

Effects of Silvicultural Management on Gypsy Moth Dynamics and Impact: An Eight-Year Study

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ABSTRACT A long-term study initiated in 1989 at the West Virginia University Forest contrasted the effects of silvicultural treatments on the development of gypsy moth (*Lymantria dispar* L.) outbreaks and their impacts. The area is a relatively susceptible *Quercus* spp./mixed hardwood forest. Egg mass densities, survivorship, and mortality from natural enemies differed little between stands that were treated silviculturally and those that were not. However, stands that were thinned had less overstory mortality than unthinned stands despite incurring comparable levels of defoliation.

THE GYPSY MOTH (*Lymantria dispar* L.) is a polyphagous insect first introduced into North America in the late 1860s. Since that time, its range has expanded steadily from the northeastern United States to large areas of commercial forests in the Appalachian Mountains. Outbreaks are likely to be intense and substantially affect forest resources in those areas. While it is possible to reduce defoliation levels by applying pesticides aerially, other approaches to managing gypsy moth are needed because of the expense and ecological impact of pesticides on the environment. Several silvicultural approaches to managing gypsy moth populations have been proposed over the last 100 years (Fiske 1913, Clement and Munro 1917, Behre 1939, Bess et al. 1947, Gottschalk 1993). All have emphasized the use of sanitation thinning to reduce or eliminate host species preferred by the gypsy moth. Theoretically, this technique would lower stand susceptibility (defoliation potential). Gottschalk (1993) also proposed the use of presalvage thinning to remove low-vigor host trees to reduce stand vulnerability (likelihood of mortality following defoliation).

Of the relatively few studies that have examined the effectiveness of silvicultural manipulations in reducing stand susceptibility and vulnerability, most have focused on the effects of thinning on gypsy moth impacts with respect to forest stand structure and composition. In addition, there is a need to understand how silvicultural manipulations may influence the dynamics of gypsy moth populations. The objectives of this study were to test the effects of both presalvage and sanitation thinning on gypsy moth dynamics. Specifically, we tested how thinnings affected changes in egg mass density, patterns of within-generation survivorship, and the amount of mortality caused by various gypsy moth parasitoids and pathogens. We also evaluated the resulting forest vegetation following thinnings and the long-term impact of gypsy moth populations.

Materials and Methods

The study area was located at the West Virginia University Forest (WVUF) in Monongalia and Preston Counties. In 1989, 16 stands (average size 10.5 ha) that reflected a range of overstory types were established on the WVUF. Some stands were mixed hardwood, with only 15% oak (*Quercus* spp.) in the overstory, while others were mixed oak, with more than 80% of the basal area in oak species. Each stand was paired with an adjacent stand bearing similar vegetation and site characteristics. In the winter of 1989-90, one stand of each pair was selected for thinning. In stands where oak accounted for a low proportion of stand basal area (mostly less than 50%), a sanitation thinning was applied. The primary objectives when marking trees were to reduce total stand basal area and preferentially remove host-tree species preferred by the gypsy moth (Gottschalk 1993). In stands where oak accounted for a higher proportion of stand basal area (greater than 50%), presalvage thinning was applied. The principal objective was to remove trees in poor condition regardless of species or their preference by gypsy moth larvae (Gottschalk 1993).

Gypsy moth sampling. Gypsy moth populations were sampled before thinning and each year thereafter until 1996 by counting all egg masses in 0.01-ha (1/40-acre) plots in each stand (Liebhold et al. 1994). Within each stand, plots were located in a grid with 100 m between sampling points. Each stand had 10 to 19 permanent plots depending on stand size.

In stands where larval densities were sufficiently high, larvae were collected weekly to quantify mortality due to parasitism and disease. The first larval sample was timed to coincide with larval hatch and the last sample was taken when pupation began. When available, 100 larvae were collected each week at five sampling locations within each stand. Early instars were collected by sampling foliage of saplings and seedlings; late instars and pupae were collected from tree boles and also from burlap bands that were placed around trees.

