Predictability of Gypsy Moth Defoliation in Central Hardwoods: A Validation Study[1,2]

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Abstract: A model for predicting gypsy moth defoliation in central hardwood forests based on stand characteristics was evaluated following a 5-year outbreak in Pennsylvania and Maryland. Study area stand characteristics were similar to those of the areas used to develop the model. Comparisons are made between model predictive capability in two physiographic provinces. The tested model was inconsistent in its predictive capacity. In the Ridge and Valley province of Maryland, model predictions overestimated actual stand level defoliation. In the Appalachian Plateau of Pennsylvania, the same model underestimated stand level defoliation. The stand-based model evaluated in this study does not provide forest managers with a satisfactory method for predicting the actual amount of defoliation in a given stand. However, the model appears to be useful for estimating the relative amount of defoliation to be expected in different stands.

WHY PREDICT DEFOLIATION?

Numerous papers have described the devastating effects of gypsy moth (Lymantriidae: *Lymantria dispar* (L.)) defoliation on eastern and central hardwood forests, especially those comprised of the highly favored oak species (Kegg 1973; Campbell and Sloan 1977; Gansner and Herrick 1979; Stephens 1988; Fosbroke and Hicks 1989; Twery 1990). To limit these damages, forest managers must make decisions on the type and timing of treatments to be applied to the forests in their jurisdiction. Common sense dictates that treatment efforts be initiated in high value stands that are likely to suffer unacceptable levels of damage if defoliated. The hazard rating system outlined by Mason et al. (1986) provides a framework for setting treatment priorities. Prediction of defoliation is an important component of this hazard rating system.

PREDICTING DEFOLIATION

Many factors influence the ability of a tree or a forest stand to survive insect attack. Prime among them are the severity of attack and the number of attacks sustained during an outbreak. Individual trees, tree species and forest stands have different probabilities of being defoliated during an

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outbreak. This likelihood of defoliation, termed susceptibility, is a function of the acceptability of the plant host to the defoliator and its suitability for insect growth and development. For the gypsy moth, this involves complex interactions between larvae and host foliage (Hodkinson and Hughes 1982; Kleiner et al. 1989; Barbosa 1978). The acceptability of plant species to gypsy moth larvae has been evaluated since the late 1800's when Forbush and Fernald (1896) evaluated 477 species of trees, shrubs and plants. Subsequent work by Mosher (1915) remains the classic reference for placing plant species into gypsy moth food preference classes. These classes have been condensed by Houston and Valentine (1985) and Montgomery (1990). Recently, the suitability of several southern and western species as gypsy moth hosts has been evaluated (Miller and Hanson 1989; Barbosa et al. 1983; Witter et al. 1990; Berisford and Montgomery 1990).

Setting treatment priorities before gypsy moth infestation involves assessment of susceptibility at the stand level. Since some plant species are more susceptible than others, it should be possible to predict stand defoliation based on species composition. A variety of techniques have been used to develop such defoliation prediction models (Table 1). Though considerable effort has gone into the development of these models, their usefulness has generally not been extensively evaluated. One test of the usefulness of a model is to apply the model to a new set of conditions and compare the predicted outcome with the actual amount of defoliation occurring in the forest stand. This paper describes the results of this type of validation for one gypsy moth defoliation prediction model selected from the literature.

Table 1.—Published equations for the prediction of stand level defoliation

Study	**Prediction variables**	**Equation form**
Campbell and Standaert (1974)	Egg Mass Density Preferred Food Density Prior Defoliation Total Foliage Available	Multiple Regression
Gansner et al. (1985)	Egg Mass Density	Non-linear Regression
Herrick and Gansner (1986)	Basal Area of Oak Basal Area of Black and Chestnut Oak Basal Area of Trees w/ Good Crowns Mean Stand Diameter	Classification Tree (AID)
Valentine and Houston (1979)	$\sum$ Diameter Preferred Host $\sum$ Basal Area Preferred Host $\sum$ Diameter Preferred Host w/ more than 1 Deep Fissure $\sum$ Diameter Preferred Host w/ more than 1 Bark Flap Quadratic Mean Diameter of Preferred Host	Discriminant Analysis
Valentine and Houston (1984)	$\sum$ Diameter Preferred Host $\sum$ Basal Area Preferred Host Analysis Quadradic Mean Diameter of Preferred Host	Discriminant

Though it would be desirable to evaluate each model available from the literature, models that incorporate gypsy moth population parameters were not evaluated. The reasons for this are two-fold: first, gypsy moth population parameters were known for only a small sample of our study sites; second, the authors feel that proper planning of gypsy moth treatments requires estimating defoliation potential long before gypsy moth life stages build up within a stand. To even consider the full range of silvicultural options outlined in Gottschalk's (1987, 1993) guidelines requires making plans at least three years before defoliation is expected. For these reasons, the models which could be evaluated were the Automatic Interaction Detection (AID) model published by Herrick and Gansner (1986) and the Discriminant model published by Valentine and Houston (1984). Since study site stand characteristics were not within the standard deviations published in the Valentine and Houston paper, the discrimenant model was also eliminated from the analyses. Therefore, the AID model published by Herrick and Gansner was the model selected to be evaluated.

