ASSESSING MANAGEMENT OPTIONS FOR GYPSY MOTH

Daniel A. Herms,[1] Associate Professor in the Department of Entomology at the Ohio Agricultural Research and Development Center, discusses the ecological impacts of *Bt* applications and gypsy moth defoliation, as well as the efficacy of alternative approaches for managing gypsy moth.

Introduction

Gypsy moth (*Lymantria dispar*), which is native to hardwood forests throughout Europe, Northern Africa, and Asia, has become the most important defoliator of deciduous trees in the United States. Gypsy moth defoliates thousands to millions of hectares per year in the U.S., with substantial economic and ecological consequences in natural and urban forests (Figure 1). Defoliation stresses and kills trees, and indirect effects of defoliation can reverberate throughout forested ecosystems. Social impacts are also substantial. Recreational use of parks and campgrounds is sharply curtailed during outbreaks, and the substantial nuisance created by large numbers of wandering larvae and frass raining from trees exacerbates its pest status in urban areas.

The extremely wide host range of gypsy moth, which exceeds 300 species of trees and shrubs, contributes greatly to its substantial impact. Every tree in a forest may be defoliated during outbreaks. Favored hosts include oak, aspen, birch, basswood, willow, sweetgum, crabapple, hawthorn, and mountain ash. Beech, red maple, sugar maple, hickory, cherry, sassafras, pines, spruce, and hemlock are less preferred. Some trees are immune including honeylocust, black locust, silver maple, green ash, white ash, dogwood, sycamore, horsechestnut, firs, and tulip tree.

The invasion of the eastern United States by gypsy moth has continued since its accidental introduction near Boston, Massachusetts in 1869. Since then, gypsy moth has spread north into Canada, south into North Carolina, and west into Ohio. A separate introduction in Michigan in the 1950s continues to spread through the upper Great Lakes region into Wisconsin, and south into Indiana and Illinois. Inevitably, gypsy moth will continue to spread throughout the hardwood forests of the eastern United States and southern Canada.

Gypsy moth can't be eradicated, but there are strategies that effectively minimize gypsy moth defoliation and its impact. However, a number of commonly recommended management tactics are ineffective at preventing gypsy moth defoliation during outbreaks. Outbreak populations are commonly treated with aerial applications of an insecticide derived from the naturally occurring bacterium, *Bacillus thuringiensis*, commonly known as *Bt*. The *Bt* formulations used for gypsy moth affect only Lepidoptera larvae (caterpillar stage of butterflies and moths), and are harmless to other animals, including bees and other insects, birds, pets, and humans. Aerial applications of *Bt* are effective but controversial because of potential impacts on native Lepidoptera. Opponents to *Bt* applications often advocate alternative approaches. However, research has shown most of these approaches to be of little value in preventing defoliation during outbreaks.

Gypsy moth defoliation is itself an ecological disturbance, with numerous direct and indirect detrimental effects on ecosystems, including negative impacts on native Lepidoptera. These environmental impacts of gypsy moth defoliation must be balanced against the impact of *Bt* on native Lepidoptera when deciding whether to spray. This article focuses on the ecological impacts of *Bt* applications and gypsy moth defoliation, as well as the efficacy of alternative approaches for managing gypsy moth.

Biological control of gypsy moth

Numerous natural enemies including pathogens, parasitoids, and predators, can be very effective at maintaining gypsy moth at low densities, and once gypsy moth has become firmly established in a region, major outbreaks do not occur in most years. However, for reasons that are not well understood, gypsy moth populations periodically undergo dramatic eruptions despite the impact of natural enemies. When outbreaks do occur, releasing or otherwise manipulating natural enemies has little impact on gypsy moth populations.

Numerous insect predators and parasites of gypsy moth have been released in North America in an attempt to control gypsy moth biologically, and several are well established. Unfortunately, substantial research has shown that none are capable of reducing gypsy moth populations during outbreaks (Elkinton and Liebhold, 1990). Furthermore, only one of these biocontrol agents, the parasitic fly *Compsilura concinnata*, is capable of suppressing low-density gypsy moth populations. Unfortunately, it also attacks numerous native butterfly and moth species, and there is strong evidence that this parasite is responsible for long-term declines in populations of native silk moths in New England (Boettner *et al.*, 2000). Native predators including insects, birds, and small mammals also feed on gypsy moth. Mice are thought to be especially key predators, especially when gypsy moth populations are low.

