Forest Susceptibility to the Gyps

By Andrew M. Liebhold, Kurt W. Gottschalk, Douglas A. Mason, and Renate R. Bush

A gypsy moth infestation killed these oaks in south-central Pennsylvania in the 1980s. Such scenes may become common in the West and South as the gypsy moth, which feeds on many hosts, marches on.

M. Twery

Since 1868 or 1869, when it was introduced near Boston, the gypsy moth has been slowly expanding its range to include the entire northeastern United States and portions of Virginia, West Virginia, North Carolina, Ohio, and Michigan (Liebhold et al. 1992, 1996). It is inevitable that the gypsy moth will continue to spread south and west over the next century.

The extent of gypsy moth defoliation has already been documented via aerial sketch mapping, among other techniques. This information has been used to map the distribution of forests susceptible to the gypsy moth within the infested region (Liebhold and Elkinton 1989; Liebhold et al. 1994). To manage the gypsy moth over the next decade and beyond, however, foresters need to delimit the distribution of susceptible stands in areas that are not yet infested.

The gypsy moth is a polyphagous insect; North American populations feed on more than 300 shrub and tree species (Leonard 1981; Liebhold et al. 1995). Despite this breadth of host preference, forests in the Northeast have varied considerably in their susceptibility to defoliation. We define *susceptibility* as the probability or frequency of defoliation given an established gypsy moth population (Gottschalk 1993).

Several studies have identified the characteristics of susceptible forests and yielded susceptibility models of varying levels of complexity. Probably the most important factor affecting stand susceptibility is the proportion of basal area represented by the gypsy moth's preferred species (Herrick and Gansner 1986). Other variables, such as the predominance of chestnut oak, the abundance of bark flaps and other structural features of trees, and various site characteristics, such as soils, have also been correlated with susceptibility (Bess et al. 1947; Valentine and Houston 1979; Herrick and Gansner 1986). Use of these variables is often limited, however, because the correlations are specific to certain regions, or the variables are rarely measured in most forest inventories.

Gansner et al. (1993) demonstrated how susceptibility models can be applied to forest inventory data to map forest susceptibility at the landscape level. Their analysis was applied to only a few mid-Atlantic states. In this study, we used a similar technique to map forest susceptibility over the conterminous United States.

Moth

Methods

Assessment of forest susceptibility was based on existing forest inventory data. In the eastern United States, all inventory data were obtained from the USDA Forest Service Forest Inventory and Analysis (FIA) group (Hansen et al. 1993). In the East, FIA data are available for federal as well as private land. Inventories are usually conducted every five to 15 years and typically include more than 1,000 irregularly spaced plots in each state. For the West, where FIA does not inventory national forests, we used a mixture of FIA data and inventories made by individual national forests. For a complete description of the data compiled for this analysis, see Liebhold et al. (1997).

Sampling methods used for inventorying forest resources varied by region and organization, but all inventory data contained information on both individual trees and plots. Individual tree records were used to sum total basal area by species for each plot. These plot records were then expanded (using appropriate expansion factors) to county-level estimates of basal area per acre. Basal area was summarized at the county level because the exact locations of many plots were not available and counties were thus the most precise locators.

Although inventory data exist for most of the conterminous United States, complete inventories were lacking in certain areas (designated "no data" in *figs. 1–5)*. State and private lands in the western two-thirds of Oklahoma and Texas, for example, were not inventoried by FIA, and in certain portions of the West, complete national forest inventory data were not available.

We adopted proportion of basal area represented by preferred species as the measure of forest susceptibility because it appears to be the most important factor explaining stand susceptibility (Herrick and Gansner 1986). Although other variables (such as proportion of chestnut oak) may add to