Larvae were placed in individual 30 ml plastic cups containing artificial diet. The cups were placed in an outdoor insectary located on the WVUF so that temperature and phenological development were approximately the same as that for field populations. Each cup was checked weekly until eclosion. The presence of parasitoids in each cup was recorded and cadavers were inspected microscopically for viral polyocclusion bodies or fungal spores. The maximum percent mortality among collections was used as the estimate of mortality occurring for each agent in the field. Peak percentage mortality is the best measure of parasitoid and disease impact under the sampling plan used in this study (Gould et al. 1989).

Because mortality caused by various gypsy moth parasitoids and pathogens is density dependent (Elkinton and Liebhold 1990), we wanted to evaluate the effect of thinning on mortality using an analysis that accounted for variation in host density. Stepwise regression (Draper and Smith 1981) was used to model peak mortality (transformed using an arcsine-square root transformation) as a linear function of: (1) N_t , gypsy moth density [$\log(x+1)$] at the beginning of the current generation; and (2) N_{t-1} , gypsy moth density [$\log(x+1)$] at the beginning of the prior generation. Each of these independent variables was successively added to the model; the probability associated with the F statistic ($P < 0.05$) for each independent variable was used as the criterion for entering and retaining each term in the model. These selected variables were included as covariates in an analysis of variance where we assumed a randomized complete-block design (Steel and Torrie 1980). Peak percent

mortality was the response, N_t and N_{t-1} were included as covariates (only if they were significant in the stepwise regression), and treatment (thinning) and block were the effects.

Vegetation sampling. Overstory vegetation was sampled in 1989 prior to silvicultural treatments, and each year thereafter. Measurements were taken on overstory vegetation on each of 20 0.04-ha (0.1-acre) plots in the 16 stands. All overstory vegetation (dbh \geq 6.3 cm) in each plot was identified as to species and measured. Defoliation estimates were taken on each overstory tree. The percentage of foliage removed was estimated visually and the estimates weighted by the diameter of the defoliated tree.

Results and Discussion

In this study, eight distinct causes of larval mortality were identified across all stands (Table 1). Unidentifiable causes, however, accounted for the majority of gypsy moth larval mortality in each year except 1991. Not all mortality agents were recovered in all stands.

Table 1. Peak percent mortality each year from mortality agents of gypsy moth, based on weekly collections of larvae and pupae

| Item | 1990 | 1991 | 1992 | 1993 | 1994 |
|--------------------------------|------|------|------|------|--------------|
| Unidentified | 71.0 | 47.5 | 86.8 | 91.1 | 90.1 |
| NPV | 34.7 | 86.3 | 51.4 | 41.5 | 17.6 |
| <i>Entomophaga maimaiga</i> | 0 | 0 | 5.7 | 36.7 | 2.0 |
| <i>Parasetigena silvestris</i> | 1.1 | 19.8 | 25.2 | 30.3 | 36.2 |
| <i>Cotesia melanoscela</i> | 0 | 1.7 | 11.6 | 28.7 | 19.8 |
| <i>Blepharipa pratensis</i> | 22.7 | 13.4 | 20.3 | 8.4 | ^a |
| <i>Brachymeria intermedia</i> | 3.4 | 19.8 | 2.9 | 3.0 | ^a |
| <i>Compsilura concinnata</i> | 1.0 | 16.2 | 6.9 | 5.6 | 16.8 |
| <i>Phobocampe uncinata</i> | 0 | 0 | 6.8 | 3.0 | 9.2 |

^a Incomplete data

The relationship between parasitism and host density varied considerably among parasitoid species (Table 2). Parasitism by *Brachymeria intermedia*, *Compsilura concinnata*, *Cotesia melanoscela*, and *Parasetigena silvestris* was positively related to density in the current generation, N_t , and parasitism by *Blepharipa pratensis* was inversely related to N_t , reflecting the delayed density dependence of these parasitoids.

