Snags and Down Wood on Upland Oak Sites in the Missouri Ozark Forest Ecosystem Project

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Abstract.—We analyzed volume, surface area, and percent cover of down wood to determine if there were pre-treatment differences among the sites in the Missouri Ozark Forest Ecosystem Project. We also compared pre-treatment values for the number and basal area of snags. We observed no statistically significant differences ($P > 0.05$) among treatment classes for these characteristics. This is the desired condition prior to treatment. The assignment of replicates to blocks was not effective in reducing variability among treatments. The number (12/ac or 30/ha) and basal area (5 ft^2/ac or 1 m^2/ha) of snags ≥ 4.5 in. (11 cm) d.b.h. observed at the MOFEP sites were similar to values observed at another second-growth tract and an old-growth tract located in the same region. The volume of down wood observed at the MOFEP sites (241 ft^3/ac or 17 m^3/ha) was similar to that at the second-growth site but approximately half the volume at the old-growth tract.

Snags and down logs are important components of forest ecosystems. 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) indicate that 36 species of cavity-nesting birds occurring in the Northeastern United States are greatly influenced by the number and type of snags. Snags and down logs are important in cycling nutrients and energy, in providing substrate for vascular plants and fungi, and in limiting rates of soil and water movement.

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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, Brookshire *et al.* 1997). In this paper we present information about the volume of down wood and the number and size of snags observed for the nine sites (or compartments) of MOFEP prior to harvest treatments. We compare values by site and treatment class to determine if there are differences in initial conditions. To put the MOFEP observations in perspective, we compare values for the MOFEP sites to observations for another second-growth upland forest and an old-growth upland forest in the same region. Finally, we present some relationships that express the number of snags as a function of the number and size of live trees at the MOFEP sites.

METHODS AND DATA

We used 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 and are located in the Ozark highlands of southeastern Missouri.

MOFEP Sites

The MOFEP study includes nine sites (administrative compartments) that range in size from 657 to 1,302 ac (266 to 527 ha) (see figure 1 in Brookshire *et al.* 1997). In 1990-1992, before any experimental treatments, 645 sample plots were established to sample woody and herbaceous vegetation at the MOFEP sites. Plots were distributed to ensure that at least one plot fell within each identified stand; plot placement within each stand was random (see figure 5 (folded map in back of publication), Brookshire *et al.* 1997). Live and dead trees ≥ 4.5 in. (11 cm) d.b.h. were sampled on 0.5-ac (0.2-ha) circular plots. Live trees ≥ 1.5 in. (4 cm) and < 4.5 in. (11 cm) d.b.h. were sampled on four 0.05-ac (0.02-ha) circular subplots within the main plot. Live trees ≥ 3.3 ft (1 m) in height and < 1.5 in. (4 cm) d.b.h. were sampled on four 0.01-ac (0.004-ha) circular subplots within the main plot (see figure 4 in Brookshire *et al.* 1997). Characteristics recorded for each tree included species, d.b.h., status (i.e., live or dead) and decay stage.

An additional inventory of the percent of the ground covered by down wood was made for each of these plots using a line transect. The transect length for each plot totaled 226 ft (70 m) and was comprised of four 56.5-ft (17.2-m) transect segments oriented along the cardinal directions. Down wood was tallied when it was ≥ 2 in. (5 cm) in diameter at the transect and ≥ 2 ft (0.6 m) in length. Additionally, 99 plots (11 per compartment) were randomly selected, and detailed measurements of down wood were made in 1995. Down wood on those 99 plots was inventoried on 0.25-ac (0.1-ha) circular plots concentric with the 0.5-ac (0.2-ha) plots used for overstory characteristics. The length and midpoint diameter were recorded for each down log ≥ 4 in. (10 cm) in diameter (or portion thereof). To the extent possible, each down log was measured as a single piece. When necessary, broken logs, forked logs, and large branches were tallied as multiple pieces.

Stands sampled in this dataset originated following the widespread harvesting that occurred in the early 1900's. The sites are generally in the 70- to 90-year age class, but the harvesting at the turn of the century left many residual trees that were unmerchantable due to size or quality, and some of those trees still exist in the overstory of the current forest. The sites were subjected to the periodic spring burning and open livestock grazing that were widespread in that region before 1950. These tracts have had little anthropogenic disturbance since 1950.