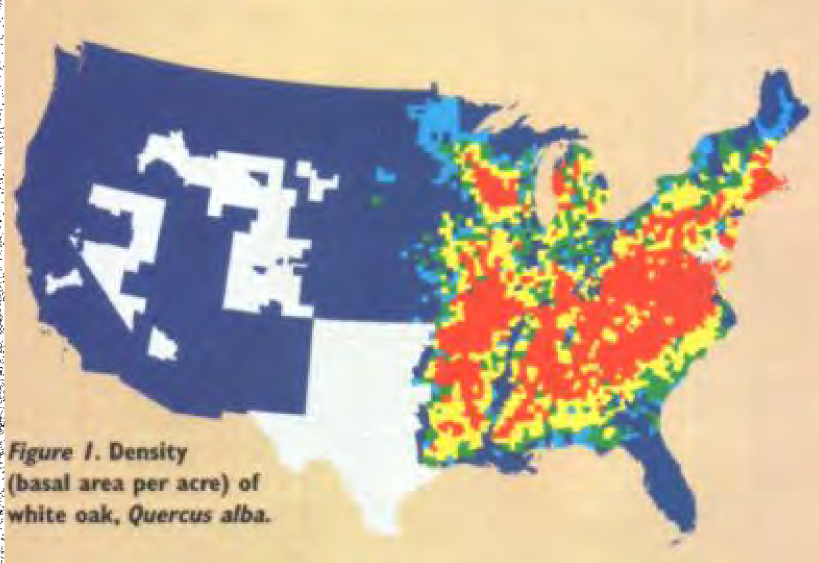

***Figure 1.* Density (basal area per acre) of white oak, *Quercus alba*.**

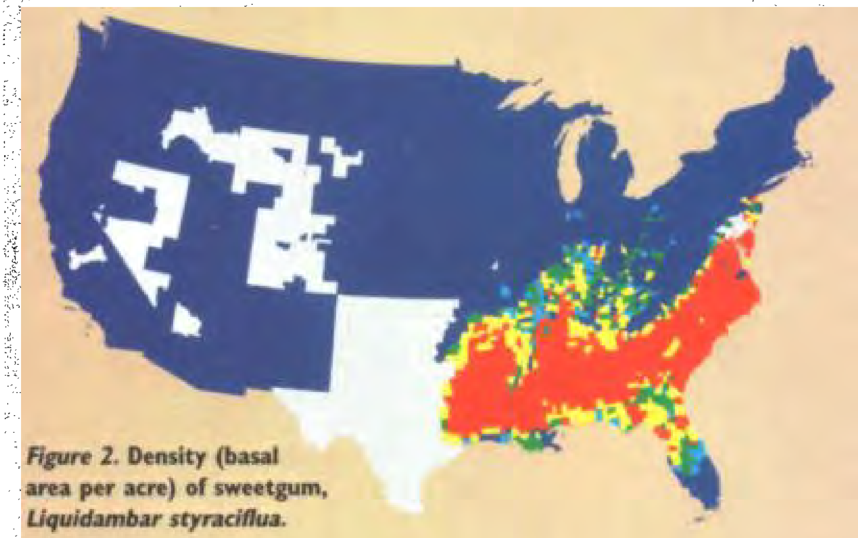

***Figure 2.* Density (basal area per acre) of sweetgum, *Liquidambar styraciflua*.**

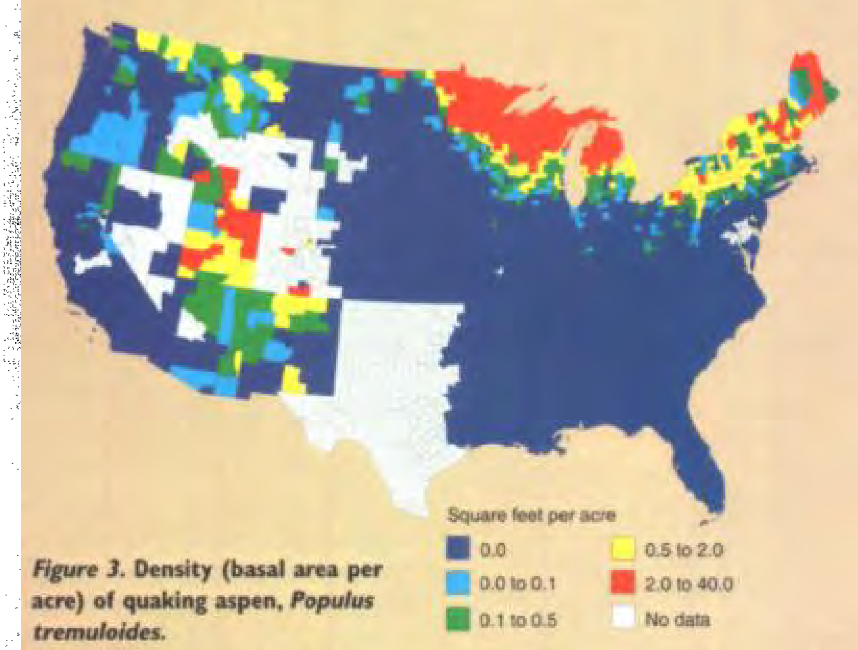

***Figure 3.* Density (basal area per acre) of quaking aspen, *Populus tremuloides*.**

Table 1. Twenty most abundant preferred tree species ranked on total basal area.