Parasitism by *C. concinnata*, *C. melanoscela*, and *P. silvestris* was inversely related to host density in the previous generation, N_{t-1} . These patterns are mostly in agreement with previous studies (Elkinton and Liebhold 1990, Williams et al. 1992, 1993).

Mortality caused by the nuclearpolyhedrosis virus (NPV) was highest in 1991 but only in defoliated stands where it caused populations to decline in subsequent years. Overall, virus mortality was positively related to both density in the current and previous generation (Table 2), and generally concurs with existing knowledge of NPV epizootiology (Doane 1970, Woods et al. 1991). By contrast, *Entomophaga maimaiga* caused considerable mortality in 1993 but much less mortality in 1992 and 1994, and no mortality prior to 1992. Mortality caused by *E. maimaiga* was first discovered in North America in New England in

1989. By 1992, this pathogen apparently expanded its range to encompass nearly the entire range of the gypsy moth (Hajek et al. 1995). Thus, its absence in our samples from 1989 to 1991 can be explained by its general absence from the region during that period.

Table 2. Results of stepwise regression of peak mortality on egg mass density (N_t) and lag egg mass density (N_{t-1})

| Dependent variable | Independent variable ^a | Estimate | Probability of $\alpha > F$ |
|--------------------------------|-----------------------------------|----------|-----------------------------|
| <i>Blepharipa pratensis</i> | N_t | -0.070 | 0.047 |
| | N_{t-1} | 0.12 | 0.002 |
| <i>Brachymeria intermedia</i> | N_t | 0.14 | 0.0006 |
| <i>Compsilura concinnata</i> | N_t | 0.12 | 0.0001 |
| | N_{t-1} | -0.077 | 0.006 |
| <i>Cotesia melanoscela</i> | N_t | 0.12 | 0.003 |
| | N_{t-1} | -0.20 | 0.0001 |
| <i>Phobocampe uncinata</i> | N_{t-1} | -0.061 | 0.002 |
| <i>Parasetigena silvestris</i> | N_t | 0.10 | 0.012 |
| | N_{t-1} | -0.20 | 0.0001 |
| NPV | N_t | 0.16 | 0.003 |
| | N_{t-1} | 0.13 | 0.009 |
| unknown | N_{t-1} | -0.14 | 0.0001 |

^a N_t = egg mass density at the beginning of the same generation [$\log(1 + \text{egg mass/ha})$], N_{t-1} = egg mass density at the beginning of the previous generation [$\log(1 + \text{egg mass/ha})$].

Rates of parasitism by *P. silvestris* and *C. melanoscela* generally increased from 1989 through 1994. Perhaps this is related to the increasing population densities of gypsy moth over this period. Another cause of the increase in parasitism rates is that they tend to be low in newly established populations along the expanding population front; range expansion by parasitoids tends to lag behind the expansion of host gypsy moth populations (Ticehurst et al. 1978).

When gypsy moth larval mortality between thinned and unthinned stands was compared using a paired *t*-test (Sokal and Rohlf 1981), we found parasitism by *B. intermedia* and *C. melanoscela* significantly higher in thinned stands, and mortality caused by NPV significantly lower in thinned stands (Table 3). However, the results in Table 2 indicate that mortality is often closely associated with gypsy moth densities. Therefore, the differences in mortality rates may be due to differences in gypsy moth densities between thinned and unthinned stands. As a result, it was necessary to assess the significance of thinning on mortality rates using an analysis of covariance, where gypsy moth density and/or lagged density were used as covariates. The least squares means in Table 3 adjust mortality rates based on the known relationship(s) with gypsy moth density. None of the least squares means indicated a significant effect on thinning. Thus, the adjusted analysis indicated that thinning had no effect on mortality rates.

