THE DISTRIBUTION AND DYNAMICS OF FOREST FUELS IN THE LOW ELEVATION FORESTS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

RESEARCH/RESOURCES MANAGEMENT REPORT No. 32

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THE DISTRIBUTION AND DYNAMICS
OF FOREST FUELS IN THE LOW ELEVATION FORESTS
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Research/Resources Management Report No. 32

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Research funded by the National Park Service, Department of the Interior

Final project for a special problem course under the direction of Dr. Jerry S. Olson at the University of Tennessee, Knoxville

Harmon, Mark E. 1980. The Distribution and Dynamics of Forest Fuels in the Low Elevation Forests of Great Smoky Mountains National Park. NPS-SER Research/Resources Management Report No. 32. 86 pp.

ABSTRACT

The importance of factors related to time (post-disturbance), climate, biota, and topography in determining forest floor biomass, decay rates, and vegetation structure was examined in 35 low elevation stands to assess the impact of 37 years of fire suppression in GRSM. Topographic-moisture, elevation, and disturbance are the most important gradients affecting the present-day vegetation structure. Annual leaf litter production increased significantly with both basal area and stem density. Forests with basal areas above 10 m^2 ha^{-1}, and stem densities above 1,000 ha^{-1} produced between 350 to 450 g of leaf litter m^{-2} yr^{-1}, regardless of topographic position, aspect, and species composition. Biomass of litter (01) horizons also increased significantly with basal area and stem density; forest covers differed significantly; cove forests had 263 to 598, oak forests had 535 to 792, and pine-oak forests had 882 to 1,120 g of 01 m^{-2}. Significant differences in fermentation (F) accumulation were found between forest covers. Cove forest without rhododendron had 2 to 252; oak forests, 415 to 578; and pine-oak and rhododendron coves had 726 to 966 g of F m^{-2}. Humus (H) biomass increases significantly with elevation (860 g m^{-2} per 100 m gained) in pine-oak forests but not under other covers. Ash-free H biomass in g m^{-2} ranged between 32 to 179 in cove forest without rhododendron, 310 to 1,787 in mixed oak-hardwood forest, 1,387 to 2,818 in chestnut oak forest, and 1,785 to 3,339 in pine-oak forests. Small downed wood biomass appeared to decrease with stem density, basal area, and on northern slopes. The mean downed wood biomass in g m^{-2} of undisturbed forest was 48 in twigs (0 - 7 mm), 59 in small branches (7 - 25 mm), 157 in large branches (25 - 76 mm), and 200 to 1,700 in boles (76 mm plus). Downed wood biomass was largest in stands disturbed by chestnut blight (1.5 - 10.0 kg m^{-2}) and southern pine bark beetle (1.0 - 2.5 kg m^{-2}). Wood decay rates were found to differ between species and downed versus standing position. Standing dead oak lost 15 to 17% dry wt yr^{-1}, while pine, red maple, and rhododendron lost 3 to 7% dry wt yr^{-1}. Downed wood decayed 2 to 5 times faster than standing wood for pine and oaks. Leaf decay losses after 320 days at 600 m were 40 to 50% for north-facing forests and 15 to 28% for south-facing forests. Fires removed 90% of the 01 and between 0 to 97% of the 02, depending upon forest cover, fire density, and season. Fire reduced stand basal areas 2 to 12% in cool fires and 60 to 90% in hot fires and added an estimated 600 to 800 and 10,000 to 15,000 g m^{-2} to the detrital pool, respectively. Thirty-seven years of fire suppression has led to an increase in forest fuels, but most forests have reached "steady state" conditions and no major changes are expected. High elevation pine forests and severely disturbed stands will continue to accumulate debris, although the latter will eventually decline to usual levels after 15 to 20 yr.

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ABBREVIATIONS AND COMMON CONVERSIONS

°C	Celsius (temperature) where 1 degree C is equivalent to 1.8 degrees Fahrenheit
cm	centimeter (length) where 1 cm equals 0.39 inches
g	gram (weight) where 1 g equals 0.0022 pounds
ha	hectare (area) where 1 ha equals 2,471 acres
kg	kilogram (weight); 1 kg equals 1000 g or 2.2 pounds
m	meter (length); 1 m equals 100 cm or 0.33 feet
mm	millimeter (length); 1 mm equals 0.039 inches
%	percent
t	metric ton (weight); 1 t equals 1000 kg or 2200 pounds or 0.984 long tons
wt	weight
yr	year

INTRODUCTION

Years of successful fire suppression have effectively shifted the balance of producers and decomposers in many ecosystems. Lacking fire "respiration", forest fuels have tended to increase and now threaten the existence of plant communities which once were dependent on frequent fires (Kozlowski and Algren 1975). To adequately deal with the fuel "build-up" problem, attention must be given to accumulation-controlling processes in conjunction with fire. For example, decay process in a pine forest is exceedingly slow, and between 50 to 100 yr may be required for a steady state balance of producers and decomposers to be reached. In direct contrast, a cove hardwood forest may take only 4 to 8 yr to reach a steady state balance (Olson 1963). In the first case, fire suppression will have dramatic and long term effects, whereas the same policy for the second case will have few ramifications in terms of fuel accumulation. Since controlling processes are likely to vary throughout a park, attention must also be focused on the underlying causes of fuel differences.

Jenny (1941) suggested soil processes or functions are controlled by five major factors: time (t), parent material (p), climate (c), biota (b), and topography (r). Jenny summarized this relationship mathematically as:

$$S = f\ (t, p, c, b, r) \qquad (1)$$

$$s = f\ (t, p, c, b, r) \qquad (2)$$

where S is a soil body as a whole and s is any one property of a soil body. Although ecosystem factor-function relationships are complex (Olson 1958), the above mathematical abstractions (equations 1 and 2) provide a suitable framework on which to examine ecosystem differences.

The present study attempts to apply Jenny and Olson's framework to the fuel accumulation problem in low elevation forests of the Great Smoky Mountains National Park (GRSM). The major questions to be answered are: (1) What factors account for the variance in ecosystem properties, and (2) how do these factors interact with fire to either ameliorate or increase the fuel "build-up" problem?

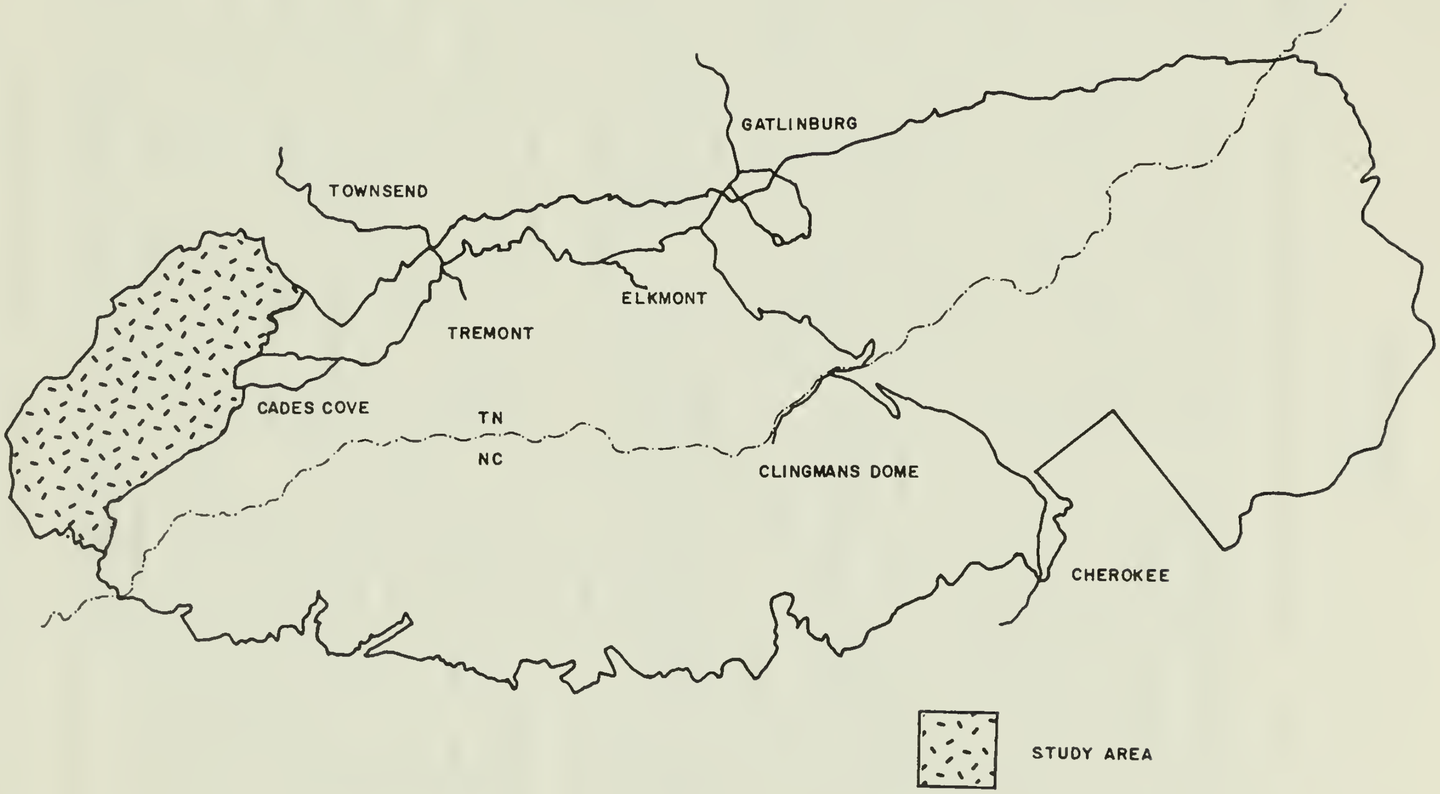


Figure 1. Study area for forest fuel inventory, fall 1977., Great Smoky Mountains National Park.

STUDY AREA

The study area is located in the westernmost portion of GRSM (Fig. 1). Southwest-northeast trending ridges with 60 to 300 m of local relief dominate the area and form a series of steep foothills between the Great Valley and the high peaks of the Great Smoky Mountains. The highest point of area is 1000 m on the crest of Mount Lanier, while the lowest point is 257 m at the mouth of Abrams Creek. The majority of the area is drained by Abrams Creek and is underlain by slightly metamorphosed Precambrian sediments of the Ocoee Series (King et al. 1968). At 600 m, the soil temperature at 15 cm depth ranges from a minimum of 4.4°C in March to a high of 18.3°C in August to September (Shanks 1956). The mean soil temperature is 11.7°C at 600 m (Shanks 1956). Air temperatures are usually 2 to 25 degrees warmer than soils during the growing season, and both cool at an average rate of 1.64° to 1.66°C per 300 m of elevation gained (Shanks 1956). Rainfall patterns at Cades Cove Ranger Station usually show a minimum during April and September-October (D. Silsbee and G. Larson, unpublished data). Total rainfall during a dry year (1976) was 38 cm lower than a typical wet year (1972), which had 198 cm. Fires were once very frequent in prepark days; Ayres and Ash (1905) estimated that up to one-half the watershed was burned over in any given year. At present, many stands have not burned for at least 35 to 40 yr.

METHODS

Vegetation

During the summer of 1977, forest vegetation was sampled as part of a vegetation survey for the GRSM. Forty-eight sites were selected to give a systematic sample of important environmental gradients. Fire history, moisture, and elevation were the major independent variables evaluated. Stands that had obviously been affected by anthropogenic clearing were excluded from the sample, whereas those influenced by minor disturbances (e.g., selective cutting and grazing) were included. Once a stand was selected (usually from a map), a .1-ha rectangular plot was located within homogeneous vegetation. The plots were permanently marked with four steel rods for future reference.

Woody plants above 1 cm diameter at breast height (dbh) were tallied by 1-cm size classes. Standing dead trees above 10 cm were also included in the tally. Woody plants less than 1 cm at dbh (shrubs) were sampled in 25 randomly located 4-m^2 quadrats. Both shrub cover and density were recorded for each quadrat. Herbaceous vascular plant cover was recorded in 1-m^2 subquadrats nested in the lower righthand corner of the shrub quadrats.

Forest Floor Biomass

Thirty-five stands sampled in the vegetation survey were revisited in fall 1977 for a forest floor inventory. Stands were sampled as time allowed; consequently, certain sites are under-represented (e.g., coves). Since forest floor material is partitioned along arbitrary lines, a brief description of each component follows. Wood was separated into standing dead, surface dead and downed, and buried dead. Standing dead was defined as material which makes an angle greater than 45 degrees with the forest floor. Surface dead and down was divided into four diameter classes: (1) twigs 0 to 7 mm, (2) small branches 7 to 25 mm, (3) large branches 25 to 76 mm, and (4) boles 76 mm plus. These size classes correspond to the 1-hour, 10-hour, 100-hour, and 100-hour-plus time-lag classes outlined by Fosberg (1976) for fire management purposes. Buried dead wood was defined as wood covered by organic soil horizons and was pooled for the 01 and 02 horizons. Soil organic horizons were divided into (1) new leafy litter (011); (2) old leafy litter (012); (3) fermentation (021); and (4) humus (022). The exact location of organic soil horizons is somewhat subjective, but the variation between observers was found to be reasonable.

In each stand, five stations were randomly located. At each station, leaf litter and buried wood were collected in four .05-square-meter circular quadrats. On 30 plots, newly fallen leaf litter was separated from the partially decomposed older material. Once the litter was removed, fermentation and humus thickness was measured to the nearest millimeter. Fermentation and humus biomass were estimated by multiplying volume and bulk density. Since some mineral soil is mixed into the humus layer, 3 humus samples of each major forest cover were ashed at 300°C for 3 hours. Humus weights are reported as ash and ash-free weights.

Surface dead and down wood was sampled using planar transects as described by Brown (1974). The method basically involves counting wood particle intersections with a vertical plane. Only visible wood can be inventoried using this technique. By either measuring each particle diameter or using average values, one can calculate wood volume:

$$V = \frac{\Sigma^2 \Pi^2}{8L}$$

where V is the wood volume area^{-1}, D is the average or actual particle diameter, and L is the transect length. Multiplication of volume by bulk density converts the estimates to biomass. Corrections for slope and nonhorizontal bias were included in the calculations. The reader is referred to Brown (1974) and Brown and Roussopoulos (1974) for more detail.

Wood larger than 76-mm diameter was tallied along a single 240-meter transect. Diameter, degree of rot, and the fraction missing were noted for each piece. If no boles were encountered on a transect but were present in the plot, their volume was noted and biomass estimates were adjusted accordingly. The three smallest wood classes: twigs, small branches, and large branches were sampled along 2-, 4-, and 10-m transects, respectively. At each station, two small wood transects were sampled, one up and another across slope.

All collected material was oven dried at 105°C for 12 hours. Wood, humus, and fermentation biomass were calculated using bulk densities from material dried for 12 hours at 105°C.

Site Characteristics

Site slope, aspect, topographic position, elevation, slope position, fire history, distance from water, and other topographic parameters were determined from field observation or from topographic maps. Disturbances other than fire were recorded; chestnut blight, southern pine bark beetle, windthrow, and rooting by the European wild boar were among the most common. Fire history prior to 1930 was determined by sectioning basal wounds of trees and examining scar tissue (Arno and Sneck 1977).

Decay Rates

Freshly fallen leaves were collected from five stands on Pine Mountain. The stands represent a moisture as well as a vegetation gradient (Table 6). After air drying, leaves were stuffed into 100-cm^2 fiberglass screen bags. Since the screen mesh was 1 to 2 mm wide, large invertebrates were, for the most part, excluded. Original dry weights were estimated by oven drying a sample and then correcting for moisture content. On 16 December 1977 the filled bags were placed on the litter surface of source stands. Ten bags were removed per stand at approximately 3-month intervals, and final dry weights were determined by oven drying at 105°C for 12 hours.

Wood decay rates were estimated by comparing rotted wood density to that of fresh (Swift et al. 1976). Two recently burned sites in the Gatlinburg area were used for the wood decay study. By assuming the date of fire occurrence and death were the same, an accurate date of mortality could be established. However, mortality may occur up to 6 months after a fire (Stickel 1935). One tree per species was selected, and 5 to 15 sections were removed with a handsaw or pruning shears. Section volumes were estimated by measuring 4 diameters and 4 lengths to the nearest millimeter. Adjustments were made for sections missing bark by comparing the area covered and bark weight. All wood was dried for 24 hours at 105°C and then weighed.

Statistical Analysis

Descriptive statistics for the raw data were calculated using SAS 76 Proc MEANS (Barr et al. 1976). Multiple regressions using station or stand summaries were also calculated by using the SAS 76 Proc GLM program. Unbalanced ANOVA designs were calculated by hand, as were the a *posteriori* mean sorts. Considerable danger exists in using multiple regression for screening causal factors. Often one can construct models which are statistically valid but have no underlying ecological meaning. To reduce this error, factors were used for which some reasonable causal relationship could be constructed. Many multiple regressions generated in this study were significant (as indicated by the F-test) but had low coefficients of determination (r^2). Regressions are not reported here unless they explain over 40% of the variation. Raw data from the vegetation survey was summarized by a FORTRAN program developed by Dr. Susan P. Bratton.