Common name	Species	Total basal area (ft^2/ac)
White oak	*Quercus alba*	1,425,469,238
Sweetgum	*Liquidambar styraciflua*	1,160,080,502
Quaking aspen	*Populus tremuloides*	1,008,381,226
Northern red oak	*Quercus rubra*	961,704,056
Black oak	*Quercus velutina*	730,510,718
Chestnut oak	*Quercus prinus*	684,442,053
Post oak	*Quercus stellata*	547,079,960
Water oak	*Quercus nigra*	433,745,718
Paper birch	*Betula papyrifera*	381,347,899
Southern red oak	*Quercus falcata*	375,025,826
Scarlet oak	*Quercus coccinea*	331,007,331
Western larch	*Larix occidentalis*	239,768,697
Laurel oak	*Quercus laurifolia*	194,413,538
Bigtooth aspen	*Populus grandidentata*	190,339,657
Tanoak	*Lithocarpus densiflorus*	164,425,005
Willow oak	*Quercus phellos*	148,909,445
California red oak	*Quercus kelloggii*	145,454,922
Eastern hophornbeam	*Ostrya virginiana*	125,861,257
Canyon live oak	*Quercus chrysolepis*	113,521,616
Bur oak	*Quercus macrocarpa*	110,982,005

the precision of susceptibility predictions, these models are less applicable outside the range of data originally used to calibrate them. Montgomery's (1991) classification was used to categorize each tree species as susceptible (= preferred), resistant, or immune. This classification was based on a summary of field and laboratory studies, as well as extrapolations based on taxonomic affinity, and is described in detail elsewhere (Liebhold et al. 1995).

To validate the susceptibility model and data used in this analysis, we compared county-level predictions of susceptibility with historical defoliation observed in infested areas. Specifically, we made five computations for each county in Massachusetts, Connecticut, New Jersey, and Pennsylvania:

1. total basal area of preferred species;
2. proportion of stand basal area in preferred species;
3. proportion of land area covered by susceptible stands (>20 percent of basal area in preferred species);
4. proportion of land area covered by highly susceptible stands (>50 percent of basal area in preferred species); and
5. proportion of land area covered by extremely susceptible stands (>80 percent of basal area in preferred species).

We examined the correlation of each variable with average defoliation in each county. Average defoliation was computed by first scanning historical aerial sketch maps and then overlaying all years to obtain a historical defoliation frequency (Liebhold et al. 1994, 1995, 1997). For Massachusetts, the maps were dated 1961–1990; for Connecticut, 1965–1990; for New Jersey, 1968–1990; and for Pennsylvania, 1969–1990. In Pennsylvania and New Jersey, defoliation frequency was adjusted based on the number of years the area had been part of the generally infested area (Liebhold et al. 1994). Defoliation frequency in each 2-square-kilometer cell was averaged for each county and then compared with the susceptibility values in the same county

Results and Discussion

Table 1 lists the 20 most abundant preferred species, ranked on their total basal area over the inventoried area. Of the 10 most highly ranked species, only one—quaking aspen—occurs in the West. Some caution should be used in interpreting this ranking because the lack of inventory data in certain western counties *(fig. 1)* resulted in a bias favoring eastern species. Nevertheless, these data indicate that most of the susceptible forests are concentrated in the East

White oak was the highest-ranked susceptible species *(table 1).* Although white oak grows throughout the East, the highest concentrations exist in the Ozarks, the Cumberland Plateau, and the southern Appalachians. Most of these areas are beyond the current range of the gypsy moth. Sweetgum was the second most abundant susceptible species. This species is common throughout the Piedmont from North Carolina to Louisiana but also grows mainly beyond the moth's current range *(fig. 2).* Quaking aspen, the third most abundant preferred species, is one of only a few tree species with a transcontinental distribution. It is most abundant in the northern portions of the Lake States *(fig. 3).* Figures depicting the range of other gypsy

Table 2. Correlation coefficients of county-level measurements of susceptibility with historical frequency of defoliation averaged over each county.

