POTENTIAL DEFOLIATION OF TREES BY OUTBREAK POPULATIONS OF GYPSY MOTH IN THE CHICAGO AREA

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Abstract. The gypsy moth, *Lymantria dispar*, will soon become established in much of the Midwest. If an outbreak with extremely high population levels of this serious defoliator is allowed to occur in the Chicago area, what kind of damage can be expected? A model for defoliation, refoliation and mortality was developed based on the number of trees and associated leaf biomass for each tree species classified according to its attractiveness to or probability of infestation by gypsy moth. Data for eight land uses in the Chicago metropolitan area were used in the model. Vacant lands, institutional lands dominated by vegetation (e.g., parks, cemeteries, golf courses), and residential areas have the highest tree densities and other characteristics that make them valuable as well as vulnerable to gypsy moth infestation. The highest percentage of most-preferred tree species and highest percent defoliation is predicted to occur on vacant lands, followed by institutional lands dominated by vegetation, and residential areas. The potential defoliation by gypsy moth in the Chicago area is relatively modest, ranging from 14% in Chicago and suburban Cook County to 26% in DuPage County. Localized defoliation can be higher, however, particularly on institutional lands dominated by vegetation and vacant lands, where defoliation estimates range between 23 and 40%. Less than one-tenth of one percent of the total number of trees in the entire Chicago area are predicted to die because of gypsy moth defoliation during an outbreak.

The gypsy moth, *Lymantria dispar*, has a long history of defoliating forests and city trees in the northeastern part of the United States (1,4). However, few studies of gypsy moth infestations in urban areas have been performed (3,16). In urban settings, this pest can adversely influence landscape aesthetics, property values, recreation, microclimate, and wildlife such as non-target Lepidoptera (5,6,16). In addition, repeated defoliation by this pest can kill trees.

The westward invasion of the gypsy moth is now threatening Wisconsin, Indiana, and Illinois, with the official front of established populations still in Michigan. The goal of this paper is to predict potential defoliation levels to trees in the Chicago, Illinois, area after the establishment and possible outbreak of this pest. In this paper, we are not concerned about attempts at eradication, which aim to eliminate isolated populations with insecticide applications before they become established (2). The approach taken in this study can be used to determine the potential damage by this insect in a major urban center and to illustrate how defoliation can vary across an urban landscape. Urban areas often have different species compositions from natural forests (12). Thus, the ecological and socioeconomic impacts of damage by this pest in cities will differ from the impacts in forests.

Methods

Our procedure for estimating the impact of a gypsy moth outbreak on urban trees involved three major steps. First, the number of trees and associated leaf biomass for each tree species was determined. Second, each tree species was classified according to its attractiveness to or probability of infestation by gypsy moth. Third, a model for defoliation, refoliation and mortality was developed based on published information and the data described above.

I. Chicago's tree population and leaf biomass. The Chicago study area encompasses Cook and DuPage Counties (3,310 km^2) and contains nearly six million people. To reveal regional variation, the study area was divided into the City of Chicago, Cook County exclusive of Chicago (hereafter referred to as suburban Cook County), and DuPage County. Chicago is the most densely populated sector, accounting for 18% of the entire study area and 47% of the total population. Suburban Cook County contains 56% of the study area and 40% of the total population, and has many of the older suburban communities in the Chicago region. DuPage County is the least densely populated, most agricultural, and most

rapidly urbanizing sector within the study area. It contains 13% of the population and occupies 26% of the study area.

The study area was also analyzed within eight land use types: vacant; 1-2 family residential; multi-family apartments; institutional lands dominated by vegetation (e.g., parks, cemeteries, golf courses); institutional lands dominated by buildings (e.g., schools); agriculture, commercial/industrial, and transportation (e.g., airports, freeways, railroads).

Assessments of canopy cover and tree species information were conducted as part of the Chicago Urban Forest Climate Project (12). Leaf biomass by tree species was estimated for the Chicago area based primarily on leaf biomass formulas (13). However, for the 8.4% of the tree population for which the leaf biomass formulas could not be used with confidence, leaf biomass was estimated with a standard conversion from measured tree-crown volumes (12).

