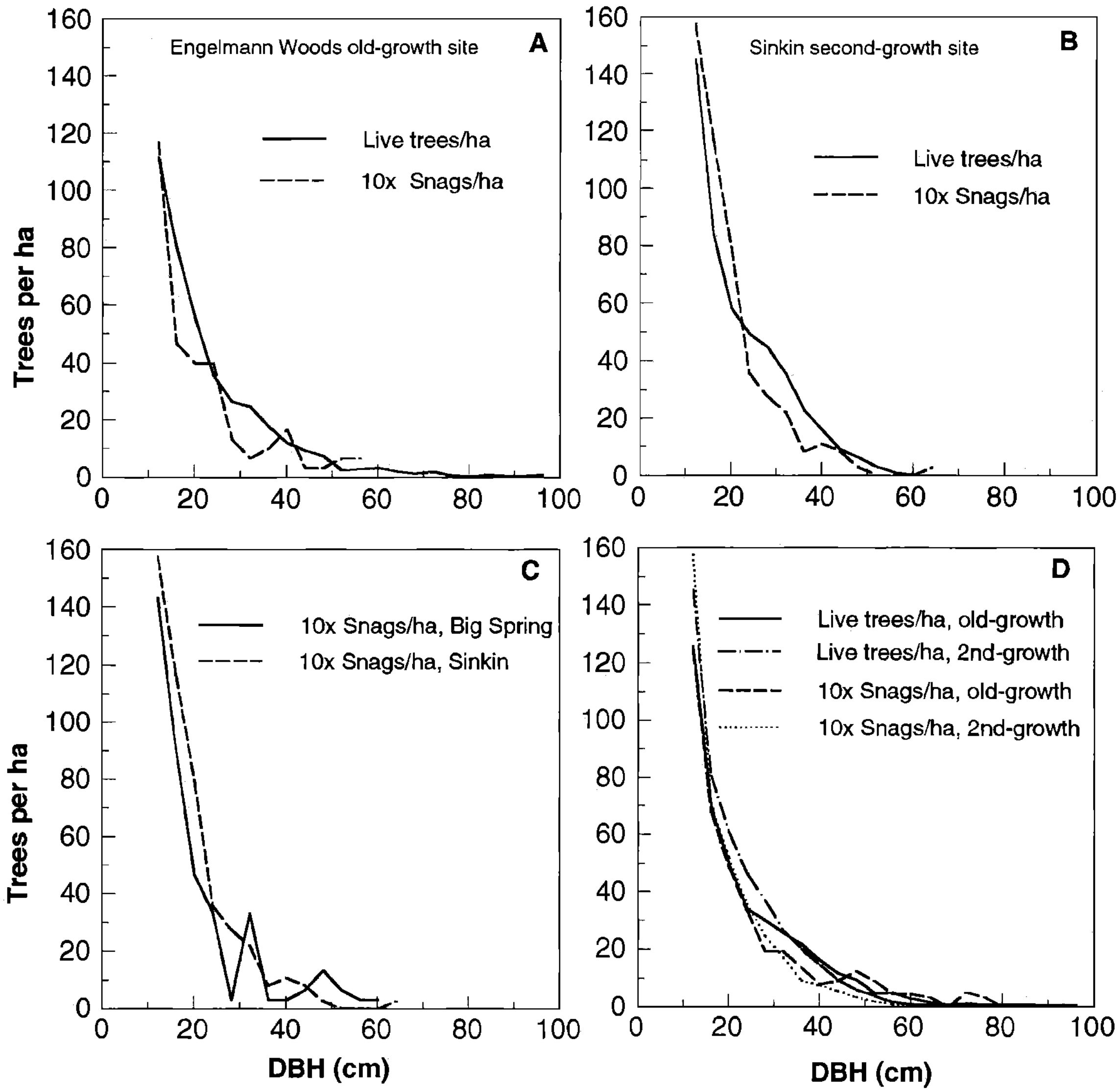

Figure 3. Number of live and (10x) standing dead trees by dbh class. (A) Live trees and snags (10x) for the Engelmann Woods old-growth site. (B) Live trees and snags (10x) for the Sinkin Experimental Forest second-growth site. (C) Comparison of live trees and snags for the Big Spring old-growth site and the Sinkin second-growth site. (D) Composite comparison of all live trees and snags for old growth and second-growth sites. Old-growth sites include Big Spring, Dark Hollow, Engelmann Woods, and Roaring River. Second-growth sites include the Sinkin Experimental Forest and MOFEP sites.

if that relationship is constant or at least consistent. Such a relationship allows information about live trees (which is commonly available) to be used to estimate the number of snags. At an aggregate level for the old-growth tracts, a good rule of thumb was to estimate the diameter distribution of snags at 9% of the live tree diameter distribution. For the relatively undisturbed, mature second-growth forests we studied, a snag diameter distribution at approximately 8% the level of live trees was a reasonable estimate. McComb and Muller (1983) found the mean number of standing dead trees was 10%, the number of live trees for an old-growth tract in Kentucky. However, the observed ratio of dead to live trees at that site varied from 12% for trees less than 10 cm dbh to 2.5% for trees ≥ 20 cm dbh. The overall ratio of dead to live trees reported for a 35-yr-old comparison site in Kentucky was 20% but also varied considerably by dbh class, from 24% for trees less than 10 cm dbh to 4% for trees ≥ 20 cm dbh (McComb and Muller 1983).

