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ENVIRONMENTAL EFFECTS OF INSECT DEFOLIATION[1]

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Abstract. Feeding behavior of insect defoliators and the factors that influence a tree's response to defoliation are briefly described. Arborists and landscape architects can help to mitigate the effects of defoliation through careful selection and maintenance of plant materials. Biological and sociopolitical difficulties that contribute to the gypsy moth problem are discussed.

Recent large outbreaks of gypsy moth, spruce budworms, and Douglas-fir tussock moth have focused public attention on insect defoliators. Major research programs for these pests emphasized the economic and ecological effects of defoliation and an array of management techniques were developed to limit damage in forested communities.

Defoliation attains special significance when urban trees are affected. The threshold above which defoliation of ornamentals and shade trees becomes aesthetically intolerable is substantially lower than the acceptable economic thresholds for production forestry and preservation of watershed and wildlife habitats.

Know your pest. Pest management should focus on an understanding of insect and plant ecology. Effective and acceptable use of direct control techniques (such as microbial insecticides, synthetic organic insecticides or insect-produced odorants) is based on the assumption that we know how these tools influence the insect-plant interaction and associated life systems. The objective of direct control is to protect or save the resource through an immediate reduction in pest numbers. A pest control specialist, arborist or homeowner uses this approach in response to a crisis. Ideally, however, we should emphasize long term crisis prevention. Arborists and landscape architects can play a major role in prevention when they understand the ecology of systems that they wish to manage or manipulate.

This discussion reviews major types of feeding and highlights environmental factors that determine the net effect of defoliation. In my use, "environment" includes the dominant biological and physical variables that influence an insect/tree interaction (3), as well as the political and sociological constraints that all too frequently dictate pest management activities (16).

Life style of insect defoliators. With few exceptions, most important insect defoliators are larvae that belong to one of two major groups: moths and butterflies (Order Lepidoptera) or sawflies (Order Hymenoptera). Many of these species are solitary feeders, but some are gregarious. A majority are free living and spend their larval life exposed on or beneath foliage. Some species, however, build elaborate shelters out of silk (Fig. 1), rolled or folded leaves (Fig. 2) or a combination of silk and foliage (Fig. 3). Several thrive on a relatively restricted menu, while others feed on a wide variety of plants. The birch leafminer, which feeds on only 3 species of *Betula* is an example of the former and gypsy moth, whose host list exceeds 300 species (8), and includes both broadleaved and coniferous species, is a classic example of the latter.

Behavior is important in terms of aesthetic impact, because even sparse populations of leafminers, nest makers and other colonial insects

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Fig. 1. Eastern tent caterpillar nest.

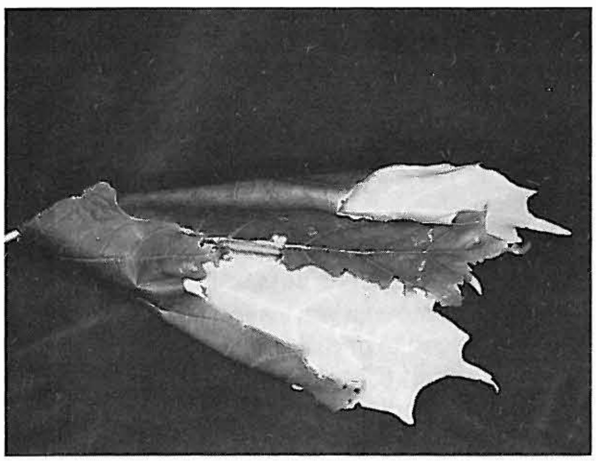

Fig. 2. A sugar maple leaf folder.

Fig. 3. Fall webworm nest.

may detract from the visual quality of an ornamental tree (Fig. 4). For example, a few fall webworm nests, a single group of eastern tent caterpillars or a colony of sawflies may not harm the tree physiologically, but their presence, the materials they produce, such as silk and frass, or their style of feeding may reduce plant quality in the eyes of an intolerant homeowner.

Manner of feeding. Insect defoliators may also be categorized by the manner in which they consume foliage (7). *Whole-leaf feeders* consume all parts of a leaf or needle, including the epidermis and major veins (Figs. 5, 6). When this type of defoliator infests broad-leaved trees it usually feeds on the margin of the leaf, but members of one family of moths, the loopers or geometrids, typically chew holes that give foliage a shot-hole effect (Fig. 7). Nonetheless, loopers consume portions of all parts of the leaf blade.

Leaf miners feed on tissue between the epidermal layers of a leaf to produce intact, but discolored and shriveled foliage (Fig. 8). True *skeletonizers* remove everything except major leaf veins so that damaged foliage is lacey. More common, however, is a modification of skeletonizing, called "window feeding" in which the insect leaves the major veins and one surface of epidermis intact (Fig. 9). Many leafrollers, leaf folders and leaftiers are window feeders. Several insects begin life as a leafminer or skeletonizer, but change to whole-leaf feeders when they become larger.

