TREE MORTALITY FOLLOWING GYPSY MOTH DEFOLIATION IN SOUTHWESTERN PENNSYLVANIA[1]

David E. Fosbroke

and

Ray R. Hicks, Jr.[2]

Abstract.--Approximately 200 0.1-acre plots have been monitored in southwestern Pennsylvania since 1985 in order to measure the impact(s) of Gypsy moth (Lymantria dispar (L.)) defoliation on forest stands of the Appalachian Plateau. Plots were located in both defoliated and undefoliated stands. Average defoliation (in defoliated stands) was 33% in 1985, 50% in 1986, 19% in 1987 and 8% in 1988 and ranged from no defoliation on non-host species (e.g. yellow-poplar) to complete defoliation on many of the oaks. An average of 24% of the trees in defoliated stands had died as of July 1988. Defoliated stands lost an average of 34 square feet of basal area per acre. Thirty percent of the oak basal area was dead following defoliation. Mortality varied by species, aspect, site index and crown condition.

INTRODUCTION

In recent years, the gypsy moth (Lymantria dispar (L.)) has extended its range into the Appalachian Plateau region of southwestern Pennsylvania. Gypsy moth defoliation often results in tree mortality. Mortality results from a combination of a reduction in photosynthetic capacity caused by leaf removal, a loss of root starch reserves during the refoliation process, stress induced during frost and drought periods, and secondary attack by the shoe-string root rot fungus (Armillaria mellea (Vahl.: Fr.)Kummer) and the two-lined chestnut borer (Agrilus bilineatus (Weber)) (Parker 1981, Wargo 1972 1977). Growth loss is a more subtle affect of defoliation that is often overshadowed by the more noticeable nature of mortality. Defoliation also opens the forest canopy during the growing season, drastically altering the understory environment. This opening of the canopy combined with selective tree mortality, reduction in acorn production, and the decrease in sprouting ability typical in defoliated stands, alters stand regeneration species composition.

Gypsy moth defoliation also substantially affects decisions made by natural resource managers and controllers of political purse strings. A 1984 damage survey conducted by the Pennsylvania Department of Environmental Resources of 691 000 acres demonstrates how severe tree mortality can be (Quimby 1987). Volume losses were 218 million cubic feet of pulpwood and 951 million board feet of

---

[1] Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989.

[2] The authors are Research Assistant and Professor, Division of Forestry, West Virginia University, Morgantown, WV.
Published with the approval of the Director of the West Virginia Agricultural and Forestry Experiment Station as Scientific Article 2142. This research was supported by funds provided by the U.S.D.A. Forest Service, Northeastern Forest Experiment Station.

The authors would like to thank Dr. Harry V. Wiant, Jr., Professor Anthony Tomkowski, Dr. Linda Butler, Brad Sample, Dale Thurber and two anonymous reviewers for their review of earlier drafts of this manuscript.

sawtimber. The combined value of dead wood based on stumpage values current at the time of the study amounted to $104 million or approximately $151 per acre. Herrick and Gansner (1987) reported more conservative loss estimates in separate studies in central Pennsylvania and the Pocono Region of Pennsylvania. Median losses were approximately 6 percent (about 1 cord/acre) and median value losses were $4.40 and $3.50 per acre respectively. However, losses did reach 20 cords per acre and $50.00 per acre in some plots. Forest managers are frequently forced into salvaging stands to prevent losses of these magnitudes. Prevention of gypsy moth defoliation by aerial application of insecticide is also costly as evidenced by project costs reported by several states at the 1985 National Gypsy Moth Review in Columbus, Ohio (Table 1). Costs varied between $4.13 and $14.87 per acre. The average cost for the spray projects reported by Delaware, New Jersey, Pennsylvania, and West Virginia was $9.31 per acre. The total project costs for these four states in 1985 was approximately $3.4 million. As more acreage is defoliated by the gypsy moth, financial and human resources become limiting factors for suppression programs. Then it becomes imperative that priorities be made as to which forest areas can be treated. The highest priority will be high-value stands where the insect is a pest to the citizenry, such as residential areas, campgrounds and scenic vistas. This is likely to leave few resources for the protection of uninhabited forest land. Therefore, treatment should be considered only for those stands that are both high-value and at a high risk of tree mortality. It is hoped that the information collected in this study can be useful in determining the relative risk of different stands. Presented here is a descriptive summary of defoliation and tree mortality in southwestern Pennsylvania.