THE AID MODEL

Herrick and Gansner (1986) developed a defoliation prediction model from data collected on approximately 600 plots established between Carlisle and State College, Pennsylvania in 1978. Defoliation levels were variable from 1979 through 1983. Defoliation was most widespread in these central Pennsylvania study sites in 1981 when forty-seven percent of the plots received at least 30 percent defoliation. Pre-defoliation stand conditions for the data used to develop the model are shown in Table 2.

Table 2.—Selected plot variables describing pre-defoliation stand conditions in the central Pennsylvania plots used by Herrick and Gansner to develop the AID defoliation model[1]

Variable	Mean	Range
Dbh	7.4	3.9-13.4
Trees/acre	255	80-650
BA/Acre	90	15-190
Stocking	81	20-158
% BA in oak	68	0-100
Avg NRO SI	61	25-100
Stand age	71	15-175

[1]Source: Herrick and Gansner (1986).

Herrick and Gansner used Automatic Interaction Detection (AID), a statistical tree classification technique, for determining the "best predictors" of stand defoliation. The AID technique divides a sample in a series of two-way splits into subgroups. At each split, the chosen predictor variable forms two new groups so that the reduction in the variance of the dependent variable is maximized. In the Herrick and Gansner model, the dependent (i.e. outcome) variable is termed defoliation potential, a value equivalent to a 3-year average percent defoliation. Predictor variables selected by the AID technique are the percent basal area in oak, the percent basal area in black and chestnut oak, the percent basal area in trees with good crowns, and the average stand diameter in inches. Figure 1 is the dendrogram used by Herrick and Ganser (1986) to show their results.

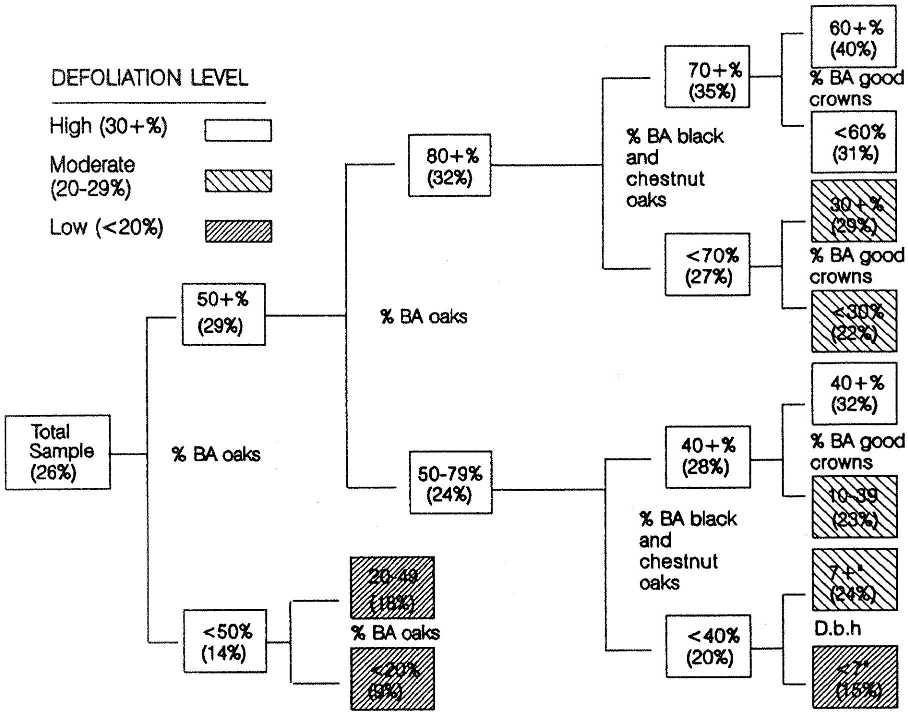

Figure 1.—Guide for estimating gypsy moth defoliation potential. Adapted from Herrick and Gansner (1986).