RESULTS

Vegetation Pattern

Site moisture relationships appear to be the most important factors in explaining overall vegetation patterns in the low elevation forests of the Great Smoky Mountains. In addition, disturbance history and elevation usually account for major deviations from this moisture influenced pattern. As in Whittaker (1956) and Golden (1974), species exhibit a continuum of response to environmental gradients; sharp breaks in species distribution usually correspond to discontinuous environmental factors.

Soil moisture conditions are the sum of many interacting elements and are difficult to measure directly in a meaningful way. Certain parameters, such as aspect and slope position, can be used, however, as relative indices of soil moisture. When attributes of vegetation are plotted on axes of slope position and aspect, a recognizable pattern emerges (Figs. 2 and 3). In using only two criteria for defining moisture, one assumes southwest ridges and northeast ravines and coves form the dry and wet ends of a gradient. Soil depth and texture, as well as slope steepness, are apt to cause exceptions to this general rule. Moreover, slope position and aspect are complex factor gradients (Whittaker 1975) along which moisture, nutrient, light, and biotic influences are likely to change.

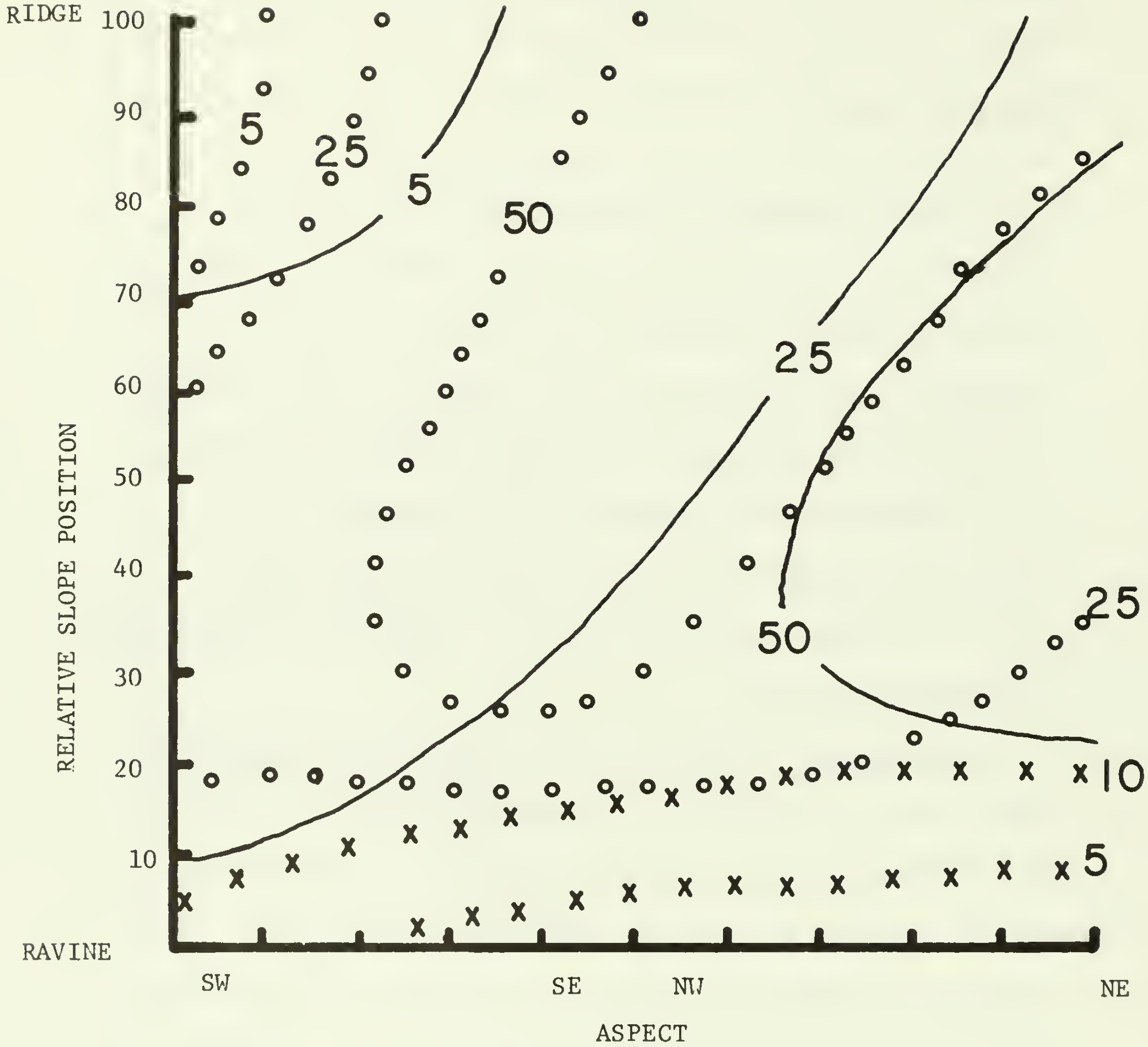


Figure 2. Distribution of hardwood vegetation groups on 2 complex environmental gradients: slope position and aspect. The lines represent isodems of relative basal area for each group. X X X X X X Evergreen heath; o o o o o o Oaks and Hickories; ———— Mixed hardwoods.

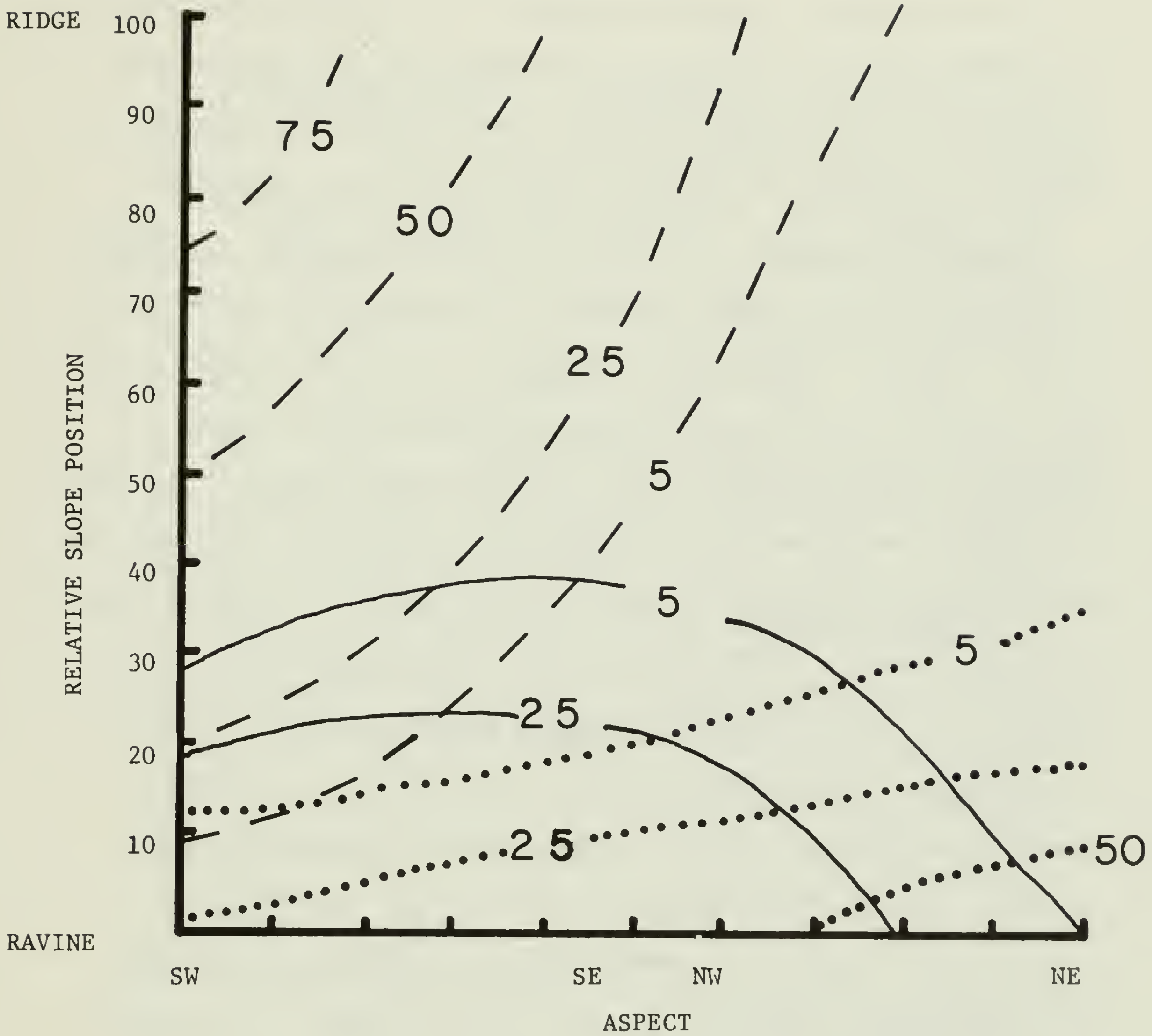


Figure 3. Distribution of conifer vegetation groups on 2 complex environmental gradients: Slope position and aspect. The lines represent isodems of relative basal area for each group. ••••••••••• Hemlock; ———— White Pine; — — — — Yellow Pines.

In an analysis of community structure the choice of vegetation parameters is usually arbitrary. Basal area was used here because of its close relationship to biomass contributions. Species were grouped by taxonomic and ecologic affinities for this analysis.

South-Facing Slopes. Yellow pines (*Pinus virginiana*, *P. rigida*, *P. echinata*, and *P. pungens*) dominate on the driest sites overlying a dense blueberry (*Vaccinium* sp.) groundcover (Fig 3). Progressing down southern slopes towards ravines, the dominance of mixed hardwoods, oaks, white pine, and evergreen heath increases. Although basal areas remain between 20 to 35 m^2 ha^{-1}, the increase in mountain laurel (*Kalmia latifolia*) on lower slopes leads to a twofold increase in density (3,000 - 3,500 versus 5,000 - 7,000 stems ha^{-1}). On the lowermost one-third slope, *Rhododendron maximum* gradually replaces *K. latifolia*, forming dense thickets in the ravines. In general, south-facing ravines and lower slopes have less hemlock and mixed hardwoods and more white pine and oak than their north-facing counterparts. There is an absence of herbaceous growth in ravines when *Rhododendron maximum* is present. Ravines appear to be conducive to tree growth; basal areas are up to twice those of upper slope forests (30 - 55 m^2 ha^{-1}). However, ravine sites are also less apt to burn and are relatively well protected from disturbance. South-facing slopes which are concave (i.e., draws) will tend to contain more oak than pine in the canopy. In general, a concave shape tends to shift the vegetation pattern described to more mesic species, whereas convex slopes have the opposite effect.

North-Facing Slopes. Oaks (*Quercus* sp.) and hickories (*Carya* sp.) dominate both the north-facing upper and midslopes, intergrading with white and yellow pines on southeastern and western slopes. In spite of similar basal areas on north and south upper slopes (20 - 35 m^2 ha^{-1}), stem density decreases on north slopes to the 1,500 to 2,500 m range. A dense understory layer of huckleberry (*Gaylussacia ursina*), blueberry (*Vaccinium vacillans*, *V. stamineum*), and greenbriar (*Smilax glanca*, *S. rotundifolia*) on upper northern slopes is gradually replaced by a herb understory composed of ferns, snakeroot (*Eupatorium* spp.), and beggar lice (*Desmodium* spp.) by midslope. On northeast-facing midslopes and northwest-northeast draws, mixed hardwoods assume dominance over oaks. The exact species assemblage in the latter stands is variable, but yellow poplar (*Liriodendron tulipifera*), black locust (*Robinia pseudo-acacia*), maples (*Acer rubrum*, *A. pensylvanicum*), dogwood (*Cornus florida*), silverbell (*Halesia carolina*), and magnolia (*Magnolia fraseri*) are the most common. In the Great Smoky Mountains, hardwood-dominated forests once contained many massive chestnuts (*Castanea dentata*) (Shanks and Woods 1959), and chestnut removal might account for their current low basal area (15 - 25 m^2 ha^{-1}).

Deciduous cove hardwood forests as described by both Whittaker (1956) and Golden (1974) are rare in the western low elevation forests of the Great Smoky Mountains. Deciduous coves and hemlock-dominated coves without *Rhododendron maximum* occur in sheltered north-facing draws and lower slopes. In contrast to stands with *R. maximum*, these cove forests contain a thick, diverse herb carpet with foam flower (*Tiarella cordifolia*), bugbane (*Cimicifuga racemosa*), rue anemone (*Amenonella thalictroides*), touch-me-not (*Impatiens* sp.), blue cohosh (*Caulophyllum thalictroides*), and assorted ferns dominating. As in south-facing lower slopes, ravines are filled with dense thickets of *R. maximum*. The canopy is dominated by hemlock (*Tsuga canadensis*), although mixed hardwoods such as yellow poplar (*Liriodendron tulipifera*), buckeye (*Aesculus octandra*), ash (*Fraxinus americana*), and basswood (*Tilia heterophylla*) occur in the most sheltered ravines.

Individual Species Distributions. The species groups used in this analysis are useful, but further explanation of three groups is warranted. The richness of the Great Smoky Mountains woody flora, however, restricts the detail which can be presented, especially for the mixed hardwood group. A complex treatment is presented for the latter group by Whittaker (1956) and Golden (1974) for the central Great Smoky Mountains. These descriptions also closely represent the situation in the low elevation western forests, except for the lack of black cherry

(*Prunus serotina*) and sugar maple (*Acer saccharum*).

Of the 10 oak species found within the park, six are common in the study area. Blackjack (*Quercus marilandica*), and scarlet oak (*Q. coccinea*) are usually found in association with pines on southern slopes and ridges. Scarlet, blackjack, black (*Q. velutina*), and chestnut oak (*Q. prinus*) mixtures occur where both pines and oaks share dominance. Northern ridgetops and upper slopes are dominated by a chestnut oak and sometimes a black oak canopy. Progressing down northern slopes, one is apt to find mixtures of white (*Q. alba*), black, chestnut, or northern red oak (*Q. rubra*). Each one of these oak species can dominate a given stand, and exact relationships are difficult to establish. Three hickories are commonly found with oaks in western GRSM. Pignut (*Carya glabra*) appears to be in more xeric stands than mockernut (*Carya tomentosa*), although both species distributions overlap considerably. Bitternut (*C. cordiformis*) is usually only found on very sheltered sites with other typical cove species (e.g., ash, buckeye, basswood, and beech).

The most obvious feature of yellow pine distribution is replacement along the elevation gradient, where *Pinus virginiana*, *P. rigida*, and *P. pungens* switch dominance as elevation increases. There are numerous exceptions, but *P. virginiana* dominates stands below 600 m and *P. pungens* dominates above 900 m. *P. rigida* tends to dominate in the 600 - 900 m range and is often replaced by *P. echinata* below 750 m.

Disturbance History

The vegetation patterns outlined above are shifted by two major disturbances: (1) fire, and (2) southern pine bark beetle attack (Kuykendall 1978). Chestnut blight (_Endothia parasitica_) killed most chestnuts of the southern Appalachians by the late 1930's (Stupka 1964) and profoundly influenced forest structure (Shanks and Woods 1959). However, changes attributable to this disturbance alone are probably diminishing as other species replace chestnut. Other disturbances, such as the exotic European wild boar (_Sus scrofa_) (Howe and Bratton 1976, Bratton 1975), and windthrow are of localized importance: the latter appears to provide sufficient openings for "shade intolerant" species such as sweet birch to reproduce (L. Barden, personal communication).

All of the stands examined showed signs of fire, such as basal scars or soil charcoal. However, natural and man-caused fires appear to exert the strongest influence on upper slopes and ridges. Before 1940 many upland sites had fires which scarred trees once every 15 to 25 years. Since the 1940's, many stands have remained unburned. On southern slopes both white and yellow pine reproduction is dense (8,000 seedlings ha^{-1}) after fire, especially in hot spots where canopy cover is thinned and thick organic horizons are greatly reduced. Pine seedlings germinate on mineral soil substrates where the canopy has not been thinned but will probably not reach canopy structure. Closed pine forest with light groundfires are therefore apt to undergo hardwood replacement (Barden 1974). On northern Slopes, black locust (*Robinia pseudo-acacia*), sourwood (*Oxydendrum arboreum*), sassafras (*Sassafras albidum*), devil's club (*Aralis spinosa*), and dogwood (*Cornus florida*) predominate after severe fires.

Classification of Communities

The community types presented here are based on dominant canopy species and are arbitrarily defined. Stands which represent each type described can be found in Appendix A.