Table 1. --Cost of the 1985 gypsy moth aerial spray programs in four selected eastern states.[1]

State	Area Treated	Cost/Acre	Total Cost
	(Acres)	($)[2]	
DE	67 000+	7.47	502 000
NJ	39 922	8.97[3]	358 100
PA	29 722	14.87	441 966
	70 882	11.73	830 742
	102 217	10.09	1 031 369
WV	54 020	4.13	223 102
Total			3 387 279

[1] Data in this table is taken from information reported by each state in the Proceedings of the 1985 National Gypsy Moth Review, Columbus, Ohio, Nov. 18-21.

[2] In some cases, these values do not include the costs of survey, administration, or treatment of small special use areas.

[3] This value is an unweighted average of the high and low costs reported by New Jersey in the proceedings.

PROCEDURES

To assist resource managers in the Appalachian Plateau region in determining which stands are at a high risk, 237 0.1-acre circular plots were established in Cambria and Somerset counties in southwestern Pennsylvania (fig. 1). Plots were located in both defoliated and undefoliated stands. A stand was considered "defoliated" when more than half of the plots in the stand received greater than 50% defoliation. At the time of establishment (1985 & 1986), a variety of tree characteristics, site conditions, and understory information were recorded for each plot (Table 2). Site index is an average of site index values calculated from four dominant or codominant oak trees per plot whenever possible. Separate equations were used for the white oak group and the red oak group using equations developed by Wiant and Lamson (1986). Volume equations were

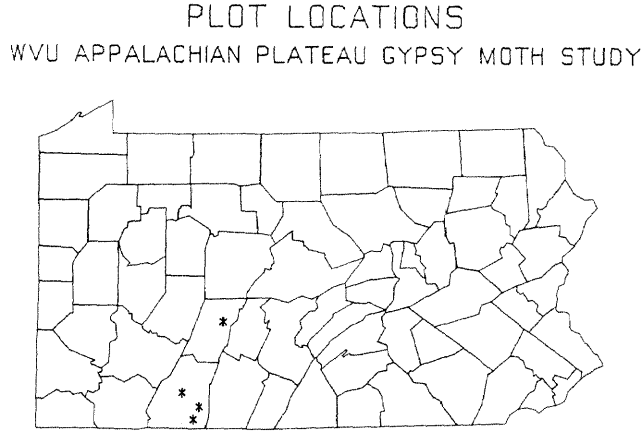

Figure 1.--Location of gypsy moth research plots established by West Virginia University in 1985 and 1986.

Table 2.--Data Collected - WVU Appalachian Plateau Gypsy Moth Study.

Tree Characteristics	Site Conditions
DBH	Site Index
Total Height	SCS Soil Type
Merchantable Height (8" top)	Percent Slope
Species	Slope Position
Crown Class	Aspect
Crown Vigor	Understory Information
Defoliation	Species
Tree Grade	Height Class

based on Wiant's (1986) formula for estimating form class 78 volume by International 1/4-inch rule. Tree grades were assigned using the dichotomous key published by Miller et.al. (1986). Since establishment, every plot has been revisited prior to defoliation each spring (mid May) to assess tree condition and again during peak defoliation each summer (late June through early July) to assess defoliation levels.

STUDY AREA AND STAND CONDITIONS

The study was conducted on separate parcels managed by the Pennsylvania Game Commission, WESTVACO, and an individual landowner near the eastern border of the Appalachian Plateau in southwestern Pennsylvania. The topography of the plateau ranges from relatively flat to very steep in a short distance and elevations vary from 1300 to 2550 feet above mean sea level. The highest point in Pennsylvania, Mt. Davis, is near the Somerset county study areas. The dissected topography on the plateau forms a dendritic drainage pattern. As a result, aspect is important in determining species composition.

