Chapter 18

Integrated Pest Management

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1. Introduction

Insect, disease, and weed problems are familiar to those maintaining urban trees. Since the 1950s, the use of pesticides has been the primary means to control these pests. Pesticides are easy to use; they are very effective, have a quick kill rate, and are simple to use compared to the more complex and labor intensive nonchemical options. These Pesticides are also readily available and relatively inexpensive. Pesticides have simplified pest control, and in fact have become the primary means of insect, disease, and weed control in tree maintenance programs.

Traditional tree maintenance to manage insects and disease in the past has centered upon involves reliance on broadcast pesticide cover sprays. With this method, all plants in the landscape are covered with synthetic pesticides in order to kill existing pest populations. Cover sprays are typically applied according to the calendar or to a spray guide. For example, 5 to 10 all-purpose (insecticide/fungicide) cover sprays a season may be scheduled, to all trees on the property, on a monthly or bimonthly basis. Cover spray maintenance programs can achieve high levels of pest control and are an easy way to give the customer a pest-free environment.

It is important to realize that no one method of pest control, including pesticides, can keep a landscape totally free of insect, disease, and weed problems for extended periods of time. Intense pesticide reliance by the green industry (lawn, landscape, greenhouse, nursery, and arborist) created rising societal concerns by the late 1960s about potential human health and environmental hazards.

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Urban and Community Forestry in the Northeast, 2nd ed., edited by, J. E. Kuser.

1.1. Pest Resistance

Over 450 insect species are now resistant to one or more pesticides. If a pesticide is sprayed again and again onto a pest population, eventually (through mutations) a resistant strain will develop. For example, it took only 1 year before the first insect became resistant to DDT (Dichloro diphenyl trichloroethane).

Pesticide resistance can develop within just a few insect generations. For example, if a specific pesticide is sprayed onto an aphid population, the vast majority will be killed. A few, however, may survive if they have a gene for a substance that can metabolize the pesticide. The offspring of these individuals will be more highly represented in the next generation. If sprayed again, this further increases the selective pressures, and the third generation has an even higher representation of this special gene. Hence, this special aphid population is well on its way toward resistance to this pesticide. There are at least 36 known examples in the landscape of insects and mite pests resistant to one or more pesticides (Raupp *et al.*, 1994), including black vine weevil, bag-worm, spider mites, some aphids, several scale insects, Japanese beetle, and others.

1.2. Target Pest Resurgence

Natural enemies (also called beneficial insects or beneficials) are important for keeping pest populations in check. When pesticides are used as cover sprays, or if the control timing is wrong for the pest, the beneficials will be killed. Meanwhile, the pests rebound from lack of competition. A common example is the sequence of events when pesticides are applied for control of armored scale insects outside of their immature crawler emergence period: In this scenario, the naturally occurring beneficial insects are killed, allowing for population explosions of the scale. It has been shown that beneficial insects recover more slowly from pesticide treatments—up to 1 year before full recovery—than do the pests (Smith, 1970).

1.3. Secondary Pest Outbreaks

Pesticides often kill not only the target pest but also any beneficial insects present. Sometimes minor or secondary pests were present on the plan and that had been out-competed by the target pest and kept under control by natural enemies. These secondary pests may not be killed by the spray, and subsequently their population explodes. A good example is the use of the insecticide carbaryl (Sevin) for control of aphids. Aphids and spider mites often coexist on the same plant. Carbaryl is a weak toxin against aphids; it may kill some aphids, yet will kill all beneficial insects present, while not affecting mites at all. The lack of competition often results in a damaging outbreak of spider mites. In fact, the carbaryl label encourages the user to add a miticide to the spray tank to prevent spider mite flare-ups.

In order to discourage the resurgence of target pests and outbreaks of secondary pests, applicators often increase pesticide dosages to higher, and/or levels, increase the frequency of application. This "pesticide treadmill" has had an effect on human health and environmental pollution.

The effects of long-term, low-level dosages of pesticides to human health is the subject of ongoing research, since pesticides have been implicated in cancer

(Wassermann *et al*., 1976; Eckholm, 1977). Nonfatal human poisoning cases from pesticide exposure are estimated to be more than 100,000 per year (Pimentel *et al*. 1978). Persistent pesticides (including DDT) accumulate in the food chain, where they become more concentrated and may significantly affect wildlife and honeybees. Run off of rain and irrigation water can further contribute to pesticide spread to adjacent land areas, into bodies of water, and into groundwater. Public concern about pesticides has led to more stringent regulation and registration. These drawbacks have not been demonstrated for all pesticides, yet underscore the importance of proper usage, in order to minimize their side effects.

Reliance on pesticides to eradicate all pests from the landscape thus is not justified from an ecological, cost, material, or labor perspective. The Federal Government has reviewed and removed many pesticides from use via FIFRA (the Fed Insecticide, Fungicide & Rodenticide Act.) The pesticide industry has responded to these issues by offering insecticides with narrower spectrums and low persistence, as well as implant and injection methods of application (Raupp *et al*., 1994). Many commercial horticulture professionals have also turned to an alternative pest control strategy called integrated pest management (IPM). The IPM stresses the balanced *management* of quality landscape plants, as opposed to chemical annihilation of pests. If methods are used correctly, IPM is *the* most efficient and economical method of pest control in the lawn and landscape.

1.4. IPM-Multiple Strategies

The word "integrated" means that numerous techniques or approaches are used to manage plants in the landscape as a balanced ecosystem. Pesticides are often used in IPM, but the emphasis is on keeping pests at low levels through the judicious use of other alternative pest control strategies so that pesticides are used less often and the least toxic product is used. Rather than trying to eliminate all pests, a variety of control strategies are used to reduce pests to low, tolerable levels in order to maintain populations of natural enemies (beneficial organisms). The IPM differs from traditional pest control in that it employs a variety of control strategies, rather than relying on a single pesticide strategy. These strategies include the use of biological control, resistant plant varieties, the use of biorational, low-toxicity pest control products, cultural control, proper plant selection for the site, mechanical, and chemical controls, usually with two or more techniques employed at a time.

Integrated Pest Management IPM focuses on the long-term suppression or prevention of pest problems below a damaging level, with minimal impact on the environment, nontarget organisms, and human health. The IPM programs first stress the cultural considerations of growing healthy plants (Plant Health Care) to naturally reduce pest problems. A healthy plant is much less susceptible to severe pest problems, and the presence of pests usually is an indication that management efficiency has broken down somewhere. Pests attack to take advantage of a change within the plant: perhaps it is under environmental stress (drought stress, improperly sited, and so on.), or conversely the plant is extremely vigorous (overfertilized, excess new growth, and so forth.). The IPM manager therefore can alter the landscape to the benefit or detriment of pests by manipulating the plant, the site, the pests, and so forth.

2. Monitoring

For IPM to be successful, a monitoring program is required. Monitoring is the close inspection of plants for insects, disease, and abiotic problems on a regular basis throughout the growing season. The IPM managers use this compiled plant and pest information to detect, appraise, and predict pest outbreaks.

Traditional cover spray programs are based on the calendar. Sprays are applied at certain times of the year, regardless of whether the pest is actually present. An industry shift has occurred within the last decade toward a "see it and spray it" approach to pest control, in which a pest is sprayed when it is noticed. Unfortunately, in this method damage often precedes obvious observation of the pest. Additionally the pest may be at population levels where the only management option is the use of pesticides. What makes an IPM program superior to See and Spray Programs is the utilization of monitoring, or scouting, of plants in the landscape.