State	Preferred basal area (ft^2/ac)	Proportion of basal area in preferred species	Land area >20%	Land area >50%	Land area >80%	Number of counties
Connecticut	0.58386	0.57715	0.63023	0.67538	0.54242	8
Massachusetts	0.08076	0.44005	0.41143	0.51479	0.44216	11
New Jersey	0.36070	0.21427	0.39413	0.29875	–0.02275	16
Pennsylvania	0.61277	0.39152	0.65013	0.60254	0.49057	60
Combined	**0.52268**	**0.37590**	**0.54628**	**0.54624**	**0.35872**	**95**

moth hosts can be found in Liebhold et al. (1997).

Overall forest susceptibility for each county was quantified using the five measures listed above *(figs. 4 and 5).* All five measures yielded maps that indicated similar distributions of susceptible forests over the conterminous United States (Liebhold et al. 1997). The areas with the highest concentration of susceptible forests were in the central and southern Appalachians, the Cumberland Plateau, the Ozark Mountains, and the northern Lake States. Comparison of these maps with the distribution of individual susceptible species (*figs. 1–3* and Liebhold et al. 1997) indicates that oaks are the major component of susceptible forests in the Appalachian, Cumberland, and Ozark areas, but quaking aspen is the major susceptible species in the northern Lake States. One interesting note is that even though sweetgum is the second most abundant susceptible species *(table 1)*, it apparently does not cause high levels of *stand* susceptibility. It is rarely associated with other susceptible species in an abundance sufficient to make mixed stands in the Piedmont highly susceptible, nor does it occur in pure stands.

Statistics showing correlations of the five measures of susceptibility with historical defoliation are shown in *table 2.* When data for all four states were combined, the highest correlation with defoliation was with proportion of land where more than 20 percent of the stand basal area was in preferred species. Basal area per acre of preferred species had a correlation coefficient that was nearly as large, and so did proportion of land with more than 50 percent of the stand basal area in preferred species. In general, correlations were higher in Pennsylvania and Connecticut than in New Jersey and Massachusetts.

There are several possible sources for variation in defoliation frequency that is not explained by forest composition. First, urban forests were not inventoried even though substantial defoliation may have been recorded in urban forests. Second, various factors other than forest composition—soils, for example, or the abundance of deer mice and other predators—may help explain forest susceptibility (Bess et al. 1947; Valentine and Houston 1979; Herrick and Gansner 1986). It is possible that these other sources of variation may have substantially contributed to overall susceptibility in Massachusetts and New Jersey but to a lesser extent in Pennsylvania and Connecticut, thus explaining the lower correlations with defoliation in these states.

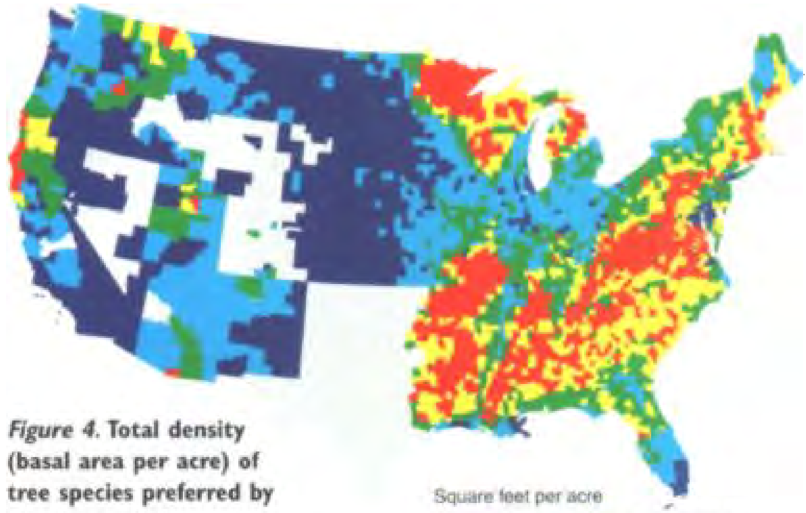

Figure 4. **Total density (basal area per acre) of tree species preferred by the gypsy moth.**