Forests of the plateau represent a boundary between the Mixed-Mesophytic forest described by E. Lucy Braun (1950) and a southern arm of the birch-beech-maple type of the Northern Hardwood forest (SAF 1980). Braun described the Mixed-Mesophytic forest as being dominated by American beech (Fagus grandifolia), tuliptree (Liriodendron tulipifera), basswood (Tilia heterophylla), sugar maple (Acer saccharum), chestnut (Castanea dentata), sweet buckeye (Aesculus octandra), northern red oak (Quercus rubra) borealis), white oak (Quercus alba), and eastern hemlock (Tsuga canadensis). Additional locally abundant species listed were black birch (Betula lenta), black cherry (Prunus serotina), cucumber tree (Magnolia acuminata), white ash (Fraxinus americana), and red maple (Acer rubrum). Sour gum (Nyssa sylvatica), black walnut (Juglans nigra), and species of hickory (especially Carya ovata and C. cordiformis) occur in a large proportion of the stands, but are never abundant. As Braun noted, there is a large number of dominants in this type, therefore composition and relative abundance vary greatly from place to place. There are few exceptions to Braun's description in the southwestern Pennsylvania gypsy moth sample. Of course American chestnut is restricted to the understory. Also basswood and sweet buckeye were essentially missing from the sample. Red maple and chestnut oak (Quercus prinus) were dominant species and black oak (Quercus velutina) and scarlet oak (Quercus coccinea) were locally abundant.

Pre-defoliation overstory composition in defoliated and undefoliated plots are compared in figure 2. Maple

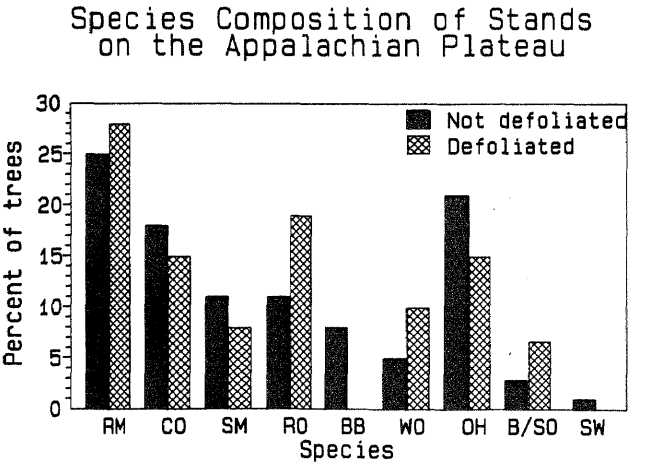

Figure 2.--Pre-defoliation overstory species composition of defoliated and undefoliated plots - WVU Appalachian Plateau gypsy moth study.

---

* RM=Red Maple, CO=Chestnut Oak, SM=Sugar Maple, BB=Black Birch and Yellow Birch combined, WO=White Oak, OH=Other Hardwood and B/SO=Black/Scarlet Oak.

accounted for 36% of the trees in the sample in both cases. The defoliated plots had a larger oak component (51% vs. 37%). Undefoliated plots showed a decrease in northern red oak and white oak and an increase in sugar maple and black birch when compared to defoliated plots.

The sample includes the wide range of forest conditions found in southwestern Pennsylvania. The most noticeable difference between the defoliated and the undefoliated stands is the larger oak component and lower stand density (basal area/acre) in the defoliated stands (Table 3). Conditions were similar in a study in central Pennsylvania reported by Herrick and Gansner (1987).

Table 3.--Pre-defoliation stand conditions of defoliated and undefoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

	DEFOLIATED		UNDEFOLIATED	
Variable	Mean	Range	Mean	Range
Ave. dbh (in)	7.7	3-45	8.3	3-36
Trees/ac (no.)	266	-	266	-
BA/ac (sq. ft.)	118	40-259	140	82-199
Stand age (yr.)	78	49-140	74	46-111
Site idx (Oak)	53	32-91	60	40-81
BA in Oak (%)	74	10-100	57	12-100
Vol/ac (bd ft:)	8195	294-27518	8905	1977-21128
Slope pct (%)	23	0-58	21	0-46
% Exposed Rock	6	0-80	22	0-80