The xeric communities can be separated into yellow pine, pine-oak, and chestnut oak forests. The chestnut oak forest defined here does not possess the mountain laurel layer often found in the central Smoky Mountains. Stands occupying an intermediate position on the moisture gradient can be divided into mixed oak and mixed oak-hardwood communities. Finally, the most mesic and sheltered sites are occupied by deciduous cove, hemlock cove, and rhododendron-cove forests.

Forest Floor Biomass

Accumulations of organic matter reflect a balance of two ecosystem processes: (1) production, and (2) decomposition (Olson 1963). Variations in organic matter accumulations imply basic differences in ecosystem function. Although complex environmental gradients such as elevation may not be the actual cause of these differences, they are often correlated to causal factors. Establishing accumulation-environmental relationships, therefore, serves as an important intermediary step in deciphering the causes of ecosystem differences.

Litter Production. Separation of newly fallen and older decomposed matter immediately after leaf drop allows a minimal estimate of litter production (Jenny et al. 1958; Olson 1963). Two errors affect these estimates: (1) Litter falling in seasons other than autumn may be overlooked and/or suffer decay losses, and (2) leaves decay at varying rates depending upon community. Cove hardwood stands, for example, may lose between 10 to 20% litter dry wt 1 to 2 months after leaf drop. On the other hand, litter in pine stands may lose less than 5% of its original biomass during a similar time period. In this case, hardwood litter production is likely to be underestimated. Although coniferous forests, especially pine, have an autumn litter-fall peak, considerable biomass falls in other seasons (Bray and Gorham 1964). Moreover, new versus old litter boundaries are not as distinct in pine as in hardwood forests. Even though the "separation" method has obvious shortcomings, it allows a large number of stands to be inventoried.

Leaf litter production is not significantly related to elevation, aspect, slope position, slope form, or vegetation gradients. Succession-related gradients (e.g., basal area and stem density), on the other hand, explain a significant portion ($p < .01$) of the litter production variance (Fig. 4). The regression equation does

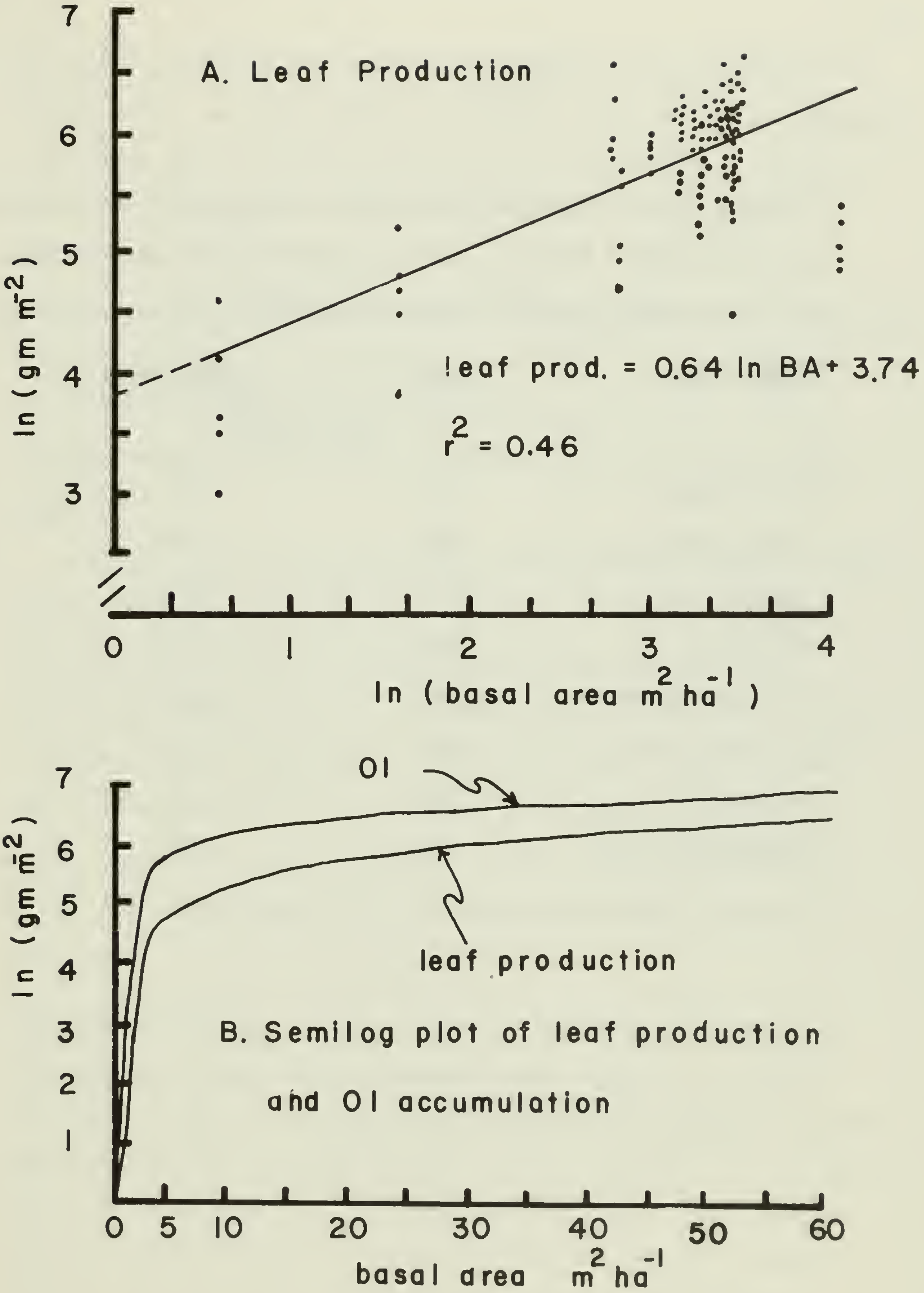


Figure 4. Predicted and observed litter production and biomass in low elevation forests of the Great Smoky Mountains

Table 1. Mean litter and fermentation standing crops for selected forest covers in low elevation forest of western Great Smoky Mountains. (Also see Appendix B.)

FOREST COVER	LITTER	FERMENTATION
	Grams $meter^{-2}$	
Yellow Pine	882	966
Yellow Pine-Oak	1120	726
Chestnut Oak	535	578
Mixed Oak	792	415
Mixed Oak-Hardwood	495	526
Deciduous Cove	598	2
Hemlock Cove	263	252
Rhododendron Cove	344	952

not predict a leveling of production as might be expected (Bray and Gorham 1964). A semilog plot of production versus basal area indicates a leveling after stands reach basal areas of 10 m^2 ha^{-1}. The range in litter production for this part of the curve is considerable, enclosing values between 200 to 400 g m^{-2} yr^{-1}. The majority of stands examined had litter production ranging between 340 to 450 g m^{-2}. Litter production regressions using stem density as an independent variable are similar to those produced using basal area. Litter production is predicted to level off when stands have 1,000 or more stems ha^{-1}.

Apparently, litter production is only reduced noticeably if large portions of a mature canopy (i.e., over two-thirds) are eliminated. The exact time required to progress from severe disturbance to production maximum was difficult to establish for the stands. Natural disturbance often leaves much of the canopy intact. One pine stand which had been severely fire-disturbed 21 yr prior to sampling had litter production values comparable to older, slightly fire-damaged stands (397 versus 419 g m^{-2}). This suggests an upper limit for recovery on dry sites of less than 20 yr.

Litter, Fermentation, and Humus layers. Significant differences in total litter 01 biomass exist between forest types (F = 15.005**). A posteriori mean sort (Student-Newman-Keuls, SNK) separated 4 groups from a range of 8. In ascending order, these groups are (1) hemlock cove; (2) rhododendron and deciduous coves, chestnut oak, mixed oak, and mixed oak-hardwood; (3) yellow pine; and (4) pine-oak (refer to Table 1). Canopy type is an ambiguous variable corresponding to

**Significant at the 0.01 level

variations in leaf substrate, light, moisture, nutrient status, and temperature. Multiple regressions using substrate ash content, aspect, elevation, slope position, and slope steepness were not able to separate these effects to any significant degree. A statistical relationship was found, however, between 01, basal area, and stem density which essentially parallels litter production regressions but at higher level (Fig. 5). Litter accumulation can be followed after cool ground fire by assembling a composite of stands burned at different times (Fig. 5). Accumulation proceeds rapidly at first, but then asymptotically approaches a "steady state". Even in pine forest, litter accumulation is rapid, reaching 71% of the 40-yr-plus value in only 2 yr. Less data is available for oak forest floors after fire, but chestnut oak stands reach 75% of the steady value in 2 yr. One mixed oak stand, 2 yr after fire, had 01 values in excess of a similar undisturbed stand.

There are significant differences in fermentation (F) accumulations between forest covers (F = 9.023**). Forests are lumped by SNK which occupy opposite ends of the moisture gradient, indicating leaf substrate character is an important factor. The broad overlap between means makes the interpretation of SNK results difficult (Table 1). Deciduous cove and hemlock cove forests are distinct from other forests, with F accumulations ranging between 578 to 966 g m^{-2}. Overlaps occur between the hemlock cove and mixed oak (252 to 415 g m^{-2}) and mixed oak, chestnut oak, and mixed oak-hardwoods (415 to 578 g m^{-2}).

Regressions of site variables against F layers were not significant. The lack of relationships between F biomass and basal area is interesting and indicates factors concerning decomposition generally mask the effect of production in this horizon. Within pine forests a suggestive trend between aspect and organic matter buildups is apparent. An east-facing pine stand had 251 fewer g F per m^2 than a similar southwest-facing stand. At a slightly lower elevation, a southeastern forest had 539 fewer g F per m^2 than an equivalent southwestern stand. A semilog of organic accumulations indicates a slight decrease in F and H layers as aspects shift from southwest to southeast. As slopes become more exposed to sunlight, quicker drying and hence decreased decay rates might be expected.

Although significant differences in humus (H) buildups occur between forest types (F = 8.0493**), only rhododendron coves differ enough to be separated by SNK. Trends are apparent between forest covers (Table 2) but high variances obscure differences in the statistical tests. Hemlock and deciduous coves have the least H (54 - 299 g m^{-2}), and mixed oak forests tend to have higher levels (664 - 919 g m^{-2}). Mixed oak-hardwood stands are highly variable, ranging from 518 to 2979 g m^{-2}. The wide range in these stands probably reflects differences in composition; stands with increasing amounts of oaks and hickories tend to have more humus than those with mixed hardwoods alone. Chestnut oak stands rank fourth, with H standing crops ranging from 1632 to 3315 g m^{-2}. Yellow pine forest at low elevations has less H than chestnut oak and mixed oak-hardwood forests. At higher elevations (above 750 m) pine H

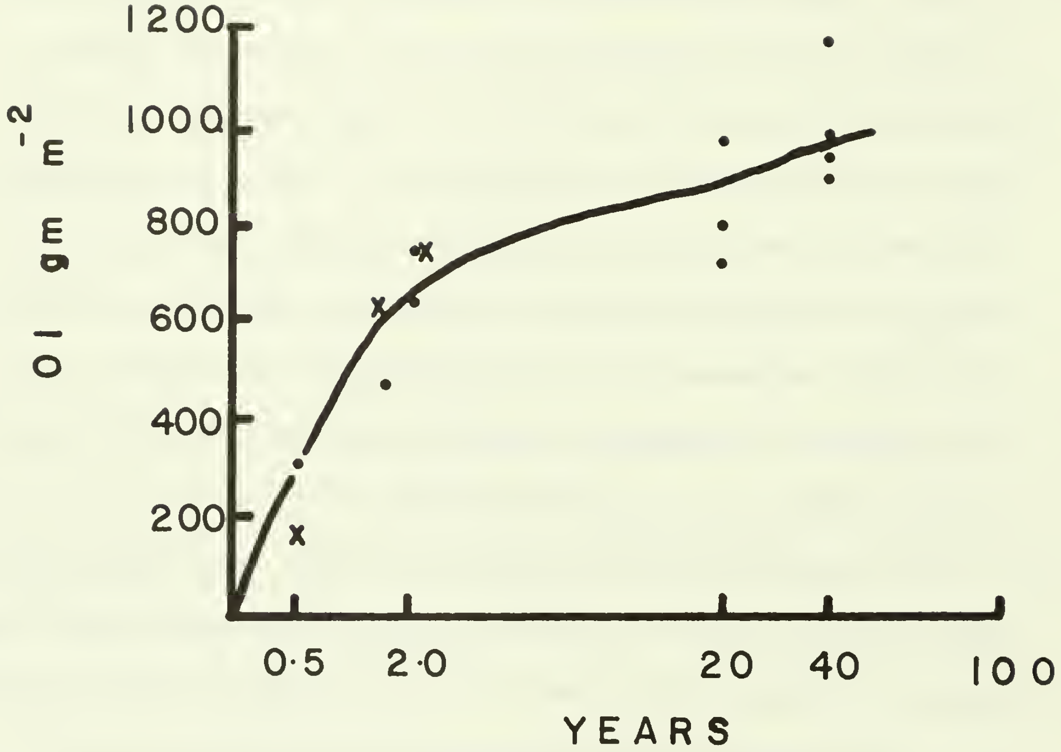


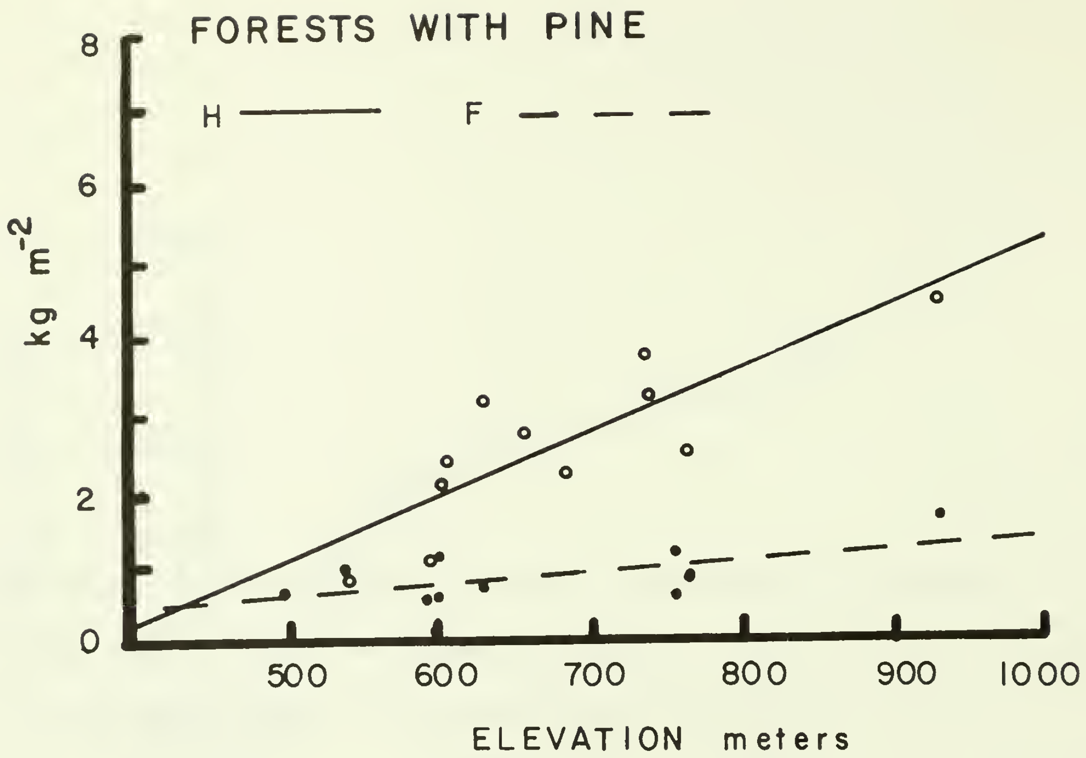
Figure 5. Accumulation of litter in pine forest following a ground fire. X denotes a predicted value, assuming a yearly decay constant of k = 0.07 and a yearly litter input of 400 grams meter^{-2}. The dots represent actual values and the curve is fitted by eye.