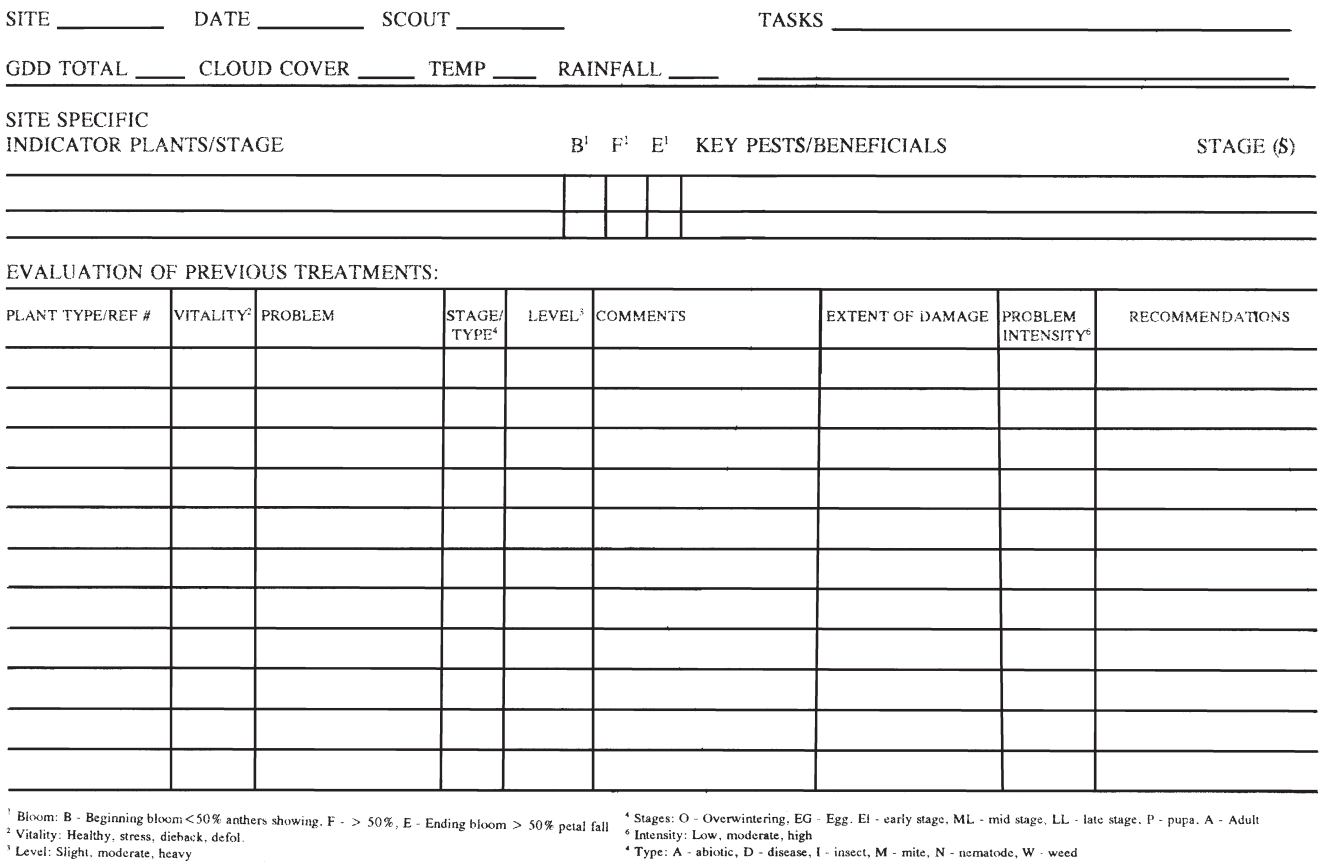
Monitoring is close inspection of the plant from top to bottom, looking for both obvious and not so obvious signs and symptoms of pests and poor health. This requires more knowledge on the part of the monitor: knowledge of plant identification, damage symptoms, insect and disease life cycles, population thresholds, and the advantages of various control measures. Monitors look for indicators of insect activity, such as frass from caterpillars or honeydew from aphids, to pinpoint a problem or potential problem. Regular plant inspections (every 2 to 4 weeks) are an essential way to keep track of changes in pest problems and plant health.

Pest control decisions are made according to the actual presence of the pest and on their most susceptible life stage, not on their hypothesized presence. For example, instead of spraying every arborvitae for bagworms in July, (when perhaps they were a problem in the past), the IPM monitor inspects plants months beforehand for the telltale overwintering bag. The monitor also handpicks any bags found (which may contain up to 800 eggs each), and re-inspects the plants closely in early-mid June, when the eggs would hatch. If young bagworms are spotted at potentially damaging levels, a spray could be made in June, while they are immature, before noticeable damage occurs, and while some alternative pesticide products (such as the entomopathogenic bacteria *Bacillus thuringiensis*), could be very successfully used.

Note that not every plant is sprayed; only plants which have a damaging level of the pest present are treated. This is called *spot treatment*. Spot treatment can significantly reduce pesticide usage merely by not spraying every single susceptible plant and focusing on those with moderate levels of the pest. Spot treatment maintains naturally occuring populations of beneficials.

Regular monitoring prevents pest problems since potential infestations are discovered when pests are small and damage is low; before they become serious. Damage is thus prevented. Alternative controls to traditional pesticides are also best used on smaller/immature pests. Monitoring also tends to alert the landscape manager to previously undetected pest problems, so plant quality improves. In addition, when plants are inspected on a regular basis it is possible to keep track of beneficial organisms (predators and parasitoids) that may be naturally reducing the pest population.

Record keeping (Fig. 1) is an essential part of monitoring. Good records are kept of all monitoring actions: early signs and symptoms of pest activity, pest levels related


SITE ________ DATE ________ SCOUT ________ TASKS ________________________________

GDD TOTAL ____ CLOUD COVER ____ TEMP ____ RAINFALL ____ ________________________________

SITE SPECIFIC

INDICATOR PLANTS/STAGE	B[1]	F[1]	E[1]	KEY PESTS/BENEFICIALS	STAGE (S)

EVALUATION OF PREVIOUS TREATMENTS:

PLANT TYPE/REF #	VITALITY[2]	PROBLEM	STAGE/ TYPE[4]	LEVEL[3]	COMMENTS	EXTENT OF DAMAGE	PROBLEM INTENSITY[6]	RECOMMENDATIONS

[1] Bloom: B - Beginning bloom < 50% anthers showing, F - > 50%, E - Ending bloom > 50% petal fall

[2] Vitality: Healthy, stress, dieback, defol.

[3] Level: Slight, moderate, heavy

[4] Stages: O - Overwintering, EG - Egg, EI - early stage, ML - mid stage, LL - late stage, P - pupa, A - Adult

[6] Intensity: Low, moderate, high

[4] Type: A - abiotic, D - disease, I - insect, M - mite, N - nematode, W - weed

FIGURE 1. Sample IPM monitoring form (from the Rutgers Cooperative Extension Landscape IPM program).

to the condition of the plant, beneficial organisms present and their levels of control, predictions of when and where the pest may attack, temperature and rainfall, life stage(s) of the pest, plant vitality, and results of control tactics. A formal record-keeping system that is consistently used while monitoring is essential to a successful IPM program.

Some IPM practitioners use rough landscape maps that are copied and notes written on the copy at each monitoring visit. Others use simple checkoff charts, which highlight the presence, location, and level of the pest. Handheld computer data loggers are popular, as are computer recordkeeping systems for the office. Monitoring records should certainly be a part of an updated street tree inventory. Records are critical in order to evaluate the effectiveness of the program and predict future pest activity.