TREE DEFOLIATION

Gypsy moth defoliation in southwestern Pennsylvania has been sporadic since 1980. An attempt was made to sample stands just prior to initial defoliation based on egg mass counts, aerial sketch maps, and aerial photography. Since 1985, defoliation estimates have been made for every tree within 166 plots. Each estimate is the average of ocular estimates (20% classes) made by two independent observers. Figure 3 shows the average defoliation of the major species in 1986, the year of heaviest defoliation. These averages provide a relative susceptibility rating guide for the Appalachian Plateau in southwestern Pennsylvania. This guide is similar to the "general guide for gauging relative

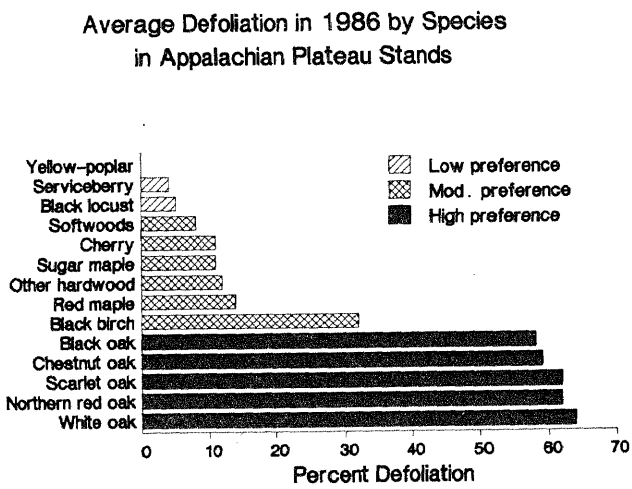

Figure 3.--Average individual tree defoliation by species in 1986 - WVU Appalachian Plateau Gypsy Moth Study.

susceptibility (of species) in central Pennsylvania" published by Herrick and Gansner (1987).

As expected, the oaks suffered the brunt of the attack. The average oak defoliation was 62% or approximately the defoliation level often stated as the threshold for defoliation. Herrick and Gansner (1987) reported less severe defoliation on white oak (34%), northern red oak (41%), and scarlet oak (47%) in central Pennsylvania stands which were heavily defoliated in 1981. Though the initial stand conditions of both studies were similar, the central Pennsylvania stands were less severely defoliated (avg. = 39%) in 1981 (Herrick and Gansner 1987) than the southwestern Pennsylvania plots were in 1986. Results from our stands in southwestern Pennsylvania indicate that the oaks are all equally susceptible to defoliation (figure 3). Generally, black birch was in the intermediate or overtopped crown position underneath oak canopies. In 1986, black birch suffered an average defoliation of 32%. Defoliation was hardly noticeable on the remaining species.

STAND DEFOLIATION

Defoliation intensity and duration are key factors in assessing potential stand mortality. A stand was considered "defoliated" when more than half of the plots in the stand received greater than 50% defoliation. Mortality increased with increasing number of years of defoliation (Table 4.). The mortality rate sharply increases when a stand receives its second defoliation. However, in some cases a single defoliation resulted in

Table 4.--Tree mortality by defoliation history - WVU Appalachian Plateau Gypsy Moth Study.

No. of Annual Defoliations	Mortality within Category (%)	Proportion of Sample (%)	Proportion of Total Mortality
0	11	15	8
1	11	27	13
2	28	39	50
3	34	18	28
4	36	<1	1

substantial mortality.

A simple average percent defoliation for each stand is of limited value in assessing defoliation intensity because simple averages do not take into account differences in crown volume between trees. Therefore, defoliation was weighted by dbh squared as suggested by Herrick and Gansner (1986). Table 5 shows the severity of defoliation on the Appalachian Plateau plots since 1985. The heaviest defoliation was in 1985 and 1986. Even a few plots in the "undefoliated" control group were moderately defoliated in both years. This is because the defoliation category was based on a stand average and not on individual plot averages.

Table 5.--Weighted plot defoliation averages 1985-1988 - WVU Appalachian Plateau Gypsy Moth Study.