Figure 6. Relationship of H and F accumulations to elevation for forests with and without pine present. Open circles represent H, and dots are F. Humus in pine forest increases by the formula,

$H = 0.0086\ (\text{elev}) - 3.246\ (r^2 = 0.673).$

Fermentation increases in pine forest at the rate

$\text{Ferm} = 0.0019\ (\text{elev}) - 0.364\ (r^2 = 0.184).$


FORESTS WITH PINE
H
F
kg m^{-2}
0
2
4
6
8
500
600
700
800
900
1000
ELEVATION meters

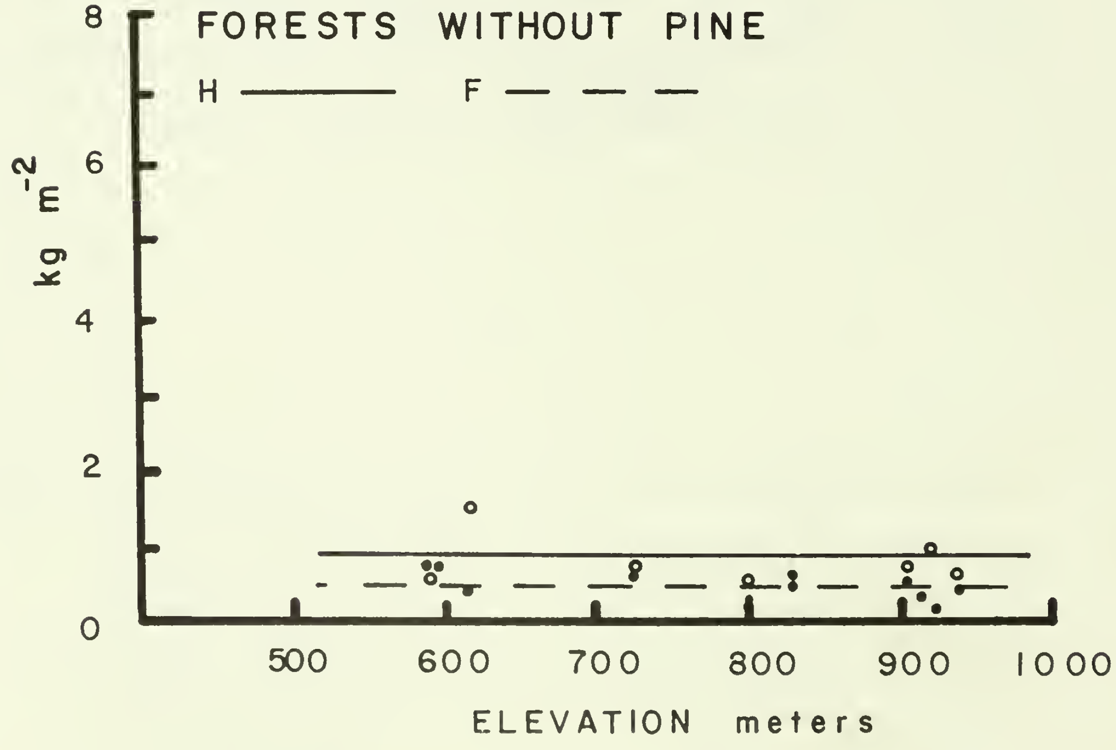

FORESTS WITHOUT PINE
H
F
kg m^{-2}
0
2
4
6
8
500
600
700
800
900
1000
ELEVATION meters

Table 2. Range of humus accumulations in various communities of the 550 to 650 meter elevation belt. An upper limit is presented for ash contents.

FOREST COVER	% ASH CONTENT	HUMUS ACCUMULATIONS g m^{-2} No correction	 Ash correction
Pine	15	2100-2440	1785-2074
Pine-oak	15	3166-3928	2690-3339
Chestnut oak	15	1632-3315	1387-2818
Mixed oak	25	664-919	498-690
Mixed oak hardwood	40	518-2979	310-1787
Hemlock-deciduous coves	40	54-299	32-179
Rhododendron cove	15	6993	5944

layers become considerably thicker (3216 to 4585 g m^{-2}). Pine-oak H layers are very thick (3166 to 3928 g m^{-2}) and rank second only to rhododendron coves with 6993 g m^{-2}. The high ash content of mixed oak-hardwood H (approximately 45%) inflates humus biomass values. After adjustment these forests have ranges similar to mixed oak forest.

Humus accumulations are apparently affected by moisture within a forest cover. Humus shows an increase as aspects shift from northeast to southwest. A southeast-facing pine stand at an elevation of 600 m had 340 less g H per m^2 than a matching southwestern stand. At 750 m elevation, an east-facing pine forest had 599 g less H than a southwestern stand. Presumably, increased drying on southwestern slopes would cause these differences in accumulation.

H layers in pine and pine-oak forests increase at a rate of 862 g m^{-2} per 100 m elevation gained (Fig. 6). In direct contrast, hardwood forests show no significant increase in H, with elevation and range about 874 g m^{-2}. Evidently, the combination of substrate and changing environmental factors associated with elevation interact, causing two different patterns to emerge.

The frequency of humus within a stand is a useful index to categorize forest floors. Considerable inferences about humus inputs can be provided by examining these distributions. The three forests examined in detail here show marked differences (Fig. 8). The deepest pockets in all three stands correspond to very old fallen boles. Observations in these stands indicate that between 10 and 20% of H

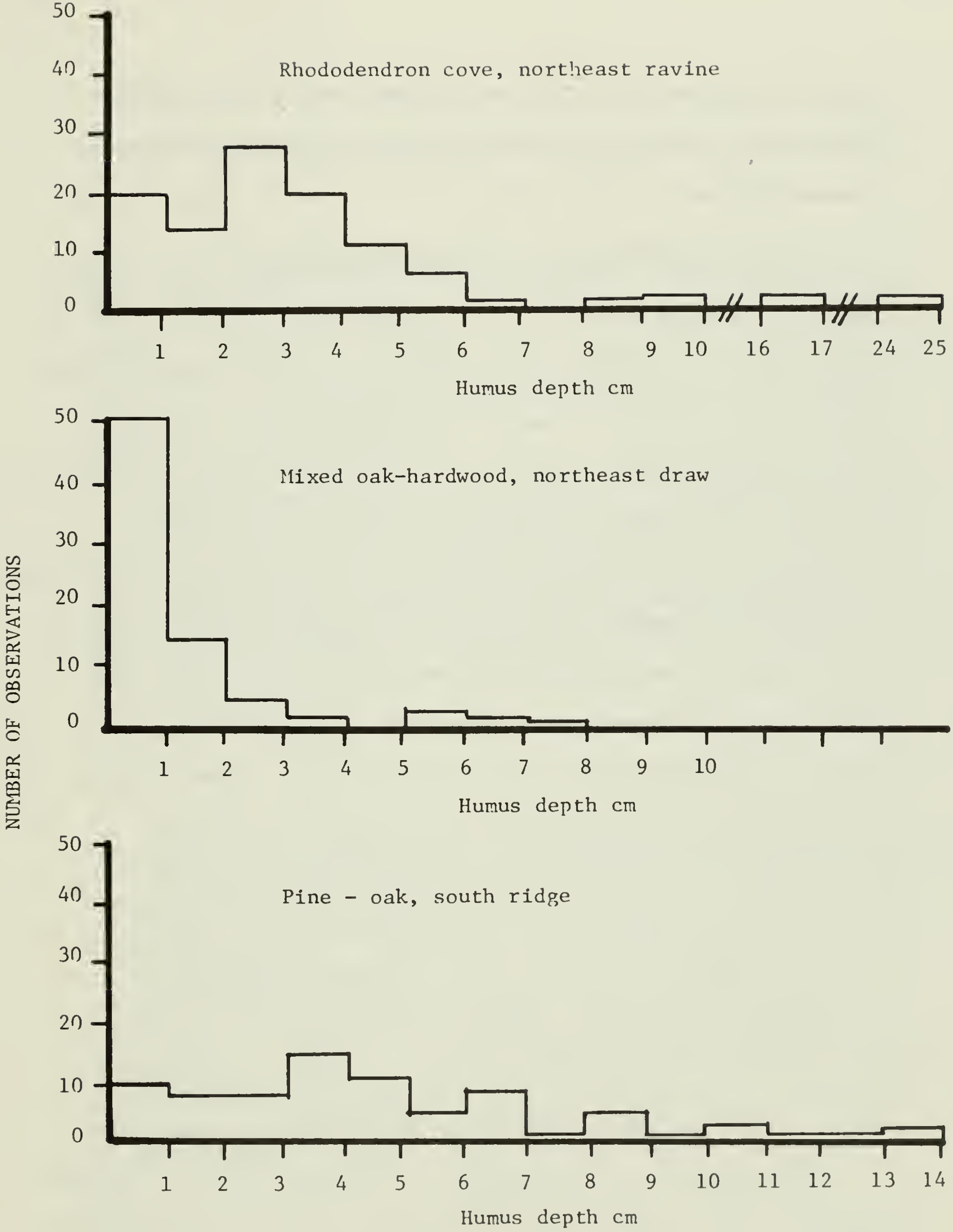


Figure 7. Distribution of humus depths for 3 contrasting types of forests between 510 and 600 m elevation.

biomass is attributable to leaves and small wood. Major canopy disturbances, therefore, are very important in causing variations in humus thickness.

Dead and Down Wood. Although significant differences exist between undisturbed forests (F = 2.24), the overall pattern is one of random variability. No consistent relationships were found between downed wood and slope position, elevation, and forest cover. A slight decrease in downed wood biomass may be associated with an increase in basal area, stem density, and northern aspects. The "random" variability model is somewhat surprising, since wood decay rates change in a predictable manner. Hardwoods, for instance, would be expected to decay faster than conifers (Allison 1961). Since ravines and draws are more sheltered than ridges, one might expect higher production and faster decay rates in the former. A lack of correspondence between vegetation-site variables and wood accumulations would result if the balance of production and decomposition was similar for xeric and mesic sites. However, it is more probable that wood input is largely independent of vegetation-site variables. Sizable variations in wood inputs caused by storm damage, stem mortality, pruning, and so on could therefore mask vegetation-site-caused differences in decay rates.

Downed bole biomass is greatest in stands affected by chestnut blight (Fig. 8). Numerous old chestnut boles increase forest floor biomass between 1.5 and 10.0 kg m^{-2} in mixed oak-hardwood and cove forests. Pine forests affected by southern pine bark beetle also have large bole accumulations which range between 1.0 and 2.5 kg m^{-2}. Undisturbed forests of all compositions have downed bole biomass values ranging from 0.2 to 1.5 kg m^{-2}. The range of small wood biomass is similar to downed bole wood in undisturbed stands (100 - 1200 m^2). Two years after fire disturbance, small wood biomass is similar to or higher than undisturbed forests. Evidently, wood lost via combustion has been replaced by the rapid falling of fire-killed trees and shrubs.

Plots of wood biomass and frequency are all skewed to the right (Figs. 8 and 9). Bole distributions are even more skewed than small wood distributions. Although disturbed and undisturbed distributions have considerable overlap, upper and lower bounds have been suggested (see Figs. 9 and 10).

Decay Rates

Wood Decay. Although not entirely conclusive, smaller standing dead branches have a lower exponential decay constant, k, than similar downed wood (Table 4). Since the wood was exposed for different lengths of time, k is the most appropriate parameter to examine (Olson 1963). Changes in moisture regime probably account for the twofold to fivefold increase in decay for downed wood as compared to standing dead. Possibly larger wood pieces would show similar effects. In two of the nine species examined (*Pinus strobus* and *P. virginiana*), small branchwood decayed slower than large (Table 5). No difference or an increase in k was found for oaks, red maple,

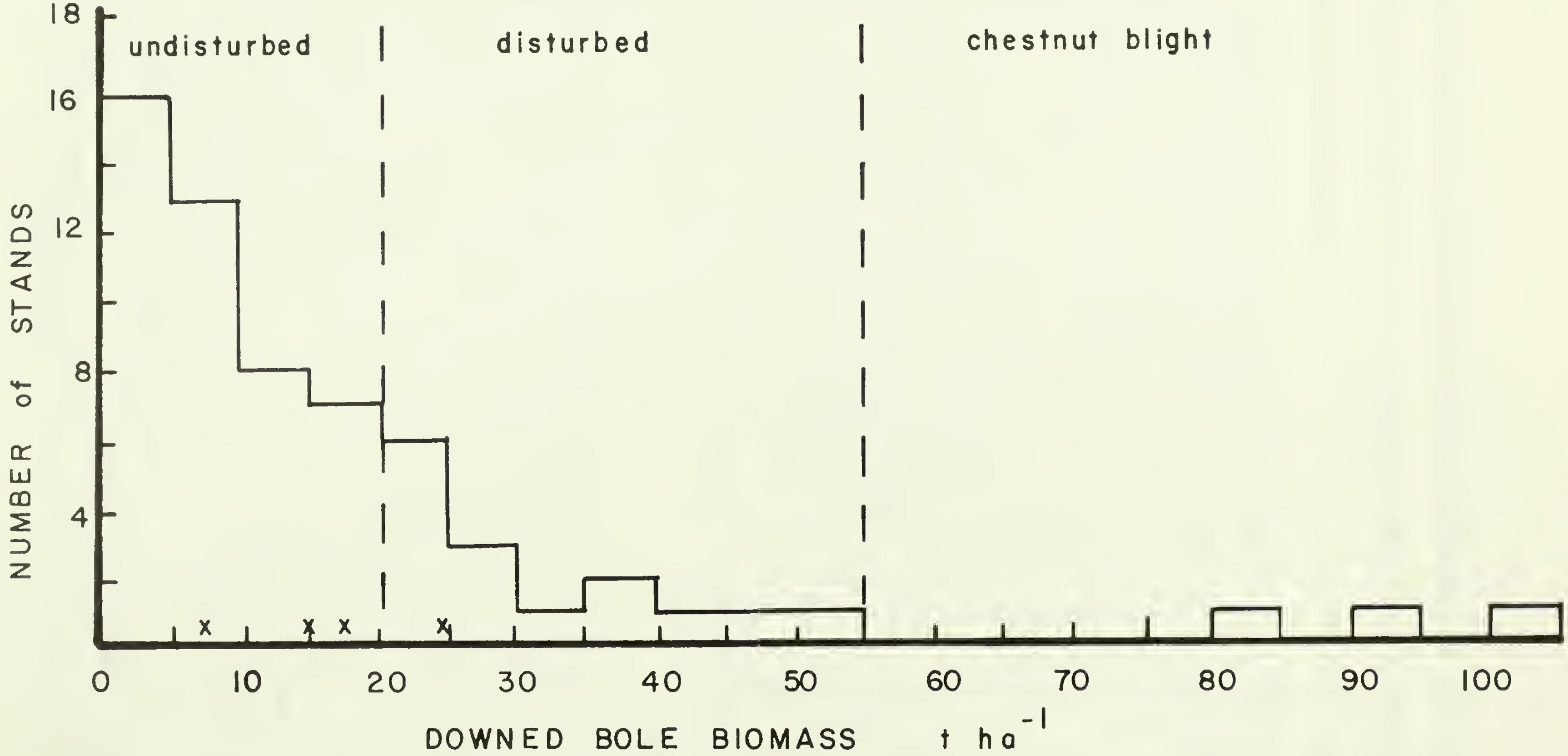


Figure 8. Distribution of downed bole biomass for all forest stands inventoried. Dashed lines indicate estimated limits of disturbed versus undisturbed forests. X denotes data from Harris et al. on a low elevation watershed.

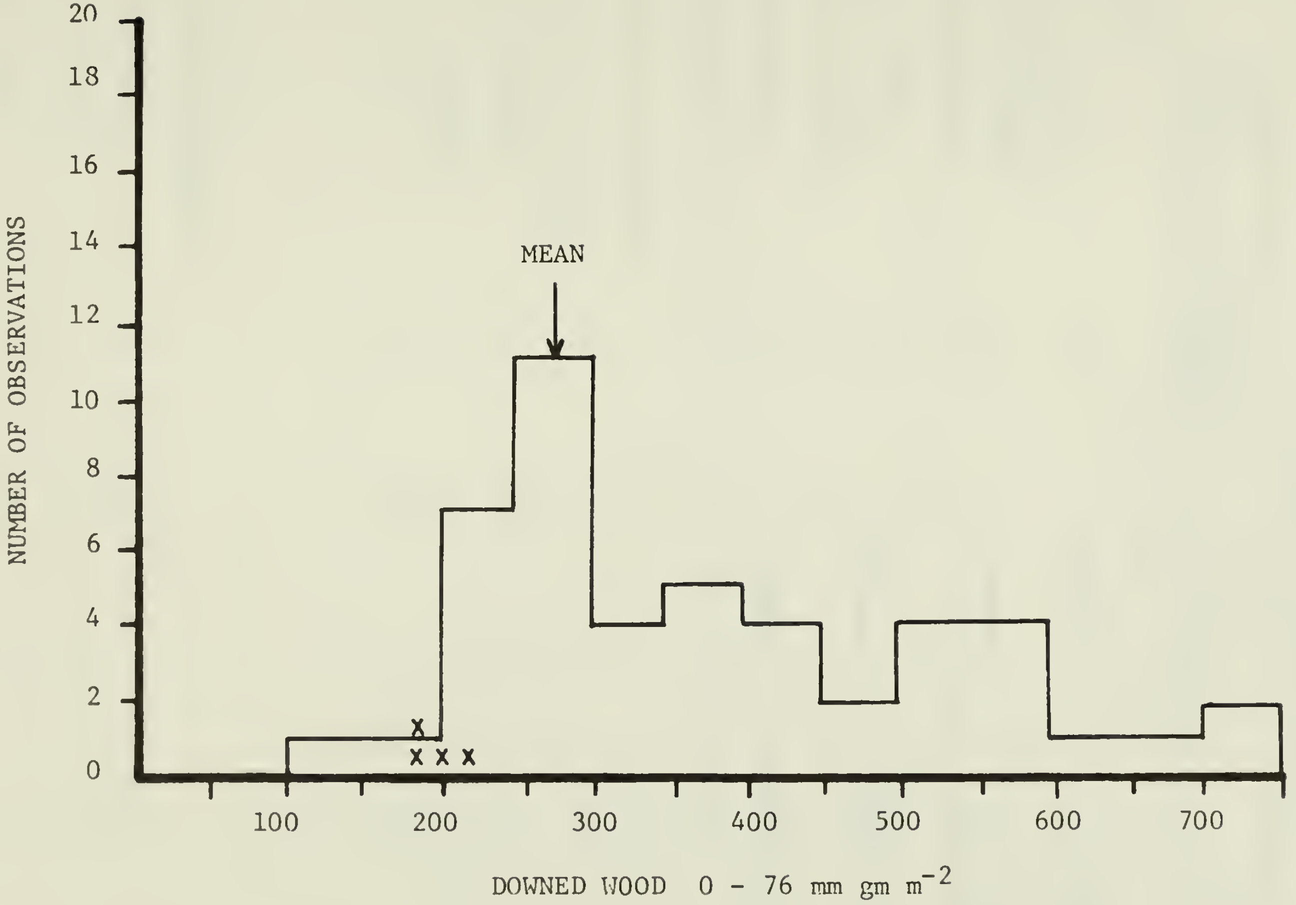


Figure 9. Distribution of small downed wood (< 7.5 cm) for forest stands inventoried. X's mark data of Harris et al. which excluded the 1.0 - 7.5 cm size class. To adjust to Harris et al. scheme, subtract 150 grams.