Sinkin Experimental Forest

We used the 4,000-ac (1,619-ha) Sinkin Experimental Forest, located in Dent and Reynolds Counties, as a second-growth comparison site. 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-year age class. Some areas have received experimental silvicultural treatments. Ninety-six 0.25-ac (0.1-ha) plots were established in 1992-93 on a systematic grid covering the Sinkin (Shifley *et al.* 1995). We limited our analysis to 73 plots that had received no cultural treatments in the prior 40 years. On each plot we recorded the number, length, decay class, and midpoint diameter of down logs or portions of down logs ≥ 4 in. (10 cm) in diameter. To the extent possible, each down log was measured as a single piece. When necessary, broken logs, forked logs, and large branches were tallied as multiple pieces. Snags and live trees ≥ 4 in. (10 cm) d.b.h. were sampled on the same plots.

Big Spring Old-Growth Site

In 1992 we inventoried a 330-ac (134-ha) old-growth upland forest near Big Spring in Carter County, Missouri (Shifley *et al.* 1995). We systematically established thirty 0.25-ac (0.1-ha) circular plots on a square grid. Plots were approximately 625 ft (190 m) apart and were distributed to cover the entire tract. Sampling procedures were identical to those used on the Sinkin Experimental Forest. This old-growth tract has some dominant trees that exceed 200 years in age. Although this tract has had periodic fires and occasional grazing (events that prior to 1950 were common throughout the region), it remains one of the best examples of upland remnant old-growth forest in Missouri.

Analytical Methods

For each 0.25-ac (0.1-ha) plot, volume and surface area of each piece of down wood were computed by assuming each piece 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. For line transects, the percent of the ground covered by down wood was estimated as the percent of the transect length covered by down wood. Transects included down wood as small as 2 in. (5 cm) in diameter although the fixed-size plots included only down wood ≥ 4 in. (10 cm) in diameter. Analyses of pre-treatment differences at the MOFEP sites were based on a randomized complete block design with three treatments (even-aged, uneven-aged, and no-harvest treatments) (Sheriff and He 1997). Replicates were arranged in three blocks with sites assigned to blocks based on their spatial proximity and the general condition of their vegetation. Assignment of treatments within blocks was random. Although treatment assignments have been made, the analyses that follow are based on data collected before any of the MOFEP harvest treatments were implemented. The null hypothesis is that values for all treatment classes are equal prior to the implementation of the treatments. Lack of significant differences among means indicates similarity of initial conditions and is the desired pre-treatment condition. The general form of the analysis of variance (ANOVA) to test all variables investigated is shown in table 1. Observations involving proportions were transformed with an arcsin transformation before the ANOVA was run (Neter and Wasserman 1974). Table 2 indicates treatment and block assignments as well as the number of plots used as subsamples at each site.

Table 1.—*General form of ANOVA for null hypothesis that the means for MOFEP treatment units are equal. Design is a randomized complete block.*

Source	d.f.	Note
Treatment	2	3 treatments
Block	2	3 blocks
Error	4	
Total	8	9 sites

RESULTS

Down Wood

Volume of down wood ≥ 4 in (10 cm) in diameter was highly variable at the MOFEP sites, ranging from 107 to 429 ft^3/ac (8 to 30 m^3/ha) by site (table 3). Down wood volumes were also variable within sites; coefficients of variation for plots within a single site were typically 70 percent or greater. The estimated surface area of down wood also varied greatly among sites, ranging from 733 to 2,190 ft^2/ac (168 to 502 m^2/ha). Differences among treatment means were not statistically significant (P ≥ 0.38) for either volume or surface area of down wood (table 4).