In addition to plant inspections, insects are monitored through the use of insect *traps* (blacklight traps, pheromone traps, pitfall traps). These traps can indicate when an insect is first present in an area and how its population is changing. Traps are often used to monitor pest activity levels to better time controls. Pheromone traps, for example, can determine when adults of gypsy moth, Japanese beetle, clearwing borers, and tip moths are active and would begin egg laying. Sticky traps are useful to monitor emergence or population levels of adult insects (such as the birch leafminer, whiteflies) or scale insects (immature/crawler stages). Burlap bands are refugia that can monitor levels of insect pests in trees, such as elm leaf beetle or gypsy moth.

Augmenting plant pest monitoring observations is *environmental monitoring*. Environmental monitoring is keeping track of environmental conditions that favor a particular disease or insect. For example, sycamore anthracnose foliar outbreaks are common under conditions of wet weather and temperatures between 16° and 20°C. On the other hand, sycamore anthracnose twig blight/canker outbreaks are associated with cool temperatures (12° and 13°C) during spring budbreak, which slows foliar growth while allowing the pathogen to gain a foothold. When temperatures are warm in the spring, the quick growth of twigs reduces their susceptibility to this disease (see Case Study A). Forecasting systems and models to keep track of rainfall and temperature levels have been developed and are valuable for predicting disease. Knowing whether the conditions are conducive for a disease outbreak may influence the need to apply a fungicide, not apply a fungicide, or wait to see how both the weather and the pathogen progress. The use of accumulated heat units (growing degree days) uses temperature information to predict insect emergence. Plant phenological or developmental models to predict pest emergence according to plant flowering are also used. For example, the bagworm is expected to hatch once 600 growing degree days have accumulated, about the time the mountain laurel, catalpa, and mockorange bloom. Weather conditions condusive for pest at breaks can be placed in computer databases.

Based on monitoring, pest control decisions can be made according to what pests are known to be present, as opposed to when they are thought to be present. This becomes a decision-making process, based on the knowledge of the IPM manager weighing the success of all the management options. Regular monitoring can therefore prevent pest damage, since potentially serious infestations are discovered and managed while they are still minor. In addition, when plants are inspected on a regular basis it is possible to keep track of population levels of beneficial organisms, such as ladybird beetles or mite parasites, which may be slowly controlling the pest. Many

IPM monitors make timely plant control treatments on the spot in order to save time returning to a site.

An IPM monitor might find it useful to carry the following monitoring equipment: 10x hand lens, pocket knife, white clipboard, pruners, plastic zip-lock sample bags, vials (some with alcohol), flagging tape, trowel, flashlight, and pest control guidebooks. For record keeping, essentials are monitoring forms (Fig. 1), a monitoring notebook or pocket tape recorder, or a modern handheld computer data logger. Optional equipment includes camera, aspirator, pH meter, burlap bands, pitfall trap and other traps, drop cloth, thermometer, sunscreen, pocketsized textbooks/references. Monitors also have a backpack or handheld sprayer back in their vehicle, available if needed for spot treatment applications.

Monitoring also alerts the landscaper to previously undetected pest problems, so ultimately plant quality improves. Monitoring records are very useful in evaluating IPM programs at the end of the year for predicting future problems and ordering pest control materials. Marketing IPM begins with marketing monitoring services.

2.1. Thresholds

The most difficult task facing the landscape manager is identifying the pest in the landscape and then determining whether it is abundant enough to warrant control. Because an ornamental plant is valued for its aesthetic appeal, the degree of damage that is tolerated is called the aesthetic injury level. This is the threshold at which damage is perceived and a remedy is required. Research shows that most people, including customers and professionals, perceive that a plant is damaged when exhibiting only 10% damage symptoms; on young plants this drops to 5% damage (Sadof & Raupp, 198-). Plants are thus treated for pests once damage exceeds 10%. Customers, however, may have different expectations (or pest tolerance) of the degree of maintenance for a high-valued plant, which must be incorporated into the IPM program. Thus, an IPM manager may monitor priority sites/plants versus low-priority sites/plants at different aesthetic thresholds.

3. Key Plants and Key Pests

Any one landscape site contains many numbers and species of trees. A survey of municipal foresters found that over 200 species or cultivars comprised the urban forest in Western cities (Kielbaso and Kennedy, 1983).

Of these numerous trees & shrubs, some are more prone to pests than others. The reason(s) for this could be innate (genetic; native species versus introduced species) or acquired (sub par siting/planting, monoculture situation, and so on).

A key plant is defined as a plant that has an increased level of pest susceptibility. It is likely to incur pest problems year after year. Key plants are more pest prone and require greater, repeated annual pest control measures. They must be monitored more closely, and long-term maintenance is more costly. Key plants should be highlighted during the landscape design process or the initial walk-through because of the maintenance consequences of planting and maintaining them. They also should alert the

IPM practitioner to concentrate monitoring attention on these plants; to confront problems before they become oppressive.

Many of these key plants are the ones that have been repeatedly sprayed over time. In many cases, environmental stress predisposes the plant to be more susceptible to insects and disease. Correcting the site conditions and their associations with the pests can reduce the severity of the problem and the likelihood of repeat occurrences.

Key plants may also be plants which are favored by the customer, or significant to the client for some reason. An example is a mildew-ridden lilac that was planted in honor of the deceased/a loved one. Because of the emotional attachment to the plant, it must be kept healthy and pest free at any cost. Another example is a disease-prone flowering cherry located at the front entry of the house. As a focal point plant, it is significant to the client & must be kept healthy.

Many key plants are common species that are widely planted. They may be inexpensive & available at mass market retailers.

1. **Key plants in the Northeast:**
   Austrian pine
   Azalea
   Crab apple
   Dwarf Alberta spruce
   Eastern flowering dogwood
   Euonymus
   Hawthorn
   Hemlock
   Rhododendron
   Sycamore
   White birch

The pests that commonly attack these key plants ate called key pests. Key pests are the most common or most frequently encountered insects and diseases causing damage in the landscape. The list of key pests may vary from region to region, depending on what plants are common:

2. **Key pests in the Northeast:**
   Anthracnose
   Aphids
   Bagworm
   Birch leafminer
   Black vine weevil
   Bronze birch borer
   Crabapple scab
   Elongate hemlock scale
   Euonymus scale
   Hemlock woolly adelgid
   Lacebug
   Sphaeropsis (*Diplodia*) tip blight
   Spider mites

Research shows that a limited number of pests create the majority of landscape problems that are damaging enough to warrant control. In Maryland, data from IPM programs in suburban residential areas found that 10 pest species accounted for more than 83% of the total insect and diseases found in the landscapes (Raupp *et al.*, 1985). A national survey of arborists found that 10 insect species accounted for 63% of the total insect problems encountered (Wu *et al.*, 1991). Plants that are host to these key pests are often key plants; they must be monitored more closely and may be more costly to maintain.

4. IPM Pest Control Strategies

A well-trained IPM manager can answer these questions *before* a pest control tactic is used:

- IS: *the pest present*.
- WHERE: is *the pest located, on how many plants*.
- WHEN: is *the most susceptible lifestage of the pest*?
- WHICH: *control product is most effective and least toxic to use*?

4.1. Cultural Control/"Plant Health Care"

The IPM principles are based on holistic approaches to bolster plant health via manipulation of the environment/site. Plants are managed to maintain balanced, healthy growth, which invigorates them, making them less susceptible to insect and disease problems. Thus, the IPM practitioner is first and foremost a good horticulturist.

