

Forest Pest Control

Category 2

Iowa Commercial Pesticide Applicator Manual

IOWA STATE UNIVERSITY
Extension and Outreach



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About this manual

This manual was prepared for regional use in U.S. Environmental Protection Agency (EPA) Pesticide Applicator Training Programs and is intended to provide information needed to meet the minimum EPA standards for certification of commercial applicators under the Federal Insecticide, Fungicide, and Rodenticide Act.

This manual is for individuals to become certified in commercial pesticide applicator Category 2, Forest Pest Control. It is intended for use as a supplement to the general information in the Iowa Core Manual (IC445), and should not be used for certification purposes without reference to the Iowa core Manual.

Acknowledgments

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Forest Pest Control
Category 2

Iowa Commercial Pesticide Applicator Manual

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Contents

1
Worker Protection Standard

The objective of this chapter is to provide certified applicators with an overview of the U.S. Environmental Protection Agency's Worker Protection Standard (WPS). This chapter also includes information on how to comply with the WPS when using a pesticide product with a label that refers to the WPS.

The Worker Protection Standard is a regulation issued by the U.S. Environmental Protection Agency. It covers pesticides that are used in the production of agricultural plants on farms, forests, nurseries, and greenhouses. The WPS requires you to take steps to reduce the risk of pesticide-related illness and injury if you (1) use such pesticides, or (2) employ workers or pesticide handlers who are exposed to such pesticides.

If you are an agricultural pesticide user or an employer of agricultural workers or pesticide handlers, the WPS requires you to provide the following to your employees and, in some cases, to yourself and to others:

- Information about exposure to pesticides.
- Protection against exposures to pesticides.
- Ways to mitigate exposures to pesticides.

Which pesticide uses are covered?

Most pesticide uses involved in the production of agricultural plants on a farm, forest, nursery, or greenhouse are covered by the WPS. This includes pesticides used on plants and pesticides used on the soil or planting medium in which the plants are (or will be) grown. Both general-use and restricted-use pesticides are covered by the WPS. You will know that the product is covered by the WPS if you see the following statement in the "Directions for Use" section of the pesticide labeling:

> ***Agricultural Use Requirements***
> *Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR 170. This standard contains requirements for the protection of agricultural workers on farms, forests, nurseries, and greenhouses, and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification, and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about personal protective equipment, notification of workers, and restricted-entry intervals.*

If you are using a pesticide product with labeling that refers to the Worker Protection Standard, you must comply with the WPS.

Learning objectives

After reading this chapter, you should be able to

- Explain the basic intent of the Worker Protection Standard (WPS).
- List the scenarios in which you must follow the WPS.
- List the duties of the employer under the WPS.

How do I get information to comply with WPS?

The EPA manual *How To Comply with the Worker Protection Standard for Agricultural Pesticides: What Employers Need to Know* (available online at epa.gov/agriculture/htc.html) provides information to help you comply with the requirements of the WPS for agricultural pesticides you use. EPA may issue additional regulations and guidance about the WPS, which may be amended in the future.

Some states, tribes, or local governments with jurisdiction over pesticide enforcement may have additional worker protection requirements beyond the requirements described in the federal manual. Check with these agencies to obtain the information you need to comply with all applicable state, tribal, or local requirements.

When does the Worker Protection Standard apply to you?

You need the information contained in the *How to Comply with the Worker Protection Standard for Agricultural Pesticides* manual if

- You own or manage a farm, forest, nursery, or greenhouse where pesticides are used in the production of agricultural plants.
- You hire or contract for the services of agricultural workers.
- You operate a business in which you (or people you employ) apply pesticides.
- You operate a business in which you (or people you employ) perform tasks as a crop adviser.

If you are in any of these categories, you must comply with WPS.

Who does the WPS protect?

The WPS requires employers to take steps to protect two types of agricultural employees: workers and pesticide handlers. The terms "worker" and "pesticide handler" are defined specifically in the WPS, and employers of persons who meet these definitions must comply with the WPS.