Table 2.—*Summary of MOFEP treatments and number of plots by site. Each site corresponds to the MOFEP compartment of the same number (Brookshire* et al. *1997).*

Site	Treatment	Number of 0.25-ac plots[1] for down wood volume, surface area, and percent ground covered	Number of 0.5-ac plots for snags and line transects for percent ground covered
1	No harvest	11	73
2	Uneven-aged	11	73
3	Even-aged	11	72
4	Uneven-aged	11	74
5	Even-aged	11	70
6	No harvest	11	71
7	Uneven-aged	11	71
8	No harvest	11	70
9	Even-aged	11	71
Total		99	645

[1] Metric equivalents: 0.25 ac = 0.1 ha; 0.5 ac = 0.2 ha.

Table 3.—*Estimated mean volume, surface area, and percent of ground covered by down wood at each MOFEP site prior to treatment. Standard deviations are shown in parentheses for the plot observations used to compute each site mean. Number of plots varied by site and by observed characteristic as indicated in table 2.*

Site	Block	Treatment	Vol. of down wood[1]	Surface area of down wood	Ground covered by down wood (0.25-ac plots)	Ground covered by down wood (line transects)
			Ft³/ac	*Ft²/ac*	*Percent*	*Percent*
1	1	No harvest	194 (127)	1,126 (619)	0.8 (0.5)	1.8 (1.0)
2	1	Uneven-aged	155 (103)	965 (479)	0.7 (0.4)	1.5 (0.9)
3	1	Even-aged	302 (266)	1,691 (1,082)	1.2 (0.8)	1.6 (1.2)
4	2	Uneven-aged	107 (67)	733 (423)	0.5 (0.3)	1.7 (1.4)
5	2	Even-aged	153 (106)	966 (506)	0.7 (0.4)	1.7 (1.4)
6	2	No harvest	429 (426)	2,190 (1,794)	1.6 (1.3)	2.9 (1.6)
7	3	Uneven-aged	225 (312)	1,369 (1,526)	1.0 (1.1)	1.6 (1.1)
8	3	No harvest	250 (166)	1,623 (852)	1.2 (0.6)	1.6 (1.2)
9	3	Even-aged	355 (259)	1,492 (885)	1.1 (0.6)	1.2 (1.0)
Overall mean			241	1,350	1.0	1.7

[1] Metric equivalents: 0.25 ac = 0.1 ha; m³/ha = (ft³/ac)/14.29; m²/ha = (ft²/ac)/4.356.

Table 4.—*Pre-treatment means by treatment group for volume, surface area, and percent of ground covered by down wood. The two different estimates of percent ground cover are described in the text. None of these pre-treatment differences were statistically significant ($P \geq 0.21$). See also table 1.*

Treatment group	No. of sites	Volume of down wood[1]	Surface area of down wood	Ground covered by down wood (0.25-ac plots)	Ground covered by down wood (line transects)
		Ft³/ac	*Ft²/ac*	*Percent*	*Percent*
Even-aged	3	270	1,383	1.0	1.5
Uneven-aged	3	162	1,022	0.8	2.1
No harvest	3	291	1,646	1.2	1.6
Test of differences among column means					
$F_{(2,4)}$		1.07	1.22	1.33	2.40
P-value		0.42	0.38	0.36	0.21

[1] Metric equivalents: 0.25 ac = 0.1 ha; m³/ha = (ft³/ac)/14.29; m²/ha = (ft²/ac)/4.356.

The percentage of ground area covered by down wood was estimated in two separate inventories. One estimate was based on the same eleven 0.25-ac (0.1-ha) plots used to measure volume and surface area of down wood for each site. The other was made using line transects within the plots used to measure forest overstory characteristics (table 2). Percentage ground cover estimates based on the line transects were consistently larger than estimates based on the fixed-size plots, but the line transects included material as small as 2 in. (5 cm) in diameter, while the fixed-size plots included only material ≥ 4 in. (10 cm) in diameter (table 3). Pre-treatment observations of percentage ground cover were not significantly different by treatment class for either method of estimation (table 4). P-values for the test of equality of treatment means (before treatment) were 0.36 and 0.21 for the fixed plots and line transect methods, respectively.