	DEFOLIATED			UNDEFOLIATED		
Year	N	Mean	Range	N	Mean	Range
1985	99	32.99	0-99	21	7.36	0-36
1986	166	49.48	1-100	28	15.12	0-50
1987	166	19.40	0-74	28	6.86	0-33
1988	166	8.50	0-48	28	1.83	0-11

TREE MORTALITY

As of July, 1988, twenty-four percent of the trees (3.0 inches dbh and larger) in the defoliated stands died compared with 11% in undefoliated areas (Table 6). Defoliated stands lost an average of 34 square feet of basal area per acre. Overall basal area losses increased by 15% due to defoliation. The oaks suffered most, losing 30% of their collective basal area.

The defoliated stands were separated into categories based on the proportion of oak relative to all other species (Table 7). The mortality rate increased sharply when oak made up more than 60% of the stand's basal area. In fact, when the oak component made up less than 60% of the stand, average losses were no greater than in undefoliated stands (Table 6 & Table 7).

Table 6.--Percent mortality in defoliated and undefoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

Species	DEFOL.	UNDEFOL.
All (% tree loss)	24	11
(% basal area loss)	23	8
Oak (% tree loss)	39	16
(% basal area loss)	30	8

Table 7.--Percent tree loss in defoliated stands with different oak components - WVU Appalachian Plateau Gypsy Moth Study.

% Oak	% Mortality	% Sample	% Total Mortality
<10	0	0.5	0
11-20	2.5	2.5	0.5
31-40	11.0	5.0	2.5
41-50	8.0	5.5	2.0
51-60	9.0	6.5	2.5
61-70	15.5	10.0	6.5
71-80	21.0	16.5	14.0
81-90	21.0	26.5	24.0
91-100	43.0	27.0	48.0

Comparison of stem mortality for each oak species shows that scarlet, black, and chestnut oaks were particularly vulnerable with 57%, 46%, and 44% mortality respectively (Table 8). White oak and northern red oak fared a little better with 35% and 31% stem loss. It should be noted that scarlet and black oak represented a small proportion of the total sample, however even these small proportions represent 84 black oaks and 259 scarlet oaks. Red maple and sugar maple were included in the table in order to compare the oak mortality with species which were unaffected by the gypsy moth.

Mortality rates (Table 9) were lowest (15%) on the northeast and east aspects and on level sites where sugar maple, northern red oak and red maple dominated (i.e. made up the majority of the trees 3.0 inches dbh or larger). Where chestnut oak and red maple were the dominants (south and southeastern aspects) mortality

was the heaviest (30%). Mortality rates were intermediate on the remaining aspects (north, southwest, west and northwest) where red maple dominated with northern red oak or white oak.

Table 8.--Percent mortality for selected species in defoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

Species	%Species Mortality	%Sample	%Total Mortality
Scarlet Oak	57	6	14
Black Oak	46	2	4
Chestnut Oak	44	18	31
White Oak	35	10	15
N. Red Oak	31	17	22
Sugar Maple	5	7	1
Red Maple	4	25	6

Table 9.--Percent mortality and species mixture on different aspects - WVU Appalachian Plateau Gypsy Moth Study.

Aspect	Species Mixture	%Mortality
N	33% RM-26% RO	21
NE	23% SM-22% RO-19% RM	12
E	30% SM-21% RO-14% RM	14
SE	28% CO-24% RM-16% RO	36
S	30% CO-24% RM-37% MO[1]	34
SW	22% RM-22% WO-20% RO	22
W	29% RM-16% RO-14% CO-14% WO	28
NW	26% RM-24% RO-20% CO	25
FLAT	30% SM-21% RO-14% WO-10% OH[2]	13

[1] MO=about 10% each of white oak, northern red oak and scarlet oak.

[2] OH-other hardwoods.

Site index was grouped into three classes: 60, 60-70, and 70. Twenty-six percent of the trees on poor sites (SI < 60) died while only 16% died on average sites (SI 60-70) and 14% died on good (SI > 70) sites. Mortality was also greater on slopes steeper than 15% (28% loss) than on slopes which were less than 15% (15% loss). As with aspect, species is probably the overriding factor in these site/mortality relationships as the oak component was higher on the steep slopes and poor sites.

