Preparing for the Gypsy Moth — Design and Analysis for Stand Management Dorr Run, Wayne National Forest

J. J. Colbert, Phil Perry, and Bradley Onken[1]

Abstract.—As the advancing front of the gypsy moth continues its spread throughout Ohio, silviculturists on the Wayne National Forest are preparing themselves for potential gypsy moth outbreaks in the coming decade. Through a cooperative effort between the Northeastern Forest Experiment Station and Northeastern Area, Forest Health Protection, the Wayne National Forest, Ohio, is utilizing computer models to identify high-risk stands and evaluate the predicted outcome of several management options. The efforts involve the Stand-Damage Model, a portion of the Gypsy Moth Life System Model and GypsES, a decision support system that provides the transport and storage medium for the forest inventory data used in analysis and stand mapping capabilities. The process involves identifying high-risk stands and simulating development of these stands forward from the inventory year to 1997. A series of three simulations were designed to assess the range of possible tree mortality from none, to light, to heavy outbreak scenarios. If a stand contains sufficient growing stock, a simulated pre-salvage thinning was conducted using two alternative criteria. Stands with a relative stand density greater than 70 percent were cut to 60, and stands with relative stand density greater than 90 percent were cut to 80 percent. Results are given in terms of stem counts, basal area, volumes, and present dollar values. Results show the savings that could be expected if outbreaks occur following these silvicultural treatments and help to prioritize treatment schedules. The results will be used in the decisionmaking process, are documented in an Environmental Assessment as a means to inform the public as to the consequences of each proposed alternative, and will be used in the implementation of site-specific management alternatives.

INTRODUCTION

Gypsy moth (*Lymantria dispar* L.) has been spreading from its origin of introduction into North America and is currently established in western Pennsylvania, most of West Virginia, and northeastern Ohio (Liebhold et al. 1997). Gypsy moth is expected to become established in and around the Wayne National Forest in the coming decade: 1998-2007 (Fig. 1). New gypsy moth populations cause significant damage, due in part to the lack of co-establishment of its full natural enemy complex. It is expected that losses will occur in Ohio similar to those found over the past two decades in western Pennsylvania. The part of the Wayne National Forest that is of greatest concern to the forest silvicultural staff is the Dorr Run Area because this area has the highest proportion of high-hazard stands. The Dorr Run Area is located on the Athens Ranger District in Green and Ward Townships, Hocking County, Ohio, in the unglaciated Allegheny Plateau.

Because of the dense stocking, growth has slowed on a large number of trees. Gypsy moths have been trapped at increasing rates in Hocking and surrounding counties for several years. It is expected that gypsy moths could have a serious impact in this area because of the high proportion of oak and other preferred species and the generally over-stocked and low-vigor conditions that exist in many of the stands. Some mortality of oak trees is beginning to occur from shoestring root rot (*Armillaria mellea*) and twolined chestnut borer (*Agrilus bilineatus*).

Land management objectives for the Dorr Run Project Area are described in the Wayne National Forest Land and Resource Management Plan (USDA Forest Service 1988[2]). The objectives for this management area are to maintain wildlife habitat diversity, provide high-quality hardwoods on a sustained yield basis, provide various dispersed recreation opportunities, and provide off-road vehicle use.

Because of the foregoing forest health conditions and to implement the Land and Resource Management Plan, the Dorr Run Area was selected for analysis and development of vegetation management proposals. The purpose and need of the Dorr Run project is to maintain and improve forest health. Thomas (1996)[3] characterized healthy forests as "...those where biotic and abiotic influences do not seriously threaten resource management objectives, now or in the future, nor do resource management activities seriously threaten sustainability or biodiversity."

This project was a joint effort among all three branches of the USDA Forest Service. The Wayne National Forest was interested in determining what damage could occur from gypsy moth defoliation. There was interest in using the results of the Gypsy Moth Stand-Damage Model in an environmental analysis to explain to the public what the potential damage could be from gypsy moth defoliation for each of the alternatives. In addition, the data produced for individual stands would be valuable in prescribing silvicultural treatments and developing marking guidelines for specific stands. Research was interested in this project to demonstrate new modelling technology and to investigate a

[1]Research Mathematician, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV; Forest Silviculturist, Wayne National Forest, 219 Columbus Road, Athens, OH; Entomologist, Northeastern Area State & Private Forestry, Forest Health Protection, 180 Canfield St., Morgantown, WV; respectively.

[2]U. S. Department of Agriculture, Forest Service. 1988. Land and Resource Management Plan: Wayne National Forest. As amended. Wayne National Forest, 219 Columbus Road, Athens, OH 45701-1399.

[3]Thomas, Jerome. 1996. 3400 Memo of 1/25/96 on Southern Tier Forest Health Conference Call Summary. USDA, Forest Service, Eastern Region. 310 W. Wisconsin Ave., Rm. 500, Milwaukee, WI 53203.