Snags

Snags (i.e., standing dead trees) at least 4.5 in. (11 cm) d.b.h. and at least 8 ft (3.4 m) tall averaged 12 per acre (30/ha) with a range of 6 to 21 per acre (15 to 52/ha) across the nine MOFEP sites. Basal area for these trees averaged 5.3 ft^2/ac (1.2 m^2/ha) with a quadratic mean d.b.h. of 9 in. (23 cm) (table 5). The ratio of snags to live trees can also be a useful relative indicator of forest structure that takes into account the live tree component. Mean values for the number of snags, for the basal area of snags, and for the ratio of snags to live trees were not significantly different ($P \geq 0.2$) by MOFEP treatment class for pre-treatment conditions (table 6).

Comparison to Other Sites

Comparisons among characteristics observed for the MOFEP sites, the Sinkin Experimental Forest second-growth site, and the Big Spring old-growth sites are summarized in table 7. Reported confidence intervals for the MOFEP data are based on observed values for the nine MOFEP sites, and they indicate the variability associated with each measured attribute. In the context of this analysis, the Sinkin site and the Big Spring site represent single observations of Ozark second-growth forest and old-growth forest, respectively. This precludes direct tests of differences between either of those sites and the MOFEP sites. Qualitatively, however, attribute values for Sinkin and Big Spring sites that fall within the confidence intervals for the MOFEP sites indicate similarity with the MOFEP sites.

Table 5.—*Estimated number and basal area of snags at each MOFEP site prior to treatment. Standard deviations are shown in parentheses for the plot observations used to compute each site mean. Number of plots differed by site and by observed characteristic as indicated in table 2.*

Site	Block	Treatment	Density[1]	Basal area	Quad. mean d.b.h.	Ratio of snags to live trees
			No./ac	*Ft²/ac*	*In.*	*Percent*
1	1	No harvest	11 (7)	4.0 (3.1)	8.2	6
2	1	Uneven-aged	10 (6)	4.2 (2.9)	8.6	6
3	1	Even-aged	9 (6)	4.1 (3.3)	9.2	5
4	2	Uneven-aged	9 (7)	3.7 (3.1)	8.5	5
5	2	Even-aged	10 (6)	4.1 (3.0)	8.9	6
6	2	No harvest	13 (6)	7.3 (4.5)	10.3	8
7	3	Uneven-aged	17 (11)	7.3 (5.9)	9.0	12
8	3	No harvest	21 (12)	9.6 (6.1)	9.2	16
9	3	Even-aged	6 (5)	3.8 (3.7)	11.0	5
Overall mean			12	5.3	9.1	8

[1] Metric equivalents: number per ha = 2.47(number per ac); $m^2/ha = (ft^2/ac)/4.356$; 2.54 cm =1 in.

Table 6.—*Number and basal area of snags ≥ 4.5 in. (11 cm) d.b.h. prior to treatment. Pre-treatment differences among classes were not statistically significant (P ≥ 0.2).*

Treatment	Snags ≥ 4.5 in. d.b.h.[1]	Snags ≥ 4.5 in d.b.h.	Ratio of snags to live trees
	No./ac	*Ft²/ac*	*Percent*
Even-aged	8	4.0	5
Uneven-aged	12	5.1	8
No harvest	15	7.0	10
Test of differences among column means			
$F_{(2,4)}$	2.07	2.50	1.72
P-value	0.24	0.20	0.29

[1] Metric equivalents: 4.5 in. = 11 cm; number per ha = 2.47(number per ac); m^2/ha = (ft^2/ac)/4.356.

DISCUSSION

There were no differences among the pre-treatment means for any of the down wood or snag characteristics evaluated. Consequently, with regard to these variables, the treatment units are judged to be essentially equivalent before treatment. This is the desired condition before implementation of experimental treatments.

Assignment of treatment units to blocks was based on their spatial proximity but was not particularly effective in reducing variation among sites for snags and down wood. Block effects (not shown) had P-values that were ≥ 0.17 ($F_{(2,4)}$) for all reported attributes. With respect to snags and down wood characteristics, a completely random design would generally have been better than the randomized complete block design based on the current assignments of treatments to blocks. Site 6 had a particularly large volume of down wood, and Site 9 had a particularly small number (but not basal area) of snags. Based on initial volume of down wood and snag densities, Sites 6 and 9 appear poorly matched with the other sites in their assigned blocks (tables 3 and 5). Moreover, sites 6, 7, and 8 all stand out for having snags that are large in number and in basal area compared to the other sites. Snag basal area on Sites 6, 7, and 8 is roughly double that observed for the other sites. Site 9 has the fewest snags per acre but the largest mean snag d.b.h. Based on these observations, Sites 6, 7, and 8 seem better candidates for an experimental block than the current arrangement, which combines Sites 4-6 and Sites 7-9 into blocks.