Tree response to defoliation. It makes little difference whether you manage large, relatively undisturbed forests or you deal with plant materials in urban woodlands or as shade trees and ornamentals. A tree's response to, and ability to recover from, defoliation is largely determined by species of tree, proportion of foliage removed, defoliation history, time of year, tree vigor, susceptibility to secondary organisms, weather and site conditions (e.g., 5, 14, 15). The interaction of these variables makes it difficult to establish a direct cause and effect relationship between defoliation and the ultimate fate of a tree. In other words, the outcome of defoliation is probalistic due to the influence of associated biological and physical events (18). Stated quite simply, extensive and repeated defoliation stresses a tree physiologically and makes it more susceptible to secondary agents and weather factors (19). Organisms such as root rot fungi, bark beetles or wood borers are considered secondary only in an ecological sense. That is, they are usually associated with a predisposing condition (e.g., defoliation, drought, soil compaction, excessive road salt, nutrient deficiency) and seldom establish themselves in vigorous trees.

Attraction of lethal bark beetle populations to stressed broad-leaved trees (10) and conifers (1) is often expedited by release of defoliation-initiated host plant volatiles, followed by insect-produced aggregation and sex pheromones (semiochemicals). This complex (and fascinating) scenario allows many secondary insects to quickly locate and colonize weakened trees. Defoliation may also cause physiological changes in the host tree that encourage fungi to colonize the root system. The fungus *Armellariella mellea,* for example, is more likely to invade the roots of defoliated trees, because glucose and fructose concentrate in the root system following defoliation. These sugars constitute an excellent substrate for *Armellariella* (11).

Occasionally defolation by itself is lethal (e.g., a single complete defoliation of an evergreen or 2-3 years of heavy defoliation to a broad-leaved tree), but usually trees are killed by secondary organisms whose invasion of the tree was precipitated by defoliation.

People who are responsible for growing and maintaining shade and ornamental trees obviously have little influence over such things as the timing of defoliation or weather. It is through judicious selection, establishment and maintenance of plant materials, however, that we can minimize the physiological stress of defoliation. Good cultural techniques are also beneficial because they may reduce the need for costly and ecologically disruptive direct control measures.

Crisis prevention. In order to maintain insect populations below damaging levels or to minimize the effects of defoliation once it occurs, you must

Fig. 4. Redheaded pine sawfly damage.

Fig. 5. Saddled prominent, a whole-leaf feeder.

first appreciate the fact that many problems arise because man has altered the insect or plant life systems in ways that favor the herbivore. It is also important to realize that rarely are you dealing solely with "an insect" problem. Rather, you are faced with a maze of biological and physical parameters, the interaction of which may result in tree mortality. Understanding the ecological complexity of the problem is important. This complexity is the reason why there are no silver bullets or simple answers for dealing with most insect pests.

Direct control measures such as chemical spraying temporarily reduce insect numbers below noxious levels, but they do nothing to alter the ecological conditions that set the stage for the problem in the first place. Chemical control will always have a place in tree or forest management, but concomitantly methods should be pursued that help to permanently dampen population oscillations or minimize the frequency with which damaging populations occur.

When it comes to crisis prevention, arborists and landscape architects are in a good position to help mitigate ornamental and shade tree problems. Basically, this can be accomplished by selecting plant materials that are well suited to site conditions and, to some extent, by encouraging diversity (species and age classes) in urban plant communities.

A primary means of enhancing vigor is to place the tree on a good site for that species. Off-site planting is often a major reason that trees are unable to recover from defoliation or succumb to secondary agents. Site conditions such as exposure, soil type, moisture and available nutrients can significantly influence a tree's resilience to the stress of defoliation.

Though it has not been demonstrated that diversity, *per se,* minimizes insect problems, intuitively diversity makes ecological sense. The more difficult it is for an insect to mate, find food or locate oviposition sites, the less likely it is that outbreaks will occur. Even when a population does reach damaging levels or exceeds an aesthetic threshold, fewer trees are affected in diverse plant communities (i.e., relatively few susceptible hosts are available), and the total impact to an urban area is reduced. The devastating effect of Dutch elm disease, for example, is a sobering reminder of what can happen if communities plant too much of one species. On the other hand, relatively few tree species are well adapted to stressed urban environments. It has been effectively argued (12) that the unproven advantages of species diversity must be carefully weighed against losses in functional value and potential replacement costs when untested species are overplanted solely to enhance diversity. The modicum of diversity that is created when even a few species are interplanted and a mosiac of age classes are maintained, however, may help to minimize catastrophic losses. Urban settings have