MANAGEMENT IMPLICATIONS

Gypsy moth host preference classes were developed by Mosher (1915) and modified by Houston (1979). Oaks are considered high on the list of plant species "favored" by the gypsy moth; white oaks are considered particularly susceptible. Harrick and Gansner (1987) found that white oak in central Pennsylvania received only half of the defoliation that chestnut oak and black oak did. Based on the results of our study in the Appalachian Plateau (fig. 3), any of the oaks (northern red, black, scarlet, white, and chestnut) should be considered equally likely to be defoliated during a year of heavy defoliation such as 1986.

Even though the average defoliation of all the oak species was about 60%, scarlet, black and chestnut oak suffered heavier mortality than did white and northern red oak. This is not to say that the mortality of these latter two species was minimal by any means. Chestnut oak mortality accounted for almost one-third of the total mortality. This was a function of both the proportion of chestnut oak in the sample and chestnut oak's high mortality rate. When a stand's oak component exceeded about 60%, there was a substantial increase in tree mortality.

Mortality appears to be heavier on poor sites, steep slopes and some aspects largely because these sites support a large oak component. In the Appalachian Plateau of Pennsylvania, aspect seems to have such an influence on species composition that table 10 could be useful in establishing an initial hazard rating based on topographic maps in the absence of stand composition information. Though there are probably sites which do not fit the pattern in this table, the consistency of the relationship is surprising. Then results from a stand exam could be used in a final hazard rating.

Tree mortality due to insect defoliation is a complicated process involving interactions between trees, defoliators, secondary organisms and environmental factors. The most useful variables for predicting tree mortality following gypsy moth defoliation are defoliation duration, defoliation intensity and species composition. This paper provided summaries of this type of information for forest stands on the Appalachian Plateau of southwestern Pennsylvania. The next step is to determine what other variables might be useful in separating mortality differences within varying levels of defoliation and oak composition.

LITERATURE CITED

Braun, E. L. 1950. Deciduous forests of eastern North America. Hafner Press, N.Y., N.Y. 596 p.

Herrick, O.W. and D.A. Gansner. 1987. Gypsy moth defoliation on the new frontier: forest tree defoliation and mortality. Northern Journal of Applied Forestry 4(3):128-133.

Herrick, O.W. and D.A. Gansner. 1986. Rating forest stands for gypsy moth defoliation. USDA Forest Service Research Paper NE-583. 4 p.

Houston, D.R. 1979. Classifying forest susceptibility to gypsy moth defoliation. USDA Handbook 542. 23 p.

Miller, G.W., L.F. Hanks and Harry V. Wiant, Jr. 1986. A key for the Forest Service hardwood tree grades. Northern Journal of Applied Forestry 3:19-22.

Mosher, F.H. 1915. Food plants of the gypsy moth in America. USDA Agricultural Bulletin 250. 39 p.

Parker, J. 1981. Effects of defoliation on oak chemistry. p. 219-225. In C.C. Doane and M.L. McManus eds. The gypsy moth: research toward integrated pest management. USDA Technical Bulletin 1584.

Quimby, J.W. 1987. Impact of gypsy moth defoliation on forest stands. p. 21-29. In Coping with the gypsy moth in the new frontier. Morgantown WV., August 4-6.

Society of American Foresters. 1980. F.H. Eyre ed. Forest cover types of the United States and Canada. Society of American Foresters, Washington, D.C. 148 p.

Wargo, P.M. 1977. Armillaria mellea and Agrilus bilineatus and mortality of defoliated oak trees. Forest Science 23:485-492.

Wargo, P.M. 1972. Defoliation induced chemical changes in sugar maple roots stimulate growth of Armillaria mellea. Phytopathology 62:1278-1283.

Wiant, H. V., Jr. 1986. Formulas for Mesavage and Girard's volume tables. Northern Journal of Applied Forestry 3:124.

Wiant, H.V., Jr., and N.I. Lamson. 1983. Site index equations for evenaged oak stands in northwestern West Virginia. West Virginia Forestry Notes 10:11-12.