GROUND COVER IN OLD-GROWTH FORESTS
OF THE CENTRAL HARDWOOD REGION

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Abstract: Differences in ground cover (percent cover of litter, percent cover of vegetation and litter weight) in old-growth forests across this region are not well understood. We initiated a long-term study in a three-state region to enhance knowledge in this area. We present baseline results for ground cover and compare these data across productivity regions. Thirty 0.25-ac (0.1-ha) main plots and 120 subplots 27 ft^2 (2.5 m^2) in size were established in each old-growth forest and used to inventory ground cover. We estimated percent cover of: bare ground, boles of woody vegetation, dead leaves, downed woody material, exposed rock, and herbaceous cover. In addition, 240 subplots 1.35 ft^2 (0.125 m^2) in size were used to estimate dry weight of litter down to the mineral soil horizon. Trends among sites were compared to a regional productivity gradient. Across all sites, mean values for percent ground cover were: bare ground, 6% (SD 10%); boles of woody vegetation ≥ 3.3 ft tall, 2% (SD 1%); dead leaves and dead herbaceous vegetation, 85% (SD 10%); downed woody material, 5% (SD 1%); exposed rock, 1% (SD 2%); other, 1% (SD 2%). Mean litter weight across all sites was 6.8 tons/ac (SD 3.1 tons/ac) [15.3 metric tons/ha (SD 7 metric tons/ha)]. Differences in litter weight were not significant between northeast and southwest slopes. The inverse relationship of percent cover of exposed rock to regional productivity class was highly significant (R^2 = 0.88 for negative exponential model, p-value < 0.01). The positive linear relationship between litter weight and productivity class was also significant (R^2 = 0.55, p-value = 0.01).

INTRODUCTION

Parker (1989) defines mesic old-growth in the central hardwood region as those forests with overstory canopy trees > 150 years old, little human-caused understory disturbance during the past 80 to 100 years, all-aged structure, multilayered canopies with dominant canopy trees from 30 to 65 in dbh and understories of late-seral, shade-tolerant trees. He also describes a mosaic of all-aged canopy gaps and significant standing and downed dead trees. Martin (1992) defines mixed mesophytic old-growth forests of the Appalachians similarly but with some additional characteristics such as canopy trees > 200 years old, canopy trees at 100 trees/ac, basal areas averaging 110 ft^2/ac and undisturbed soils with macropores. However, little work has been done on soils of old-growth forests of the region (Lindsey and others 1965, Auten 1941). Although total litterfall tends to increase with above-ground net primary production (O'Neill and DeAngelis 1981), this relationship of litterfall vs. productivity has not been tested for midwestern old-growth forests.

We established this study to collect baseline data as part of the initial stage of a long-term study of midwestern old-growth forests. Because litter weight was the most costly measurement in both time and money, we also explore some relationships between litter dry weight and ground cover that could help us increase efficiency of future inventories. Study objectives were to determine: (1) regional baseline statistics for percent cover and litter weights in midwestern old-growth forests as well as relative variability of these factors, (2) how these factors vary across a regional forest productivity gradient, and (3) the relationship between percent cover of dead vegetation and litter weight.

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METHODS

Site Selection

Old-growth forests were considered as those forests having significant amounts of deadwood, little human disturbance, large old trees, multilayered canopies and trees > 150 years old (Parker 1989). We selected 10 old-growth sites (Table 1) out of the public trust old-growth forests considered to be the least disturbed sites in Indiana, Illinois and Missouri.

Table 1.—Ten old-growth sites inventoried for percent ground cover and litter weight.