II. Gypsy moth tree species feeding preferences. Tree species were classified as either preferred, intermediate or least-preferred based on information provided by Houston and Valentine (11), Gerardi and Grimm (8), and Shank (15). For species with multiple classifications among the reference articles, the most common preference classification for the species was used. For nine genera, we found no information in the literature, so we assigned intermediate or least-preferred status to them according to our best understanding of gypsy moth preference. *Rhamnus* (buckthorn) and *Elaeagnus angustifolia* (Russian olive) are intermediately preferred in our model, and *Ailanthus altissima, Ginkgo biloba, Koelreuteria paniculata* (raintree), *Chamaecyparus, Cotinus, Cupressocyparis,* and *Taxus* are least preferred. In the Chicago area, these nine genera are either rare trees or smaller common trees with minor amounts of biomass; therefore, any misclassifications will not significantly influence the conclusions. The spruces (*Picea*) are the exception to the rule that members of a genus tend to have the same feeding preference classification.

III. Mathematical model: Defoliation. We assume that the amount of leaf mass defoliated by the gypsy-moth population increases from zero in early May to a maximum in late June for the Chicago area. Thus, for this analysis, all defoliation is complete in July. Refoliation, discussed below, starts in July.

The percentage of preferred trees in an area can significantly influence gypsy moth defoliation. A forest is less susceptible to defoliation when oaks comprise less than 25% of trees (4, p. 28). Maximum levels of defoliation are usually associated with dense stands of trees with a high percentage of preferred hosts. Over a ten-year period, Baker and Cline (3) observed a continuous relationship between the percentage of preferred hosts and total proportion of trees defoliated.

In the main model, if the percentage of preferred hosts, PREF, is greater than 25%, the maximum values of defoliation (MAX) in July are 95% and 57% for the preferred and intermediate hosts, respectively, based on data reported by Baker and Cline (3). If PREF is less than 25%, the maximum values (MAX) drop to 35% and 7% for the two classes of hosts (3). The proportion of canopy defoliated (DEFOL) within each feeding preference class by land use type was calculated as:

$$DEFOL = PREF \times MAX \times BIOMASS$$

where PREF is the proportion of total land use tree density that is in the preferred feeding class, MAX is the maximum proportional defoliation, and BIOMASS is the proportion of total leaf biomass in the feeding preference class.

Two other versions of this model were calculated. The second version ignores the PREF=25% threshold that is used in the main model. The same maximum values (MAX) of 95% and 57% are used regardless of the percentage of preferred hosts. This version follows from the continuous relationship between defoliation and PREF observed by Baker and Cline (3). The third version is similar to the second, but the maximum values (MAX) are changed to 90% and 45% for the preferred and intermediate hosts, respectively. The third version was studied to discover how sensitive the results are to small adjustments in the parameter values.

Refoliation. During the months of August and September, some of the canopy that was defoliated will refoliate. Refoliation is significant only when defoliation exceeds 50 percent (10). As refoliation generally begins 8-34 days after the end of defoliation (10), new leaves were assumed to refoliate by August. When the proportional defoliation in July (PREF x MAX) is greater than 0.50, the proportion of the canopy defoliated in August and September ($DEFOL_2$) equals

$$DEFOL_2 = (0.50 - ((PREF \times MAX) - 0.50)/4) \times BIOMASS$$

This formula is based on the work of Heichel and Turner (10). When PREF x MAX in July is below 0.50, no refoliation is expected to occur (i.e., $DEFOL_2$ = PREF x MAX x BIOMASS).

Tree mortality. Mortality is usually low unless the defoliated trees are already stressed by other factors (4). Some researchers have concluded that mortality will definitely not occur without repeated defoliation of at least 60% to 75% per year (4, p. 288). Since we are limiting defoliation in intermediate species to less than 57% each year, they will not be killed in this model.

Preferred hosts are expected to die, if DEFOL>60%, at the levels of 10% after one year of defoliation and 25% after two years. These mortality estimates

Table 1. Characteristics of urban forest by land use in the Chicago area.