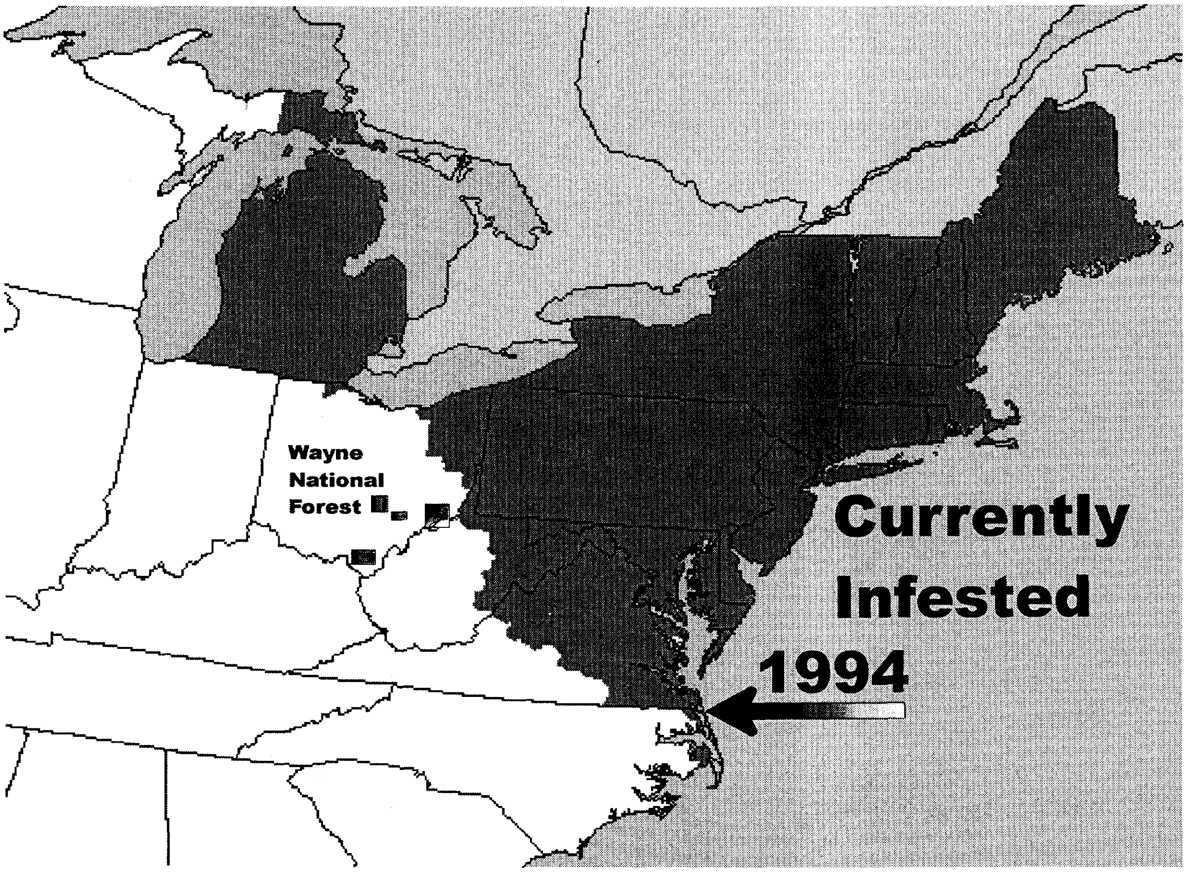

Figure 1.—Area currently infested with gypsy moth, as of 1994, and the location of the Wayne National Forest in southeastern Ohio.

significant problem using current inventory data from the Wayne National Forest. Moreover, there is a need to constantly validate models. We will be able to compare these predicted results to later actual management practices and defoliation effects, extending our knowledge of the geographic and ecological range of model applicability. State and Private Forestry's role is to coordinate between national forests and the research branches of the Forest Service, and to assist in the collection, management, and transfer of data used to support forest health assessments. Forest Health Protection's mission is to disseminate information based upon research that can be utilized not only in the management of national forests, but also on state forests and private lands.

The Environmental Assessment for the Dorr Run Project Area states that the purpose of silvicultural treatments is to "restore vigor, shape species composition, and work toward the establishment of the next forest" (USDA Forest Service 1997[4]). Five alternatives were developed and analyzed in the environmental analysis to determined how well each alternative achieved the purpose and to analyze the effects on the environment of each alternative. The analysis in this paper was utilized in documenting the environmental consequences of each of the alternatives. Silvicultural treatments were proposed to reduce damage, such as mortality or loss of mast production, by removing highly vulnerable trees before they are defoliated and die.

METHODS

Within the Dorr Run Project Area there are 5,183 acres of national forest land and approximately 3,200 acres of private land. Thirteen forest types have been identified, and six of these are oak-hickory forest types that total 3,231 acres or 62 percent of national forest land within the project area. In addition there are 39 acres of aspen stands. Oaks and aspen are preferred food species of the gypsy moth (Liebhold et al. 1995). The remaining acreage consists of a variety of non-oak hardwoods with a small amount of pine. Most of the forest in this area is greater than 60 years old, and 91 percent of this is in the oak-hickory forest types. Site Index (50-year black oak, Carmean et al. 1989) averaged 73.6 over the stands included in the initial sample and ranged from 65 to 94, with mean equal to 73 across the 24 stands used in the final analysis.

In the Dorr Run Area, oak-hickory stands are found on the more xeric sites located on ridgetops, middle to upper place

[4]U.S. Department of Agriculture, Forest Service. 1997. Environmental Assessment: Dorr Run, Hocking County, Ohio, Athens Ranger District, Wayne National Forest, March 1997. Wayne National Forest, 219 Columbus Road, Athens, OH 45701-1399. 98 p.