THE WVU GYPSY MOTH PLOTS

The AID prediction model described above was applied to data from 0.10-acre plots established in the Appalachian Plateau physiographic province of western Pennsylvania and the Ridge and Valley province of western Maryland. The plots were established between 1984 and 1986 as a part of a cooperative research agreement between West Virginia University and the U.S.D.A. Forest Service. Specifics about plot establishment and gypsy moth impacts in these study areas are detailed elsewhere (Hix et al. 1991, Fosbroke and Hicks 1989, Crow and Hicks 1990). Since these study plots were located in two different physiographic provinces, comparisons between defoliation predicted by the AID model and actual defoliation were made separately for the Pennsylvania and the Maryland data sets.

From 1985 through 1989, each tree on the WVU study plots was revisited when defoliation was at its peak (late June-early July). Ocular estimates of defoliation were made for each tree by two crew members. These two ocular estimates were averaged to obtain an individual tree defoliation level (ITDL). A weighted average plot defoliation level (WAPDL) was calculated for each plot using the method of Gansner and Herrick (1985), where ITDL values were weighted by the tree's diameter. These weighted ITDL estimates were than averaged over the plot producing the WAPDL. The resulting estimate represents the proportion of the plot that would appear to be defoliated if viewed from an airplane.

Initial Stand Conditions - Appalachian Plateau Province

Prior to defoliation in 1985, the Appalachian Plateau study sites were primarily in fully-stocked, mixed-oak stands that averaged 236 trees/acre and 107 square feet of basal area/acre. Table 3 compares pre-defoliation stand conditions of defoliated plots— those with a WAPDL greater than 30 percent in one or more years— with non-defoliated plots— those that never had a WAPDL exceeding 30 percent. Defoliated plots had a significantly (two-tailed t-test) greater level of stocking, larger oak component, and older stand age than did the non-defoliated plots when the study began. There was no significant difference in the average stand diameter, site quality (n. red oak site index), number of trees/acre, basal area/acre or volume/acre between defoliated and non-defoliated plots. Thirty percent of the trees in non-defoliated plots were species in Mosher's (1915) preferred food class compared to 55 percent of the trees in defoliated plots. Non-defoliated plots had a higher maple component than defoliated study areas, mostly due to an abundance of sugar maple. The difference in oak composition already noted is due to the increased proportion of chestnut oak, white oak, and northern red oak in the defoliated plots.

Table 3.—A comparison of stand conditions prior to defoliation between defoliated and non-defoliated plots in the Appalachian Plateau[1]

Variable	Defoliated			Non-defoliated		
	N	Mean	Std	N	Mean	Std
Dbh	157	8.13[a]	1.50	70	7.80[a]	1.45
Trees/acre	157	234.20[b]	65.29	70	239.57[b]	70.86
BA/acre	157	109.11[c]	35.84	70	102.12[c]	39.80
Stocking	157	80.47	19.54	70	72.52	24.59
Vol/acre	148	8438.06[d]	5758.63	67	6947.24[d]	4820.43
% BA in oak	157	79.82	16.19	70	47.43	31.09
% Trees in oak	157	53.78	24.39	70	27.18	24.22
Avg NRO SI	156	55.28[e]	8.31	60	60.04[e]	11.57
Stand age	156	78.80	17.63	69	74.28	17.94

[1]Comparisons based on two-tailed t-test.

Initial Stand Conditions - Ridge and Valley Province

As in the Appalachian Plateau, study sites were located in fully-stocked, mixed-oak stands. Prior to defoliation in 1985, Ridge and Valley stands averaged 238 trees/acre and 102 square feet of basal area per acre. Defoliated plots began with significantly (two-tailed t-test) more trees/acre, greater stocking, higher n. red oak site index, greater proportion of oak, and smaller stand diameters than non-defoliated plots (Table 4). There was no significant difference between defoliated and non-defoliated areas in the basal area/acre, average stand age, or sawtimber volume. There was little difference in the proportion of the stand that was made up of trees from Mosher's (1915) prefered food group. In fact, non-defoliated plots in the Ridge and Valley had more favored trees than did defoliated plots. Though both defoliated and non-defoliated plots averaged 85-91 percent of their basal area in oak (Table 4), the relative contribution of the five oak species to the overall stand composition was different in defoliated and non-defoliated plots. In defoliated plots, nearly 60 percent of the stand composition consisted of chestnut oak while white oak made up 10 percent of the stand and n. red oak was nearly non-existent. In contrast, white oak made up nearly 30 percent of the non-defoliated plots, followed by chestnut oak (21%) and n. red oak (11%). Though individual species of pine varied, both defoliated and non-defoliated plots averaged 7 to 8 percent conifer species. In contrast with the Appalachian Plateau, maple was a small component of all Ridge and Valley stands and hickory represented 7 to 8 percent of Ridge and Valley stands.