WPS terms you need to know

The following definitions will help you determine whether you are affected by the Worker Protection Standard:

Term	Definition	Further information
Agricultural plants	Plants grown or maintained for commercial or research purposes.	**Examples:** Food, feed and fiber plants, trees, turfgrass, flowers, shrubs, ornamentals, and seedlings.
Farms	Operations, other than nurseries or forests, that produce agricultural plants outdoors.	
Forests	Operations that produce agricultural plants outdoors for wood fiber or timber products.	For purposes of WPS, forests include Christmas tree, forest nursery, and seed orchard operations.
Greenhouses	Operations that produce agricultural plants indoors in an area that is enclosed with nonporous covering and that is large enough to allow a person to enter.	**Examples:** Polyhouses, mushroom houses and caves, and rhubarb houses, as well as traditional greenhouses. Malls, atriums, conservatories, arboretums, and office buildings that grow or maintain plants primarily for decorative or environmental benefits are not included.
Nurseries	Operations that produce agricultural plants outdoors for transplanting to another location or for flower or fern cuttings.	**Examples:** Flowering and foliage plants or trees; tree seedlings; live Christmas trees; vegetable, fruit and ornamental transplants; and turfgrass produced for sod.
Pesticide handlers	Anyone who is employed (including self-employed) for any type of compensation by an agricultural establishment or a commercial pesticide handling establishment that uses pesticides and is doing such tasks as: mixing, loading, transferring, and applying pesticides; cleaning, handling, adjusting, or repairing equipment used in mixing, loading, and application; entering a greenhouse or other enclosed area after application and before the inhalation exposure level listed on the product labeling has been reached or one of the WPS ventilation criteria has been met. See the How to Comply manual for additional examples.	**Exception:** A person is not a handler if he or she only handles pesticide containers that have been emptied or cleaned according to instructions on pesticide product labeling or, if the labeling has no such instructions, have been triple-rinsed or cleaned by an equivalent method, such as pressure rinsing. **Exception:** A person is not a handler if he or she (1) is only handling pesticide containers that are unopened and (2) is not, at the same time, also doing any handling task (such as mixing or loading).
Workers	Anyone who is employed (including self-employed) for any type of compensation and is doing tasks such as harvesting, weeding, or watering relating to the production of agricultural plants.	

Duties for all employers

There are some exemptions for owners of agricultural establishments and members of their immediate family. The following information does not include the exceptions that may permit you to do less or options that may involve different requirements and additional duties to meet your responsibilities for workers and handlers.

Do not retaliate

Do not retaliate against a worker or handler who attempts to comply with WPS.

Inform your employees

In an easily seen, central location on each agricultural establishment, you must display the following materials and information:

- EPA WPS safety poster.
- Name, address, and telephone number of the nearest medical facility.
- Specific information about each pesticide application from the time application begins until 30 days after the restricted-entry interval (REI):
  - Product name, EPA registration number, and active ingredient(s).
  - Location and description of treated area.
  - Time and date of application and the REI.

You must tell workers and handlers where the information is posted, and allow them access. Keep the posted information legible. Keep the posted information up to date. Tell workers if emergency facility information changes and update the posted information.

Exception: If the workplace is a forest, you may display the information near the forest. It must be in a location where workers and handlers can easily see and read it and where they are likely to gather or pass by. For example, you might display the information with the decontamination supplies or at an equipment storage site.

Provide training to your employees

Each worker and handler must be trained. This requirement is met if the worker or handler is currently a certified applicator of restricted-use pesticides. Unless they possess a valid EPA-approved training card, train handlers and workers before they begin work and at least once each five years.

As part of the training, you must do one or more of the following:

- Use written or audiovisual materials, or both.
- Use EPA WPS handler training materials for training handlers.
- Use EPA WPS worker training materials for training workers.
- Have a certified applicator or trained trainer conduct the training orally or audiovisually in a manner the employees can understand, using easily understood terms, and respond to questions.

Provide decontamination supplies

Establish accessible decontamination supplies located together within ¼ mile of all workers and handlers. Required supplies include the following:

- Enough water for routine and emergency whole-body washing and for eye flushing.
- Plenty of soap and single-use towels.
- Clean coveralls.

Provide water that is clean, safe, and cool enough for washing, for eye flushing and for drinking. Do not use tank-stored water that is also used for mixing pesticides.