Cultural management tactics are those practices that are performed to change the site to favor the plant, as opposed to the pest (see Case Study B). For example, excessive fertilizer may cause new growth flushes of highly nutritious foliage, which is readily fed upon by many sucking and chewing insects, as well as more prone to attack by disease organisms. It has been demonstrated, for example, that the performance of the sucking insects hemlock woolly adelgid and elongate hemlock scale on hemlock improved under fertilization (McClure, 1991). Underfertilization, on the other hand, may weaken a plant and make it more susceptible to insect borers or canker diseases. Therefore, a balance of fertilizer, based on soil test results, is needed to favor the plant versus the pest. Proper mulching, fertilization, watering, soil preparation, staking, and so forth, are all important to plant longevity.

Since proper siting is crucial for optimal plant growth, advance planning for landscape designs may eliminate the need for future pest treatments by choosing a species that can tolerate the stresses in the specific environment. Plants that are tolerant of drought conditions, such as Ginkgo or Japanese Zelkova, will not be as predisposed to pest attack in a dry site as would a nonadapted, more sensitive tree such as Sugar Maple. Additionally, selection of a plant inherently resistant to specific pest problems is wise.

The landscape design process is often artistry at the expense of pest management. Monoculture planting might be pleasing to the eye, yet repetitive placing of the same plant species or cultivar makes it easy for a pest to attack first one, plant and then the entire planting. It is thus important to diversify the planting to include many different types of plants; this diversity will minimize potential losses to any one host-specific insect or pathogen.

Using good pruning techniques to prune out deadwood is another cultural control tactic. No stubs are left that could act as an entry port to pests. Thinning of dense, overcrowded branches can increase air movement for drying of foliage, which is important to minimize diseases spread by water. Removing sucker growth can reduce the number of aphids feeding on the succulent foliage. On the other hand, pruning an elm prior to spring activity of the European elm bark beetle (the vector of Dutch elm disease) may increase its susceptibility to this pest, as it is attracted to fresh wounds (Barger and Cannon, 1987).

Reducing drought stress can also enhance tolerance to pests. For example, watering and mulching a drought-stressed white birch increases its vigor, helps it defend itself from the bronze birch borer that is attracted to stressed trees. Sites may be modified to reduce overwintering sites for insects (such as removing a nearby weedy hedgerow) or to encourage beneficial insects (by planting flowers under a tree to provide a food source for adult beneficials).

Existing problems often can be minimized by improving the growing conditions. Proper mulching to conserve moisture, proper fertilizer, and proper watering are all basics of good horticulture. A healthy plant also can compensate on a short-term basis for stressful changes in the environment, such as a period of drought stress.

Some of the pest problems seen in the landscape are actually secondary problems, the direct result of plant stress from poor soil conditions, poor plant quality, improper plant site (wrong amount of sun, soil moisture, and so on), poor planting, improper pruning, fertilization, and watering, lack of weed control, and so on. Regular soil tests can provide a great deal of useful information about plant growing conditions that the landscaper can use to prevent pest problems. Mulching to retain moisture, aeration to control compaction, and pruning out deadwood/suckers will improve the health of most plants. Arborists must be aware of the role that temperature, humidity, irrigation, and fertilization can play in the development of plant diseases. While the first two cannot be controlled, the latter two can be manipulated to help reduce the incidence of diseases.

4.1.1. Resistant Plant Varieties

Many landscape plants, including some native plants, have evolved to be resistant to many pest problems. Other plant cultivars and varieties have been bred to be resistant to insects or diseases. Use of these plants can have a positive impact in the reduction of pest problems. For example, while crab apple scab is a key pest of crab apple, there are many crab apple varieties and cultivars that are resistant to scab. Likewise, there are varieties and cultivars that are also resistant to rust and fireblight (Smith-Fiola, 2004).

These pest resistant plants can be used to "relandscape" a site, particularly to replace key plants (those plants that incur the most problems year after year). For example, if a white birch is planted in full sun in a droughty site, it is quite prone to attack from the bronze birch borer. Why not substitute the 'Heritage' river birch or the newer cultivar 'DURA HEAT' in its place? River birch (*Betula nigra*) is adapted to floodplains and can withstand both flood and drought conditions. While the river birch species has brown bark, the cultivar 'Heritage' has been selected for white bark, which peels off as does that of the white birch. Thus, 'Heritage' can be used as a substitute in the landscape design for a white, multistemmed tree, without the high maintenance of controlling the bronze birch borer.

The use of a plant resistant to one pest may not make it resistant to another pest (see Case Study C). Limited breeding programs, reluctance of the nursery industry to increase production of these varieties, and the failure of landscape architects to recommend these plants all impede the more widespread use of resistant plant material (Raupp *et al.*, 1989).

4.2. Mechanical Control

The IPM methods performed manually, by hand specifically, to reduce the potential of attack, from a specific pest are called mechanical controls. Sanitation, or removal of undesirable plant parts, is one mechanical control tactic. For example, numerous pathogens overwinter in infested plant material. Many leaf spot diseases overwinter in fallen leaves. These can be raked up and removed from the site, in order to reduce the inoculum required for the pathogen to reinfest the following year. Likewise, many cankers and twig blights can be pruned out when noticed, to remove the origin of the problem and minimize its future spread.

Sometimes the pest itself can be controlled by hand. Bagworms, as previously mentioned, can be handpicked off the plant. Considering that hundreds of eggs of the next generation are inside the bag 10 months of the year, handpicking can be feasible on small plants. Egg masses of other insects, such as gypsy moth and Eastern tent caterpillar, can be also handpicked/scraped and destroyed. Some web-making caterpillars, such as mimosa webworm, Eastern tent caterpillar, or fall webworm, can be pruned out by hand or by using pole pruners to efficiently remove early infestations before major damage has occurred.

Washing a plant with a strong stream of water will destroy a certain number of aphids and mites and knock others off onto the ground where they are attacked by spiders and other predators. Barriers, such as burlap or sticky tree bands, also can be somewhat effective to reduce the size of an insect population. Insects, such as gypsy moth caterpillars, black vine weevils, and elm leaf beetles, will hide under the bands during the day, where they can be destroyed, or get stuck in the sticky trunk barrier as they migrate up and down the tree.

Some diseases require two alternate plant hosts. Cedar apple rust, for example, requires an apple/crab apple host as well as a juniper host for the pathogen to complete its life cycle. The disease has noticeable foliar symptoms on the ornamental crab apple, while native cedars (*Juniperus virginiana*) may be in the vicinity harboring the sporulating stage of the pathogen. In this example, the alternate host (the cedars) could be removed from the surrounding area to break the life cycle of the disease. (On the other hand, beware of planting susceptible groundcover junipers beneath susceptible crab apple trees!)

Many pest problems can be prevented with physical means. Sticky traps are used not only as a population monitoring tool, but are sometimes used as a means for direct control of insects such as potato leafhoppers, aphids, and other small flying insects. A dropcloth placed early in the morning under plants infested by Japanese beetles/black vine weevils and shaken can dislodge pests present to drop onto the cloth, from which they can be removed and disposed of. Success of utilizing mechanical controls relies on early recognition of the problem, and early intervention.

4.3. Biological Control

Biological control is the use of one organism to control another organism. Within the balance of nature, there are abundant, naturally occurring predators and parasitoids that consume insect pests. These natural enemies have evolved with the pest as a natural control mechanism. Thus, if a pest has been introduced into this country (e.g., Japanese beetle, gypsy moth), no natural enemies typically exist in the new habitat; and with no natural checks the pest population often explodes, resulting in significant pest outbreaks. In some cases, scientists have returned to the country of origin to collect natural enemies, import them, mass rear them in a laboratory, and release them in this country. Many natural enemies of the gypsy moth, for example, have been imported and mass reared out through cooperative US Department of Agriculture (USDA) programs (see Case Study D).