Table 4.—A comparison of stand conditions prior to defoliation between defoliated and non-defoliated plots in the Ridge and Valley[1]

	Defoliated			Non-defoliated		
Variable	**N**	**Mean**	**Std**	**N**	**Mean**	**Std**
Dbh	67	8.09	1.35	91	8.72	1.58
Trees/acre	67	265.20	76.80	91	218.02	74.84
BA/acre	67	102.53[a]	17.95	91	100.83[a]	22.87
Stocking	67	90.96	14.78	91	81.76	16.67
Vol/acre	65	6663.07[b]	4418.47	88	8069.62[b]	4453.93
% BA in oak	67	91.01	10.63	91	85.36	20.51
% Trees in oak	67	82.21	15.03	91	74.33	22.15
Avg NRO SI	63	58.01	7.52	79	55.83	8.17
Stand age	63	73.90[c]	14.18	79	77.47[c]	15.18

[1]Comparisons based on two-tailed t-test.

Stand Level Defoliation - Appalachian Plateau

Defoliation was spotty in the Appalachian Plateau, being concentrated in some stands and absent in others (Table 5). The Pennsylvania plots received the most defoliation in 1985 and 1986 (Tables 5 and 6), averaging over 50 percent in the defoliated plots (Table 5). By 1988, the gypsy moth population had declined and the average plot defoliation was less than 10 percent (Table 6). Nine stands were heavily defoliated (WAPDL ≥50%) in 1985 and/or 1986 (Table 5). Six stands received moderate levels of defoliation (30% ≤ WAPDL < 50%) in one or both of those years. One stand was moderately defoliated in 1987. The remaining two stands recieved essentially no defoliation during the study. Only one stand received three years of moderate or heavy defoliation while seven stands had at least 2 years of moderate defoliation or greater.

Table 5.—Defoliation history of Appalachian Plateau stands in southwestern Pennsylvania[1]

Stand #	**1**	**3**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**25**	**26**	**27**	**28**	**29**
# Plots	**8**	**8**	**11**	**29**	**16**	**7**	**5**	**7**	**5**	**6**	**12**	**10**	**14**	**5**	**25**	**13**	**8**	**5**
	----- Average defoliation (Percent)[2] -----																	
Year																		
1985	48	0	33	34	50	7	39	31	24	*	*	1	100	*	*	*	*	*
1986	5	57	41	80	45	16	40	48	28	31	93	6	12	75	52	35	54	65
1987	15	10	7	17	17	3	12	30	30	42	33	0	43	17	13	31	11	21
1988	2	4	11	3	13	1	3	11	10	14	23	0	15	4	7	9	3	13
1989	11	12	7	8	13	6	10	10	10	11	7	0	5	12	6	10	8	10
85&86	27	52	37	74	46	12	39	40	26	31	93	4	56	75	52	35	55	65
85-89	17	21	21	34	26	8	23	27	20	25	39	6	37	27	20	21	21	27

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

[2] Study areas that were established after defoliation in 1985 and before defoliation in 1986 are indicated with an "*".

Table 6.—Comparison of annual defoliation levels in defoliated and non-defoliated plots in the Appalachian Plateau study areas[1]

	Nondefoliated plots		**Defoliated plots**		**All plots**	
Year	**(%)**	**(N)**	**(%)**	**(N)**	**(%)**	**(N)**
1985	4.35	(60)	55.51	(62)	30.34	(122)
1986	11.65	(37)	55.82	(157)	47.39	(194)
1987	3.71	(37)	23.01	(157)	19.33	(194)
1988	2.94	(37)	9.51	(157)	8.25	(194)
1989	6.73	(37)	9.55	(155)	9.01	(192)
85&86	10.26	(37)	58.90	(157)	49.62	(194)
85-89	7.21	(52)	28.83	(157)	23.45	(209)

[1] A plot was considered defoliated if the weighted average plot defoliation level exceeded 30 percent in at least one year.