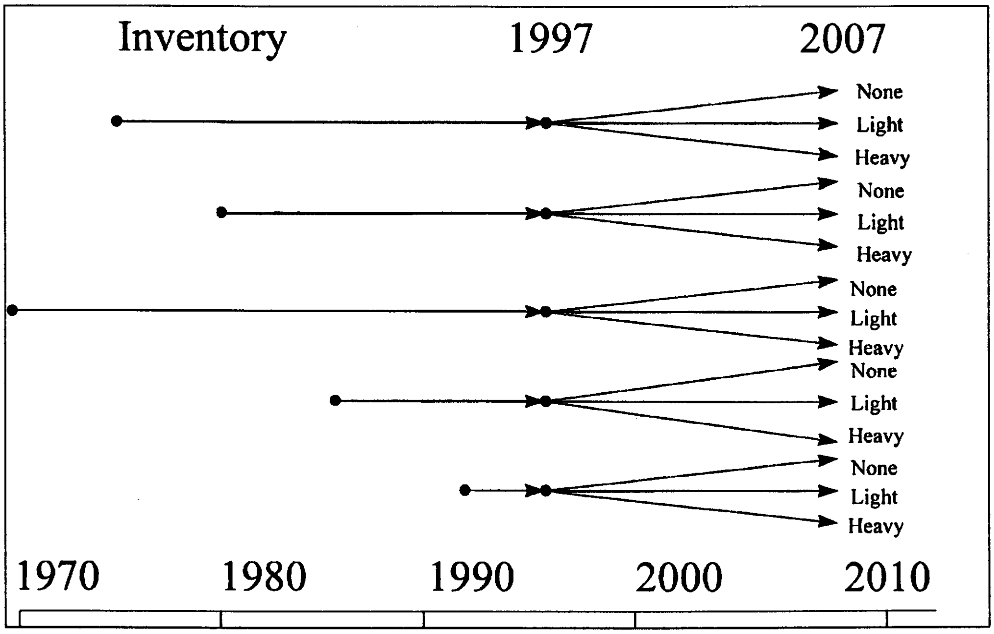

Figure 2.—Process of simulations: inventories for each stand are grown forward to 1997; if silvicultural prescriptions are to be simulated, that happens next; finally the three 10-year simulation scenarios (none, light, and heavy outbreak) ending in 2007 are executed.

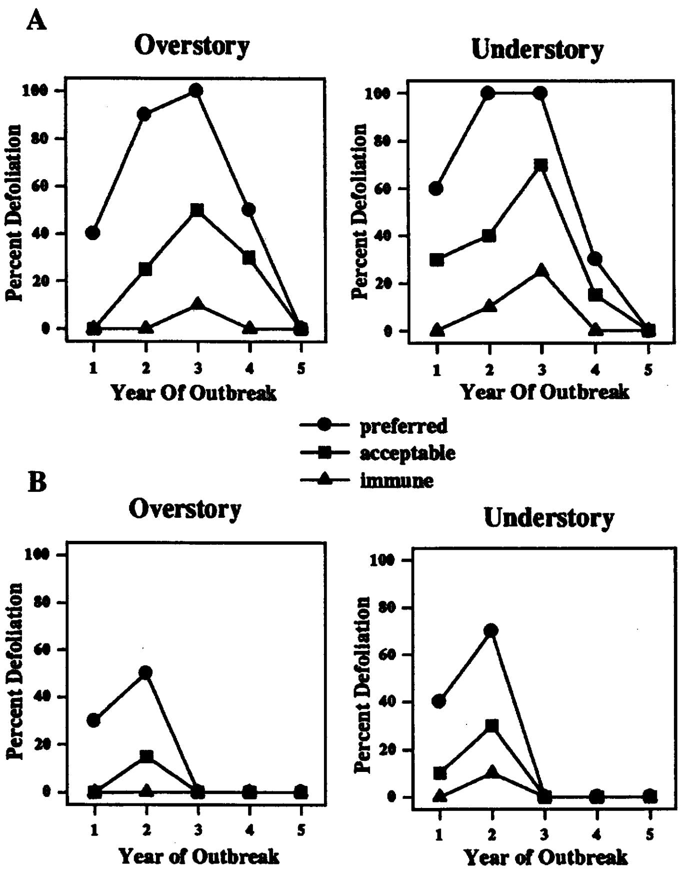

Figure 3.—A. Heavy outbreak defoliation intensities in the overstory and understory for 5 years. Gypsy moth host tree species determines feeding preference class. Each simulation repeats this 5-year sequence twice over the 10-year simulation. B. Light outbreak defoliation intensities.

slopes on southeast to northwest aspects, and upper slopes on the northeast aspect. The majority of this area is densely stocked.

Analysis was based upon compartment examination data that are routinely collected by Wayne National Forest personnel. Individual tree data were collected on 10 BAF variable-radius plots. The forest types used in the analysis were [1] black oak—scarlet oak—hickory; [2] white oak; [3] yellow-poplar—white oak group—red oak group; and [4] mixed oak. Chestnut oak forest type and northern red oak forest type were not used because these types occurred on too few stands.

To assess the possible damage caused by future gypsy moth outbreaks in the Dorr Run Area we used a sample of 38 stands that were well distributed across six compartments and the four principal oak-hickory forest types that the gypsy moth is known to find most preferable, representing both the spatial mixture and the ecological range of potential impacts. The available inventory was categorize to compartment and forest type; a balanced random sample was chosen from within this stratification. We investigated potential losses by producing a series of stand growth and defoliation scenarios using the Gypsy Moth Stand-Damage Model (Colbert and Racin 1995, Colbert and Sheehan 1995). First, the model was used to grow all tree data from previous inventories forward through 1996 to represent the current condition of each stand. Growth scenarios, each a 10-year projection, were then constructed to estimate potential tree mortality (Fig. 2). Simulations were run with and without defoliation and following selected silvicultural activities simulated to take in 1997. Figure 3 shows the heavy and light defoliation scenarios that were used in this analysis. These scenarios are the same duration and intensity as those developed for loss assessments in the National Gypsy Moth Environmental Impact Statement (Northeastern Area, State and Private Forestry 1995). Each decade simulation consisted of two 5-year outbreak cycles. The amount of defoliation to a particular tree depended upon its location in the stand canopy and the feeding preference of gypsy moth to that tree species (Liebhold et al. 1995).