The mean number of snags per acre on the MOFEP sites was virtually identical to the number observed at the Big Spring (old-growth) site but smaller than that observed on the Sinkin (second-growth) site (table 7). Mean basal area of snags for the MOFEP sites was slightly below that of the other two forests. The volume of down wood on the second-growth sites (MOFEP and Sinkin) was roughly half that observed at the Big Spring old-growth site. This result is consistent with observations for other old-growth sites in Missouri (Shifley *et al.*, in press). With the exception of down wood volume and percentage ground cover, values observed at the MOFEP sites are consistent with values observed at Sinkin and Big Spring (table 7).

We expect the volume of down wood to increase in the no-harvest treatment, eventually approaching the levels observed at the Big Spring site. The MOFEP sites receiving the even-aged and uneven-aged treatments may, however, see an even greater increase in down wood volume. Logging residue can create large volumes of down wood for several decades following harvest. For mesic hardwood forests in Indiana, Jenkins and Parker (1997) reported the greatest volume of down wood in stands immediately following regeneration cuts (clearcuts or group openings). They found that down wood volume decreased exponentially with time since harvest for a 25-year chronosequence of regeneration harvests. Stands in the first 25 years following harvest had down wood volumes that were significantly greater than those observed for 80-

Table 7.—*Comparison of down wood and snags among the MOFEP sites, the Sinkin Experimental Forest second-growth site, and the Big Spring old-growth site. MOFEP values are means for the nine sites with 95 percent confidence intervals for the MOFEP means in parentheses.*

Characteristic	MOFEP Mean	MOFEP (95 percent C.I.)	Sinkin Exp. Forest	Big Spring
Live trees (no./ac for trees ≥ 4.5 in. d.b.h.)[1]	157	(142, 172)	164	160
Live tree basal area (ft^2/ac for trees ≥ 4.5 in. d.b.h.)	82	(79, 85)	87	91
Snags (no./ac for trees ≥ 4.5 in. d.b.h.)	12	(8, 15)	16	12
Snag basal area (ft^2/ac for trees ≥ 4.5 in. d.b.h.)	5	(4, 7)	7	7
Ratio of snags to live trees (percent)	7.6	(4.8, 10.4)	9.8	7.5
Ratio of snag basal area to live basal area (percent)	6.5	(4.6, 8.4)	8.0	7.7
Quadratic mean d.b.h. (inches for trees ≥ 4.5 in. d.b.h.)	9.9	(9.5, 10.4)	9.9	10.2
Down wood (ft^3/ac for pieces ≥ 4 in. diameter)	241	(161, 322)	240	457
Down wood ground cover (percent for pieces ≥ 4 in. diameter)	1.0	(0.7, 1.2)	1.1	1.5

[1] Metric equivalents: 4.5 in. = 11 cm; 4 in. = 10 cm; number/ha = 2.47(number/ac); m^2/ha = (ft^2/ac)/4.356; m^3/ha = (ft^3/ac)/14.29.

year-old stands in the same vicinity. If those observations apply in Ozark forests, it would mean that the MOFEP sites, due to their age and lack of recent harvest disturbance, have down wood volumes that are currently low relative to other stages of stand development. Consequently, down wood volume may increase on all of the MOFEP sites, but will likely increase more rapidly on the even-aged and uneven-aged treatments than on the no-harvest treatment.