In addition, for handlers:

- Provide the same supplies where personal protective equipment (PPE) is removed at the end of a task.
- Provide the same supplies at each mixing and loading site.
- In areas being treated, put decontamination supplies in enclosed containers.
- Make at least one pint of eye flush water immediately accessible to each.

In addition,

- Do not put worker decontamination supplies in areas being treated or under an REI.

Exception: If the workplace is a forest and the tasks are performed more than ¼ mile from the nearest point reachable by vehicles (cars, trucks, or tractors), the decontamination supplies may be at the access point. In this circumstance, clean water from springs, streams, lakes, or other sources may be used for decontamination if such water is more readily available than the water at the access point.

Provide application information

Before any application, commercial handler employers must make sure the operator of the agricultural establishment where a pesticide will be applied is aware of the following:

- Location and description of area to be treated.
- Time and date of application.
- Product name, EPA registration number, active ingredient(s), and REI.
- Whether the product label requires both oral warnings and treated area posting.
- All other safety requirements on labeling for workers or other people.

Operators of agricultural establishments must make sure any commercial pesticide establishment operator they hire is aware of the location of all areas on the agricultural establishment where pesticides will be applied or where an REI will be in effect while the commercial handler is on the establishment, and restrictions on entering those areas.

Under most circumstances, employers must make sure that workers are notified about areas where pesticide applications are taking place or where restricted-entry intervals are in effect. Some pesticide labels require you to notify workers both orally and with signs posted at entrances to the treated area. Unless the pesticide labeling requires both types of notification in its "Directions for Use," workers must be notified either orally or by the posting of warning signs at entrances to treated areas.

Post WPS-design signs so they can be seen from all points where workers usually enter a treated area. If there are no usual points of worker entry, post the signs in the corners of the treated area or in places where they will be most easily seen. On farms and forests, smaller signs may be used if the treated area is too small to accommodate 14- by 16-inch signs. For example, where a single tree needs to be posted, a smaller sign would be appropriate. Wherever a small sign is used, there are specific posting distances depending on the size of the lettering and symbol on the sign.

Provide emergency assistance

When any handler or worker may have been poisoned or injured by pesticides, promptly make transportation available to an appropriate medical facility. You must also promptly provide the following information to the victim and to medical personnel:

- Product name, EPA registration number, and **active ingredient**.
- All first aid and medical information from label.
- Description of how the pesticide was used.
- Information about victim's exposure.

Additional worker and handler duties

There are additional specific duties for employers of workers or handlers. To meet those requirements, you must refer to the How to Comply manual, where you can find out about WPS exceptions and additional duties. Also, the How to Comply manual contains sample forms, fact sheets, and checklists to assist in complying with the WPS regulation.

Noncompliance

If you do not comply with the WPS requirements, you will be in violation of state and federal law, since it is illegal to use a pesticide product in a manner inconsistent with its labeling.

REVIEW QUESTIONS
Worker Protection Standard

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. The Worker Protection Standard (WPS) only applies to persons who actually handle pesticides.
   A. True
   B. False

2. General-use pesticides are not covered by the WPS
   A. True
   B. False

3. What is the name of the publication that provides information to help you comply with the WPS?

4. When does a worker become a pesticide handler?
   A. Handling pesticide containers that have been emptied and cleaned according to product labeling.
   B. Handling unopened pesticide containers and not, at the same time, involved in mixing, loading, applying, or cleaning.
   C. Entering a greenhouse or other enclosed area after application and before the inhalation exposure level listed on the product label has been reached or one of the WPS ventilation criteria have been met.
   D. Working in areas adjacent to where pesticides have been applied.

5. What three items does an employer where pesticides are applied need to display in an easily seen, central location?

6. What is the exception to the location of the above information when the treated area is a forest?

7. Which form of training does not meet WPS standards?
   A. Use of written or audiovisual materials.
   B. Use of EPA WPS worker training materials for handlers.
   C. Use of EPA WPS worker training materials for workers.
   D. Have a certified applicator or trained trainer conduct training orally in a manner that the employees easily understand.