A predator is an insect that usually consumes its insect prey completely. Common predators include lady beetles, green lacewings, spiders, ground beetles, and predaceous mites. An example of an introduced predator is *Chilocorus kuwanae*, a lady beetle that feeds on euonymus scale.

A parasitoid is an insect that lays an egg(s) in or on an insect prey; the egg hatches and feeds as an immature on the host insect, slowly killing it. Parasitoids are usually tiny wasps or flies. Many parasitoids are so small that they are seldom seen, such as the *Trichogramma* wasp, which is the size of a speck of dust. Monitoring for parasitoid activity commonly detects evidence of activity, such as swollen, parasitized aphid mummies, or scale insects with holes in their waxy cover (exit holes of new adult parasitic wasps).

Entomopathogenic nematodes, which are microscopic worms that carry lethal insect killing bacteria in their gut, are effective on many larval insects, including Japanese beetle grubs, clearwing borers, and black vine weevil. These are purchased commercially in an infective juvenile stage, mixed with water and sprayed through conventional spray equipment. Nematode species must be carefully chosen according to the target host and applied under specific environmental conditions to achieve levels of control similar to that of pesticides. Entomopathogenic nematodes kill their prey within 48 h and are extremely safe to the applicator, the environment, and nontarget organisms. Research using these nematodes on clearwing borers has shown from 20% control to 84% control, for example, depending on the nematode species chosen and the time of year (see Case Study E).

When the use of pesticides is limited, conserving naturally occurring predators and parasitoids is fostered. For example, a large pine needle scale population was naturally reduced by the twice-stabbed lady beetle, *Chilocorus stigma*, during a 3-year study in Maryland at a Christmas tree plantation (DeBoo and Wiedhaas, 1976). Natural enemies also may be purchased from insectuaries and introduced/augmented into the site. Note that success of using this latter method is complex, weighing the right beneficial(s), the correct timing, ideal weather conditions for release, and the appropriate prey present. Landscape successes with biological control have recently involved the release of predaceous mites against pest mites, green lacewing larvae against lacebugs (Shrewsbury and Smith-Fiola, 1998), *Pseu-doscymnus* (an Asian lady beetle) against hemlock woolly adelgid (see Case Study F), and *Cybocephalus* (a lady beetle) against the euonymus scale (Drea and Carlson, 1988).

Biological control may be the ideal pest control method, since it is environmentally safe and ecologically sound. However, biological control usually does not completely eliminate a pest population but maintains low levels of the pest. There remains a lack of practical research on using biological control organisms in landscape settings (see Case Study G).

4.4. Microbial and Viral Control

The use of certain microbes, for example, bacteria, which attacks specific stages of specific pests, is a very safe alternative to the use of pesticides in IPM. For example, a naturally occurring virus (nuclear polyhedrosis virus) attacks gypsy moth larvae when populations get too large or crowded. A pathogenic, antagonistic bacterium is now commercially available to control crown gall disease.

The most popular microbial is *Bacillus thuringiensi* (BT), a bacterium that is ingested by young caterpillars and slowly kills them by rupturing their stomach lining. The BT works well on populations of *young* caterpillars (1st to 3rd instars) under dry conditions. Caterpillars ingest the bacteria and die slowly over 3 to 10 days. The BT kills only immature caterpillars, although new strains also kill some immature beetles (elm leaf beetle, Japanese beetle) and mosquito larvae. The BT as been a major weapon in the battle against the gypsy moth nationally.

New research has shown some promising new microbial pesticides, many of which are derivatives of bacterial fermentation. Examples include Abamectin, a miticide, and Spinosad, an insecticide.

4.5. Pesticides and Biorational Pesticides

As mentioned earlier, pesticides are part of an IPM program, but they are used differently than in a conventional pest control program. Pesticides are not applied preventatively but in accordance with monitoring results. By monitoring specific plants/areas of the landscape, where a problem is serious enough to warrant a control, can be pinpointed. Treatments are timed for application when the most susceptible life stage of the pest is present. Spot sprays of individual infested plants only can represent a great savings in the amount of pesticide applied to a property when compared with a conventional program in which all plants would be sprayed. When pesticides are necessary, an IPM program makes their use more efficient.

Integrated pest management programs also stress the use of the least toxic pesticides that have minimal negative environmental impact because of short residual times and negligible effect on beneficials. Biorational pesticides are naturally occurring products or synthetic mimics of naturally occurring products that exercise pesticidal action. Examples of these least toxic alternatives include horticultural oil (petroleum oils similar to baby oil, that suffocate insects), insecticidal soap (fatty acids of potassium salts, which dessicate insects), neem oil (activity includes insect growth regulator, repellent, and antifeedent), pyrethrin (synthetic mimic of pyrethrum, a contact insecticide), silica gel (dessicant), and others. Research shows results similar to those of pesticides with proper use of these products.

5. Summary

By the 21st century, it may become illegal to spray pesticides in the same manner as in the past. Thus, landscape pests will be managed differently, with an IPM approach representing the most feasible option. The IPM programs across the country have proven to be economically and environmentally viable. Pesticide use is often significantly reduced, without a loss of plant quality. In Maryland, landscape IPM programs have reduced pesticide use by 40% to 83% in residential communities. In California, an IPM program on municipal street trees reduced pesticide use by over 90%, resulting in a $22,500 savings. In New York greenhouses, pesticide use has been reduced by 45% under IPM. The National Park Service has implemented IPM at all park sites across the country, reducing pesticide use by 70%.

Reduced pesticide use will save money, and such savings can be rolled over to offset any additional labor costs from monitoring. The IPM is a concept that is growing in acceptance and is here to stay.

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Case Study A

Sycamore Anthracnose, *Apiognomonia veneta*

by John E. Kuser

Approach: Resistance Breeding and Selection

The most conspicuous and probably best known of leaf anthracnoses in the Northeast is sycamore anthracnose, *Apiognomonia veneta*, which attacks native sycamores (*Platanus occidentalis*) severely and London planes (*P. X acerifolia*) to a lesser extent. With the coming of warm weather in the spring, sycamore buds swell, and if the warm weather holds on for a few days, the buds burst and new growth begins. Then (usually) cool, wet weather comes back. At lower temperatures (below 12° to 13°C) shoot growth and leaf expansion slow down, and conditions are ideal for *Apiognomia* to attack and kill the tender new growth. This often causes sycamores to be bare as late as June, long after other trees have leafed out. It may kill several cycles of the trees' attempts to resume new growth, if warm spells are followed by cool spells. It also causes formation of witches' broom at the ends of branches, a characteristic that can be used to differentiate sycamores from London planes. Later in the spring, as warmer temperatures (above 15° to 16°C) prevail, growth of new shoots and leaves resumes, twig killing ceases, and the trees leaf out normally (Sinclair *et al.*, 1987). Because this warm weather recovery can reliably be expected, fungicides are not recommended to control anthracnose.

Sycamore grows to be one of the largest, most massive trees in the Northeast in spite of yearly defoliation. Sanitation (raking up leaves when they drop) can be used to lessen the amount of inoculum.

Because annual defoliation of sycamore makes it so unsightly, most municipalities prefer to plant the London plane tree, a hybrid of sycamore crossed with anthracnose-resistant Oriental plane (*P. orientalis*). Caution is in order when doing this, however, because much nursery stock of London plane is seed-grown and seedling clones vary widely in resistance. Only vegetatively propagated trees of the resistant cultivars Columbia and Liberty and the original anthracnose-resistant clone of Bloodgood (which also resists powdery mildew) should be used (Smith-Fiola, 2004).