We used data from Schnabel Woods to investigate whether the relationship of the number of standing dead to live trees would be reproduced at a small spatial scale. The Schnabel Woods site has two 0.6 ha plots on opposite sides of a major ridge. One plot has a southeastern aspect, and the other has a northwestern aspect. Figure 4 illustrates the consistency of the relationship between live and standing dead trees, even for the relatively small area of the combined plots (1.2 ha). The pattern was not clearly evident in either of the individual 0.6 ha plots. For this one site where we had suitable data available, this result corroborates the observation that for old-growth sites, the number of standing dead trees by dbh class is approximately 9% the number of live trees, and this phenomenon occurs at a small spatial scale.

Managers should recognize that we found strong similarities between old-growth and second-growth forests in the size distribution of snags. The primary difference between old-growth and second-growth sites was the presence of a few large diameter snags per ha at the old-growth sites that were not present at the second-growth tracts. These boosted the snag basal area on old-growth sites to the point that snag basal area was significantly greater on old-growth sites, even though the number of snags was statistically equivalent between old-growth and second-growth tracts. Because relatively little has been reported about snag densities, it is useful to note that the number and basal area of snags relative to live trees ranged from 5 to 14% with mean ratios of 7 to 8%. In the absence of site-specific information on snags, these values provide a rough rule of thumb for estimating the number of snags relative to live trees for stands similar to those we studied. These ratios provide a mental framework for thinking about snags relative to the live trees which are typically inventoried in greater detail. Our data do not provide information for younger stands nor intensively managed stands, although for the latter we would expect intermediate harvesting to reduce the relative number of snags by removing many trees that would be likely to die and become snags.

Also of importance to managers is a recognition that the distribution of snags by dbh class can closely parallel that of live trees. For our stands we could easily arrive at a rough estimate of the number and size distribution of snags by examining the size distribution of live trees and assuming that the number of snags by dbh class was about 8% of the number of live trees by dbh class. This relationship was evident for both old-growth and second-growth sites based on all species combined. While this relationship may not hold in young stands or intensively managed stands, it provides a good starting point for estimating the number and size of snags present in older forests when an explicit inventory of snags is lacking.

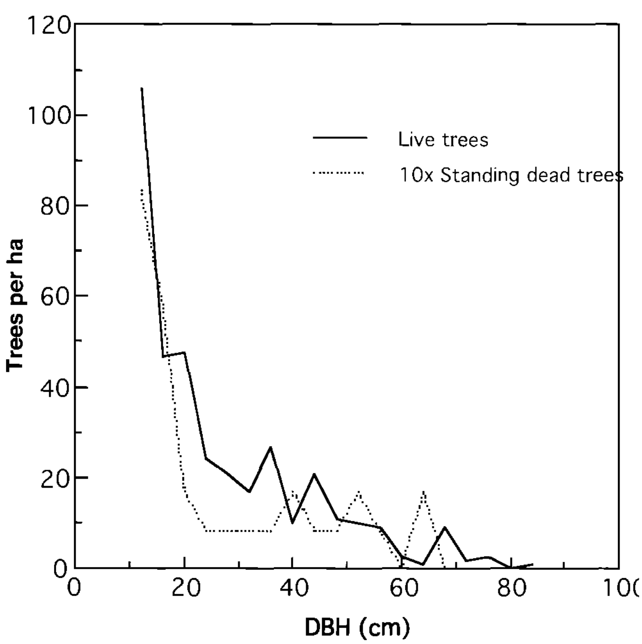

Figure 4. Number of live and 10x standing dead trees by dbh class for two 0.6 ha plots at Schnabel Woods.

Conclusions

For the tracts we measured, the volume of down wood on the old-growth sites was approximately double that observed for mature, second-growth comparison sites. The surface area of down wood and the percent of the ground area covered by down wood were also significantly greater on the old-growth sites. Much of this difference can be traced to large pieces of down wood (midpoint diameter greater than 20 cm) which were more abundant on old-growth tracts. Below this size limit there was great similarity in the number of pieces of down wood by diameter class for the old-growth and second-growth sites.

The mean basal area (but not the number) of standing dead trees per ha was significantly greater on the old-growth sites than on the second-growth sites. The ratio of standing dead trees to standing live trees per ha was 9% on the old-growth tracts and 8% for the second-growth tracts. For both the old-growth and second-growth sites, the number of standing dead trees by dbh class followed a negative exponential form. Moreover, frequency distributions of standing dead trees by dbh class closely followed the shape of those for live trees on the same sites. There was great similarity between old-growth and second-growth sites in both the number of live trees by dbh class and in the number of snags by dbh class when data were averaged across tracts. However, the old-growth tracts consistently had a few more trees per ha in the dbh classes ≥ 40 cm than were present at the second-growth sites. This translates to greater basal area of snags, greater opportunity for cavity formation, and greater input and accumulation of woody biomass on the forest floor of the old-growth tracts.

Increasingly, forest managers will need to be cognizant of the structure of dead wood in the forests under their care. We find it useful to think of "yield" of down wood as a quantity that will generally increase as forests mature and move into an old-growth condition. Because trees that at one time were in the overstory are the source of down wood, the accumulation of down wood will typically lag behind the accumulation of live volume.

It is far easier to observe the size structure of live trees than of snags, so it is helpful to know that the size distribution of snags often has a shape that is similar to that of the live trees in the stand. For our sites, estimating the number of snags by dbh class as 8 or 10% of the corresponding number of live trees was a good rule of thumb. While this relationship will not hold for all stands, it is a good starting point for thinking about relations between size distributions of live and dead trees.

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