Table 1.—Stumpage price in 1997 dollars per thousand board-feet (Source: 1995 Ironton R. D. sales, Timber Sales Staff, Wayne National Forest).

Common name	Scientific name	Price
		Dollars
White Ash	*Fraxinus americana* L.	240.00
Black Walnut	*Juglans nigra* L.	240.00
Yellow Poplar	*Liriodendron tulipifera* L.	60.00
Black Cherry	*Prunus serotina* Ehrh.	240.00
White Oak	*Quercus alba* L.	150.00
Scarlet Oak	*Quercus coccinea* Muenchh.	55.00
Chestnut Oak	*Quercus prinus* L.	55.00
Red Oak	*Quercus rubra* L.	195.00
Black Oak	*Quercus velutina* Lam.	195.00

Under each alternative a no-defoliation scenario was used as the control to base the effects of defoliation upon each variable, summarized to the stand level in 2007, at the end of the simulation. Stem count, relative density (Stout and Nyland 1986), basal area, board-foot volume, and net present value were used to characterize each stand. To calculate the potential dollar losses, local stumpage values ($/MBF) for the most commercially important species were determined (Table 1). All other species were set to $35.00/MBF as the default 1997 value. Net present values (1997) for final 2007 stumpages were calculated using a 5 percent discount rate.

The two silvicultural alternatives chosen for this study consist of prescribing three parameters, the second of which depends upon the stands relative density in 1997. First, all stems less than 6 inches are removed. Second, the residual stand density is set either to 60 percent or to 80 percent of full stocking, if the 1997 relative density is above 70 percent or 90 percent, respectively. Finally, the removals are weighted toward higher removal of smaller stems, 20 percent more is removed from the smallest diameter class than is removed from the largest diameter class present and this weight is scaled down linearly from the smallest to the largest diameter class.

The GypsES Decision Support System is an expert system shell and GIS to support management of gypsy moth problems (Gottschalk et al. 1996). Besides providing access to the tree data organized in an efficiently linked database, this system provides access to stand level information, which links the models directly to the database for setting initial conditions and providing an efficient means to compile the 18 tables from each simulation of each stand for each treatment into compact files for further analysis. The menu-based selection of particular stands and system's ability to recall the structure and format designations for simulation outputs made the operation of repeated simulations much more efficient than the process would have been otherwise.

The entries provided in the summary tables were obtained as follows: first the totals across all trees in each stand simulation were calculated, then the loss in each stand was calculated as the difference between the outbreak and the no-outbreak totals. For example, the basal area is calculated and summed for all trees in each stand for each of the three simulations (no defoliation, heavy outbreak, and light outbreak), then the difference is calculated on a stand-by-stand basis (heavy minus none and light minus none), and finally the mean of these differences in basal area for each stand is presented here, as the average loss in basal area. The range of variability among the stands used in this study is also reported.

RESULTS

Three sets of alternative management scenarios were investigated: no action, light presalvage thinning to 80 percent relative stocking, and presalvage thinning to 60 percent relative stocking (B-line). The no-action alternative serves both as one alternative and as the basis for comparing effectiveness of alternate possible actions.

No Action Alternative

To ascertain how silvicultural manipulations aimed to reduce potential gypsy moth impacts could improve these stands, base-line information on the range of potential impacts is needed. The first step in this process is to simulate growth of the inventory data to the current year (1997) to provide equivalent starting points. Then each stand was projected forward from 1997 to 2007 three times: a) to estimate stand conditions in the absence of gypsy moth; b) to assess impacts of defoliation under the light outbreak scenario; and c) under the heavy outbreak scenario. These data provide the no-action alternative and bounds for assessing the effectiveness of silvicultural alternatives. By summarizing the means and extremes across these stands, we obtain the most probable boundary conditions and the basis for measuring management effects. Table 2 provides estimates of these conditions on a per acre basis.

First note that these ranges are assessed independently within each column. That is, the stand that has the smallest number of trees lost may not be the same stand that has the smallest stocking reduction, and both of these may be different from the stand with the smallest basal area loss. In this and following tables, the losses provided are due to defoliation of the residual stand following treatment and do

Table 2.—Future stand conditions following heavy and light outbreaks—losses calculated from the results of simulations on 38 stands.

Stand category	Trees lost	Stocking reduction	Basal area lost	Volume lost
	Trees/acre	Percentage	ft²/acre	MBF/acre
		Heavy Outbreak		
Average	55.9	45.0	52.0	3.0
Best	[44.0]	19.0	19.5	0.7
Worst	383.0	79.0	84.1	5.1
		Light Outbreak		
Average	19.5	6.8	7.7	0.4
Best	0.0	1.0	1.5	0.0
Worst	179.0	21.0	22.3	1.5

Note: the brackets indicate a net gain rather than a loss.

Table 3.—Losses due to defoliation calculated for the 24 stands that qualify for both presalvage treatments (no presalvage thinning done).