STATE	OLD-GROWTH SITE	SITE CODE	PRODUCTIVITY REGION [a]	PRODUCTIVITY VOLUME [b] (ft^3/ac/yr)	DATES LITTER SAMPLED	STAND ft^2/ac	ANNUAL TEMPERATURE (degrees F)	ANNUAL PRECIPITATION (in)
INDIANA	LAUGHERY BLUFF	LA	UPLAND FLATS	87	JUNE 1993	91.4	51.6	41.9
INDIANA	HEMMER WOODS	HE	LOWER WABASH	87	MAY 1993	109.1	55.8	43.1
INDIANA	DAVIS WOODS	DA	NORTHERN	86	MAY 1992	139.9	49.3	36.6
INDIANA	DONALDSON'S WOODS	DO	KNOBS	86	JULY 1992	140.6	53.4	47.3
INDIANA	PIONEER MOTHER RNA	PM	KNOBS	86	JUNE 1992	123.2	53.4	47.3
ILLINOIS	SPITTLER WOODS	SW	PRAIRIE	77	JUNE 1993	132.4	52.8	40.2
MISSOURI	DARK HOLLOW	DH	PRAIRIE	60	MAY 1993	108.2	51.7	36.4
MISSOURI	ENGELMAN WOODS	EW	RIVERBORDER	56	MAY-JUNE 1993	105.3	54.8	37.9
MISSOURI	BIG SPRINGS	BS	EAST OZARKS	54	SEPT-OCT. 1992	104.8	54.9	47.0
MISSOURI	ROARING RIVER	RR	SW OZARKS	52	JUNE-AUG. 1992	108.0	55.1	44.4

[a] Productivity region refers to the multi-county inventory regions used to report forest inventory statistics.

[b] Productivity volume is an estimate of the inherent capacity of forests to grow crops of industrial wood averaged across all upland oak forests in the productivity region

Percent Cover

Thirty 0.25-ac (0.1-ha) main plots were systematically established to inventory forest overstory characteristics at each old-growth site. Main plot centers were at least 40 m apart within each forest. Within each plot, four subplots of 27 ft^2 (2.5 m^2) each were established to inventory percent ground cover of: bare ground, boles of woody vegetation (trees and shrubs > 3.3 ft [1 m] tall), dead leaves, downed woody material, and exposed rock. Values for these variables totaled 100%. Estimates for each subplot were made using a square frame with 10 equal intervals delineated on each side. Cover of live herbaceous and woody vegetation less than 3.3 ft (1 m) tall was also estimated. Values were averaged across all plots per site to obtain the mean site values that were used in subsequent analysis.

Forest Litter

Litter samples were taken at eight subplots distributed across each main plot. At each subplot a square wooden template was used to delineate a 1.35 ft^2 (0.125 m^2) forest floor subplot. Forest floor litter was removed down to the mineral soil layer at each subplot. The eight subsamples were combined for a plot estimate of moist weight. Combined litter samples were either returned to the lab in their entirety for dry weight determination or a moist weight was taken in the field with a sample of litter returned to the lab for determination of a dry to moist weight ratio. The ratio of dry/moist weight of this sample was used to estimate the dry weight of the eight combined litter subsamples.

Productivity Regions

There is a general gradient of increasing site productivity across the study area from southwestern Missouri to eastern Indiana. Direct estimation of site quality at a given site and direct comparison of site quality among sites is difficult. Due to the age of overstory dominants and the periods of suppression often associated with trees at these sites, measurement of site index is problematic. However, statewide inventories show clear patterns of increasing cubic foot volume productivity in upland-oak forests along this gradient. Data from statewide forest inventories were used to document the general gradient of increasing cubic foot volume productivity for upland oak forests across the three-state region (Hahn 1985, Hahn 1989, Smith and Golitz 1986, Brand and Walkowiak 1990). A regional productivity estimate was assigned to each old-growth tract based on the mean productivity for upland oak forests in the multi-county Forest Service inventory unit in which it falls (Table 1). Some differences in productivity among sites are undoubtedly related to differences in precipitation and climate (Table 1). However, differences in productivity are difficult to assign to climatic differences alone. We would, however, expect site-specific estimates of basal area to be related to productivity region, and they generally were (Table 1). The Laughry Bluff site was damaged by a wind storm 2 weeks prior to measurement and consequently had an uncharacteristically low basal area. Excluding the Laughry Bluff site, the correlation between basal area and the regional productivity estimates was 0.74.

Statistical Methods

We used standard descriptive statistics to establish the baseline means and variances for this long-term study. Coefficient of variation (CV) was used to compute relative variability among the 10 sites for each measured variable.

Linear and nonlinear regression were used to quantify the relation between forest floor characteristics and the regional productivity gradient and also between leaf litter cover percent and litter weight. Spearman rank correlation was also used to test associations between productivity class and forest floor cover.

RESULTS

Percent Cover

Mean percent cover was greatest for dead leaves and herbaceous vegetation at 85% and least for exposed rock at 1% (Table 2). Across the 10 sites percent cover of bare ground had the greatest variation with a CV of 164%. Percent cover of dead leaves and dead herbaceous vegetation showed the least variation across the region with a CV of 12%.