Land Use	% Area[a]	No. of trees	%Pop[b]	Leaf biomass[c]	% Leaf biomass	Trees per hectare
Inst-Veg[d]	13.3	24,990	49.2	120,270	36.8	563
Residential	43.9	13,080	25.7	170,000	52.0	89
Vacant	6.6	10,800	21.2	28,770	8.8	488
Other[e]	36.2	1,960	3.9	8,050	2.4	16
Entire area	100.0	50,830	100.0	327,090	100.0	152

[a] Percent of study area occupied by land use
[b] Percent of total tree population
[c] Metric tons of leaf biomass.
[d] Institutional lands dominated by vegetation (e.g., parks, cemeteries, golf courses).
[e] Other land uses (i.e., agriculture, commercial, industrial, transportation, institutional lands dominated by buildings (e.g., schools)).

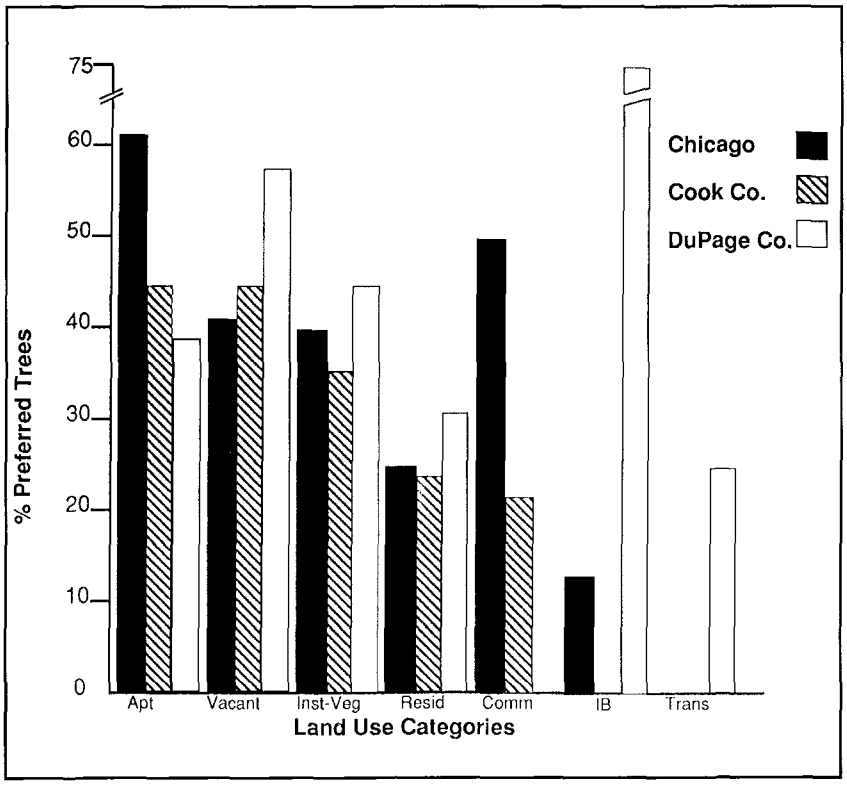


Figure 1. Percentage of preferred tree species in each land-use category in each of the three regions: Chicago, Cook County except the city of Chicago, and DuPage County. The land-use categories are apartments (Apt); vacant land; parks, preserves and golf courses (Inst-Veg); residential (Resid); commercial (Comm); institutional lands dominated by buildings (IB); and transportation areas and corridors (Trans).

Table 2. Dry-weight leaf biomass (metric tons) and number of trees by feeding preference class (L, I, and M are least, intermediately, and most preferred hosts), percentage of most preferred hosts, and percentage of canopy defoliated in July by land use in the Chicago area.