Many other trees, including various species of ash, oak, maple, walnut, hickory, elm, hazel, redbud, birch, and so forth, suffer from anthracnose or leaf-spot diseases. Outbreaks are usually associated with wet spring weather. There is probably clonal and species variation in susceptibility; this is mentioned as to oaks by Sinclair *et al.* (1987), and exists among specimens of white ash on the Rutgers University campus in New Jersey. Because no systematic observations or selection for resistance have been reported (Sinclair *et al.*, 1987), the best recommendation is to follow cultural practices that maximize tree health. These include selection of a site appropriate for the species, provision of sufficient soil, good drainage, fertilization, irrigation (if necessary), and protection from harmful insects.

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Case Study B

Eastern Tent Caterpillar, *Malacosoma americanum*

by Steven Rettke

Approach 1: Cultural & Mechanical Controls
Approach 2: Biological Controls (Disease, Natural Enemies, & Starvation)

The eastern tent caterpillar, *Malacosoma* spp., is native to North America, found throughout the United States east of the Great Plains, and in the southern part of eastern Canada. This pest is considered to be one of the most significant defoliators of deciduous shade trees (Penn State Cooperative Extension, 1991). Their preferred hosts include isolated, open-grown trees, especially wild cherry, crab apple, and apple. During outbreak years, which frequently occur at 8- to 10-year intervals, this pest will also occasionally attack pecan, hawthorn, beech, willow, and other shade trees (USDA Forest Service, 1990).

Eastern tent caterpillars construct conspicuous silk nests in the forks of trees, which are easily recognized during the spring months. The noticeable tents/nests cause an exaggeration of their impact as pests. Defoliation by this caterpillar will rarely cause tree mortality, as trees will refoliate. The reduced aesthetic value of trees in urban and suburban areas is the primary harm created by the activities of this pest (Coulson and Witter, 1984). Outbreak years also arouse much concern among area residents when the caterpillars migrate en mass across landscapes in search of new food or a place to complete their development. Nevertheless, unlike the gypsy moth, the eastern tent caterpillar has never been a major threat to the vitality of our forests and rarely reach large populations in ornamental trees (Shetlar and Chatfield, 1995).

Tent caterpillars spend the winter in brown masses of 150–350 eggs that the adult female attaches around small twigs. These shiny brown bands are readily recognized and removed by hand. During the late 1800s and early 1900s, whole communities mobilized to combat the perceived threat of infestation by the eastern tent caterpillar. In an early eradication campaign in Connecticut in 1913, for example, more than 10 million egg clusters were destroyed when the extension service offered a $25 prize to the school child who collected the most (Fitzgerald, 1995). Such mechanical control efforts still overlooked as many as 20% of the eggs. Therefore, after larvae hatched in the spring and the silk tents formed, prize money was again offered to school children in numerous towns for the number of tents they collected. In one such town, the children collected nearly 17,000 tents, weighing over half a ton. Then, usually with great vengeance and satisfaction, these tents were torched by flames or viciously stomped upon. Many of these same towns also offered a reward of 10 cents per quart filled with pupal cocoons of this insect. For instance, in 1899, at Glens Falls, New York, 1350 quarts containing the cocoons were turned in (Fitzgerald, 1995).

The simple mechanical methods of removing and destroying egg masses, tents, and pupal cases of tent caterpillars were and continue to be environmentally friendly ways of effectively suppressing their numbers in small, localized areas. However, even though these cultural practices should continue to be encouraged where they are practical, their limitations will always be evident.

Disease, natural enemies, and starvation are the primary environmental factors involved in the suppression of tent caterpillar species, which act to curb cyclical outbreaks

(*continued*)

Case Study B (*continued*)

of tent caterpillars. Numerous predators (i.e., spiders, ants, yellow jackets, birds) and parasitoids (i.e., braconid wasps, ichneumonid wasps, tachinid flies) attack tent caterpillars, but in some years these beneficials do not arrive in time or in sufficient numbers to adequately control them every season (Coulson and Witter, 1984).

During tent caterpillar outbreaks, the higher competition invariably results in lower food quality and greater vulnerability to infection by viral (i.e., NPV), bacterial (*Clostridium*), and fungal (i.e., *Entomophaga*) diseases. Pupal parasitism of the caterpillar also increases with outbreaks of long duration (Coulson and Witter, 1984). Finally, weather factors often play a key role toward the collapse of tent caterpillar outbreaks. For optimal survival, egg hatch in the spring is synchronized with the development of host tree foliage. Observations have indicated over 99% mortality of tent caterpillars from starvation in regions where unusual weather patterns caused the forestalling of the development of the leaves on the trees (Fitzgerald, 1995).

Occasionally cultural and biological control strategies will fail to adequately keep their populations in check in specific areas. Environmentally friendly, biorational products such as horticultural oil and insecticidal soap can suppress young larvae upon direct contact. The biological insecticide material of choice against *young* tent caterpillars is the bacterium (*Bacillus thuringiensis*). Costly protection efforts to prevent damage to trees are rarely justified. Pesticide treatments may then be used as the option of last resort and then only on trees of high value or in areas of important recreational uses.

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Case Study C

Dutch Elm Disease, *Ophiostoma ulmi*

by John E. Kuser

Approach: Selection for Resistance

Until the advent of Dutch elm disease (DED), American elm, *Ulmus americana*, was one of the most widely used shade trees in the United States (Harlow *et al*., 1996). Cities and towns in the Northeast and Midwest lined all or nearly all of their streets with elms, because they were tall, stately, fast-growing, easy to transplant, and tolerant of a wide range of soils and sites (Del Tredici, 1998). In addition, elm was one of the few species known in the early 1900s to grow well in the upper Midwest. Consequently, when Dutch elm disease arrived in 1930 on veneer logs imported from Europe (Schreiber and Peacock, 1980), disaster ensued.

Symptoms of DED include wilted terminals and flagging of infected branches with leaves all turning yellow beyond where the vascular system is blocked. Occasionally the whole tree may die at once. Laboratory examination is necessary to determine whether the cause of flagging is drought, senescence, phloem necrosis, or DED (several branches from affected parts of the tree should be examined, because some may not show the characteristic streaking).

Up to this point, the history of DED runs parallel with that of chestnut blight: a pathogen coevolved with its host in Eurasia, came to the United States and devastated a related host that had never been exposed. But from here on the story is different: DED did not rapidly or completely destroy its host. *Ophiostoma ulmi* has two means of spreading: (1) its spores are carried by two species of bark beetles: *Hylurgopinus rufipes* and *Scolytus multistriatus*, (USDA, 1971; Johnson and Lyon, 1976), and (2) by root grafts (Schreiber and Peacock, 1980). Where elm trees were not plentiful, the bark beetles did not always find them; also, the beetles' preference for larger, older trees meant that many elms could reach seed-bearing age and perpetuate their species before being attacked.

Some temporary success in controlling DED has been achieved by rigorous sanitation programs (Schreiber and Peacock, 1980) and by annual fungicide injections. For example, Princeton University has maintained 120 elms on campus for several decades by promptly removing diseased limbs and dead trees to eliminate the inoculum. Beetle populations are monitored with pheromone traps to determine population levels and treatment timing; trees were formerly (1970s) sprayed with methoxychlor for beetles when necessary but are not sprayed now. They may be sprayed again if a suitable pyrethrin becomes available. Campus elms also are injected with fungicide. The cost of the combined treatments is estimated at $300/tree per year (Consolloy *et al*., 1998; J. W. Consolloy, personal communication). This approach is not feasible for elms growing in the wild, nor is it affordable for many communities. What else can be done?