Table 4. Comparison of decay parameters of standing dead and downed branchwood (25 mm diameter).

SPECIES	N	POSITION	EXPOSURE TIME Months	% LOST	k $year^{-1}$
Pinus virginiana	7	Standing	31	5	0.020
Pinus virginiana	8	Downed	11	10	0.115
Quercus prinus	4	Standing	19	24	0.173
Quercus prinus	8	Downed	11	21	0.257

Table 5. Decay parameters for standing dead wood after various periods of natural decomposition. The parameter k is calculated as in Olson (1963), assuming decay proceeds as negative exponential function. 3/k is the time needed, in years, for 95% of the wood to disappear.

SPECIES	N	EXPOSURE TIME	% LOSS	k yr^{-1}	3/k
Small Branches <25 mm diameter					
Quercus prinus	7	31	25	0.111	27
Quercus alba	4	19	30	0.225	13
Quercus coccinea	6	31	8	0.032	93
Acer rubrum	9	19	15	0.103	29
Acer rubrum	6	31	18	0.077	38
Rhododendron maximum	5	19	5	0.032	94
Rhododendron maximum	8	31	7	0.028	107
Tsuga canadensis	6	19	13	0.088	34
Pinus virginiana	7	31	5	0.020	150
Pinus strobus	7	31	6	0.024	125
Large Branches 25-100 mm diameter					
Quercus prinus	5	19	24	0.173	17
Quercus prinus	4	31	33	0.155	19
Quercus alba	6	19	23	0.165	18
Quercus rubra	3	31	38	0.185	16
Quercus coccinea	3	31	26	0.117	26

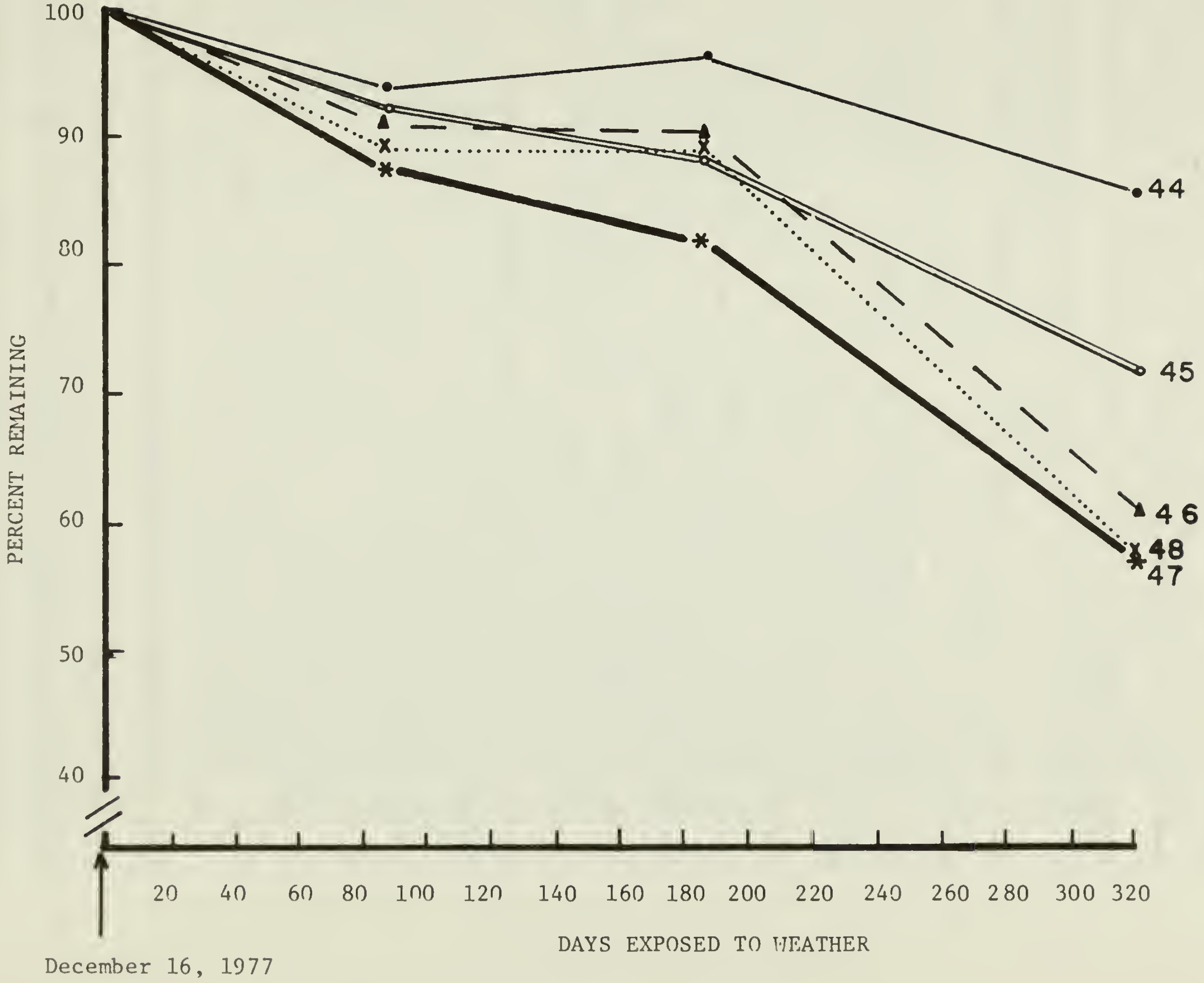
Table 5. Continued.

SPECIES	N	EXPOSURE TIME	% LOSS	k yr^{-1}	3/k
Acer rubrum	6	19	5	0.032	94
Acer rubrum	3	31	7	0.028	107
Rhododendron maximum	3	19	1	0.006	500
Rhododendron maximum	6	31	17	0.072	42
Tsuga canadensis	6	19	14	0.095	32
Tsuga canadensis	5	31	25	0.111	27
Pinus virginiana	11	11	7	0.079	38
Pinus virginiana	5	31	14	0.058	52
Pinus strobus	7	31	32	0.149	20

Table 6. Site characteristics of litter decay stands, 1977-78, in the Great Smoky Mountains National Park

STAND NUMBER	ELEVATION	ASPECT	TOPOGRAPHIC POSITION	VEGETATION
44	608	230	Open slope	Yellow pines-blueberry
45	632	190	Ridge	Yellow pine-oak-huckleberry
46	620	350	Open slope	Chestnut oak-huckleberry
47	590	65	Draw	Mixed oak hardwood
48	578	360	Ravine	Cove hardwood-rhododendron
G1 and G2			Open slope	Second growth, oak-hardwoods

Figure 10. Loss of litter confined in fiberglass mesh bags for 322 days. Plot number codes: 44 - pine on SW slope; 45 - pine and oak on a south ridge; 46 - chestnut oak on a NW slope; 47 - mixed oak hardwoods on a NE draw; and 48 - rhododendron cove in a NE-facing ravine.


PERCENT REMAINING
100
90
80
70
60
50
40
44
45
46
48
47
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
DAYS EXPOSED TO WEATHER
December 16, 1977

hemlock, and rhododendron when small and large branchwood was compared. This may indicate that factors correlated to size other than moisture retention are important. All oaks except scarlet (*Quercus coccinea*) decay at an average rate of 15 to 17% dry wt yr^{-1} in the standing position. Scarlet oak, hemlock (*Tsuga canadensis*), and white pine (*Pinus strobus*) decay at intermediate rates, losing 9 to 12% dry wt yr^{-1} on an average. The slowest decaying species are virginia pine (*Pinus virginiana*), rhododendron (*Rhodendron maximum*), and red maple (*Acer rubrum*), losing between 3 and 7% dry wt yr^{-1}. The exponential decay constants, k, exhibit the same pattern as average losses and are fairly constant within a species. Red maple instantaneous decay rates, for example, were 0.032 and 0.028, even though the constants were derived after 19 and 31 months of decay. The only exception to this pattern is rhododendron. Decay differences were also apparent within single trees according to position. In both pines and oaks the bases of trees (up to 1.0 m) were observed to be in a more advanced decay state than wood farther up the stem. After 31 months of decay, pines lost between 25 and 40% and oaks between 37 and 43% dry wt at the base of standing dead trees. Above the base, losses were 20 to 30% in pines and 23 to 33% in oaks.

Leaf Litter Decay. Decay on north slopes was significantly greater ($p < .01$) than south slopes after 320 days (Fig. 1). Litter in rhododendron cove, mixed oak-hardwoods, and chestnut oak forests all lost between 40 and 45% dry wt during this period. A south-facing pine-oak forest, on the other hand, lost 28% dry wt. The driest site with a pine canopy lost only 15% of its original dry wt. A spring drought probably caused a decrease in decay during the spring quarter. Decay rates were highest during summer when moisture and temperature conditions were probably most favorable.

Decay rates in leaf bags for the first 320 days do not account for the differences in 02 accumulations between forest covers. Stands with very similar litter decay rates and production have very different 02 standing crops (rhododendron cove = 6.0 and mixed hardwood = 1.7 kg m^{-2}). One source of discrepancy may be due to wood inputs. However, the stand with the least amount of 02 was affected most by chestnut blight. A more probable cause of discrepancies might be that decay rates for these stands differ after 2 to 3 yr, although the original rates are similar.

By assuming forest floors are in steady state, one can calculate exponential decay rates constant, k, by knowing the average forest floor inputs, I, and standing crops, X, and using the formula, $k = \frac{I}{X}$ (Jenny et al. 1948, Olson 1963). In temperate deciduous forests, litter input approximates a sawtooth curve. Litter production estimates used in this study quantified the height of this sawtooth peak somewhat but are probably low due to decay and unavoidable oversights. The underestimate of the height of the "sawtooth" peak of litter input leads to subsequent underestimate of decay rates. Organic matter standing crops are also measured with some error, especially by mull-type humus where ash contents are between 30 and 50%. The overestimate of biomass by ash inclusion will also lead to an underestimate of k.

Errors in pine and xeric forests are probably smaller than for mesic types, which have faster decay and mull-type humus. Wood also contributes to humus biomass and, where these contributions are large, leaf decay rates are likely to be underestimated. Therefore, the estimates presented here are probably lower bounds for the long term decay of leafy litter.

Decay constants (k) based on litter input-accumulation ratios are all lower than the 320-day litter bag values (Table 7). This difference is smallest in pine forest and largest in rhododendron cove, which exhibits a tenfold departure. The rate differences may reflect the concentration of recalcitrant materials (e.g., lignin) in leaves (Cromack and Monk 1975).

Since decay parameter calculations are sensitive to both wood inputs and 02 ash contents, an adjustment for these factors is warranted. A second set of decay values, also presented in Table 7, assumes wood contributes 15% to 02 biomass. An adjustment was also made to account for the variable ash content of 02 layers. Taking ash and wood into account increases decay constants, but the only major change is for the mixed oak-hardwood forests where rates are roughly doubled. Forests, in order of slowest to fastest decay rates, are rhododendron cove, high elevation pine, pine-oak, pine, chestnut oak, mixed oak, mixed oak-hardwoods, and deciduous cove. Hemlock coves are probably close to deciduous coves in decay rates,

Table 7. Decay parameters based on litter bag and litter input-accumulation ratios (I/X) for various forest covers and elevations. The different values have been calculated depending upon the assumptions discussed in text.

COVER	ELEVATION	LITTER BAGS yr^{-1}		INPUT AND ACCUMULATION yr^{-1}				
				No adjustment			Adjustment for wood & ash	
		k	k'	k	k'	3/k	k	k'
Pine	540	--	--	0.163	0.134	21	0.181	0.166
Pine	600	0.163	0.134	0.091	0.087	32	0.114	0.108
Pine	730	--	--	0.095	0.091	32	0.121	0.114
Pine	760	--	--	0.108	0.102	28	0.136	0.127
Pine	930	--	--	0.050	0.049	60	0.063	0.061
Pine-oak	700	0.329	0.252	0.093	0.089	32	0.113	0.107
Chestnut oak	615	0.510	0.362	0.097	0.092	31	0.122	0.115
Chestnut oak	920	--	--	0.215	0.193	14	0.268	0.176
Mixed oak	900	--	--	0.224	0.201	13	0.265	0.233
Mixed oak hardwood	700	0.562	0.391	0.189	0.172	16	0.345	0.292
Deciduous cove	850	--	--	0.709	0.508	4	0.709	0.508
Rhododendron cove	580	0.562	0.391	0.041	0.040	73	0.054	0.053

Table 8. Estimated losses of forest floor layers after a lightning fire occurred during the months of July and August. Control stands were of similar elevation and forest cover.

FOREST COVER	SEVERITY	PERCENT REDUCTION	
		F	H
Pine	Hot	89	78
Pine	Hot	96	67
Pine	Hot	85	85
Pine	Cool	84	65
Pine	Cool	93	65
Pine-Laurel	Cool	77	71
Pine-oak	Cool	67	20
Chestnut oak	Cool	83	0
Mixed oak	Cool	< 5	< 5

Table 9. Forest floor reduction following fires of different seasons and severity in pine communities. Control stands are of similar elevation and aspect.

SEASON	SEVERITY	PERCENT REDUCTION	
		F	H
Summer*	Cool	98	97
Summer*	Hot	98	97
Summer**	Cool	93	65
Summer**	Hot	89	78
Winter***	Cool	63	0
Winter***	Hot	84	0

* Natural fire which may have started after extensive drought.

** Natural fire which burned through numerous precipitation events.

***Man-caused fire.

although no calculations could be made.

An exponential model, $X_t = \frac{I}{k}(1-e^{-kt})$, probably fits the general pattern of litter buildup after a ground fire has removed organic horizon standing crops. In this model, X_t is the litter biomass at time, I is the mean annual litter input, k is the decay constant, and t is the time in years. The time required for a stand to reach 95% of the "steady state" litter value ($Xss_{.95}$) can be calculated by the formula given by Olson (1963): time = $\frac{3}{k}$. The slowest responding communities are high elevation pine and rhododendron coves, which reach $Xss_{.95}$ in 60 to 73 yr. Most pine, pine-oak, and chestnut oak forests are intermediate in response, taking 21 to 32 yr to reach $Xss_{.95}$. Depending on the values used, mixed oak-hardwood communities reach $Xss_{.95}$ in 9 to 16 yr, while deciduous coves take as little as 4 yr.

Organic Matter Input and Removal by Fires. Organic matter inventories were also conducted immediately following fires. By assuming stands of similar type, age, and elevation were suitable controls, the removal effects of fire could be assessed. More layers enter the combustion process as fire severity increases (Table 8). Over 90% of the L layer was removed, regardless of forest cover and severity. In pine forest, similar amounts of F are removed in "hot" and "cool" fires, although the latter removed less H. Very little H is removed when oaks or other hardwoods are present. Within pine communities, removal of fire differs between seasons (Table 9). Summer fires remove more F and H than winter fires. The causes of differences between fires is not known, but moisture content (Van Wagner 1972), mineral content, and bulk density all may have some bearing on the problem. Wood removal was not measured directly, but it was observed most wood below 25 mm diameter was consumed. Usually the most rotted wood was apt to burn when diameters were larger than 25 mm. Wood in excess of 100 mm diameter was not more than 50% consumed, even in severe fires. The general conclusion is that considerable litter and wood remain after fires in the southern Appalachians, even under severe conditions. Fires often create as much or more debris than they remove. The largest source of fire inputs are top-killed trees. Cool fires remove between 2 and 12% of the live basal area. On the other end of the scale, severe fires kill an average of 90% of the prefire basal area. By assuming basal area and biomass reductions are proportional, the expected amount of fire-generated woody debris can be calculated. Using a mean value of Whittaker's pine forest above-ground biomass data (1963) indicates mild fires would cause a 600 to 800 g m^{-2} increase in standing dead matter. Severe fires would generate between 10,000 to 15,000 g m^{-2} increase in standing dead matter. Clearly, the major role severe fires may play in organic matter budgets may be as debris creators rather than removers.