	Leaf biomass in tons			Number of trees x 1,000				
Area	L	I	M	L	I	M	PREF[a]	Defol
Chicago								
Vacant	200	1,130	2,750	130	160	200	41%	32%
Inst-Veg[b]	1,620	4,120	4,730	260	850	730	40%	26%
Resid	7,440	5,770	7,750	610	490	360	25%	6%
Other[c]	2,180	270	230	270	40	30	8%	2%
Entire area	11,440	11,290	15,460	1,270	1,540	1,320	32%	14%
Cook Co.[d]								
Vacant	550	1,650	7,600	1,070	1,120	1,680	43%	36%
Inst-Veg[b]	10,020	37,770	40,960	2,430	10,540	7,010	35%	23%
Resid	18,730	51,870	24,890	1,820	3,420	1,700	24%	3%
Other[c]	1,300	130	150	630	170	220	21%	1%
Entire area	30,600	91,420	73,600	5,950	15,250	10,610	33%	14%
DuPage Co.								
Vacant	2,010	4,860	8,020	880	1,860	3,710	58%	40%
Inst-Veg[b]	2,090	6,560	12,400	270	1,490	1,400	44%	32%
Resid	6,880	23,850	22,820	790	2,450	1,440	31%	20%
Other[c]	330	1,240	2,220	140	390	80	13%	31%
Entire area	11,310	36,510	45,460	2,080	6,190	6,630	45%	26%

[a] Percent of trees that are most preferred by gypsy moth.
[b] Institutional lands dominated by vegetation (e.g., parks, cemeteries, golf courses).
[c] Other land uses (i.e., agriculture, commercial, industrial, transportation, institutional lands dominated by buildings (e.g., schools)).
[d] Suburban Cook County (i.e., Cook county exclusive of the City of Chicago)

are derived from research on natural oak stands (4, p. 218). As urban trees can often be more stressed than natural forest trees (5,7), mortality estimates were doubled for more stressful landscapes/conditions. These more stressful conditions were assumed to be for all street trees and trees on the following land uses: commercial/industrial, transportation, apartments, and institutional lands dominated by buildings (e.g., schools).

Results

Tree crowns cover an average of 11% of the land area in Chicago, 23% in suburban Cook County, 19% in DuPage County, and 19% of the entire study area. The study area tree population is 50,830,000 with 31,810,000 trees in suburban Cook County, 14,900,000 trees in DuPage County, and 4,130,000 trees in Chicago. Tree densities average 68 trees/hectare in Chicago, 169 trees/ha in suburban Cook County, and 173 trees/ha in DuPage County (12). The greatest leaf biomass is in suburban Cook County (195,620 metric tons), followed by DuPage County (93,280 t) and Chicago (38,190t). Institutional lands dominated by vegetation had the highest tree density, followed by vacant land, residential and other land uses (Table 1). The greatest number of trees and most leaf biomass is found on institutional lands dominated by vegetation and residential lands (Table 1).

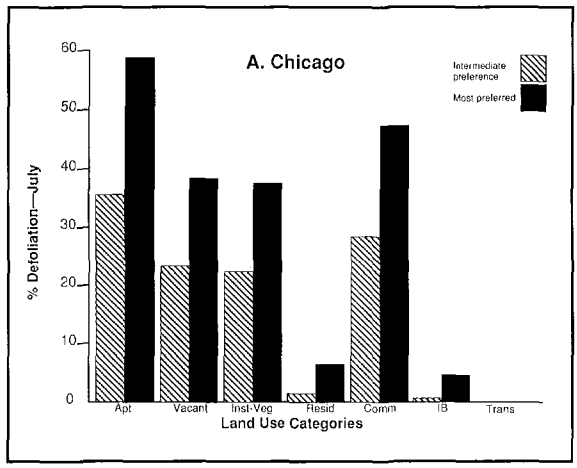
Figure 1 presents the percentage of preferred tree species (by number not leaf biomass) in each of seven land-use categories in each of the three regions of the Chicago area. Although there is much variability across the three regions, the percentages tend to decrease, on average, going from the parks and preserves on the left to transportation areas on the right in Figure 1. DuPage County lands tend to be much different from the lands in the other two regions in Cook County. The threshold value