Table 2.—Percent cover and litter weight means, standard deviations (SD) and coefficient of variation (CV) percent for the entire three-state region

% cover of:	Mean	SD	CV (%)
Dead leaves and dead herbaceous vegetation	85	10	12
Bare Ground	6	10	164
Downed woody material	5	1	26
Boles of woody vegetation >= 1 m tall	2	1	63
Exposed rock	1	2	157
*Other	1	2	132
% cover of aerial component:			
Live herbaceous cover	32	22	69
Litter weight:			
Litter (tons/ac)	7	3	46
Weight ratio (NE/SW slopes)	0.99	0.16	16

*Other = mostly moss

Litter Weight

The mean for litter weight for all 10 sites was 6.8 tons/ac (15.4 metric tons/ha) and was highly variable among sites with a CV of 46%. The mean ratio of litter weight (NE/SW slopes) was 0.99 and had the second smallest CV at 16% (Table 2).

Variability of Percent Cover and Litter Weight Across the Productivity Gradient

For most percent cover variables, the relation to the productivity gradient was weak (Table 3 and Figure 1). However, the inverse relationship of percent cover of exposed rock to regional productivity class was highly significant ($R^2 = 0.88$ for negative exponential model, p-value < 0.01) (Table 3 and Figure 1a). Given the approximate nature of the relationship between productivity classes and individual old-growth sites, we also tested the association between exposed rock and the productivity using only rank order of each variable. The Spearman rank correlation was -0.91 ($p < 0.01$). The positive linear relation between litter weight and productivity class was also significant ($p = 0.01$, $R^2 = 0.55$) as was the rank correlation (Rho = 0.71, $p = 0.02$) (Figure 1b).

Although, trends in percent cover with productivity class were weak for most variables, some interesting patterns stand out. For example Engelman Woods (EW) and Spitler Woods (SW) show percent cover values very different than the other sites (Figure 1c and Figure 1d: percent cover of dead leaves and dead vegetation, percent cover of bare ground). In the litter weight graph (Figure 1b), SW has a litter weight that is less than expected based on its productivity region. Both EW and SW have overstories of sugar maple (*Acer saccharum*) while seven of the eight other sites have overstories dominated by oak-hickory (*Quercus-Carya*). In a study by McClaughrety and others (1985) the percent of initial dry matter of litter was greater for the white oak litter type than the sugar maple litter type after both 1 and 2 year intervals, when each litter type was observed in their respective stand types. Of the eight non-maple sites only Laughery Bluff (LA) does not have an overstory dominated by oak-hickory. LA has an overstory dominated by American beech (*Fagus grandifolia*) and yellow poplar (*Liriodendron tulipifera*).

Table 3.—R^2 and p-values for simple linear regression of each listed dependent variable where the independent variable is regional productivity class.

Dependent Variable, % cover of:	R^2	p-value
Dead leaves and dead herbaceous vegetation	0.12	0.31
Bare Ground	0.03	0.63
Downed woody material	0.24	0.15
Boles of woody vegetation >= 1 m tall	0.15	0.28
Exposed rock	0.76	0.00
Dependent Variable, % cover of aerial component:		
Live herbaceous cover	0.11	0.35
Dependent Variable, weight:		
Litter (tons/ac)	0.55	0.01
Weight ratio (NE/SW slopes)	0.00	0.90

In an effort to further explain site conditions we explored potential relationships with basal area (BA). We examined total BA and BA of sugar maple at each site as well as all variables listed in table 3. Neither total BA or BA of sugar maple were as strongly related to site variables as was regional productivity.

Predicting Litter Weight

In these forests, dead leaves were the largest component of forest litter, and we expected to find a significant relationship between percent cover of dead leaves/dead herbaceous vegetation and litter weight. A simple linear model explained 69% of the variation in litter weight among sites as a function of percent cover of dead leaves and dead herbaceous vegetation.

Litter Weight (dry tons/ac) = -14.2657 + 0.2495*(percent cover) [1]

$R^2 = 0.69$ p-value < 0.01 root MSE = 1.85 n = 10

Where percent cover is cover of dead leaves and dead herbaceous vegetation measured as a percent (0-100)

We also know from Table 3 that part of the variation in litter weight can be explained by the regional productivity gradient. Model 2 illustrates the advantage of including both percent cover and regional productivity in the model. A linear model with terms for both percent cover and productivity region explained 92% of the variation in litter dry weight.