The ratio of snags to live trees is a useful relative measure of snag density. For the MOFEP sites, the number and the basal area of snags averaged between 6 and 8 percent of the corresponding values for live trees at the same site (table 7). These values were similar to those reported for the Sinkin and Big Spring sites. There were no pre-treatment differences in the ratio of snags to live trees among the MOFEP treatment groups, but this ratio is a characteristic worth monitoring as harvest treatments are implemented. It is a parameter that is sensitive to changes in both the number of live trees and the number of snags following harvest treatments. Specifically, thinnings in both the even-aged and uneven-aged treatment units should reduce the overall ratio of snags to live trees by removing trees that are poor candidates for survival while simultaneously increasing the vigor of the residual trees. Because we have no corresponding data for young stands, it is impossible to predict how regeneration cuts will affect the overall ratio of snags to live trees except in the most general sense. Oliver and Larson (1990) suggest that regenerated stands will eventually go through a period of intense competition-induced mortality (stem exclusion phase) that should temporarily increase the ratio of dead to live trees for the portion of the site in that phase of development.

For the MOFEP sites, the relative proportion of snags to live trees is reasonably constant by d.b.h. class (fig. 1). This general pattern has been previously reported for the Big Spring and Sinkin sites (Shifley *et al.* 1995). Changes in the relative size distribution of snags and live trees deserve scrutiny as harvest treatments are implemented. However, it is difficult to speculate exactly how the relative size distribution of snags will change with implementation of treatments. We

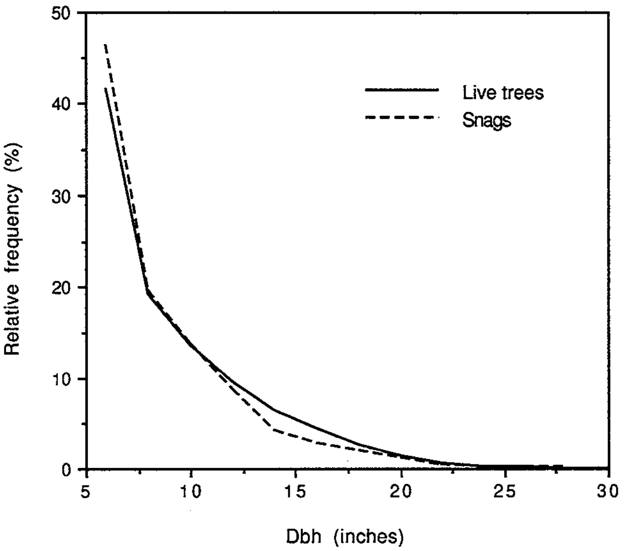

Figure 1.—*Relative frequency of number of snags and live trees by d.b.h. class for all nine MOFEP sites combined. Note the strong similarity in diameter distributions for snags and live trees.*

generally expect little change in the relative size distribution of snags for the no-harvest treatment. Intermediate thinning operations as part of the even-aged and uneven-aged treatments may eventually reduce relative snag densities by harvesting declining trees before they die, particularly trees in the commercial size classes. In the short term, however, thinning practices may have the opposite impact on the relative proportion of snags. At sites 2 through 5 (even- and uneven-aged harvest treatments), loggers exercised their option to simply girdle rather than fell many culls and submerchantable trees that were marked for removal. This will result in a large relative increase in the number of snags while temporarily delaying inputs of dead wood to the forest floor. Treatments that affect the number and size distribution of snags should eventually be reflected in differences in the quantity of down wood, because large volumes of down wood result when snags (or portions thereof) fall to the forest floor.

CONCLUSIONS

Analyses of the pre-treatment MOFEP data revealed no statistically significant ($P \geq 0.05$) differences in the number of snags or the basal area of snags by treatment class. Nor were treatment class differences observed in the volume of down wood or the percentage of the ground area covered by down wood. This is the desired condition before implementation of the treatments. For those same forest attributes, the block effect (assignment of sites to blocks based on spatial proximity) was not significant. Sites 6, 7, and 8 stand out in having more snags and higher snag basal areas than the other sites. In general, snag and down wood attributes observed for the MOFEP sites were consistent with those reported for other sites in the region. The volume of down wood is expected to increase on all sites after treatment. We suspect that the ratio of snags to live trees (in composite or by d.b.h. class) will be a reasonably sensitive indicator of changes in snag conditions over time.

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