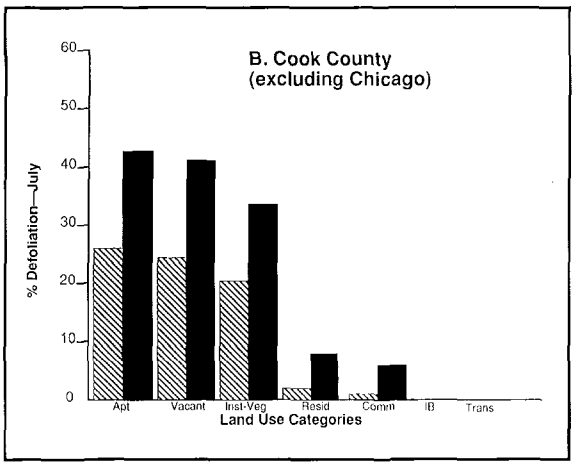
Table 3. Percent canopy defoliated in August (after adjusting for refoliation) in intermediately preferred feeding class (I), most preferred feeding class (M), and all feeding classes (Total) for each version of the model.

	Main			Second			Third		
Area	I	M	Total	I	M	Total	I	M	Total
Chicago	11.4	25.9	13.8	16.1	30.6	17.1	12.7	29.2	15.5
Cook Co.	10.3	25.9	14.2	16.6	30.6	18.9	13.1	29.0	16.7
DuPage Co.	20.3	37.2	25.8	20.4	37.2	25.8	16.1	35.7	23.5
Total area	12.9	29.1	17.2	17.6	32.5	20.5	13.9	30.9	18.4

of PREF=25% is not exceeded in the transportation areas and in several of the residential, commercial, and institutional-building categories for certain regions (Figure 1). Because PREF<25% for the agriculture category in all three areas studied, we omitted this category from the figures.

Table 2 shows tree data and predicted defoliation for major land uses in the three regions of the study area. As Table 1 demonstrated, vacant lands, institutional lands dominated by vegetation (e.g., parks, cemeteries, golf courses), and residential areas have the highest tree densities and other characteristics that make them valuable as well as vulnerable to gypsy moth infestation. The highest percentage of most-preferred tree species and highest percent defoliation are predicted to occur on vacant lands, followed by institutional lands dominated by vegetation, and residential (Table 2). DuPage Co. is predicted to suffer the highest level of defoliation (26%) for an entire region with the other two areas only incurring half as much. Although trees on vacant land are predicted to receive the highest damage of any category, the trees on the institutional lands dominated by vegetation are likely valued more by citizens and managers. These parks, cemeteries, and golf courses are predicted to be defoliated by 26%, 23%, and 32% in the City of Chicago, suburban Cook Co., and DuPage Co., respectively, during a gypsy moth outbreak. Note that the residential and other land use categories for DuPage Co. have much higher levels of predicted defoliation compared to those same land uses in Chicago and suburban Cook Co. (Table 2).





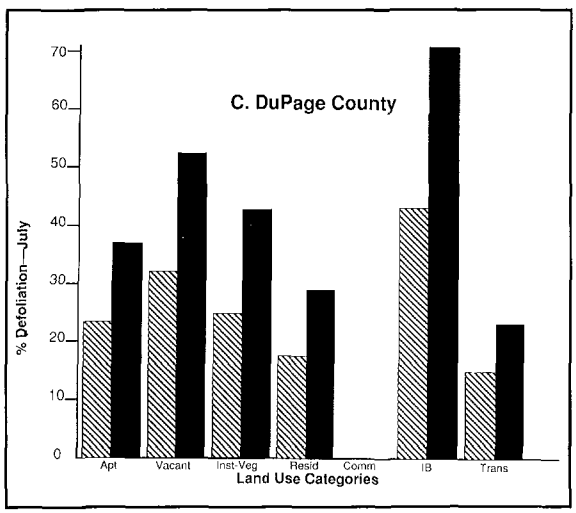


Figure 2a–c. The percentages of intermediate and preferred hosts predicted to be defoliated by a gypsy moth outbreak in the city of Chicago (a), suburban Cook County (b), and DuPage County (c). The land-use categories are apartments (Apt); vacant land; parks, preserves and golf courses (Inst-Veg); residential (Resid); commercial (Comm); institutional lands dominated by buildings (IB); and transportation areas and corridors (Trans). No trees are found in the IB and Trans categories for Cook County. No preferred host trees are found in the Trans category for Chicago and the Comm category for DuPage County.