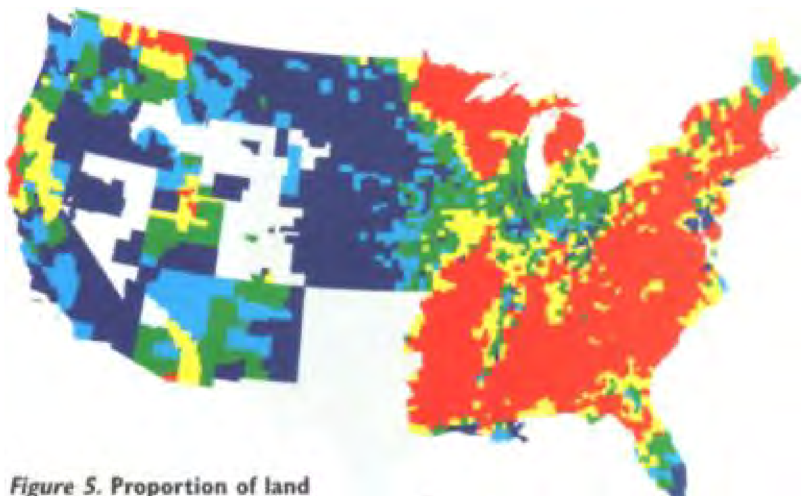

Figure 5. **Proportion of land area covered by susceptible stands (>20 percent of basal area in preferred species).**

Several caveats should be attached to the interpretation of the data. Inventories were not available from any urban forests, and inventories were missing from several forested areas in the West. Moreover, susceptibility was based on several assumptions that have not been completely proven: for many species, feeding trials have not been performed, and for other species, only laboratory data are available, and information on susceptibility to defoliation in natural forests is unknown (Liebhold et al. 1995).

Despite those limitations, these results should be useful for planning. The finding that the gypsy moth has not yet invaded most of the susceptible forests in the United States suggests that there still may be considerable value in limiting its future spread. The results also indicate that both the impacts of defoliation and the costs of gypsy moth management are likely to increase. Finally, these maps identify areas where action can be taken in advance using silviculture to reduce effects of the gypsy moth (Gottschalk 1993; see also sidebar, below). JOF

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Silvicultural Alternatives for Minimizing Gypsy Moth Effects

What silvicultural treatments can minimize gypsy moth damage to host hardwood stands? Foresters can consult decision charts that match the proper prescription to existing stand and insect population conditions (Gottschalk 1993); these treatments were developed from ecological and silvicultural information on forest–gypsy moth interactions. Some of the silvicultural treatments described here are currently being tested in several large research and demonstration studies, with encouraging preliminary results. Use of silviculture to manage gypsy moth effects gives the forester tools other than chemical or biological insecticides for developing integrated pest management programs. Prescriptions for treatments take several approaches.

Reducing stand susceptibility and the probability of defoliation. Recommended treatments include removing gypsy moth habitat features, such as trees with lots of hiding places for larvae, and reducing the amount of preferred host food in the stand. Changing the stand composition to less than 20 percent basal area of preferred species will reduce the probability of an outbreak. Treatments that accomplish this objective are *sanitation thinnings* applied as intermediate stand treatments, and *sanitation conversions* applied as regeneration treatments. The component of oaks or other preferred species in mixed hardwood or hardwood-conifer stands should be lowered to 15 to 20 percent.

Reducing stand vulnerability and the probability of mortality. Removing the trees most likely to die after defoliation and leaving the trees more likely to survive will increase the vigor of a stand. Treatments that accomplish this objective are *presalvage thinnings* applied as intermediate stand treatments, and *presalvage harvests* or *presalvage shelterwoods* applied as regeneration treatments. The more vigorous the tree—health often being indicated by crown condition (Gottschalk and MacFarlane 1993)—the likelier it is to survive defoliation. A presalvage thinning that leaves trees with high probabilities of survival increases the vigor of those residual trees, further increasing their survival chances. Thinning treatments are especially useful in stands that have high compositions of preferred species and whose susceptibility cannot be changed. Regenerating the stand will result in lower mortality because, given the same level of defoliation, young stands have lower mortality rates than older, mature stands. The regeneration treatments preserve seed production, established advanced regeneration, and stump sprouting potential.

Treating stands after defoliation. Between outbreaks—in situations where defoliation and mortality have already occurred—*salvage thinnings* are recommended. Such treatments salvage dead trees and thin live trees, resulting in a healthier stand that can better survive the next outbreak. *Salvage harvests* can regenerate stands that are understocked because of catastrophic mortality.

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