Stand Level Defoliation - Ridge and Valley

Defoliation was less severe in the Ridge and Valley plots located in western Maryland than in the Appalachian Plateau of southwestern Pennsylvania (Tables 7 and 8). Defoliation peaked in 1985 with an average over all plots of nearly 30 percent (Table 7). A year later, defoliation had declined to under 5 percent. Defoliation was greatest in stands F, G, J, K, L, and M (Table 8). Stands N and P were maintained as controls through the application of Dimilin. Stand M was clearcut in the spring of 1986 following heavy defoliation because of its high value. The remaining stand, stand I, received only a single light defoliation. Though this stand was excluded from a spray block in 1986, shortly following Dimilin application in an adjacent spray block, larval populations declined and active defoliation ceased.

Table 7.—Defoliation history of Ridge and Valley stands in western Maryland[1]

Stand	F	G	I	J	K	L	M[2]	N	P	Q
# Plots	26	8	30	13	7	13	17	16	9	37
Year					Average Defoliation (Percent)					
1985	52	35	3	67	49	51	-	10	<1	0
1986	1	0	17[3]	0	0	0		0	0	0
1987	5	3	<1	0	3	0		0	0	0
1988	1	0	1	0	0	0		1	0	16
1989	<1	<1	<1	0	0	0		1	0	4
85-89	23	19	8	35	24	38		8	2	15

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

[2] Stand M was clearcut in the spring of 1986 in a salvage operation. These plots are not included in Table 8.

[3] Larval activity and defoliation ceased in mid-season in 1986 in stand I.

Table 8.—Comparison of annual defoliation levels in defoliated and non-defoliated plots in the Ridge and Valley study areas[1]

Year	Nondefoliated plots (%)	(N)	Defoliated plots (%)	(N)	All plots (%)	(N)
1985	5.24	(75)	54.62	(62)	27.58	(137)
1986	4.62	(91)	1.38	(67)	3.24	(158)
1987	0.64	(90)	2.08	(67)	1.25	(157)
1988	1.51	(91)	9.67	(66)	4.94	(157)
1989	1.93	(91)	0.28	(67)	1.24	(158)
85&86	4.47	(91)	25.96	(67)	13.58	(158)
85-89	6.85	(83)	32.80	(67)	18.44	(150)

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

AID Model Estimates - Appalachian Plateau

Figure 2 shows the 3-year defoliation level predicted by the Herrick and Gansner guide (line) and the actual defoliation for each of the 184 plots used from the Appa-lachian Plateau data set (points).[5] The x-axis represents a counting of plots (observations) from plot n=1 to plot n=184. The model under-estimates the 3-year average percent defol-iation for those plots which had actual defol-iation levels shown above the line.

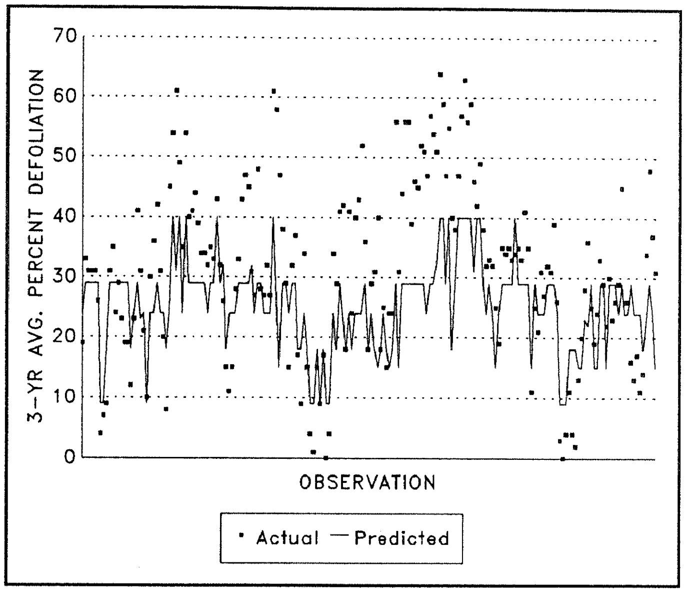

Figure 2.—Comparison of 3-year average defoliation levels predicted using the Herrick and Gansner (1986(AID model and actual 3-year average defoliation in the Appalachian Plateau plots (N=184).

In general, the model underestimated the amount of defoliation in these Pennsylvania plots. The mean predicted value for the 184 plots tested was 25.3 percent compared with an actual value of 31.4 percent. Predicted defoliation was compared to actual defoliation using a paired t-test. The resulting t-value of 4.99 with 183 degrees of freedom was significant (p=0.0001). Table 9 provides sample statistics for both predicted and actual defoliation levels.