Stand category	— Trees lost — All	0-6	6+	Stocking reduction	Basal area lost	Volume lost
	Trees/acre			Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	69.1	13.6	55.5	55.4	62.2	3.8
Best	[22.0]	[64.0]	27.0	35.0	41.2	2.4
Worst	383.0	345.0	93.0	79.0	84.1	5.1
				Light Outbreak		
Average	21.4	10.6	10.8	9.3	10.4	0.6
Best	2.0	[11.0]	1.0	2.0	2.9	0.1
Worst	179.0	177.0	24.0	21.0	22.3	1.5

Note: the brackets indicate a net gain rather than a loss.

not include the treatments themselves. These estimates provide a view of the possible range of outcomes in susceptible stands as gypsy moth becomes established in the Dorr Run area. Losses of basal area can be expected to range from a low of 20 percent to more than 80 percent in stands heavily dominated by preferred host species, with average losses per acre over the entire area expected to be above 50 square feet of basal area and nearly 3,000 board-feet per acre.

Regeneration was included in these simulations. In the "Trees Lost" column, the loss of trees includes the compensation by ingrowth predictions. Understanding these differences requires some careful interpretation and detailed review however, because replacement trees are often a different species from those lost. Because defoliation and any subsequent tree mortality will inhibit both mast production and stump sprouting, new trees will likely be species not favored by the gypsy moth or species that produce light seeds that can be carried into a stand from surrounding areas. Even as the number of trees increases in a few stands, these new trees are very small and represent natural regeneration. Although tree counts may decline minimally or increase slightly, stocking (a measure of the trees ability to fully occupy the growing space) is reduced significantly. Closely paralleling stocking, the changes in basal area better reflect the losses of the larger trees. The changes in volume per acre (measured here in thousands of board-feet [MBF]) indicate that tree values are significant. Based on market prices as of December 1996, losses may run as high as $381.00/acre from severe outbreaks with an average loss of $245.10/acre.

To permit direct contrasts between silvicultural prescriptions and no management, we again summarize only stands that will qualify for all management prescriptions (Table 3). To qualify for thinning to 80 percent relative stocking, a stand is required to be at least 90 percent fully stocked in 1997. In the Dorr Run Area, 24 stands meet that criteria. These more heavily stocked stands also tend to show higher average losses.

To assist in review of these data, we provide the mean and range for trees lost in three classes: [1] total stems count (all) [2] the small trees (less than 6 inches), and [3] large trees (6 inches and greater). Comparing Tables 2 and 3, one can see that the stands with lower relative stocking levels (the 14 stands dropped) would be affected less by defoliation. In these heavily stocked stands, expected losses will be 20 percent higher than the general average and volume losses are expected to increase more than 25 percent to nearly 4,000 board-feet per acre. This demonstrates that the potential benefits of silvicultural treatment can be substantial.

Presalvage Treatment Alternatives

Silvicultural treatment, in which the most susceptible trees were removed, provides growing space to permit the residual stand to become healthier and more resistant to defoliation as growth rates increase. In the two presalvage treatments considered in this analysis, we assumed that the trees to be removed would be those most likely to be killed by gypsy moth defoliation (Gottschalk 1993, Gottschalk and MacFarlane 1992). Gypsy moth tends to kill higher proportions of the low-vigor trees. Although tree vigor ratings have not been done in these particular stands, established estimates of tree vigor were used from similar stands in Pennsylvania where the rate of tree mortality was measured as the gypsy moth established itself over the past two decades (Gottschalk et al. In press). These stands were comparable in species composition, stand density, and site conditions, and it is expected that similar patterns of defoliation and losses will occur in the coming decade in the

Table 4.—Losses due to gypsy moth defoliation following presalvage thinning to the 80-percent line for 24 stands that will be at least 90 percent of fully stocked in 1997.

Stand category	Trees lost All	Trees lost 0-6	Trees lost 6+	Stocking reduction	Basal area lost	Volume lost
	Trees/acre			Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	[60.1]	[94.2]	34.1	38.0	43.5	1.5
Best	[106.1]	[137.0]	19.0	30.0	34.9	2.9
Worst	[26.0]	[57.0]	62.0	53.0	56.4	3.6
	Light Outbreak					
Average	[1.6]	[2.6]	1.0	2.8	3.4	0.3
Best	[10.0]	[13.0]	[1.0]	1.0	2.0	0.1
Worst	1.0	1.0	3.0	5.0	5.7	0.5

Note: the brackets indicate a net gain rather than a loss.

Dorr Run area. Vigor is rated using a three class system (Gottschalk and MacFarlane 1992) that provides significant differences in mortality prediction power by species groupings, canopy position, and defoliation intensity (Gottschalk et al. In press, Colbert et al. In press). Tree vigor rating was the single strongest predictive variable, followed by canopy position of a tree, while species group and defoliation showed nearly equal but slightly less significant predictive power.

We next considered minimal intervention, removing only the most vulnerable trees from the most heavily stocked stands. To make that assessment, we started with the same 1997 conditions and interposed the removal of those trees that are most likely to be killed by future gypsy moth outbreaks (trees with dieback or poor vigor). Of the 38 sample stands, 24 were sufficiently overstocked (relative density greater than 90 percent of fully stocked, Stout and Nyland 1986) to be considered for minimal removals to the 80-percent line. Following the removal of those trees, we again grew the stands forward 10 years to look for changes in the descriptive measures provided above. Three projections were run over the same 10-year period following simulated presalvage entries in 1997 (Table 4).

The stem count, basal area, and volume data used to generate Table 4 were also used to generate the "80%" box-and-whisker plots in Figures 4-6. The most obvious effect is that removals done as presalvage thinning will not only save residual stocking, but also will increase the number of trees significantly. Many of the new trees will be of the same species as the trees removed because the root systems of live cut trees will allow for stump sprouting to occur. Note that this minimal presalvage harvest also saves, on average, 18.7 ft²/acre (62.2-43.5) of basal area and increases relative stocking by 17.4 percent. These translate into a relative increase of 30 percent over the no action alternative. That is, there can be an expected saving of 30 percent of the residual basal area that would otherwise be lost due to severe gypsy moth defoliation. It should be noted that these differences do not consider those trees removed during the thinning operations.