DISCUSSION

Regional Overview

The results reported here indicate biomass and decay rate variances within and between ecosystems. Comparing this data set with previous studies conducted in the Southern Appalachians gives some indication of regional patterns.

Biomass. In 1958, McGuinness sampled forest floors of 14 plant communities in East Tennessee. The values reported here generally bracket McGuinness' data, especially for L and F layers (Table 10). However, marked differences are apparent between H layers, and four separate interpretations are possible: (1) increase due to leaf litter, (2) increase due to chestnut logs, (3) inclusion of upper A horizon, and (4) lack of forest cover correspondence. The first interpretation seems very likely in pine forest where litter decay rates are slow. As a conservative estimate, 02 layers in pine forests have approximately doubled in the last 20 yr at 900 m. Assuming an input of 400 g m^{-2} yr^{-1}, these stands have accumulated on an average of 100 g m^{-2} yr^{-1} over the last 20 yr. On the other hand, humus in mesic forests have also increased in spite of rapid decay. The primary cause of humus departures in mesic forests might be rotting chestnut logs. After 50 yr of decay, chestnut wood debris is now causing a twofold to fivefold increase in 02 pools. However, humus-A horizon boundaries are often difficult to establish in the field, especially in mesic forests. Including

Table 10. Biomass comparisons of selected Southern Appalachian forest stands.

FOREST COVER	LAYER	1958*	1975**	1977***
Pine at 840 m	L	762		952-1189
	F	425		816-1663
	H	1749		2617-4585
Oak-pine at 300 m	L	874		477-1120
	F	706		601-746
	H	0		0[†]
Virginia pine at 240 m	L	1121	1090	734-1189
	F	1132	02 1570	638-1177
	H	0		0[†]
Mixed oak hardwood	L	538	870	310-715
	F	448	02 1810	48-842
	H	0		518-2979
Cove hardwood	L	515	660	599
	F	695	750	56
Chestnut oak	L	941	700	480-598
	F	919	1840	413-1006
	H	0		473-3315
Mixed oak	L	751		612-972
	F	841		298-532
	H	0		664-919

* McGinness 1958

** Harris et al. 1975

*** Present study

[†] Adjusted for elevation using regression

some of the A horizon would appear to increase H biomass when no increase actually has occurred. When adjusted for ash contents, the 1977 H values still confirm an increase in total 02 biomass. Finally, discrepancies occur between the studies because forest covers do not match. For example, McGuinness' hemlock-hardwood 02 biomass matches the hemlock cove examined in this study, although the former's vegetation description matches the rhododendron cove presented in Appendix A. Harris et al. (1973) also indicate more biomass in 02 than McGuinness, supporting the notion of an actual increase after 20 yr.

The skewed distribution of wood biomass encloses the values presented by Harris et al. (1973). Assuming the differences in sampling methodologies are not large, the data here indicate Harris et al.'s results lie slightly above the mean for small wood and near the mean of the boles (Figs. 8 and 9). In the case of downed wood, the mode may represent a central tendency better than the mean. Use of the mode as a central tendency would reduce regional downed wood biomass from 2,140 to 618 g m^{-2}.

Trends of 02 accumulations with elevation were only statistically significant for pine forests. The regression predicts no H below 400 m, although H is deep under mature unburned coastal plain pine forests(Metz 1954). This indicates that below a given elevation, H biomass may remain constant for forests in "steady state". More data at both higher and lower elevations will be needed to validate the regression results presented here. Care must be taken to match these stands closely in terms of fire history and aspect. It would also be interesting to expand the hardwood data set to confirm the "no increase with elevation" hypothesis.

Transfers. Litter production values estimated by leaf separation compares favorably with estimates from litter traps. Harris et al. (1973) report annual nonwood litter fall ranging between 340 and 410 g m^{-2}, with no significant differences between forest covers. Cromack and Monk (1975) found nonwood litter fall between 320 and 330 g m^{-2} in the North Carolina mountains. Although within the expected range, the values reported here are probably somewhat low, and direct comparison of separation, trap, and allometric methods is desirable. Little difference was found here in litter production between forest covers, elevation, aspect, and topography. Ebermayer's classic study (1876), cited in Bray and Gorham (1964) indicates differences in production can be expected if sampling points along the independent variables are wide enough apart.

Fires increase the transfer rates of live to dead wood considerably. Harris et al. (1973) estimated an average bole and branch mortality of 1,280 g m^{-2} yr^{-1} at Oak Ridge, Tennessee. If a cool ground fire burned through these stands, one could expect 5 to 10% basal area mortality. Assuming a branch-bole biomass of 125,000 g m^{-2} (within range reported by Harris et al.), fire would instantaneously transfer 6,250 to 12,500 g m^{-2} of live wood to the standing dead compartment. Of course, severe but rare fires will transfer even more material.

Figure 11. Hypothetical changes in biomass pools after two types of disturbance in low elevation pine forest. The changes of biomass as a function of time presented here should be considered hypotheses to be tested in future studies.

(A) After a fire which killed 90 percent of the live above-ground biomass.

Decay is the most important loss of the standing dead wood compartment for the first 2 years, and by year 3 the majority of standing dead is transferred to the dead and down wood compartment. 01 and 02 initially lose material by fire consumption and then gradually shrink years 1 to 5, since litter production is reduced. After year 5, restored litter production and fragments of decayed dead and down wood increase the 01 and 02 compartment and cause an increase over expected steady state values.

(B) After attack by southern pine beetle, where 60 percent of the live biomass was killed.

The general patterns of standing dead and downed wood are similar to fire situation. However, the fragmentation of rotten wood, bark, etc., adds to the 01 and 02 compartment and leads to a 150 to 200 percent increase by years 20 to 40. Although 60 percent of the live above-ground biomass is killed, the release of advanced woody reproduction and surviving canopy trees probably leads to a minor decrease in litter production compared to the severe fire situation.

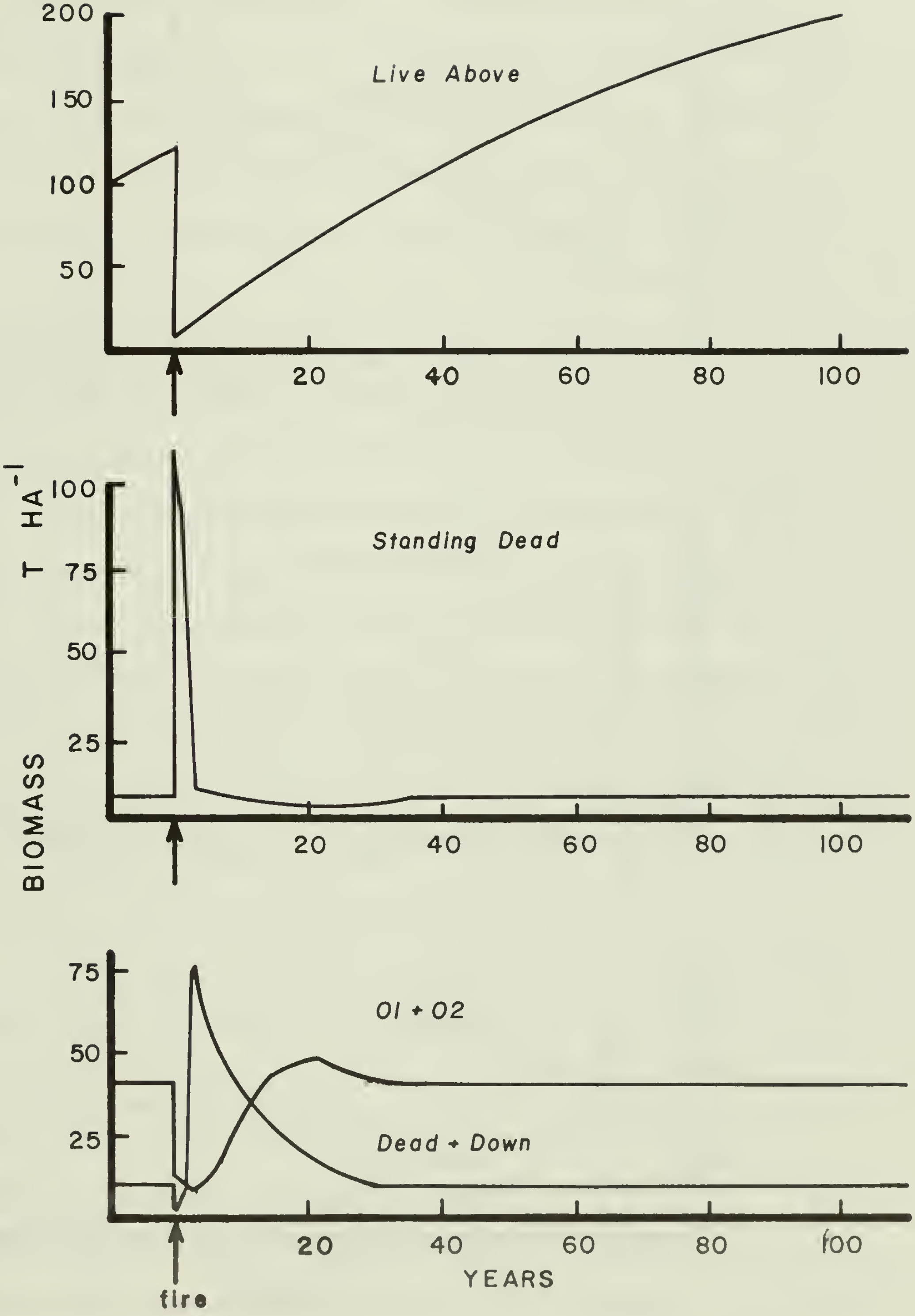


Figure 11A. After a fire which killed 90 percent of the live aboveground biomass. (Hypothetical)

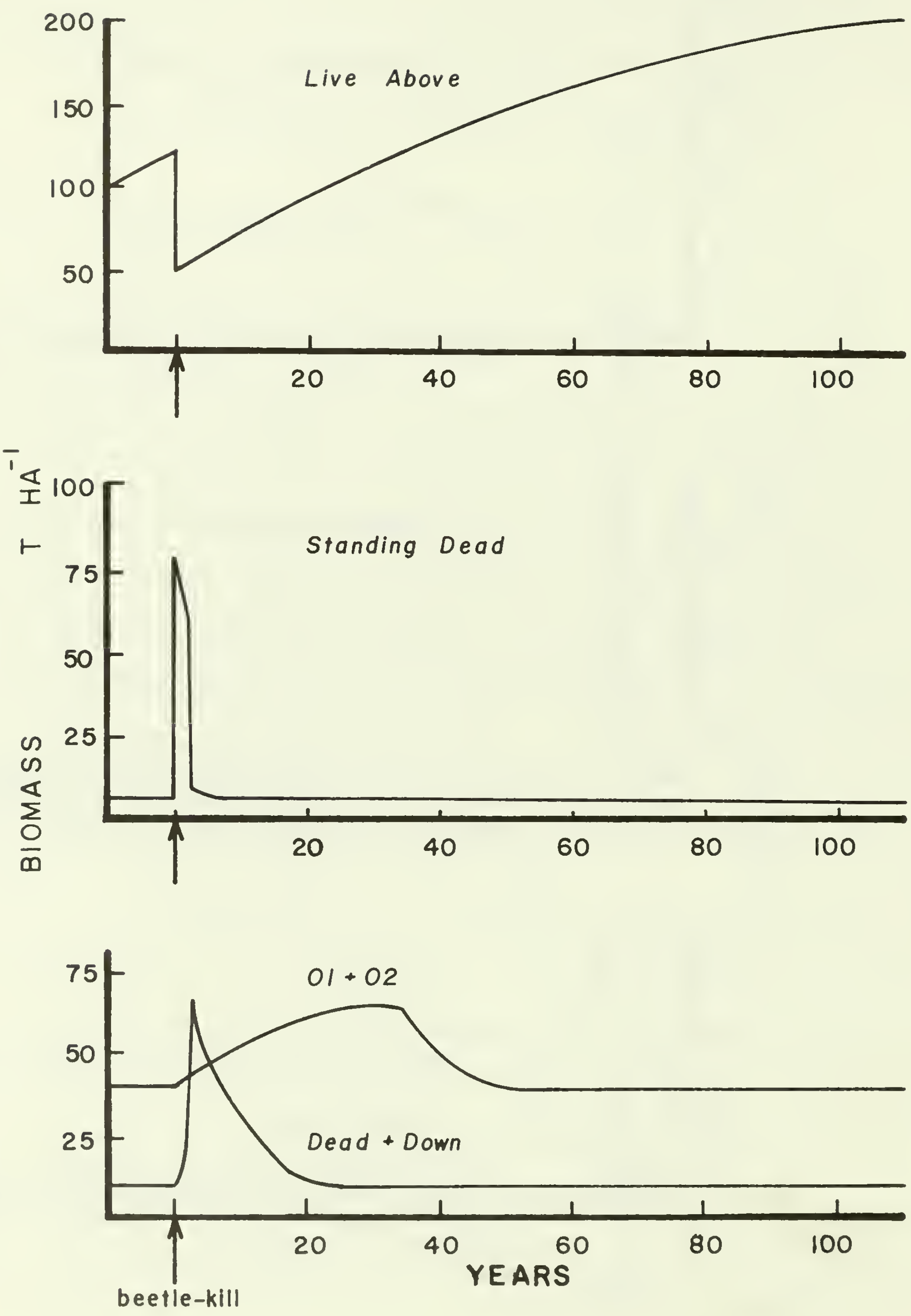


Figure 11B. After attack by southern pine beetle, where 60 percent of the live biomass was killed. (Hypothetical)

Considerable work remains in understanding the turnover of standing dead and downed wood. The relationships between biomass accumulations and functional differences are not as clear as in 01 and 02. Both wood production and decay must be examined if wood accumulation patterns are to be interpreted. In terms of fuel accumulations, it is important to know how long certain disturbances (e.g., balsam woolly aphid) will increase fuels above undisturbed levels (Fig. 11). After a hypothetical disturbance, a large proportion of live wood biomass is transferred to standing dead. With time, standing dead wood decreases after microbial respiration and losses to downed wood. Downed wood biomass is also lost via respiration, and some is transformed into 02. Each compartment (live, standing dead, and downed) reaches a high point different times after the disturbance. Although the qualitative behavior of severely disturbed stands is presently known, more data concerning decay and transfer rates must be gathered before a reasonable, quantitative explanation is available.

The wood decay rates presented here are preliminary and may overestimate decay rates. Standing dead wood decayed at an average rate of 20% dry wt yr^{-1} in an English oak woodland (Swift et al. 1976). Once on the forest floor, decay increased to an average of 25% dry wt yr^{-1}, which is very similar to the findings presented here. At Hubbard Brook, Gosz et al. (1973) found decay rates ranged between 12 and 33% dry wt yr^{-1} for wood < 5 mm diameter. In the low elevation Southern Appalachians, wood might decay at much higher rates than in New Hampshire, and yet high elevation decay rates might be similar.

Shanks and Olson (1961) found that hardwood litter decay rates decreased at a rate of 2.45% per 300 m elevation gained. No significant increase in hardwood litter biomass was noted with elevation (Fig. 11) in the present study. The high variance of both inputs and standing crops probably mask all but the most obvious elevation effects. The rapid increase of pine forest organic horizons with increasing elevation indicates an interactive effect between substrate and climate.

Fires can play an important role in total ecosystem "respiration" by short-circuiting usual decay pathways. Most fires in the Great Smoky Mountains remove 90% of the 01 and various amounts of 02, depending on forest cover, season, and severity.

Environmental Factors and Forest Fuels

Dead organic matter components (wood, 01, and 02) all respond to different sets of environmental factors (Table 11). The interaction of independent and dependent variables leads to an overall pattern which is difficult to interpret clearly.

Litter production exhibits the majority of variation along the time axis, although minor differences might be expected between forest covers, aspect, elevation, and topography. Accumulations of 01 are controlled by both time and forest cover. In 01, both production and decomposition are important factors. When litter reaches the 02 stage, production is of less consequence, whereas time since fire and decomposition factors such as forest cover (substrate), moisture (aspect), and elevation (temperature and moisture) become important. In controlling 02 accumulations, environmental factors are interactive, leading to two divergent patterns for hardwoods and pines.