Table 9.—Sample statistics of actual and predicted defoliation (percent) from the Appalachian Plateau study plots

	Predicted	**Actual**
Number of plots	184.0	184.0
Mean	25.3	31.4
Median	25.3	29.0
Minimum	9.0	0.0
Maximum	40.0	64.0
Standard deviation	7.4	14.6

[5] The Pennsylvania data set contained 227 plots. Forty-three were eliminated from the analysis because they were not revisited following establishment in 1985 (33 plots) or because they were planned as sprayed control plots and received no defoliation.

Seventy-eight of the 184 plots (42%) were correctly classified into the low (< 20%), moderate (20-29%), and high (>30%) defoliation categories used by Herrick and Gansner. Thirty-one of the 45 plots (68%) predicted to be in the low defoliation category had less than 20 percent defoliation during the 3 years. Twenty-seven of the 118 plots (23%) predicted to have moderate defoliation had 20 to 29 percent defoliation on average. Nearly all (20 of 21) of the plots predicted to receive high levels of defoliation did. Sixty-eight percent (80/118) of the plots expected to be in the moderate defoliation category were actually in the high defoliation category. No plot was predicted to exceed 40 percent defoliation over the 3 years, however 47 plots (27%) experienced greater than 40 percent defoliation with a maximum 3-year average defoliation of 64 percent. The data were grouped into Herrick and Gansner's three categories for a chi-square goodness of fit test. The test with 4 degrees of freedom had a significant chi-square value of 81.74, indicating that predicted defoliation levels did not reflect actual defoliation.

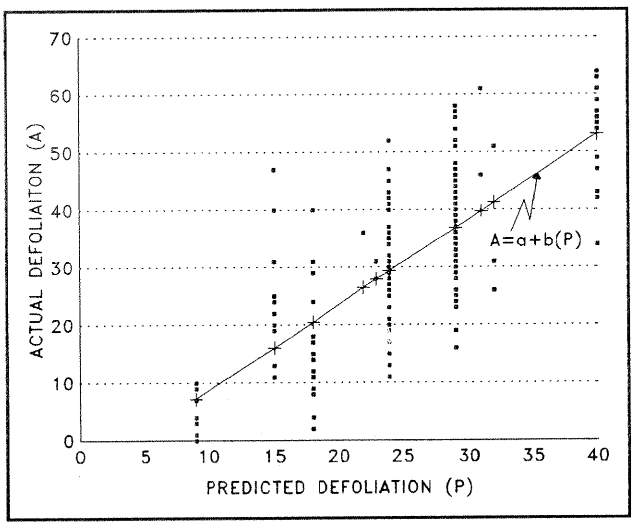

Figure 3.—Regression of 3-year defoliation levels to predicted defoliation levels using Herrick and Gansner model.

The predicted levels of defoliation from the Herrick and Gansner model were positively correlated to actual defoliation levels over a three-year period (r=0.75). The pattern of actual defoliation shown in Figure 2 reflects the pattern of predicted defoliation indicated by the line. The highest actual values of defoliation were generally on those plots that had the highest predicted values. Where predicted values are low, the actual values also tended to be low. A simple linear regression of actual to predicted defoliation is shown in Figure 3. An ideal relationship would yield an intercept of 0 and a slope of 1. Additionally, the sum of the squared residuals would approach 0. The equation— $A = -6.160914 + 1.481787\ (P)$ —describes the regression line in Figure 3. The r^2 for this line is 0.57. The student's t-test for the intercept (H_0: a=0) and the slope (H_0: b=1) were significant with t-values of -2.43 (p=0.0162) and 5.008 (p=0.0000) respectively.

AID Model Estimates - Ridge and Valley

Sixty-seven plots were used to evaluate the usefulness of the Herrick and Gansner guide for predicting gypsy moth defoliation in the Ridge and Valley province of western Maryland.[6] There was no known application of insecticide in any of these plots; however, no plot received significant defoliation for more than one year. Figure 4 is a plot of the predicted 3-year average defoliation for each plot using the Herrick and Gansner guide (line) and of the actual defoliation level that these plots averaged from 1985-1987 (points).