The second option considered was a heavier presalvage cut to remove more low-vigor trees, recover more of the projected loss, and have a healthier (faster growing) residual stand. In these scenarios, we considered presalvage thinning to a level that would maximize available growing space while maintaining recommended stocking levels (the B-line or 60 percent relative stocking). Of the 38 stands used in the analysis, 31 qualified for such management in 1997. Following this simulated removal in 1997, we projected stand growth through the 1998-2007 decade and again compared the differences between the moderate and heavy outbreak scenarios and the no-outbreak scenario (Table 5).

This level of presalvage thinning further reduces the overall impact of gypsy moth. It should be noted that the assumption here has not been to reduce the severity of defoliation, but rather to reduce the expected level of tree mortality by removing trees expected to die as a result of a gypsy moth outbreak. Preventative treatments offer substantial economic savings and improve the overall health of the residual forest. Enhanced by increased growing space and nutrient availability, both regeneration and residual trees respond with improved growth and vigor. Furthermore, these conditions improve the tree's chances to recover from defoliation with minimal damage, as is demonstrated in the heavy outbreak scenarios when we compare the average stocking among these three tables. Loss in stocking drops from a 45 percent loss with no management, to 38 percent when lightly thinned, and to a 27.6 percent loss when these forest

Table 5.—Losses due to gypsy moth defoliation following presalvage thinning to the 60-percent line for the 31 stands that will be at least 70 percent fully stocked in 1997.

Stand category	Trees lost	Stocking reduction	Basal area lost	Volume lost
	Trees/acre	Percentage	ft²/acre	MBF/acre
		Heavy Outbreak		
Average	[29.5]	27.6	32.4	2.1
Best	[80.0]	15.0	22.0	1.5
Worst	14.0	39.0	41.3	2.7
		Light Outbreak		
Average	2.7	1.5	1.9	0.1
Best	[4.0]	1.0	1.1	0.0
Worst	7.0	3.0	3.8	0.3

Note: the brackets indicate a net gain rather than a loss.

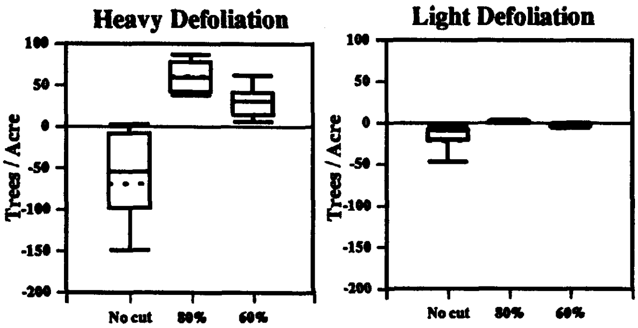

Figure 4.—Tukey box plots of predicted tree count differences in 2007 under the three alternative silvicultural practices. The whiskers are at 5 and 95 percent of the data range while the boxes span the 25 to 75 percent range with a solid 50th percentile and a dashed mean line.

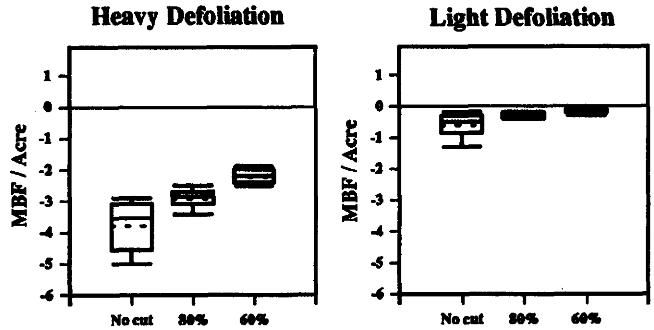

Figure 6.—Tukey box plots of standing volume differences in 2007 under the three alternative silvicultural practices.

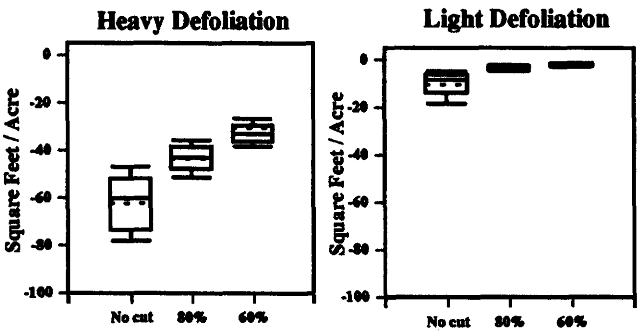

Figure 5.—Tukey box plots of basal area differences in 2007 under the three alternative silvicultural practices.

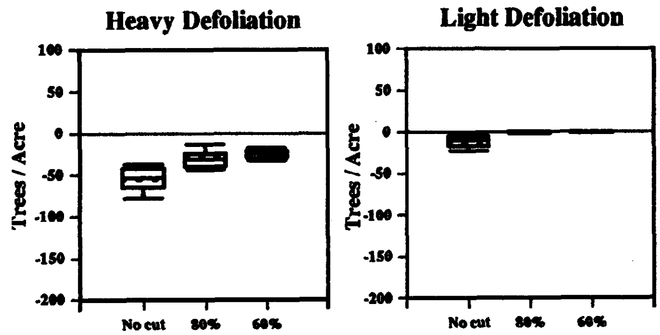

Figure 7.—Tukey box plots of predicted large (> 6 in.) tree count differences in 2007 under the three alternative silvicultural practices.

management practices are used to remove the most vulnerable trees. The end result could almost double the amount of healthy forest canopy in the average stand. To permit direct comparisons with Tables 3 and 4, we again summarize just the 24 heaviest stocked stands after cutting to the B line (Table 6).