Table 3. Unadjusted means and least squares means (adjusted for covariates listed in Table 1) for transformed peak percent mortality

| Dependent variable | Unadjusted mean | | Least squares mean | |
|--------------------------------|-----------------|---------|--------------------|---------|
| | unthinned | thinned | unthinned | thinned |
| <i>Blepharipa pratensis</i> | 0.291 | 0.306 | 0.270 | 0.327 |
| <i>Brachymeria intermedia</i> | 0.092 | 0.150* | 0.088 | 0.154 |
| <i>Compsilura concinnata</i> | 0.238 | 0.213 | 0.232 | 0.236 |
| <i>Cotesia melanoscela</i> | 0.261 | 0.271* | 0.243 | 0.309 |
| <i>Phobocampe uncinata</i> | 0.054 | 0.093 | 0.098 | 0.075 |
| <i>Parasetigena silvestris</i> | 0.334 | 0.385 | 0.357 | 0.370 |
| NPV | 0.631 | 0.549* | 0.555 | 0.583 |
| unknown | 0.973 | 1.00 | 0.994 | 1.01 |

* Significant at $\alpha = 0.05$.

Figure 1 shows the temporal pattern of gypsy moth dynamics, defoliation, and overstory mortality for paired thinned/unthinned stands with high egg mass densities. Populations of gypsy moth increased rapidly from 1989 to 1990 and egg mass density (Fig. 1a) and defoliation (Fig. 1b) were greatest in 1991. Live basal area (Fig. 1c) began to decline in 1991 and overstory mortality was greatest between 1991 and 1992. Both egg mass density and defoliation appeared to be greater in unthinned than thinned stands, but the differences were not statistically significant. It is possible that differences were not observed because gypsy moth densities were already at outbreak levels. Following 2 years of defoliation in these stands, populations collapsed to low densities such that it probably would be difficult to detect differences in densities due to thinning (Fig. 1). However, it is also apparent that thinned stands experienced less overstory mortality than their unthinned counterparts.

Since we detected a decrease in gypsy moth densities following thinning in only two of eight thinned stands, it is difficult to conclude that thinning caused a reduction in densities. However, numerous studies have reported that outbreak frequency is closely related to the proportion of stand basal area represented by host-tree species preferred by the gypsy moth (Bess et al. 1947, Houston and Valentine 1977, Herrick and Gansner 1986). Perhaps we did not observe a more dramatic decrease in gypsy moth densities in thinned stands because the proportion of basal area in preferred species was not reduced greatly in any of the stands following thinning. Nevertheless, our results suggest that any reduction in gypsy moth density caused by thinning is most likely not the result of differential response by natural enemies but rather is due to another factor, for example, mortality occurring during dispersal and/or effects on fecundity. Despite demonstration of an apparent lack of effect on gypsy moth populations caused by thinning, there was a distinct difference in overstory mortality between the thinned and unthinned stands.