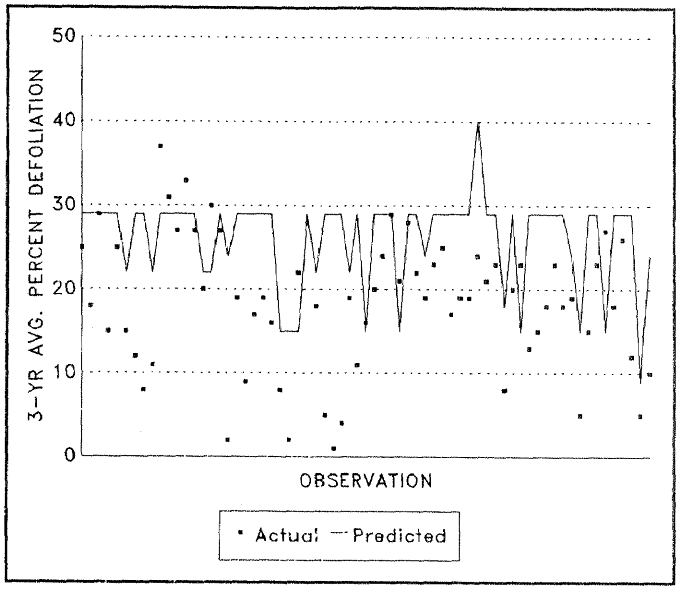

Figure 4.—Comparison of 3-year average defoliation levels predicted using the Herrick and Gansner (1986) AID model and actual 3-year average defoliation in the Ridge and Valley study plots (N=67).

In general, the model overestimated the amount of defoliation in these Maryland plots. The mean predicted defoliation level of the 67 plots was 26.1 percent compared with an actual defoliation value of 18.5 percent. A comparison of actual to predicted defoliation resulted in a t-value of -7.48 with 66 degrees of freedom. Table 10 provides sample statistics for both predicted and actual defoliation levels.

The three-year defoliation level was correctly predicted for 26 (39%) of these plots. In only 9 plots was the prediction an underestimate of the actual defoliation level. The remaining 32 plots had actual defoliation levels that were lower for the three-year period than predicted by the guide. Thirty-one of the 56 plots (55%) which were predicted to have a moderate 3-year average defoliation level actually had less than 20 percent average defoliation over the period. These data were also grouped into Herrick and Gansner's three categories for a chi-square goodness of fit test. The test with 4 degrees of freedom had a nonsignificant chi-square value of 2.484, indicating that predicted defoliation levels did reflect actual defoliation categories. Note that the 3x3 contingency table had 6 cells with expected values of less than 5. The contrast between the results in the Appalachian Plateau and in the Ridge and Valley is evident by comparing Figures 2 and 4. In general, the model underestimates defoliation in the Appalachian Plateau sites, it overestimates defoliation in the Ridge and Valley sites.

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[6] The Maryland data set contained 158 plots. Ninety-two plots were eliminated from the analysis because they were planned as sprayed controls (25 plots), appeared to have been affected by adjacent spray blocks (30 plots), or did not receive defoliation until 1988 (37 plots).

Table 10.—Sample statistics of actual and predicted defoliation from the Ridge and Valley study plots.

	Predicted	Actual
Number of plots	67.0	67.0
Mean	26.1	18.5
Median	29.0	19.0
Minimum	9.0	1.0
Maximum	40.0	37.0
Standard deviation	5.6	8.1

The predicted levels of defoliation from the Herrick and Gansner model had a weakly positive correlation to actual defoliation (r=0.30). A simple linear regression of actual to predicted defoliation is shown in Figure 5. The regression line is defined by: $A = 7.18262 + 0.432684\ (P)$. The r^2 for the line is 0.089. The student's t-test for the intercept (H_0: a=0) was not significant (t=1.56, p=0.1228) while the t-tests for the slope (H_0: b=0; b=1) was significant (t = 2.51, p = 0.0144; t = -3.295, p = 0.001).

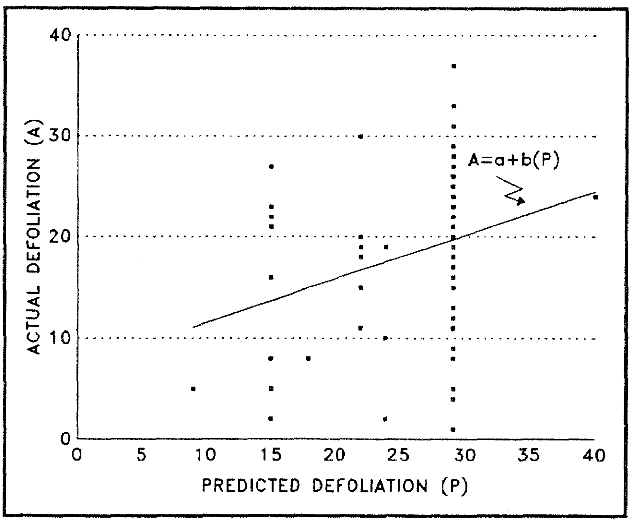

Figure 5.—Regression of 3-year defoliation levels to predicted defoliation levels using Herrick and Gansner model.