Diseases are very important in the population dynamics

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Figure 1. **Defoliation of trees in residential areas (above) and forests (right) caused by gypsy moth.**

Figure 2. **Gypsy moth larva. Gypsy moth populations can be suppressed by aerial application of *Bt* targeted at the larval stage.**

of gypsy moth. The gypsy moth nuclear polyhedrosis virus (commonly known as NPV) builds rapidly in dense populations, which usually causes outbreaks to collapse within two or three years. The virus can also be formulated as an insecticide that is specific to gypsy moth. However, since the virus can be produced only from live caterpillars, supplies are extremely limited, and application of the NPV spray is generally limited to environmentally sensitive habitats, such as those containing endangered butterflies and moths.

The fungal pathogen *Entomophaga maimaiga* also significantly impacts gypsy moth populations, even when populations are low. The fungus, which infects the caterpillar stage, can be disseminated to new gypsy moth infestations by dispersing resting spores. However, it spreads easily when environmental conditions are favorable, and quickly becomes established on its own. The effectiveness of *Entomophaga* is not predictable, being highly dependent on the occurrence of rainfall events at critical moments during the spring. Although *Entomophaga* can cause gypsy moth populations to decline dramatically in wet years, outbreaks still occur where *Entomophaga* is established, especially during dry springs.

Gypsy moth suppression with *Bt* applications

When populations are high, aerial application of *Bt* is the most widely-used strategy for preventing defoliation. *Bt* formulations used for gypsy moth suppression affect only Lepidoptera larvae, and are harmless to other animals, including bees and other insects, birds, pets, and humans. *Bt* can be very effective at preventing defoliation when applications are timed accurately (Smitley and Davis, 1993). Applications should be made when the majority of larvae (Figure 2) are second instars, as young larvae are more susceptible to *Bt*, and coverage is better when aerial applications are made before leaves fully expand and the spray can still penetrate the canopy.

There is some concern that *Bt* sprays can prolong outbreaks by interfering with natural enemies. However, this does not seem to be the case. Research has shown that aerial applications of *Bt* have little overall impact on the effectiveness of gypsy moth parasites, predators, or disease organisms (Andreadis *et al.*, 1983). On the other hand, *Bt* sprays also seem to have little effect on the inherent population dynamics of gypsy moth, the populations of which tend to increase or decrease independent of whether they had been sprayed with *Bt* in previous years (Smitley and Davis, 1993). This suggests that goals and expectations of gypsy moth suppression programs should focus on protecting trees from defoliation during gypsy moth outbreaks, rather than long-term reduction of gypsy populations.

Environmental impacts of gypsy moth suppression

Aerial applications of *Bt* are often opposed because of nontarget effects on native Lepidoptera, which have been documented in several studies. In West Virginia, a single *Bt* application decreased the diversity and abundance of butterflies and moths for one season, but the effects were smaller than natural variation in populations caused by factors such as weather (Sample *et al.*, 1996). In Oregon, where three applications of *Bt* were made during the same season in an attempt to eradicate small populations of gypsy moth, native caterpillar diversity was still lower three years after application, although overall numbers of caterpillars rebounded within one year (Miller, 1990). The short residual activity of *Bt* in the field (considered to be only a few days) is thought to minimize effects on native Lepidoptera. However, Johnson *et al.* (1995) found that foliage treated with *Bt* applied with ground equipment at a high rate remained toxic to swallowtail butterfly (*Papilio glaucus*) (Figure 3) for 30 days following application.

Potential effects of *Bt* on threatened and endangered

Figure 3. **Swallowtail butterfly. There is much concern over toxic effects of aerial applications of *Bt* on threatened and endangered butterflies and moths.**

butterflies and moths are of particular concern. For example, larvae of the endangered Karner blue butterfly (*Lycaeides melissa samuelis*) were found to feed in the oak savannas of Michigan at times that would expose them to *Bt* applications targeted at gypsy moth, and were also found to be more sensitive to *Bt* than gypsy moth (Herms *et al.*, 1997). Clearly, gypsy moth suppression programs must take great lengths to avoid critical habitats of threatened and endangered Lepidoptera.