Wood distribution indicates little about functional differences. One must appreciate the heterogeneous distribution of wood and attack the problem by quantifying production, disturbance, and decay. Wood decay itself is a complex process, and on any one site, microclimate, fauna, microflora, and substrate are important factors. Between sites, substrate, temperature, and overall moisture balance are probably most important. Inputs to forest floors tend to dominate wood distribution, and more emphasis should be placed on examining the role of fire, windthrow, disease, insects, and succession in causing dead wood biomass to increase above expected levels.

EFFECTS OF FIRE SUPPRESSION

Effective fire suppression since 1940 has reduced total ecosystem "respiration" by decreasing both fire consumption and mortality. The reduction in ecosystem respiration has probably, in turn, reduced the turnover time of many nutrient cycles and increased the portion of nutrients bound in organic horizons and dead wood. In low elevation forest where litter decay is rapid

($0.25 < k$), further litter will not increase with continued fire suppression (Fig. 12). In some communities, such as pine, pine-oak, and chestnut oak, litter may continue to increase for approximately 10 yr, depending when the last fire occurred. Dramatic increases in litter can be expected to continue for high elevation pine forests 70 to 100 yr after a fire event (Fig. 12). Frequent ground fires would reduce litter accumulations for all forest covers but would have the most dramatic effect in pine, pine-oak, and chestnut oak forests (Fig. 12). Assuming each fire event removed the same proportion of litter, a frequency of once every 20 yr would reduce the litter maximum to 85% of the present levels. A doubling of frequency to every 10 yr would reduce the litter maximum to 60% of the present levels. Fire-caused tree mortality would tend to make forest accumulate debris at a faster rate than depicted in Figure 12, although very frequent ground fires might even reduce stand mortality.

As fuels accumulate, their character as well as quantity changes. As shown above, frequently burned stands may have little humus. After fire suppression, 02 accumulates. Since 02 has closer packing, higher mineral content, and delayed moisture response, it is less apt to burn than 01 (Table 9). As a result, stands with long-term fire suppression may burn less efficiently than their earlier counterparts. This potential change in fuel character may tend to aggravate the shifts in community composition which accompany fire exclusion. For example, pine seeds germinate

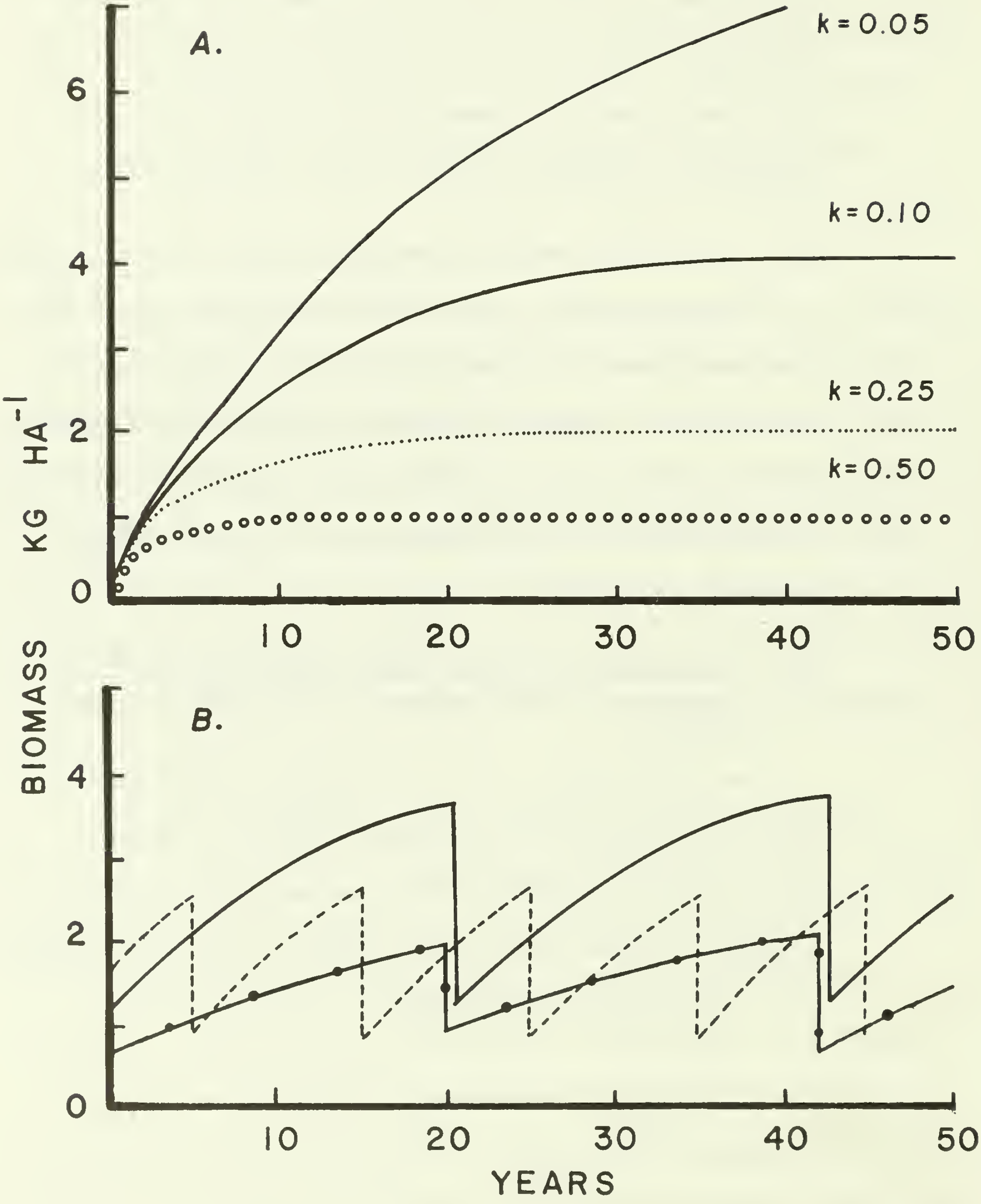
Figure 12. Accumulation of 01 and 02 layers for hypothetical communities in which litter was removed by ground fire. Fire was assumed to kill a negligible portion of the live tree biomass and each community has a litter input of 400 grams per square meter per year of organic matter.

(A) After fire removes 100 percent of the 01 and 02 layers.

When k is small, the community approaches the steady state condition at a slower rate and has a higher final accumulation. A value of k = 0.05 typifies high elevation pine forests; k = 0.10 typifies a low elevation pine forest; k = 0.25 typifies an oak forest; and k = 0.50 typifies a deciduous cove forest.

(B) Accumulation of organic matter under varying fire frequencies with 70 percent of the litter removed by each fire.

The solid line (———) represents a low elevation pine forest burned every 20 years, whereas the dashed (------) line represents a similar forest burned every 10 years. For comparison, an oak forest burned every 20 years is indicated by a solid line with large dots (—●——●—).


A.
k = 0.05
k = 0.10
k = 0.25
k = 0.50
0
2
4
6
10
20
30
40
50
B.
0
2
4
10
20
30
40
50
BIOMASS KG HA^{-1}
YEARS

best on mineral soil. If enough 02 is left after fire, then species other than pine might be favored. A shift in plant composition might also alter the quantity and quality of forest fuels. Oaks tend to invade most pine stands; yet oak litter decays faster and burns less efficiently than pine litter.

The absence of fire in pine, pine-oak, and chestnut oak communities may increase mortality after each fire. This is especially true for high elevations where continued accumlation is expected. However, most forests are probably approaching or are at "steady state" levels, and little 01 or 02 increase is expected. Present fire behavior patterns can therefore be expected to also continue. Weather is generally not extreme enough in the Southern Appalachians to cause extensive crown fires. Fires generally stay on the ground, with hotspots occurring on ridgetops or over wood "jackpots". Fire severity might be described as a function of weather, topography, and the time and severity of the last canopy disturbance. By monitoring disturbances such as beetle kills, one should be able to predict and partially control impact of fire on plant communities.

MANAGEMENT SUMMARY

(1) The distribution of forest fuels is complex and more work is required to develop predictive models for management use. This is especially true on a parkwide basis. The major problem at this point is predicting downed wood volumes.

(2) Data indicate chestnut oak, mixed oak, mixed oak-hardwood, deciduous cove, and hemlock cove forests will not accumulate more fuel unless disturbed. Yellow pine forests below 800 m (2,500 feet) will also not accumulate more fuel until attacked by southern pine beetle. Pine forest above 800 m (2,500 feet) may continue to accumulate fuel unless burned. Fire behavior in high elevation pine forest will thus continue to increase in severity.

(3) Constant burning by settlers and perhaps Indians reduced forest fuels to approximately 60% of the present levels. The most significant change has probably occurred in the yellow pine and chestnut oak forests.

(4) Fuel loadings can be expected to increase greatly after canopy disturbance. Soutern pine beetle, windthrow, fire, and chestnut blight have all been observed to increase downed wood loadings. These increases have been observed to cause erratic and sometimes severe fire behavior. More data are needed to determine the location, extent, and dynamics of

disturbance effects on fuels.

(5) Fuel reduction appears correlated to moisture content. If fuel reduction burns are attempted, moisture contents will have to be low to cause major decreases. Exposure of mineral soil will favor yellow pine establishment, while deep humus favors hardwoods. Fuel reduction burns may therefore influence forest composition. More data are required to assess the exact impact of moisture content on fuel removal.

(6) Data indicates forest type causes major differences in fuel levels, and that a vegetation map may adequately predict fuel loadings. Elevation strongly influences fuel loadings in yellow pine forests but does not appear to influence hardwood fuels. Elevation adjustments are therefore necessary to predict yellow pine loadings. In a parkwide fuel survey, the effects of forest type, elevation, aspect, and years since burn should be assessed.

ACKNOWLEDGEMENTS

This study was funded by Uplands Field Research Laboratory, National Park Service, Department of the Interior, and was written as a final project of a special problem in Ecology while author was a student at the University of Tennessee, Knoxville. Many thanks to all the people who helped in the many facets of this project. Special thanks go to Dr. Susan P. Bratton and Dr. Jerry S. Olson, who gave encouragement throughout, and to Linda Stromberg, Juliet Covell, David Silsbee, and Debby Ostronski, who helped with the many weeks of field work.

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APPENDIX A: VEGETATION TYPE EXAMPLES

TABLE 11 - YELLOW PINE

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               CANOPY COMPOSITION BY DOMINANCE

PROJECT TITLE:  CADES COVE-CALDERWOOD FIRE STUDY
SECTION:  1   PLOT:  24

TOTAL BASAL AREA = 27.256 SQ M/HA,  TOTAL STEMS = 328
CONIFERS =  76.080% OF TOTAL BASAL AREA    201 STEMS
ANGIOSPERMS =  23.920% OF TOTAL BASAL AREA    127 STEMS
EVERGREENS =  76.080% OF TOTAL BASAL AREA    201 STEMS

MAJOR CANOPY TYPES         % BASAL AREA   NUMBER STEMS
YELLOW PINES                  76.080          201
OAK-HICKORY-CHESTNUT           8.244           34
MIXED HARDWOODS               15.676           93


LIVE TREES:                    |  BASAL AREA     |  IMP  |  STEMS   |
                               | M/HA      %     |  VAL  | NO     % |
 1 PINUS PUNGENS               10.458   38.368     34.73  102  31.1
 2 PINUS RIGIDA                 7.371   27.044     18.55   33  10.1
 3 NYSSA SYLVATICA              3.651   13.394     16.30   63  19.2
 4 PINUS VIRGINIANA             2.908   10.668     15.39   66  20.1
 5 QUERCUS VELUTINA             1.382    5.069      6.50   26   7.9
 6 QUERCUS COCCINEA             0.805    2.954      1.93    3   0.9
 7 OXYDENDRUM ARBOREUM          0.416    1.527      1.53    5   1.5
 8 ACER RUBRUM                  0.166    0.608      1.07    5   1.5
 9 CASTANEA DENTATA             0.060    0.222      0.87    5   1.5
10 SASSAFRAS ALBIDUM            0.035    0.130      2.20   14   4.3
11 ILEX MONTANA                 0.005    0.017      0.92    6   1.8

DEAD TREES:

 1 PINUS PUNGENS                3.479  100.000    100.00   13 100.0
```

TABLE 12 - PINE-OAK

CANOP~~Y COMPOSITION BY~~ DOMINANCE

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PROJECT TITLE:  CADES COVE-CALDERWOOD FIRE STUDY
SECTION:  1   PLOT:  23

TOTAL BASAL AREA = 23.491 SQ M/HA,  TOTAL STEMS = 267
CONIFERS =  45.731% OF TOTAL BASAL AREA     46 STEMS
ANGIOSPERMS =  54.269% OF TOTAL BASAL AREA    221 STEMS
EVERGREENS =  45.731% OF TOTAL BASAL AREA     46 STEMS

MAJOR CANOPY TYPES          % BASAL AREA   NUMBER STEMS
WHITE PINE                      0.966           1
YELLOW PINES                   44.764          45
OAK-HICKORY-CHESTNUT           44.226          79
MIXED HARDWOODS                10.040         141
DECIDUOUS HEATH                 0.003           1


LIVE TREES:                      |  BASAL AREA    |  IMP  |  STEMS  |
                                 | M/HA      %    |  VAL  | NO    % |
 1 QUERCUS COCCINEA                7.364  31.347   19.42   20   7.5
 2 PINUS RIGIDA                    6.968  29.662   17.83   16   6.0
 3 PINUS PUNGENS                   2.942  12.524    9.26   16   6.0
 4 QUERCUS VELUTINA                2.073   8.823    9.28   26   9.7
 5 NYSSA SYLVATICA                 2.028   8.633   27.35  123  46.1
 6 QUERCUS PRINUS                  0.918   3.908    6.45   24   9.0
 7 PINUS VIRGINIANA                0.606   2.578    3.72   13   4.9
 8 ACER RUBRUM                     0.298   1.270    1.57    5   1.9
 9 PINUS STROBUS                   0.227   0.966    0.67    1   0.4
10 CARYA TOMENTOSA                 0.016   0.067    0.41    2   0.7
11 SASSAFRAS ALBIDUM               0.013   0.053    0.96    5   1.9
12 AMELANCHIER LAEVIS              0.010   0.043    0.40    2   0.7
13 CARYA GLABRA                    0.009   0.040    0.58    3   1.1
14 ILEX MONTANA                    0.009   0.040    1.14    6   2.2
15 CASTANEA DENTATA                0.009   0.040    0.77    4   1.5
16 VACCINIUM STAMINEUM             0.001   0.003    0.19    1   0.4

DEAD TREES:

 1 PINUS RIGIDA                    3.032  95.168   87.58    4  80.0
 2 PINUS PUNGENS                   0.154   4.832   12.42    1  20.0
```

TABLE 13. CHESTNUT OAK

CANOPY COMPOSITION BY DOMINANCE

PROJECT TITLE: CADES COVE-CALDERWOOD FIRE STUDY
SECTION: 1 PLOT: 6

TOTAL BASAL AREA = 28.614 SQ m/HA. TOTAL STEMS = 273
CONIFERS = 9.634% OF TOTAL BASAL AREA 45 STEMS
ANGIOSPERMS = 90.366% OF TOTAL BASAL AREA 228 STEMS
EVERGREENS = 9.634% OF TOTAL BASAL AREA 45 STEMS

MAJOR CANOPY TYPES	% BASAL AREA	NUMBER STEMS
HEMLOCK	0.036	2
WHITE PINE	3.921	28
YELLOW PINES	5.668	15
OAK-HICKORY-CHESTNUT	77.647	74
MIXED HARDWOODS	12.719	154

LIVE TREES:		BASAL AREA		IMP	STEMS	
		M/HA	%	VAL	NO	%
1	QUERCUS PRINUS	10.916	38.150	24.75	31	11.4
2	QUERCUS COCCINEA	8.914	31.153	18.69	17	6.2
3	ACER RUBRUM	2.237	7.817	21.31	95	34.8
4	QUERCUS VELUTINA	1.676	5.857	4.58	9	3.3
5	PINUS STROBUS	1.125	3.931	7.09	28	10.3
6	PINUS VIRGINIANA	0.948	3.313	2.76	6	2.2
7	OXYDENDRUM ARBOREUM	1.873	3.149	5.00	19	7.0
8	PINUS RIGIDA	0.674	2.355	2.83	9	3.3
9	QUERCUS ALBA	0.558	1.949	3.90	16	5.9
10	NYSSA SYLVATICA	0.514	1.795	7.67	37	13.6
11	CARYA GLABRA	0.154	0.538	0.45	1	0.4
12	CORNUS FLORIDA	0.016	0.058	0.58	3	1.1
13	TSUGA CANADENSIS	0.010	0.036	0.38	2	0.7

DEAD TREES

NO STEMS

TABLE 14. MIXED OAK

PROJECT TITLE: CADES COVE-CALDERWOOD FIRE STUDY
SECTION: 1 PLOT: 8

TOTAL BASAL AREA = 24.132 SQ M/HA, TOTAL STEMS = 299
CONIFERS = 9.289% OF TOTAL BASAL AREA 128 STEMS
ANGIOSPERMS = 90.711% OF TOTAL BASAL AREA 171 STEMS
EVERGREENS = 10.268% OF TOTAL BASAL AREA 139 STEMS