Table 6—Losses due to gypsy moth defoliation following presalvage thinning to the 60-percent line for the 24 stands that will be at least 90 percent fully stocked in 1997.

Stand category	— Trees lost — All	0-6	6+	Stocking reduction	Basal area lost	Volume lost
		Trees/acre		Percentage	ft²/acre	MBF/acre
				Heavy Outbreak		
Average	[30.2]	[55.5]	25.3	28.8	33.0	2.2
Best	[80.0]	[103.0]	15.0	22.0	26.6	1.9
Worst	[3.0]	[21.0]	45.0	39.0	41.3	2.7
				Light Outbreak		
Average	2.8	2.2	0.6	1.7	2.1	0.2
Best	[1.0]	[1.0]	[1.0]	1.0	1.1	0.1
Worst	7.0	6.0	2.0	3.0	3.8	0.3

Note: the brackets indicate a net gain rather than a loss.

Note that basal area and volume losses increase only slightly over the values in Table 5. Contrasting these averages with those of Tables 3 and 4 show that increased intensity of presalvage thinning will increase the savings in the residual stands. Basal area losses are reduced by 30 percent under light thinning and by 47 percent under this B-line thinning. Throughout these analyses we have concentrated on the standing timber and the residual stands, not considering the revenue generated nor any other value estimates for timber removed during these presalvage thinnings. The data used to generate Table 6 also were used to generate the Tukey box-and-whisker plots labeled "60%" in Figures 4-6.

We examined these results using analysis of variance techniques to explore variation among the compartments and forest types under consideration and found no significant differences among compartments. Thus, we conclude that these results can be applied across the area and that they represent the range of expected future impacts that gypsy moth will cause as it becomes established in the Dorr Run Area.

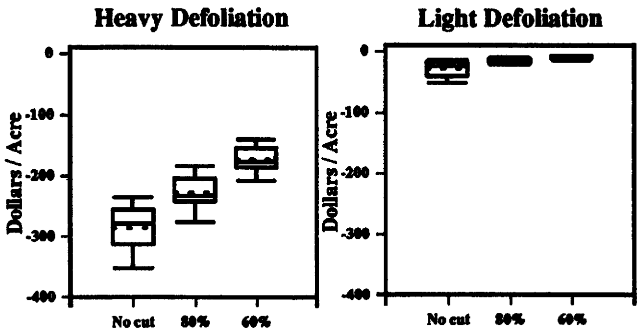

Figure 8.—Tukey box plots of volume dollar differences in 2007 (discounted to 1997 using a 5 percent rate) under the three alternative silvicultural practices.

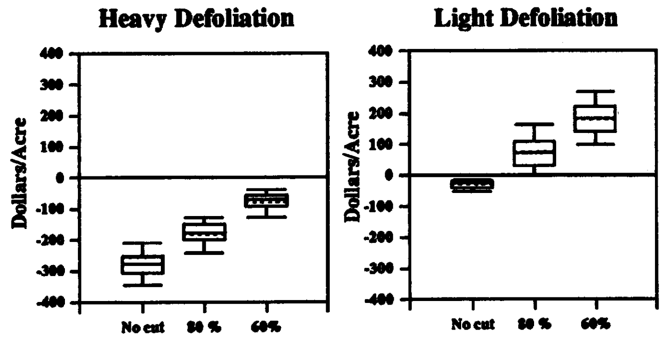

Figure 10.—Tukey box plots of net effects—sum of net present value (1997) of stands in 2007 and removal in 1997 on a stand-by-stand basis under the three alternative silvicultural practices.

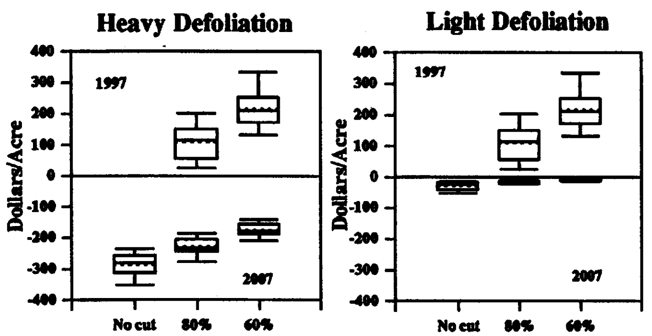

Figure 9.—Tukey box plots of present (1997) value of volume dollar differences in 2007 under the three alternative silvicultural practices, with the dollar value of the trees removed in 1997.

Ingrowth during the decade following silvicultural entry is confounding the ability to see drops in stem counts (Fig. 4). Using only trees greater than 6 inches the effect of defoliation on larger trees is apparent (Fig. 7). By comparing Figures 4 and 7, three things are made more evident: predicted ingrowth will be substantial, even in the "No cut" stands due to losses in the overstory; the range of variation in overstory stem count losses is much less than the variability in regeneration response; and silvicultural intervention will produce substantial advanced regeneration in front of the expected outbreak. Coupling these potential regeneration changes with expected basal area and volume changes in the overstory and the expected variation in average defoliation among stands following an outbreak, one can expect the losses to be reduced significantly through silvicultural intervention as selection of the highest vigor and least susceptible trees is made in the residual stands.