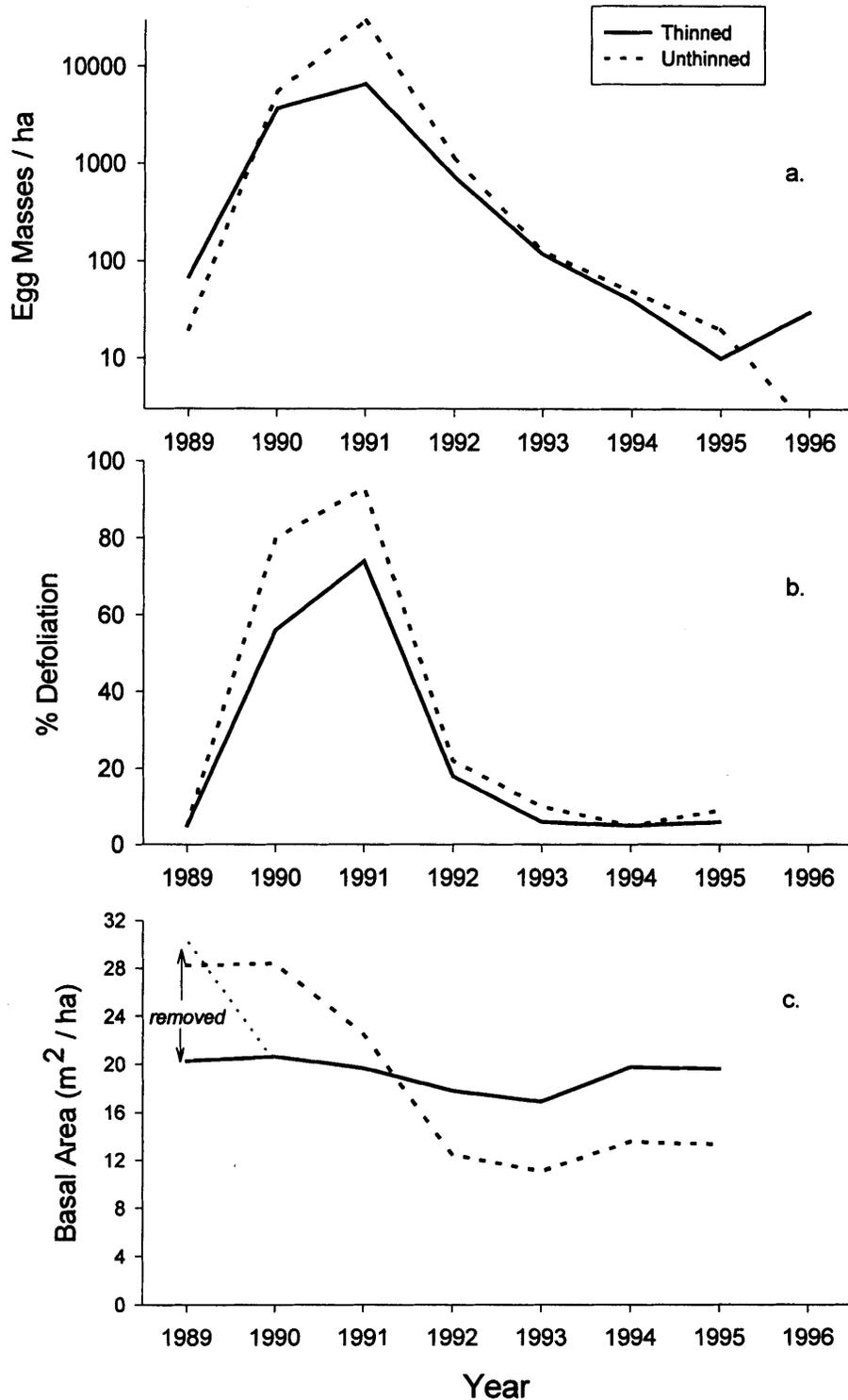


Figure 1. (a) Gypsy moth egg mass density from 1989 to 1996; (b) defoliation estimates of overstory trees from 1989 to 1995; (c) live basal area in defoliated stands; the amount of basal area removed in the silvicultural thinning is represented by the length of the arrow and small dashed line at the 1989 mark.

Conclusion

In this study we were unable to determine that thinning significantly altered rates of gypsy moth mortality caused by specific parasitoids or pathogens. Similarly, Grushecky (1995) found no effect of silvicultural thinning on predation of gypsy moth life stages. Thus, it seems unlikely that these silvicultural operations can reduce the frequency or intensity of gypsy moth outbreaks by enhancing the activity of natural enemies. However, the lack of a detectable effect of thinning on the action of these natural enemies does not preclude the feasibility of using silvicultural approaches to manage gypsy moth populations. Our data provide evidence that thinning may help to reduce mortality, though it may actually increase defoliation in certain situations.

Silvicultural manipulations are more likely to affect stand susceptibility simply by reducing the total or relative amount of host foliage (Gottschalk 1993) than by affecting gypsy moth populations directly. Moreover, silvicultural manipulations can be useful tools in gypsy moth management by removing and utilizing trees that are likely to die as a result of defoliation (i.e., those with poor crowns).

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