Because elms were not all wiped out at once, many were thought to be resistant. The USDA's research station at Delaware, Ohio, under the leadership of Drs. Joseph Kamalay and Alden Townsend, tested hundreds of these and found that most were merely escapes. But eventually the continued screening turned up two resistant clones, now introduced as 'Valley Forge' and 'New Harmony.' Their resistance has been compared with that of several widely planted elm cultivars, and is far better (Townsend *et al*., 1995).

(*continued*)

Case Study C (*continued*)

Several other elm species and relatives are resistant. In general, Asian species of *Ulmus* are resistant, so it is thought that the disease originated in Asia. Siberian elm, *U. pumila*, is highly resistant, but weak-wooded, highly susceptible to elm leaf beetle, and not an acceptable substitute; Chinese elm, *U. parvifolia*, Urban elm (a *U. glabra* hybrid), *Zelkova*, and hackberries (*Celtis* spp.) are resistant and are useful trees in their own right, but do not look quite the same as American elm.

The best hope for restoring American elm lies in planting resistant clones of *U. americana* and perhaps some of its *U. wilsoniana* look-alikes. Rutgers University is undertaking to field test several of these for their combination of disease resistance, growth rate, appearance, and geographic adaptation (Kuser, 1998).

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Case Study D

Gypsy Moth, *Porthetria dispar*

by John E. Kuser

Approach: Biological Controls (Parasitoids, Predators, Virus, Fungus)

In 1869, gypsy moth was brought from Europe to Medford, Massachusetts, by a Professor Trouvelot, an astronomer who tried to interbreed it with silkworms. A few moths escaped, and 20 years later the first serious outbreak occurred in Medford. Gypsy months are defoliators, with some of their preferred hosts being oak, apple, and birch. Conifers are less preferred, but hungry late-instar caterpillars will strip a pine or larch after other foods are gone, and one defoliation kills the conifer. Tulip tree, *Liriodendron tulipifera*, is repellant to gypsy moth caterpillars; if one drives through a defoliated oak forest in June and a few tulip poplars are present, they stand out in striking contrast.

In 1890, the Massachusetts legislature appropriated $25,000 and formed a three-person commission to exterminate the moth (USDA Forest Service, 1981). Within the next 100 years, *Porthetria* had spread over the entire Northeast and infested new areas in the South and West. In 1981, a peak year, it defoliated over 5 million acres of forestland. Possibly no other forest insect has been studied as thoroughly or has been the target of such intense containment, control, or eradication strategies (USDA, 1985), and none has cost more to control (Johnson and Lyon, 1976).

Many strategies were used in the battle against gypsy moth, and most failed because of the insects' high reproductive capacity. DDT was sprayed on forests in northeastern Pennsylvania but quickly abandoned when it killed fish in lakes. Egg masses were painted with creosote. After DDT came Sevin, which provided acceptable control but also killed bees and hymenopterous beneficial insects. *Bacillus thuringiensis* and nuclear polyhedrosis virus (NPV) were sometimes effective and other times less so, depending on strain, spray formulation, timing, and weather.

When the gypsy moth was introduced to the United States, it left its natural array of parasitoids and predators behind in Europe. In 1905, the USDA, in cooperation with several affected states, started a program of importing natural enemies of the moth. Forty-five species have been tested, and this has resulted in successful establishment of 10 species of parasites, two predators (USDA, 1985), and one highly effective fungus (USDA Forest Service, 1993; Reardon and Hajek, 1993). There also is a naturally occurring pathogen, NPV—that attacks high-density gypsy moth populations and causes them to crash; NPV has been observed and studied as long as gypsy moth has been a problem, and much work has been done to improve its potency. Other control strategies, such as the sterile insect technique, have been developed (Reardon and Mastro, 1993) with success.

Recently the fungus *Entomophaga maimaiga* has been the cause of a dramatic drop in gypsy moth populations in the Northeast. Originally brought from Nishigahara, Japan, in 1909, the fungus failed to establish then, perhaps because of unfavorable weather and an NPV outbreak. In 1984, it was reintroduced by Soper and Shimazu; isolates were evaluated in the laboratory and the most virulent one was released in New York in 1985 and in Virginia in 1986. In 1989, it was found causing extensive epizootics in seven northeastern states; and by 1990, in three other states and Ontario. It is prevalent in both low- and high-density gypsy moth populations, particularly during wet springs, causing up to 100% mortality of late stage larvae (Reardon and Hajek, 1993).

(*continued*)

Case Study D (*continued*)

In one northeastern state (New Jersey), ten predators and parasitoids had become established, but never had enough impact to prevent peak defoliations from recurring. In that state, acres defoliated totaled 258,425 in 1973; 798, 790 in 1981; 431,235 in 1990; but only 28,000 in 1993 after *Entomophaga* became epizootic and never more than that since (J. Kegg, personal communication)

The unanswered question is, what long-term effect will the fungus have? Is the current gypsy moth collapse due to a lucky combination of weather, fungus, and virus? Nobody is yet sure (Twardus, 1996), but one lesson is that perseverance with biological controls does pay.

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Case Study E

Banded Ash Clearwing Borer, *Podosesia aureocincta*

by John E. Kuser

Approaches: 1) Chemical
2) Biological Control

Ash trees grown for use as street and shade trees are a valuable landscape and nursery crop. A key pest attacking green ash, *Fraxinus pennsylvanica*, is the banded ash clearwing borer (BACB). A 1971 survey showed that approximately 50% of the green ashes in the cities of the Canadian Prairies were attacked by clearwing borers, as were 33% of the boulevard trees in Grand Forks, North Dakota (Dix *et al*., 1978). Economic losses approached $5000/acre per cropping cycle in Ohio nurseries (Purrington and Nielsen, 1977). Traditional synthetic, long-residual insecticide controls have relatively narrow treatment windows. A viable biological control option for controlling the BACB is the use of entomopathogenic nematodes (Smith-Fiola *et al*., 1996).

There is one generation per year of BACB, with adults emerging in late August and September in Ohio, Virginia, and Maryland (Gill *et al*., 1994). Females deposit eggs on tree branches and trunks, and larvae tunnel through the bark into the cambium before feeding and excavating upward and inward into the sapwood, where they overwinter. Mining causes branch dieback, disfiguration, structural weakening, and death of trees (Solomon, 1975).

Chemical control options exist during a relatively narrow window of time, just before egg deposition. Residual insecticides, such as Lindane or Dursban (chorpyrifos), are commonly applied as a protectant bark spray 10–14 days after first adult male capture in pheromone traps. A single, properly timed insecticide application provides effective control (Bone and Koehler, 1991); however, once larvae are under the bark, pesticide treatments are ineffective.

Entomopathogenic nematodes in the family *Steinernematidae* have been shown to be effective in controlling the dogwood borer, peach tree borer, western poplar clearwing borer, and clearwing borers in alder and sycamore (Davidson *et al*., 1992; Gill *et al*., 1992; Kaya and Lindegren, 1983; Kaya and Brown, 1986). The humid larval galleries are ideal for nematode searching and survival (Kaya and Brown, 1986). Nematodes are applied directly on the woody portions of trees with conventional spray equipment. The nematodes enter the borers' feeding galleries, search, and attack borer larvae. Larvae are typically killed within 48 hours of attack by the *Xenorhabdas* bacteria symbiotically sustained by the nematodes (Kaya and Gaugler, 1995).