Litter Weight (dry tons/ac) = -17.239 + 0.1033*(productivity) + 0.1996*(percent cover) [2]

$R^2 = 0.92$ p-value < 0.01 root MSE = 1.03 n=10

Where: Productivity is in (ft^3/ac/yr) units as indicated in Table 1, and percent cover is as described in [1]

Both dependent variables are highly significant ($p < 0.01$).

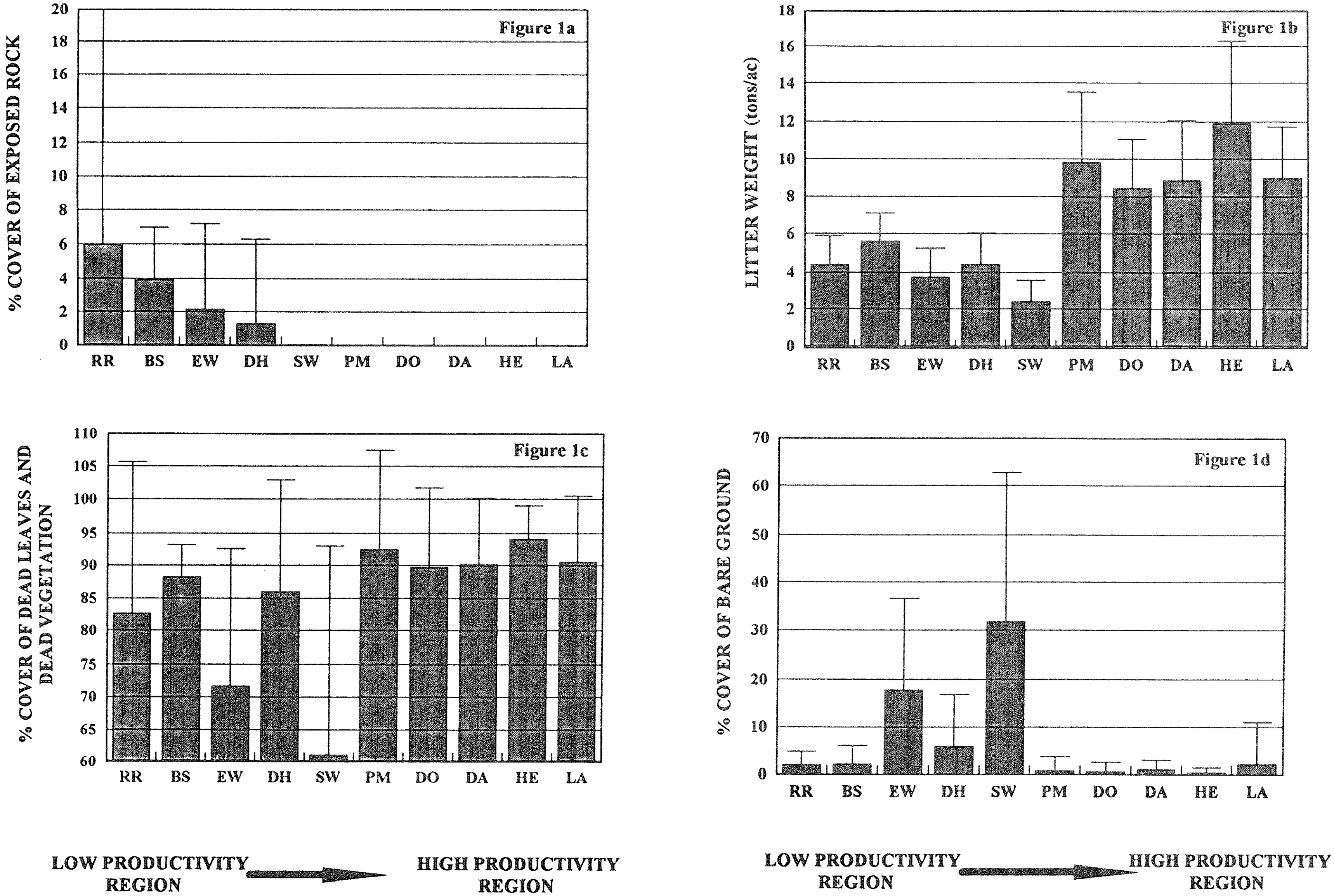

Figure 1.—Mean values and error (1 SD) for percent cover by sample site. Sites are ordered from lowest to highest regional productivity class. Site codes are given in Table 1.