8. Decontamination supplies must be located within _____ mile of all workers and handlers.
   A. ¼
   B. ½
   C. ¾
   D. 1

9. What is the exception to the location of the above decontamination supplies when the treated area is a forest?

10. What information must be supplied to the victim and medical personnel in the case of a suspected unsafe exposure to a pesticide?

Learning objectives

After reading this chapter, you should be able to

- Explain the goal of integrated pest management (IPM) programs.
- Define the term threshold level.
- List the various IPM control strategies and the circumstances in which they should be used.
- Explain the importance of evaluating pest management strategies and what kind of information should be recorded.

2
Principles of Pest Management

All parts of a tree — roots, stems, foliage, shoots, and terminal leaders — are vulnerable to attack by pests. Pest damage can range from slight damage that has no effect on the value of the harvested product to severe damage that stunts or kills the trees or reduces their market value. Tree pests include insects and mites, plant pathogens, weeds, **vertebrates,** and **nematodes**.

Managing tree pests effectively should be based on thorough consideration of ecological and economic factors. The pest, its biology, and the type of damage it causes are some of the factors that determine which control strategies and methods, if any, should be used. Pest management decisions largely determine the degree and amount of pesticide used.

Ultimately, pest management decisions represent a compromise between the value of the product, the extent of the pest damage, the relative effectiveness and cost of the control measures, and the impact on the environment.

Integrated pest management

The goal of integrated pest management (IPM) is to use all appropriate tools and tactics to prevent economically important pest damage without disrupting the environment. Information gathering and decision making are used to design and carry out a combination of measures for managing pest problems. IPM is the best approach to manage pests of trees.

What are these IPM tools and how are they used?

Monitoring

Monitoring (**scouting**) forests and newly established plantations will help detect problems early while there is still time to take action. The information gathered through monitoring is a key element in any IPM program.

For example, when monitoring or scouting an area, examine the center of the area as well as the margins. Note competition levels among trees and other plants. Note types, quantity, and location of weeds. Look for signs of animal activity. Check a representative sample of trees for signs and symptoms of insect and disease problems. Inspect all parts of the tree, from top to bottom and from branch tips to trunk. Depending on the pest, the use of traps or microscopic examination may improve the information gathered by visual examination. Record your observations. The destructive forms of many insect pests are generally most active from April through August, but infection by many plant pathogens depends more on weather conditions than on calendar date. Scouting and monitoring for all pests and pest problems must be done regularly and frequently to avoid surprises.

Weather plays an important part in pest development. Keeping track of the daily weather conditions (high and low temperatures, humidity, and the amount of rain) will make you better at forecasting pest problems.

Identification

Identification of pests and the diagnosis of pest damage are key elements of IPM. If you find perennial weeds present or signs of insect, disease, or vertebrate presence or damage, try to determine the following information:

- What kind of pest is present?
- What stage of the pest is present?
- What is the size of the pest population?
- How much damage has occurred?
- How much damage is likely to occur if no control measures are taken?
- Does the pest or damage require immediate attention, or can control measures be postponed until the trees are near harvest?

Certain tools are useful in carrying out an IPM program. A hand lens is essential for identifying disease signs, insects, and weed plant characteristics. If pests are in the tops of trees, binoculars may be beneficial. Pruning shears and a pocketknife are needed when probing for insects or disease or collecting weed specimens. Field guides, extension bulletins, or other references with pictures and biological information for identifying trees, weeds, insects, and diseases will be helpful. Have plastic bags, vials, and containers available in case you have to take samples of the pest or pest damage to someone else for identification. For weed identification, collect as much of the whole plant as possible, including flowers, leaves, and stems.

It is important to know where to find help in diagnosing pest problems. The local extension office can provide you with forms and instructions for sending samples to a laboratory for diagnosis.

Threshold level

Determine the **threshold level** — the point at which the pest or its damage becomes unacceptable. The threshold level may be related to the beauty, health, or economic value of the tree crop. Once the threshold level has been reached, you must determine what type of control procedure is needed. This decision will be based on the size of the pest population, the kind of damage the pest is causing, and the control measures that are available. It is also important to consider the cost-effectiveness of potential controls. You must carefully weigh the cost of control, the value of the tree, and the impact of the pest damage on the value of the tree.