DISCUSSION

This paper describes the results of applying a model developed in central Pennsylvania that predicts stand level defoliation to two test data sets: one data set is from the Appalachian Plateau of southwestern Pennsylvania, the other is from the Ridge and Valley of western Maryland. An important limitation of this "case study" approach to validation is the difficulty of obtaining test data that is fully comparable with the model building data set. The results of this validation are affected by differences in initial stand characteristics, defoliation histories, and gypsy moth population levels between stands used to build and test the model. Therefore, this paper demonstrates the capability of the Herrick and Gansner AID model as a predictor of the 3-year average defoliation for these two data sets. Further testing with other data sets may yield more favorable results.

The two data sets used to test the AID model have similarities and differences in stand characteristics with the central Pennsylvania data. Comparing the year of most widespread defoliation for the three areas, the central Pennsylvania data and the Ridge and Valley data had a similar proportion of their plots in the severe defoliation category (45% and 47% respectively); however, 80 percent of the Appalachian Plateau plots had severe defoliation at the peak of defoliation. On average, plots from both the Appalachian Plateau and the Ridge and Valley data had larger mean stand diameters, greater basal area per acre, fewer stems per acre, and lower site quality than plots in the central Pennsylvania data. In the Appalachian Plateau, eight stands had more than 30% defoliation for two or more years, while no stands in the Ridge and Valley had more than one year of severe defoliation. The maximum defoliation category for the AID model is 40 percent. No plots in the Ridge and Valley exceeded 40 percent defoliation; however, 27 percent of the Appalachian Plateau plots had 3-year defoliation averages in excess of this amount. The duration of intense defoliation in the Appalachian Plateau stands partially explains why the AID model underpredicted defoliation in these data. The lack of a sustained defoliation in the Ridge and Valley partially explains why the AID model overpredicted the defoliation in these data.

In both provinces, the standard deviation of the actual defoliation is nearly twice that of the predicted defoliation. The test data represent mixed-oak stands containing a high percentage of oak. Therefore, there was little variation in the parameters that define the AID model, resulting in little variation in the amounts of defoliation predicted. In fact, the AID model predicts that two-thirds of the the Ridge and Valley plots would be in the a single defoliation class (29 percent). In contrast, there was wide variation in the amount of actual defoliation during the study.

The reason for the high number of Ridge and Valley plots being placed in a single defoliation class is evident from Figure 1. Oak trees accounted for more than 80 percent of the basal area in these plots; but, chestnut oak and black oak made up less than 70 percent of the basal area. Also, more than 30 percent of the trees on these plots had good crowns before gypsy moth defoliation. These initial stand conditions yield a predicted amount of defoliation of 29 percent.

Though the AID model did not predict the magnitude of defoliation for the test data plots, if the model can predict that plots are likely to have the greatest amount of defoliation, then the model could still be a useful planning tool. The defoliation level predicted by the model was positively correlated to the actual defoliation levels in both provinces, though the relationship was stronger in the Appalachian Plateau than in the Ridge and Valley. Figures 2 and 4 show that those plots predicted to have high defoliation levels generally did have higher actual defoliation levels than plots predicted to have low defoliation values. This suggests that the major problem with the AID model is problem of scale and not a problem of direction. Therefore, the model may be useful for segregating stands into low priority and high priority areas.

The extensive literature on gypsy moth impacts suggests that forest managers need a tool, such as the AID model, for predicting defoliation levels before gypsy moth populations build to defoliating levels. However, the validation presented in this paper suggests that this model needs further testing and refinement to be used for this purpose. Part of the problem appears to be the wide variation in the defoliation of stands that have similar characteristics. The shortcomings of the AID model may simply reflect a need for additional data in model development. Montgomery (1990) stated that there is too much emphasis on the amount of non-preferred species in model development. If he is correct, we may need to concentrate model building efforts on stands that are 60 to 100 percent preferred species. In order to take this approach, it may be necessary to combine data from as many sources as possible. Currently, five major data sets that were designed to study gypsy moth impacts exist: the Melrose Highlands data (Campbell and Sloan 1977), the Pocono data (Gansner and Herrick 1979), the central Pennsylvania data (Herrick and Gansner 1986), the Appalachian Plateau, and the Ridge and Valley data (Fosbroke et al. 1991). Though there are significant differences in the data collected in these studies, integration of multiple data sets into a single analysis may provide a better accounting of the variation in defoliation between stands than has been possible in past studies.

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