DISCUSSION

It is not surprising that the majority of the forest floor was covered by dead leaves and herbaceous matter. However, the fact that the percent coverage of this variable was 85% and more than 14 times greater than the next largest component is notable. Moreover, the coefficient of variation for percent cover of leaves and dead herbaceous material was lower than for any other variables we measured.

The variable with the strongest relationship to regional productivity class was percent exposed rock. It is an indicator of the shallow, droughty soils at the southern Missouri sites.

We found a strong linear relationship between percent leaves and herbaceous cover and litter dry weight. Although our model for litter weight estimation describes the form of the relationship between leaf cover and litter weight, the data included only sites with leaf cover exceeding 60%. Additional data over a wider range of sites and percent cover values could change the shape of the relationship as it would pass through the origin. Direct measurement of litter weight is still the most reliable inventory technique until we develop a better understanding of the variability of litter weight as these forests change through time. However, the strength of the relationship between percent leaf cover and litter dry weight suggests that some form of ratio or regression estimator would be an efficient way to measure litter weight at a specific site. Such an estimator would utilize a large number of inexpensive estimates of percent cover and a small number of relatively expensive litter weight estimates.

Many of these old-growth sites are expected to undergo changes in overstory species composition which could dramatically change the forest litter dynamics. Many old-growth woodlands have overstories of *Quercus* species with understories of tolerant species such as *Acer saccharum* and *Fagus grandifolia* (Lindsey 1962, Johnson and others 1973, Schlessinger 1976, McGee 1984, McGee 1986, Ward and Parker 1989, Boerner 1991, Cho and Boener 1991, Shotola and others 1992). Others have reported regeneration dominated by these understory species (Cain 1935, Quarterman and others 1972, Abrams and Downs 1990, Boerner 1991). The use of fire, grazing, and clearing for agriculture has a long history in the region which promoted domination of forests by seral species (Parker 1993, Olson 1996). Native Americans were active in the use of fire for agricultural clearing and driving game which is the likely cause of the seral species in canopies of many old-growth forests in the region (DenUyl 1954, Campbell 1989, DeVivo 1990, Reich and others 1990, Denevan 1992). Presettlement old-growth oak forests may have been maintained by fire, however modern fire suppression has been used in the Midwest for nearly a century (Rusterholz 1991). In a review of historical data dating back to the early part of this century McCune and Menges (1986) found that old-growth forests in the region had a strong successional trend toward shade tolerant species such as sugar maple and American beech.

In addition to affecting the species composition of the overstory, changes in wildfire regimes also directly affect the quantity of lief litter. The period 1820 to 1940 which was characterized by a fire-free interval of only 4 years for the vicinity of the Big Spring site (Guyette 1995) certainly resulted in lower litter weights at Big Spring than exist today. The physical presence or absence of leaf litter alters the environment of germinating plants. In addition to altering seed bed characteristics, in some cases abundant leaf litter can act as a physical barrier to plant growth (Sydes and Grime 1981). Reductions in fire frequency may increase the sheer physical impact of litter mass relative to the period when the overstory trees in these old-growth forests were established.

We found the litter weight of northeast facing vs. southwest facing slopes within these old-growth forests to have nearly a 1- to 1-ratio across the three-state area. This surprised us because of vegetation differences between northeast and southwest facing slopes. We would expect northeast slopes to be more productive with a higher rate of litter input than the southwest facing slopes. However litter in the cooler, moister northeast slopes could also be decomposing more rapidly. If this is the actual relationship, then an equilibrium of litter inputs and decomposition is a process that may be occurring regardless of aspect in these old-growth sites. This hypothesis could easily be tested using litter traps and by measuring mineralization rates over several growing seasons. Finally, overstory composition and site conditions should be considered when interpreting and applying the results of our inventory and analysis. The majority of our study sites were upland oak forests. Some of the largest anomalies in the general trends we observed were associated with the two sites with overstories dominated by sugar maples. For instance, the rapid decomposition of sugar maple leaves and moist conditions at the Spitler Woods site were likely factors in the different than expected values there.

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