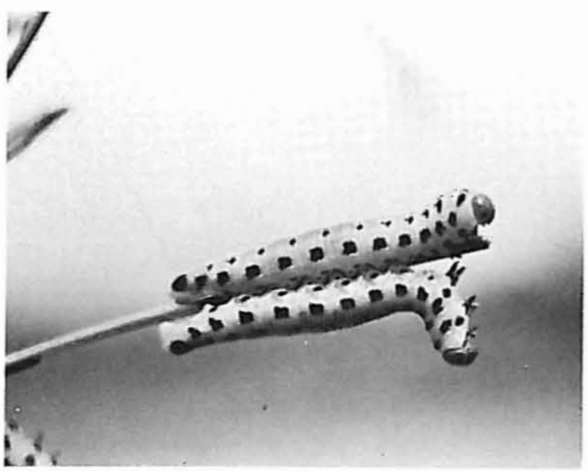

Fig. 6. Redheaded pine sawfly, a whole-leaf feeder of hard pines.

Fig. 7. Shot-hole feeding typical of many inchworms (Lepidoptera: Geometridae).

unique management objectives and relatively complex site conditions compared to forest communities, but experiences in the latter attest to the potential danger that may accompany any form of monoculture, such as that perpetuated by the "oak street," "elm street," "maple street" philosophy.

There are many excellent contemporary publications that describe tree pests. Similarly, the last decade has witnessed a burgeoning of literature on subjects such as tree nutrition, physiology, soil requirements and insect/host tree interactions. Today students and practitioners of landscape architecture and arboriculture should place as much emphasis on ecology as on design and expediency.

Gypsy Moth: A Political and Biological Nightmare

Gypsy moth (Fig. 10) has attained substantial notoriety since its introduction to North America in the late 1860s. Few insects have enjoyed comparable sociological, political and financial attention. In spite of a prodigious expenditure for research, this defoliator continues to harass homeowners, foresters, recreationists and town supervisors. Like most important defoliators, gypsy moth feeding can predispose trees to attack by mortality-causing agents. Unlike most other insects, however, it can also be a nuisance or "people problem" on a grand scale. In this respect it is somewhat exceptional, because it is perceived as a nuisance by many segments of our society. Volumes of technical information (4) and a number of excellent user manuals describe such topics as the influence of the gypsy moth on forest communities (2), classification of forest susceptibility (6), tree response to defoliation (17, 19) and management guidelines (9). Nonetheless, management of the gypsy moth remains a difficult challenge. Populations can remain at outbreak levels for several years and if suppressed by insecticides, they can quickly rebound. Impressive efforts have failed to stop the insect's movement into uninfested areas (13).

What has precipitated this nightmare? Why must we continually chase the gypsy moth and why are we seemingly unable to meet the problem head on and prevent, or at least minimize, its impact? I obviously do not know the answer to this dilemma. If I did, I would be a legend in my own time! There are, however, features of the gypsy moth's environment that I believe help to explain our failure.

Biological. Like many major animal and plant pests in North America, gypsy moth is an introduced species. The absence of adequate density responsive natural enemies that become increasingly efficient as gypsy moth populations increase, in concert with favorable climates and abundant food, allow populations to attain and maintain high densities. These high numbers and the relatively large size of the caterpillar, permit populations to remove foliage rapidly.

Even though oak, grey birch, apple, alder and willow are its favored foods, the gypsy moth can thrive on an unusually large variety of tree

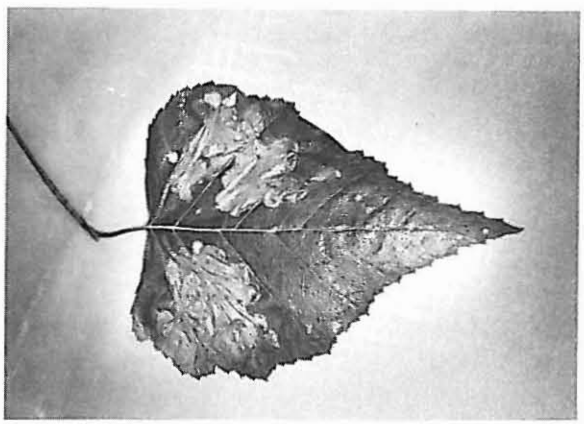

Fig. 8. Birch leafminer.