Figure 2a-c shows the percentages of intermediate and preferred hosts predicted to be defoliated by a gypsy moth outbreak by the main model. Least-preferred hosts are not defoliated. The percent defoliation exceeded 50% in only three cases involving preferred hosts: apartments (APT) in Chicago (Fig. 2a) and institutional-BLDG (IB) and vacant lands in DuPage County (Fig. 2c).

Because defoliation is much lower in intermediate species, only preferred species are predicted to refoliate with this database and model. Refoliation occurs on only three land uses, affecting 145,000 trees in Chicago's multi-family land use (apartments); 57,000 trees on institutional lands dominated by buildings in DuPage County; and 5,566,000 trees on vacant lands in DuPage County.

Mortality is predicted to occur only on institutional areas dominated by buildings in DuPage County, the only land use where defoliation exceeded 60% (Fig. 2c). This value corresponds to the highest percentage of preferred hosts in Figure 1. We predict that 8,600 (20%) and 21,500 (50%) trees will die after the first and second years of a gypsy moth outbreak in this area. These numbers are much less than one-tenth of one percent of the total number of trees in the entire Chicago area. The actual level of mortality may be less if our assumption about more stressful urban conditions is wrong.

The results for the other two versions of the model are not much different. Table 3 presents the final or August leaf biomass losses as percentages of normal levels for the three regions and the entire Chicago study area. The second version of the model, compared to the main version, produced similar or slightly higher defoliation values without the use of a threshold value for PREF (Table 3). In addition, because the highest defoliation levels are not changed by the second model, neither are the refoliation and mortality estimates described above. As expected from the lower parameter values in the third version of the model, the final defoliation levels are slightly smaller than those produced by the second version (Table 3). Generally, DuPage Co. is predicted to incur the highest levels of defoliation.

Discussion

The potential defoliation by gypsy moth in the Chicago area is relatively modest, ranging from 14% in Chicago and suburban Cook County to 26% in DuPage County. Localized defoliation can be higher, however, particularly on institutional lands dominated by vegetation and on vacant lands where defoliation estimates range between 23 and 40%. On these lands there is a high proportion of preferred tree species (35-58% of the population) and the trees are often aggregated in stand structures.

Another area of particular concern is residential lands, which contain over half of the leaf biomass in the Chicago area. Estimated defoliation in residential areas is highest in the most rural area, DuPage county (20%), and relatively low in Chicago (6%) and suburban Cook County (3%). Potential for gypsy moth defoliation is generally highest in the more rural areas and on land uses where trees remain in a more natural stand structure. As urbanization and human influences increase, tree structure, which was dominated before human settlement by most preferred and intermediately preferred species of oak and hickory (14), will tend to shift toward less preferred tree species (12).

When the gypsy moth becomes established in the Chicago area, outbreaks are not likely to cause large-scale problems requiring city- or county-wide action. However, local controls may be necessary on vacant land, institutional land dominated by vegetation, and residential lands, particularly in DuPage county and in forest stands with high usage or visibility. Park and forest preserve districts may want to develop plans for managing gypsy moth in areas with high percentages of preferred hosts. In addition, as individual residential trees can be defoliated, education programs could be developed to inform homeowners regarding trunk banding and other cultural, microbial, or chemical techniques to control gypsy moth larvae (4,16).

Many entomologists believe that low-diversity tree stands may be more susceptible to pest outbreaks than are higher-diversity stands (5). For the highly polyphagous gypsy moth, species diversity is not as important as preference-class

diversity. Our models attempt to account for this aspect of insect outbreaks by making defoliation a function of the percentage of the trees in the preferred-host class.

Our models may underestimate defoliation on intermediates and least-preferred hosts when the percentage of preferred hosts exceeds a high value, such as 40%. Data reported by Gottschalk (9), however, indicate that when preferred hosts lose 40-60% of their foliage in forest stands, intermediate and least-preferred hosts lose, respectively, less than one-half and one-tenth as much as preferred species.