MAJOR CANOPY TYPES	% BASAL AREA	NUMBER STEMS
HEMLOCK	8.208	120
WHITE PINE	1.081	8
OAK-HICKORY-CHESTNUT	65.482	58
MIXED HARDWOODS	24.237	101
EVERGREEN HEATH	0.980	11
WOODY VINES	0.013	1

LIVE TREES:		BASAL AREA		IMP	STEMS	
		M/HA	%	VAL	NO	%
1	QUERCUS ALBA	4.134	17.132	11.24	16	5.4
2	CARYA TOMENTOSA	3.930	16.286	9.82	10	3.3
3	ACER RUBRUM	2.767	11.466	13.59	47	15.7
4	QUERCUS PRINUS	2.259	9.360	7.02	14	4.7
5	TSUGA CANADENSIS	1.981	8.208	24.17	120	40.1
6	QUERCUS RUBRA	1.889	7.827	4.58	4	1.3
7	QUERCUS COCCINEA	1.707	7.075	4.04	3	1.0
8	ROBINIA PSEUCO-ACACIA	1.007	4.172	2.42	2	0.7
9	QUERCUS VELUTINA	0.862	3.570	2.29	3	1.0
10	LIRIODENDRON TULIPIFERA	0.828	3.430	2.22	3	1.0
11	CORNUS FLORIDA	0.710	2.942	6.15	28	9.4
12	CARYA GLABRA	0.675	2.796	2.57	7	2.3
13	CARYA OVATA	0.346	1.435	0.88	1	0.3
14	PINUS STROBUS	0.261	1.081	1.88	8	2.7
15	RHODODENDRON MAXIMUM	0.236	0.580	2.33	11	3.7
16	NYSSA SYLVATICA	0.174	0.723	1.87	9	3.0
17	OXYDENDRUM ARBOREUM	0.148	0.615	0.98	4	1.3
18	ACER PENSYLVANICUM	0.103	0.426	0.71	3	1.0
19	BETULA LENTA	0.079	0.325	0.33	1	0.3
20	AMELANCHIER LAEVIS	0.020	0.081	0.38	2	0.7
21	FAGUS GRANDIFOLIA	0.013	0.052	0.19	1	0.3
22	VITIS AESTIVALIS	0.003	0.013	0.17	1	0.3
23	SASSAFRAS ALBIDUM	0.001	0.003	0.17	1	0.3

DEAD TREES:

NO STEMS

15. MIXED OAK-HARDWOOD

CANOPY COMPOSITION BY DOMINANCE

PROJECT TITLE: CADES COVE-CALDERWOOD FIRE STUDY
SECTION: 1 PLOT: 29

TOTAL BASAL AREA = 19.025 SQ M/HA, TOTAL STEMS = 175
CONIFERS = 0.099% OF TOTAL BASAL AREA 3 STEMS
ANGIOSPERMS = 99.901% OF TOTAL BASAL AREA 172 STEMS
EVERGREENS = 0.099% OF TOTAL BASAL AREA 3 STEMS

MAJOR CANOPY TYPES	% BASAL AREA	NUMBER STEMS
HEMLOCK	0.017	1
WHITE PINE	0.083	2
OAK-HICKORY-CHESTNUT	37.034	41
MIXED HARDWOODS	62.529	120
WOODY VINES	0.339	11

LIVE TREES:	BASAL AREA M/HA	BASAL AREA %	IMP VAL	STEMS NO	STEMS %
1 ROBINIA PSEUDO-ACACIA	5.326	27.993	16.85	10	5.7
2 ACER RUBRUM	3.863	20.302	20.72	37	21.1
3 QUERCUS RUBRA	3.775	19.844	13.35	12	6.9
4 CARYA GLABRA	1.765	9.276	10.64	21	12.0
5 LIRIODENDRON TULIPIFERA	1.195	6.279	5.43	8	4.6
6 CARYA TOMENTOSA	1.063	5.589	4.22	5	2.9
7 CORNUS FLORIDA	0.603	3.170	14.73	46	26.3
8 MAGNOLIA FRASERI	0.449	2.361	2.32	4	2.3
9 QUERCUS PRINUS	0.347	1.825	1.48	2	1.1
10 HALESIA CAROLINA	0.243	1.280	4.35	13	7.4
11 SASSAFRAS ALBIDUM	0.218	1.143	1.14	2	1.1
12 CARYA OVATA	0.095	0.500	0.54	1	0.6
13 VITIS AESTIVALIS	0.064	0.339	3.31	11	6.3
14 PINUS STROBUS	0.016	0.083	0.61	2	1.1
15 TSUGA CANADENSIS	0.003	0.017	0.29	1	0.6

DEAD TREES:					
1 ROBINIA PSEUDO-ACACIA	0.309	73.234	69.95	2	66.7
2 QUERCUS RUBRA	0.113	26.766	30.05	1	33.3

TABLE 16. DECIDUOUS COVE

CANOPY COMPOSITION BY DOMINANCE

PROJECT TITLE: CADES COVE-CALDERWOOD FIRE STUDY
SECTION: 1 PLOT: 11

TOTAL BASAL AREA = 22.705 SQ M/HA. TOTAL STEMS = 111
ANGIOSPERMS = 100.000% OF TOTAL BASAL AREA 111 STEMS
EVERGREENS = 0.000% OF TOTAL BASAL AREA 0 STEMS

MAJOR CANOPY TYPES	% BASAL AREA	NUMBER STEMS
OAK-HICKORY-CHESTNUT	14.279	17
MIXED HARDWOODS	85.548	92
WOODY VINES	0.173	2

LIVE TREES:		BASAL AREA		IMP	STEMS	
		M/HA	%	VAL	NO	%
1	HALESIA CAROLINA	9.124	40.185	31.35	25	22.5
2	FRAXINUS PENNSYLVANICA	5.579	24.570	28.50	36	32.4
3	TILIA HETEROPHYLLA	3.991	17.579	18.25	21	18.9
4	CARYA CORDIFORMIS	1.994	8.783	7.99	8	7.2
5	CARYA TOMENTOSA	1.173	5.168	3.94	3	2.7
6	AESCULUS OCTANDRA	0.730	3.214	6.11	10	9.0
7	CARYA GLABRA	0.075	0.329	2.87	6	5.4
8	VITIS BAILEYANA	0.039	0.173	0.99	2	1.8

DEAD TREES:

NO STEMS

TABLE 17. HEMLOCK COVE

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                CANOPY COMPOSITION BY DOMINANCE

PROJECT TITLE:  CADES COVE-CALDERWOOD FIRE STUDY
SECTION:  1    PLOT:  21

TOTAL BASAL AREA = 55.854 SQ M/HA,  TOTAL STEMS = 120
CONIFERS =  54.716% OF TOTAL BASAL AREA      20 STEMS
ANGIOSPERMS =  45.284% OF TOTAL BASAL AREA     100 STEMS
EVERGREENS =  54.730% OF TOTAL BASAL AREA     22 STEMS

MAJOR CANOPY TYPES          % BASAL AREA   NUMBER STEMS
HEMLOCK                         54.716             20
OAK-HICKORY-CHESTNUT             0.013              1
MIXED HARDWOODS                 45.272             99


LIVE TREES:                           |  BASAL AREA      |  IMP  |  STEMS  |
                                      | M/HA       %     |  VAL  | NO    % |
  1 TSUGA CANADENSIS                   30.561   54.716    35.69   20   16.7
  2 LIRIODENDRON TULIPIFERA            23.333   41.776    21.72    2    1.7
  3 HALESIA CAROLINA                    1.384    2.478    30.41   70   58.3
  4 BETULA LENTA                        0.503    0.901     2.95    6    5.0
  5 AESCULUS OCTANDRA                   0.013    0.022     0.43    1    0.8
  6 CORNUS FLORIDA                      0.011    0.020     1.26    3    2.5
  7 ACER PENSYLVANICUM                  0.010    0.018     0.84    2    1.7
  8 OXYDENDRUM ARBOREUM                 0.010    0.018     0.84    2    1.7
  9 LINDERA BENZOIN                     0.010    0.018     4.18   10    8.3
 10 ILEX OPACA                          0.008    0.014     0.84    2    1.7
 11 CARYA TOMENTOSA                     0.007    0.013     0.42    1    0.8
 12 ACER RUBRUM                         0.003    0.006     0.42    1    0.8

DEAD TREES:

   NO STEMS
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TABLE 18. RHODODENDRON COVE

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                CANOPY CCMPOSITION BY DOMINANCE

PROJECT TITLE:  CADES COVE-CALDERWOOD FIRE STUDY
SECTION:  1   PLOT:  30

TOTAL BASAL AREA = 48.393 SQ M/HA,  TOTAL STEMS = 396
CONIFERS =  55.182% OF TOTAL BASAL APEA     46 STEMS
ANGIOSPERMS =  44.818% CF TOTAL BASAL AREA    350 STEMS
EVERGREENS =  68.391% CF TOTAL BASAL AREA    332 STEMS

MAJOR CANOPY TYPES          % BASAL AREA   NUMBER STEMS
HEMLOCK                        54.634          44
WHITE PINE                      0.549           2
OAK-HICKORY-CHESTNUT            0.885           2
MIXED HARDWCODS                34.011          62
DECIDUOUS HEATH                 0.146          13
EVERGREEN HEATH                 9.777         273


LIVE TREES:                        |  BASAL AREA     |  IMP  |  STEMS    |
                                   | M/HA      %     |  VAL  | NO     %  |
 1 TSUGA CANADENSIS                 26.439   54.634    32.87    44   11.1
 2 LIRIODENDRON TULIPIFERA           6.308   13.036     7.15     5    1.3
 3 BETULA LENTA                      5.694   11.766     7.15    10    2.5
 4 RHODODENDRON MAXIMUM              4.730    9.773    39.10   271   68.4
 5 ACER RUBRUM                       1.771    3.660     2.46     5    1.3
 6 ILEX OPACA                        1.661    3.433     3.36    13    3.3
 7 QUERCUS RUBRA                     0.428    0.885     0.69     2    0.5
 8 CORNUS FLORIDA                    0.335    0.693     1.61    10    2.5
 9 PINUS STROBUS                     0.265    0.549     0.53     2    0.5
10 ACER PENSYLVANICUM                0.237    0.490     0.62     3    0.8
11 HAMAMELIS VIRGINIANA              0.186    0.385     1.33     9    2.3
12 NYSSA SYLVATICA                   0.154    0.318     0.29     1    0.3
13 OXYDENDRUM ARBOREUM               0.086    0.177     0.34     2    0.5
14 CLETHRA ACUMINATA                 0.071    0.146     1.71    13    3.3
15 AMELANCHIER LAEVIS                0.016    0.032     0.27     2    0.5
16 MAGNOLIA FRASERI                  0.010    0.021     0.26     2    0.5
17 LEUCOTHOE FONTANESIANA            0.002    0.003     0.25     2    0.5

DEAD TREES:

 1 ILEX OPACA                        0.177  100.000   100.0      1  100.0
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APPENDIX B. FOREST FLOOR ORGANIC MATTER SUMMARIES FOR 24 UNBURNED STANDS

TABLE 19. Forest floor weight (grams meter^{-2}) of organic matter in low elevation pine forests of the Great Smoky Mountains National Park

	SITE			
Plot Number	27	35	36	9
Elevation (m)	540	594	594	600
Topography	Open slope	Open slope	Open slope	Open slope
Aspect	130	142	182	160
Basal Area (m^2 ha^{-1})	25.3	15.0	22.7	27.3
Density (# ha^{-1})	3200	7550	5700	3000
	LEAFY LITTER			
Litter	989	808	734	910
Fermentation	937	799	522	638
Humus	943	365	1059	2108
	WOODY LITTER			
Twigs	78	47	54	36
Small Branch	84	50	82	119
Large Branch	110	181	121	252
Boles	186	1104	4379	672
Buried Wood	332	122	75	306
TOTAL BIOMASS	3659	3476	7026	5041

TABLE 20. Forest floor weight (grams meter^{-2}) of organic matter in high elevation pine forests of the Great Smoky Mountains National Park.

	SITE			
Plot Number	44	26	24	14
Elevation (m)	608	763	732	930
Topography	Open slope	Open slope	Open slope	Open slope
Aspect	230	97	230	165
Basal Area (m^2 ha^{-1})	26.1	31.8	27.3	29.4
Density (# ha^{-1})	3030	6820	3280	3700
	LEAFY LITTER			
Litter	482	1189	992	952
Fermentation	1177	816	1177	1663
Humus	2448	2617	3216	4585
	WOODY LITTER			
Twigs	79	82	59	74
Small Branch	180	48	91	75
Large Branch	69	158	237	373
Buried Wood	ns	165	217	146
Bole	561	847	761	310
TOTAL BIOMASS	4996	5922	6750	8178

Table 21. Forest floor weight (grams meter^{-2}) of organic matter in low elevation pine-oak forests of the Great Smoky Mountains National Park.

	SITE	
Plot Number	45	23
Elevation (m)	632	732
Topography	Ridge	Open slope
Aspect	190	294
Basal Area (m^2 ha^{-1})	25.8	23.5
Density (# ha^{-1})	3100	2670
	LEAFY LITTER	
Litter	477	1120
Fermentation	746	601
Humus	3166	3828
	WOODY LITTER	
Twigs	40	56
Small Branch	109	39
Large Branch	179	140
Bole	1869	440
Buried Wood	248	157
TOTAL BIOMASS	6834	6381

TABLE 22. Forest floor weight (grams meter^{-2}) of organic matter in low elevation chestnut oak forests of the Great Smoky Mountains National Park.

		SITE		
Plot Number	6	46	15	13
Elevation (m)	613	620	902	939
Topography	Ridge	Open slope	Open slope	Ridge
Aspect	255	350	104	100
Basal Area (m^2 ha^{-1})	28.6	22.0	28.9	27.9
Density (# ha^{-1})	2730	2820	2150	1930
		LEAFY LITTER		
Litter	598	559	480	504
Fermentation	422	1006	472	413
Humus	1632	3315	713	473
		WOODY LITTER		
Twigs	29	76	50	26
Small Branch	34	113	61	53
Large Branch	143	260	198	145
Bole	424	400	1211	1419
Buried Wood	151	62	365	184
TOTAL BIOMASS	3433	5791	3550	3217

TABLE 23. Forest floor weight (grams meter^{-2}) of organic matter in low elevation mixed oak forests of the Great Smoky Mountains National Park.

	SITE	
Plot Number	17	12
Elevation (m)	725	914
Topography	Open slope	Open slope
Aspect	325	310
Basal Area (m^2 ha^{-1})	25.7	33.4
Density (# ha^{-1})	1600	1430
	LEAFY LITTER	
Litter	972	612
Fermentation	532	298
Humus	664	919
	WOODY LITTER	
Twigs	25	49
Small Branch	33	89
Large Branch	162	375
Bole	633	2322
Buried Wood	269	234
TOTAL BIOMASS	3290	4898

TABLE 24. Forest floor weight (grams meter^{-2}) of organic matter in low elevation mixed oak-hardwood forests of the Great Smoky Mountains National Park.

	SITE			
Plot Number	47	20	29	25
Elevation (m)	590	592	830	799
Topography	Draw	Sheltered slope	Draw	Open slope
Aspect	65	8	27	48
Basal Area (m^2 ha^{-1})	18.7	26.3	19.0	30.3
Density (# ha^{-1})	1680	1790	1750	1760
	LEAFY LITTER			
Litter	310	411	557	715
Fermentation	842	630	584	48
Humus	1499	641	2979	518
	WOODY LITTER			
Twiga	36	59	36	47
Small Branch	41	112	60	85
Large Branch	202	337	133	454
Bole	1726	8311	3416	10314
Buried Wood	26	155	160	163
TOTAL BIOMASS	4682	10656	7925	12341

TABLE 25. Forest floor weight (grams meter^{-2}) of organic matter in low elevation cove hardwood forests of the Great Smoky Mountains National Park.

	SITE			
Plot Number	11	21	48	28
Elevation (m)	847	525	578	830
Topography	Sheltered slope	Draw	Ravine	Ravine
Aspect	356	70	360	225
Basal Area (m^2 ha^{-1})	22.7	55.9	32.4	23.5
Density (# ha^{-1})	1110	1200	4860	4590
Vegetation	Hardwoods	Hemlock	Rhododendron	Laurel hardwoods
	LEAFY LITTER			
Litter	599	264	341	468
Fermentation	2	256	952	504
Humus	54	299	6993	1434
	WOOD LITTER			
Twigs	38	54	43	74
Small Branch	81	16	102	26
Large Branch	284	109	156	167
Bole	5282	1197	400	841
Burried Wood	174	74	68	125
TOTAL BIOMASS	6514	2265	9055	3669