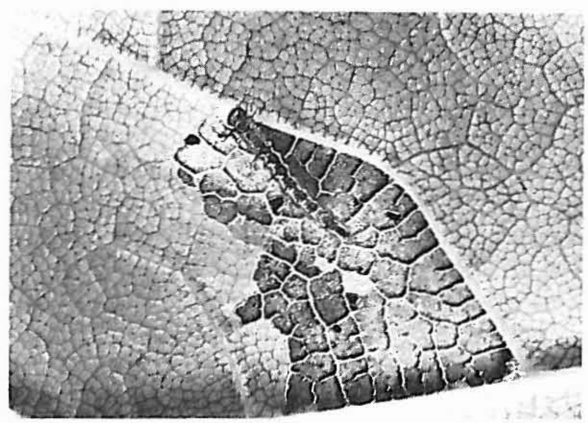

Fig. 9. A modification of skeletonizing called window feeding.

species. This makes it difficult to develop preventative measures that can discourage the occurrence or shorten the duration of outbreaks.

Each life stage (egg, larva and pupa) usually occupies a variety of habitats (e.g., foliage, bark, litter), which complicates sampling procedures. In the absence of reliable sampling methods it is difficult to measure population density or to assess the effectiveness of management tactics. Techniques required to estimate insect population density in trees and stands are usually one of the initial objectives in studies of major tree pests. After several decades of research only egg mass sampling (20) is used extensively to estimate gypsy moth numbers. This method is not strongly predictive of defoliation, because environmental and biological factors have a long time to act before the stage (large larvae) at which most of the damage occurs. Also, egg masses are difficult to locate because they are cryptic or too high in the tree crown. Inaccessibility makes it difficult to distinguish current egg masses from those deposited the previous year. This bias may also distort sampling results. Results are used to document population trend, but have limited value for determining more precise changes in population density.

Sociological. The extensive and diverse public attention focused on gypsy moth outbreaks is a double edged sword. Concern generated by the occurrence or threat of defoliation is grease to the administrative wheels that must generate funds for research and development or for large-scale state agency "control" programs. On the other hand, public interest in, and ignorance of, the problem often thwart pest management efforts. Management tactics and philosophy are all too often based on political expediency, not biological reasoning. This dilemma is not unique to the gypsy moth, but in this instance it is exacerbated by the fact that gypsy moth defoliation and control, due to the nature of the problem, impinge on a large segment of our society.

Political. Two political features pervade the gypsy moth question: 1) an array of federal agencies is responsible for gypsy moth research and, 2) an even more involved network of political units have a vested interest in pest management. Fragmentation of responsibilities makes it much more difficult to coordinate research, set reasonable research objectives and integrate research results. User needs can easily be overlooked in the heat of battle for research dollars or program support. When management tools become available as a result of research and development, effective application is often limited because conflicts arise between and among federal, state, county, town and village agencies. In the absence of a regionally coordinated management effort it is difficult to implement meaningful survey and control programs.

The gypsy moth problem will not go away. It will most likely become larger (nuisance and defoliation) following dispersal and population expansion in recently invaded areas of North America. We are not sure what the prognosis is for these newly invaded habitats. To ignore the problem, however, is folly. We must have continued support for pertinent research that will lead to a better understanding of this life system. For it is only through an understanding of gypsy moth population dynamics that we can ever hope to develop sound management strategies. The direction that basic research takes should be based on an objective assessment of what we do and do not know about gypsy moth. By the same token, research and development activities must consider needs as perceived by users, such as homeowners, pest management specialists and industry. Finally, once some

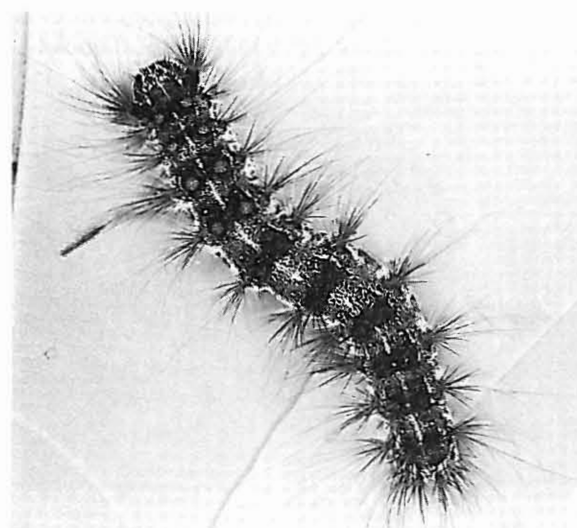

Fig. 10. Final instar of gypsy moth.

reasonable management approaches are identified, there must be both financial and political support — by decree if necessary — to permit large-scale testing of control measures. The vagaries of bureaucratic policy-making must not be allowed to impede reasonable scientific testing and demonstration.

Insect defoliators influence our environment in many ways. The physiological changes that an outbreak can inflict on trees or the degradation of amenity values that may attend relatively sparse populations are of prime concern. Direct control tactics are temporary solutions that should be combined with longer lasting preventative measures. When addressing defoliator problems in urban settings we must be especially cognizant of sociological and political pressures that influence management decisions.

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