The most important assumption in our analysis is the relative attack rates for each class of trees. Therefore, more studies are needed to determine the attractiveness of more tree species to feeding by gypsy moth. Feeding by both small and large larvae should be studied, because large larvae are typically less inhibited by host quality than first and second instar larvae.

Results from this study are likely to be similar for other Midwestern cities developed in a mixed prairie / oak-hickory forest. These results, however, may differ from results expected for cities within different forest or vegetation types. It is probable that for cities built in forested areas with many highly preferred hosts, that urbanization will tend to decrease potential defoliation levels. However, for cities developed in non-forest vegetation types or built in forests dominated with least-preferred species, urbanization through tree planting and species diversification, will tend to increase potential defoliation by the gypsy moth.

We believe that our main model can be used for other cities or for areas of particular land use smaller than a city. Users would need a tree database consisting of numbers of trees and an estimate for leaf biomass by species. Leaf biomass can be calculated from information on number and sizes of trees (13).

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Résumé. La spongieuse (*Lymantria dispar*) va bientôt s'être établie dans la plus grande partie de la région du Midwest américain. Pour déterminer le degré de dommages anticipés dans la région de Chicago, un modèle de *défoliation/nouvelle foliation/mortalité* a été développé sur la base du nombre d'arbres et de la biomasse foliaire qui est associée à chacune des espèces classifiées selon leur pouvoir attractif ou leur probabilité à être infestée. Des données sur huit catégories différentes d'utilisation du territoire ont été intégrés au modèle. Les terrains vacants, les propriétés institutionnelles dominées par la végétation (ex.: parcs, cimetières, parcours de golf) et les zones résidentielles ont les plus grandes densités en arbres, de même que les autres critères, ce qui les rend plus vulnérables à l'infestation par la spongieuse. Le degré potentiel de défoliation dans la région de Chicago est relativement modeste, celui-ci variant de 14%, à Chicago et dans la banlieue de Cook County, à 26% dans le comté DuPage. Des défoliations locales peuvent cependant être plus élevées, particulièrement sur les propriétés institutionnelles dominées par la végétation et sur les terrains vacants où le taux de défoliation est estimé entre 23 et 40%. Selon les prédictions, moins de 0.01% de tous les arbres de la région entière devraient mourir lors d'une défoliation explosive causée par la spongieuse.

Zussammenfassung. Der Schwammspinner (*Lymantria dispar*) wird bald im ganzen amerikanischen Mittelwesten verbreitet sein. Um den Grad des zu erwartenden Schadens in der Gegend von Chicago zu bestimmen, wurde ein Modell für Entlaubung, Neubelaubung und Mortalität auf Basis der Anzahl der Bäume und der assoziierten Blattbiomasse für jede Baumart entwickelt, welche nach ihrer Attraktivität oder der Wahrscheinlichkeit des Befalls klassifiziert wurden. In diesem Modell wurden die Daten von acht Landnutzungen in der Gegend von Chicago angewendet. Freie Flächen, institutionelle Flächen mit überwiegender Bedeckung durch Vegetation (z.B. Parkanlagen, Friedhöfe, Golfplätze) und bebaute Gegenden haben die größte Baumdichte und andere Charakteristiken, die sie besonders anfällig für eine Schwammspinnerplage machen. Die potentielle Entlaubung durch den Schwammspinner in der Gegend von Chicago ist relativ ernst und rangiert von 14% in Chicago und dem suburbanen Bereich von Cook County bis zu 26% im Bereich von DuPage County. Die lokale Entlaubung kann größer sein, besonders auf überwiegend mit Vegetation bedeckten, ungenutzten Flächen und institutionellen Flächen, wo die Entlaubung schätzungsweise zwischen 23 und 40% liegt. Weniger als 0.01% von der Gesamtzahl der Bäume in der ganzen Gegend werden voraussichtlich aufgrund einer aufkommenden Schwammspinnerplage absterben.