It has been suggested that *Bt* applications may impact predators of butterflies and moths by decreasing their food supply. However, studies published to date have found *Bt* to have little effect on predators such as spiders, birds, and bats. However, one study did find that when caterpillar populations were decreased by aerial application of diflubenzuron, birds consumed fewer caterpillars and spent more time foraging for food (Cooper *et al.,* 1990).

Diflubenzuron is a growth regulating insecticide that interferes with exoskeleton formation of immature insects during the molting process. It is considered more effective than *Bt* for suppressing gypsy moth, but is not used as widely because its long persistence and broad spectrum activity has generated substantial concern about its impact on nontarget organisms. Diflubenzuron affects a much broader diversity of insects than does *Bt*, and its effects can persist much longer, lasting throughout most if not the entire growing season (Eisler, 1992). Aquatic arthropods, including insects and crustaceans, are especially sensitive, but aerial applications of diflubenzuron have been shown to decrease the abundance and diversity of numerous groups of forest insects, with effects persisting beyond the year of application (*e.g.* Butler *et al.*, 1997). Residues can persist on foliage throughout the season, and soil and aquatic arthropods have been impacted by senesced leaves that abscise in autumn (Griffith *et al.*, 2000).

Environmental benefits of gypsy moth suppression

Gypsy moth is an exotic, invasive species in the U.S., and severe defoliation also represents an ecological disturbance that has a wide range of direct and indirect environmental impacts on forested ecosystems that must be balanced against the impact of *Bt* on native Lepidoptera when deciding whether to spray. These effects include detrimental effects on native Lepidoptera. For example, in the West Virginia study (Sample *et al.* 1996), gypsy moth defoliation decreased populations of native Lepidoptera by a magnitude similar to that of the *Bt* application, possibly because gypsy moth out-competed native caterpillars for available foliage. However, the negative effects of both *Bt* and gypsy moth defoliation were temporary and small relative to natural population fluctuations. They concluded that while short-term impacts of *Bt* applications on nontarget Lepidoptera were somewhat negative, that longer-term effects of decreased abundance of gypsy moth may be beneficial for some native species. For example, rates of parasitism of native Lepidoptera, including swallowtail butterflies (Redman and Scriber, 2000) and silk moths (Boettner *et al.*, 2000), were higher in the vicinity of high gypsy moth populations, because some gypsy moth parasitoids also attack these (and other) native species.

Gypsy moth defoliation can cause substantial mortality of trees. Effects of defoliation on tree growth and survival can alter the composition of forest communities, and defoliation of oaks is considered an important reason why red maple (*Acer rubrum*), which is relatively resistant to gypsy moth, is replacing oaks as a dominant species in the eastern United States (Abrams, 1998). Severe defoliation also substantially decreases or eliminates acorn production by oak, which has been shown to be key determinant of structure and function in forest communities (McShea, 2000). Effects of gypsy moth defoliation on acorn production have been shown to reduce numbers of small mammals including mice, chipmunks, and squirrels (Ostfield *et al.,* 1996). Gypsy moth defoliation has also been shown to increase the rate of nest predation of forest birds, possibly by increasing nest visibility (Thurber *et al*., 1994).

Figure 4. **Female gypsy moth depositing an egg mass.**

Other direct and indirect effects of gypsy moth defoliation on natural ecosystems have been documented. Severe defoliation disrupts natural patterns of nutrient cycling, as nutrients stored in the forest canopy are converted to frass and gypsy moth cadavers that decompose rapidly during mid-summer (Lovett *et al*., 2002). Defoliation also increases light intensity and temperature at the forest floor, and decreases soil moisture, which can be damaging for shade-adapted plants and animals, and favor invasive plants.

Can alternatives to *Bt* applications prevent gypsy moth defoliation?

Methods such as collection and destruction of egg masses (Figure 4), use of sticky bands to prevent larvae from climbing trees, removal of larvae that congregate under burlap skirts wrapped around tree trunks, and pheromone traps are often recommended as alternative approaches to managing gypsy moth. However, research has shown that these tactics are not capable of protecting trees from defoliation during outbreaks, even when used in combination (Campbell, 1983; Thorpe *et al*., 1995).