Dollar values of standing timber in 2007 can be viewed in current 1997 dollars by applying a 5 percent discount rate to arrive at a net present value. This provides a consistent measure for comparing current management alternatives and future stand conditions. Figure 8 shows the changes in the range of dollar values under the three management alternatives. Note that significant reductions in dollar losses are achieved under the minimal removal alternative, and further significant reductions are attained by normal B-line presalvage thinning under heavy defoliation only. These reductions are to the residual standing crop, and do not take into account the value of the 1997 removals (Fig. 9). Combining the dollar gains from sales with the losses, one sees the net value of management in Figure 10. Note that minimal presalvage thinning will nearly cut the losses from heavy defoliation in half, and B-line thinning will reduce losses by more than 75 percent.

CONCLUSIONS

The purpose of this study was to provide the most current management tools for silviculturists on the Wayne National Forest as they attempt to deal with the impending outbreaks of gypsy moth in southeastern Ohio. The cooperative effort provided the Wayne National Forest with the latest modelling tools and methodology integrated within a decision support shell, GypsES, that further provided the GIS tools and database resource facilities. Stand-Damage Model simulations indicate that substantial savings can be made through silvicultural management applications and that the gypsy moth can be expected to cause greater losses in the absence of management. This work provided a demonstration of management application capabilities of the models and follow-up tests done cooperatively over the coming decade will provide further examination of these working hypotheses. The stumpage prices used in this analysis are less than those in 1997 in West Virginia and Pennsylvania for these species under similar site indices. Thus, the predicted dollar losses per acre are conservative estimates, given the potential mortality. Recent presalvage and salvage treatments on the George Washington and Monongahela National Forests have shown success in providing healthy residual stands of ample productivity and were found to be profitable to local purchasers.

LITERATURE CITED

Carmean, Willard H.; Hahn, Jerold T.; Jacobs, Rodney D. 1989. **Site index curves for forest trees species in the eastern United States.** Gen. Tech. Rep. NC-128. St. Paul MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 142 p.

Colbert, J. J.; Perry, Phil; Onken, Brad. In press. **Predicting potential damage from gypsy moth defoliation and designing management actions to ameliorate losses.** Fosbroke, Sandra L. C., Gottschalk, Kurt W., eds. Proceedings, U.S. Department of Agriculture interagency gypsy moth research forum 1997; 1997 January 14-17; Annapolis, MD. Gen. Tech. Rep. NE-xxx. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Colbert, J. J.; Racin, George. 1995. **User's guide to the Stand-Damage Model: a component of the Gypsy Moth Life System Model (Version 1.1) [Computer program].** Gen. Tech. Rep. NE-207. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 38 p. [1 computer disk (3-1/2 in.); User's manual.]

Colbert, J. J.; Sheehan, Katharine A. 1995. **Description of the Stand-Damage Model: a component of the Gypsy Moth Life System Model.** Gen. Tech. Rep. NE-208. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 111 p.

Gottschalk, Kurt W. 1993. **Silvicultural guidelines for forest stands threatened by the gypsy moth.** Gen. Tech. Rep. NE-171. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 49 p.

Gottschalk, Kurt W.; Colbert, J. J.; Feicht, David L. In press. **Tree mortality risk of oak due to gypsy moth.** European Journal of Forest Pathology. 12 p.

Gottschalk, Kurt W.; MacFarlane, W. Russ. 1992. **Photographic guide to crown condition in oaks: use for gypsy moth silviculture.** Gen. Tech. Rep. NE-168. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Gottschalk, Kurt W.; Thomas, Susan J.; Twardus, Daniel B.; Ghent, John H.; Colbert, J. J.; Teske, Milton H. 1996. **GypsES: A decision support system for gypsy moth management.** In: Shore, Terry L. ; MacLean, David A., eds. Decision Support Systems for Forest Pest Management. Proceedings of a workshop at the Joint Meeting of the Entomological Societies of Canada and British Columbia; 1995, October 17; Victoria, BC. FRDA Report No. 260. Canada-British Columbia partnership Agreement on Forest Resource Development: FRDA II. November 1996. Pacific Forestry Centre, 506 W. Burnside Rd., Victoria, BC V8Z 1M5. Canadian Forest Service: 1-8.

Liebhold, Andrew M.; Gottschalk, Kurt W.; Luzader, Eugene R.; Mason, Douglas A.; Bush, Renate; Twardus, Daniel B. 1997. **Gypsy moth in the United States: an atlas.** Gen. Tech. Rep. NE-233. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Liebhold, Andrew M.; Gottschalk, Kurt W.; Muzika, Rose-Marie; Montgomery, Michael E.; Young, Regis; O'Day, Kathleen; Kelly, Brooks. 1995. **Suitability of North American tree species to gypsy moth: a summary of field and laboratory tests.** Gen. Tech. Rep. NE-211. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 34 p.

Northeastern Area State and Private Forestry. 1995. **Gypsy moth management in the United States: a cooperative approach**: Final environmental impact statement, November 1995. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. Vol. I-V.

Stout, S. L.; R. D. Nyland. 1986. **Role of species composition in relative density measurement in Allegheny hardwoods.** Canadian Journal of Forest Research. 16: 574-579.

ACKNOWLEDGMENTS

The authors thank Jim Dobson for his assistance in collecting field data, putting data into machine readable format, and transferring data to the Morgantown Lab for analysis. We thank Karen Felton for generating the simulation results used in this study. We also thank Kevin Hosman for assistance in generating summary statistics, running analyses, and generating graphics for presentations and figures.