In trials on borer-infested green ash in Maryland and New Jersey, two species of nematodes reduced the number of pupal skins per tree by 54% (*Steinernema glaseri*) and 46% (*Steinernema feltiae*), compared with 74% reduction in skins by Dursban treatment. These results are consistent with those from the California alder clearwing borer study (Kaya and Brown, 1986), where *Steinernema* trunk sprays in late September provided 77–84% control. Nematode treatments applied to dry bark did not provide acceptable control. In New Jersey, October nematode treatments (targeting newly hatched larvae) tended to give better control than summer treatments (to mature larvae). Fall treatments may be preferable to summer treatments, because trees have yet to sustain major damage and cooler temperatures are not as hostile to nematodes. Additionally, nurserymen and landscape managers are not as busy at this time of year and should welcome the opportunity to widen the spray window.

(*continued*)

Case Study E (*continued*)

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Case Study F

Hemlock Woolly Adelgid, *Adelges tsugae*

by John E. Kuser

Approaches: 1) Systemic Insecticides
2) Biological Control

The hemlock woolly adelgid is an aphidlike insect that is a serious pest of eastern and Carolina hemlocks. Native to Japan and China, it appeared in the Pacific Northwest in 1924, on western hemlock, where it is of little consequence in the forest but sometimes weakens and kills ornamental trees (Annand, 1924; Furniss and Carolin, 1977). It was discovered in Virginia in the 1950s, and has since spread throughout Pennsylvania (1960s), Connecticut, and Massachusetts (1980s), killing eastern and Carolina hemlocks in forests and landscapes from North Carolina to New England (Smith-Fiola, 1995). Eastern hemlock is important both as a forest tree and as an ornamental. It reaches impressive size in the wild, with one giant in western North Carolina measuring 169 feet tall (Turnage, 1996). It often grows in ravines, where its deep shade keeps trout stream waters cool in midsummer. As an ornamental, it is relatively easy to grow, makes a dense screen, and can be trimmed into a hedge. Infested hemlocks look grayish-green from a distance, and close inspection shows small, cottony, white adelgids at the base of each needle.

What can be done about this pest that has caused moderate to severe defoliation in 44% of a 1267-km^2 study area in New Jersey between 1984 and 1994, killing 5% of the trees (Royle and Lathrop, 1997)? It has caused one nursery owner a financial loss of \$20,000 to \$30,000 due to destruction by the insect (Smith-Fiola, 1998). It has been found that insecticidal soaps and horticultural oil give as good control as diazinon, malathion, and other insecticides if applied during June and July when the insect is in its settled nymph stage before it becomes woolly. Coverage must be complete, however; because that is difficult to achieve, the adelgid population rebuilds quickly. Therefore, soil drenching with systemic insecticides has been found to be more effective (Smith-Fiola, 1994). The cost of thus protecting a 60-foot hemlock is estimated at \$30 per year, using the insecticide imidichloprid (MERIT) and assuming that application would be made every other year (W. Porter, personal communication).

Because of the impracticality of soil treatment under forest hemlocks, Dr. Mark McClure of the Connecticut Agricultural Experiment Station began a search for a biological control in 1992. The search led him to hemlock forests in the remote mountains of Japan, where he found mites, flies, and beetles feeding on woolly adelgids. One of these beneficial insects, a lady beetle called *Pseudoscymnus tsugae*, showed the greatest promise. The New Jersey Department of Agriculture's beneficial insect laboratory is now (July 1998) producing as many beetles as it can, and has released them at ten public and private sites that will be monitored for 3 years to determine success. In earlier studies in Virginia and Connecticut, *Pseudoscymnus tsugae* reduced adelgid populations by 47% and 100%, and it also feeds on other adelgid species such as pine bark adelgid. There may be hope for hemlock.

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Case Study F (*continued*)

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Case Study G

Chestnut Blight, *Cryphonectria parasitica*

by John E. Kuser

Approaches: 1) Resistance Breeding
2) Biological Control of Pathogen

A hundred years ago, American chestnut, *Castanea dentata,* was the most important tree in the eastern hardwood forest. Its growth was rapid and its wood was as durable as redwood, slightly lighter than oak but easier to work. Unlike many other nut trees, it was a reliable annual producer of heavy nut crops that were a mainstay for deer, turkeys, squirrels, and humans. It was the most dominant hardwood species throughout its Appalachian range, from Maine to Georgia, often making up 25% of the forest. Chestnuts lived as long as 600 years, and mature trees were sometimes as large as 4–5 feet in diameter (Harlow *et al.,* 1996; American Chestnut Foundation, 1988, 1996a).

In 1904, a foliar blight was noticed on trees lining the avenues at the New York Zoological Garden. Pruning and a spray program using Bordeaux mixture failed to control or contain the new disease (Murrill, 1906). Within 50 years this had spread over the whole range of chestnut, eliminating the species as a tree. The blight did not kill the roots, however, because of the presence of soil organisms antagonistic to *Cryphonectria;* so sprouts arose repeatedly and grew rapidly until they in turn were killed. Soon after the blight was introduced, the US Department of Agriculture and the Connecticut Agricultural Experiment Station launched vigorous programs of resistance breeding, using the Chinese chestnut, *C. mollissima,* as a source of resistance genes. The latter had apparently coevolved with chestnut blight, so that *Cryphonectria* caused only cosmetic damage to it but killed American chestnut, which had never been exposed to blight. The government programs did not succeed in producing chestnuts combining the forest tree form of American chestnut with the blight resistance of Chinese, and were discontinued by 1970 (American Chestnut Foundation, 1996a).

In 1983, the ACF was formed; one of the original organizers was Dr. Charles Burnham, the eminent Minnesota plant geneticist familiar with methods of resistance breeding by crossing disease-sensitive crop plants with their disease-resistant wild relatives (American Chestnut Foundation, 1996a). In this strategy, the two plants are crossed to yield an F_1 hybrid intermediate in resistance, which is then backcrossed to the desirable parent and these B_1 progeny are selected for resistance. The most resistant are again backcrossed to form a B_2 generation, and the cycle is repeated to form a B_3. Two of the most resistant B_3s are then crossed, and some of their progeny inherit two sets of resistance genes and should be as resistant as their wild ancestors, while having the other characteristics of the desirable parent (American Chestnut Foundation, 1996b). The ACF is following this backcross breeding plan, and their Dr. Fred Hebard (personal communication) states that they expect to release B_3 nuts by 2005 or 2006.

Another approach to overcoming chestnut blight is by the use of hypovirulence, a condition caused by a virus that infects *Cryphonectria* and causes it to weaken. Hypovirulence was first noticed around 1950 in Europe, when the Italian plant pathologist Antonio Biraghi noticed that blighted chestnut trees were healing themselves and recovering (Biraghi, 1951). In 1964, French mycologist Jean Grente visited Italy, took

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Case Study G (*continued*)

samples from healing cankers to his laboratory, and from them he isolated strains of *Cryphonectria* that looked different. He called these hypovirulent (Grente, 1965). These hypovirulent forms cured existing cankers when they were inoculated into them. This suggested that in the host hyphae of the hypovirulent strain anastomosed with those of the virulent strain and passed some genetic determinant to them, which turned out to be double-stranded RNA (dsRNA) (Day *et al*., 1977; Anagnostakis and Day, 1979).

In France and Italy, hypovirulence has spread naturally. It was found that tree climbing slugs, *Lehmannia marginata,* effectively transport hypovirulent inoculum when feeding on the fungal stromata in cankers (Turchetti and Chelazzi, 1984). In the United States, however, hypovirulence has not spread. This may be because there are many vegetative compatibility groups of *Cryphonectria* here, and many are incompatible; they do not form anastomoses with others and transmit the dsRNA. The recent introduction of biotechnology into hypovirulence research promises novel methods for overcoming problems such as this (Nuss, 1996). It is clear that we are only beginning to understand the complex ecology of this system and much work remains to be done (Anagnostakis, 1987).

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