Collection and destruction of egg masses is ineffective because most egg masses are well hidden or high in the tree where they are inaccessible. Even thorough searches by experts detect only a proportion of those present. Burlap bands wrapped around the lower trunk of trees can attract large numbers of gypsy moth larvae, which hide under them during the day when they are not feeding. This tactic can be useful for detecting the presence of low gypsy moth populations, and may be useful for protecting small, isolated trees from defoliation. However, research and experience has demonstrated that trunk banding is ineffective at preventing defoliation of even moderate size trees. During outbreaks, the shear number of larvae that must be collected and disposed of daily is overwhelming, and many larvae never leave the canopy and upper branches.

The use of pheromone traps to decrease gypsy moth populations is sometime recommended, but is also futile. Only males are attracted to the traps, which are quickly saturated even when populations are very low. Pheromone traps are very useful for delineating the distribution of gypsy moth populations, and are used effectively in monitoring programs. Application of gypsy moth sex pheromone over large areas has been used successfully to suppress populations through disruption of mating (Leonhardt *et al*., 1996). Wide spread application of pheromone (usually by aircraft) saturates the environment, preventing males from detecting pheromones produced by individual females. Mating disruption is most effective when gypsy moth populations are low but starting to increase. When populations are high, the day-flying males can easily locate mates visually.

Conclusions

As gypsy moth continues to advance through the Eastern United States, defoliation of urban and natural forests will increase, and gypsy moth outbreaks will continue to occur despite the effects of natural enemies. Aerial application of *Bt* is a safe, effective approach for suppressing defoliation of trees during outbreaks, but can have negative effects on native Lepidoptera. However, gypsy moth defoliation also has detrimental effects on forest ecosystems that should be balanced against those of *Bt* when deciding whether to spray. These include negative effects on nontarget butterflies and moths that are similar in magnitude to those of *Bt*. Alternative controls such as trunk barriers, pheromones, and destruction of egg masses are not capable of reducing defoliation during outbreaks. Releasing or otherwise manipulating natural enemies also has little impact on gypsy moth populations. Such tactics can be useful for increasing public awareness and participation as part of a gypsy moth management program, but care should be taken to avoid creating false expectations regarding their effectiveness for protecting trees from defoliation.

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Dan Herms' research focuses on interactions between insects and trees in managed and natural enviroments.

FROM THE PAST

"The British Insecticide and Fungicide Council, with the agreement of the British Weed Control Council, assigned to its Recommendations Committee the preparation of a *Pesticide Manual* giving technical information on standard chemicals and those which have reached the stage of field evaluation".
Preface to the First Edition of *The Pesticide Manual* (British Crop Protection Council, 1968)

During the 19th century new inorganic materials were introduced for combating insect pests; for instance, an impure copper arsenite (Paris Green) for control of Colorado beetle in the state of Mississippi, and in 1892 lead arsenate for control of gipsy moth.
R. J. Cremlyn (1991) *Agrochemicals. Preparation and Mode of Action.*

"Over 6000 programmes of classical biological control of insect and mite pests have been executed since 1888, when the Australian ladybird, *Rodolia cardinalis*, was introduced into California to successfully control outbreaks of the introduced Australian cottony cushion scale insect, *Icerya purchasi*."
Jeff Waage (1997) *BCPC Proceedings No. 67.*

"To kill bed bugs take a convenient quantity of fresh tar, mix it with the juice of wild cucumber, let it stand a day or two, stirring it four or five times a day, then anoint the bedstead with it and all the bugs will die".
Vermin Killer (1680)

"It is a mistake to assume that biotechnology will ever permanently solve pest problems".
D. G. Bottrell (1987) *Journal of Plant Protection*, **4**.

Purple nutsedge (*Cyperus rotundus* L.) is the world's worst weed.
LeRoy Holm *et al.* (1977) *The World's Worst Weeds.*

"The discovery of the insecticidal properties of DDT 50 years ago was probably the most important development in the history of pest control that ever happened".
Keith Mellanby (1992) *The DDT Story*, British Crop Protection Council (BCPC)

"In conclusion, there appears little prospect in the medium term that biological control measures, such as the introduction of resistant crop varieties, cultural control, genetic methods, the use of natural predators, or other agrobiologicals, will displace chemical pesticides from their dominant position".
R. J. Cremlyn (1991) *Agrochemicals. Preparation and Mode of Action.*

"Rachel Carson contrasted two roads, the insecticide road and the 'other road'. The future, however, belongs to a third road – the middle road of IPM".
Helmut van Emden and David Peakall (1996) *Beyond Silent Spring.*