Management strategy

Decide on management (control) strategies. Management options may differ significantly between high-value Christmas tree species and lower value trees. The following are examples of management strategies.

Do nothing: In situations where the pest does not damage the crop value or the crop value is so low it is not cost-effective to apply a control measure, no action is needed.

Cultural management: Cultural management manipulates the environment to make it more favorable for the plant and less favorable for the pest. Cultural controls such as good site selection, planting resistant varieties, stand thinning, or selective pruning make it less likely that the pest will survive, colonize, grow, or reproduce. Cultural management can be especially effective in preventing pests from building to unacceptable levels.

Mechanical management: Some measures exclude or remove the pest from the habitat. Mechanical traps, screens, fences, and nets can remove the pest or prevent access by the pest. Tillage and mowing are used to manage weeds mechanically.

Biological management: Biological controls include the beneficial predators, parasitoids, and pathogens that kill pests. There are many more known natural enemies of insect pests than there are natural enemies of disease pests. Biological weed control is generally aimed at nonnative, introduced weeds.

Ladybugs, lacewings, and certain mites are common predators of insects. Some tiny wasps and some fly species are parasitoids of insects. Many beneficial parasites are host-specific and do not control a wide range of pests. Some natural enemies are host-specific while others are general feeders. Parasitoids and predators are often effective at keeping insect pests at low levels. For example, aphids, scales, and mites rarely build to damaging levels in pine or spruce forests because of the effectiveness of natural control agents. Insects are also affected by a variety of bacterial, fungal, and viral diseases that affect only insects.

Biological control organisms are very sensitive to pesticides. Pesticide applications to control a pest may have the unwanted side effect of wiping out part of the natural enemy complex along with the pest. This, in turn, may cause a population explosion of a different pest in the void left by the predators and parasitoids.

Chemical management: Pesticides are an important tool in IPM when large pest populations threaten high-value trees. Knowledge of the pest's life cycle, selection of an appropriate pesticide, proper timing of the application, and use of the right application equipment will improve coverage and effectiveness. The ability to recognize beneficial organisms, combined with cultural and mechanical controls, may allow you to reduce, delay, or eliminate pesticide treatment of a minor pest problem.

Evaluation

Evaluate the results of management strategies. It is important to determine the effectiveness of your management tactics. This information will determine whether follow-up treatment is needed and will improve pest management for subsequent years. Return to the area after applying a treatment and compare posttreatment pest activity to pretreatment. This is where a pest management logbook will become invaluable. Include your observations about where pests first showed up, what kinds of natural enemies you observed, where and when specific treatments were applied, and what the results were. Sound IPM practices provide economic and environmental benefits.

REVIEW QUESTIONS
Principles of Pest Management

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. Why is a good pest control decision usually a compromise?

2. Which of the following is *not* a component of scouting trees?
   A. Record observations.
   B. Examine a representative sample of trees from the site.
   C. Search for a single pest at each inspection.
   D. Examine each tree from top to bottom and from outer edges to center.

3. What is the first thing you should do when you detect the presence of a pest?
   A. Select a control tactic.
   B. Identify the organism.
   C. Determine the threshold level for control.
   D. Notify the Department of Agriculture.

4. How would you go about identifying an insect pest found on a tree?

5. What is the threshold level?

6. What IPM practice manipulates the environment to make it more favorable for plants and less favorable for pests?
   A. Biological management
   B. Mechanical management
   C. Pesticide use
   D. Cultural management

7. What IPM practice depends on natural enemies of pests?
   A. Biological management
   B. Mechanical management
   C. Pesticide use
   D. Cultural management

8. Biological control organisms are not affected by pesticides.
   A. True
   B. False

9. The effectiveness of a pesticide application is related to:
   A. Choosing the right pesticide
   B. Proper timing
   C. Good coverage
   D. All of the above

10. Why is it important to evaluate the results of IPM management strategies?

Application Methods and Equipment

Learning objectives

After reading this chapter, you should be able to

- Briefly describe the various pesticide application methods and identify the factor(s) that influence your choice of the appropriate method.
- Describe the various types of application equipment, how they operate, and their desirable features.

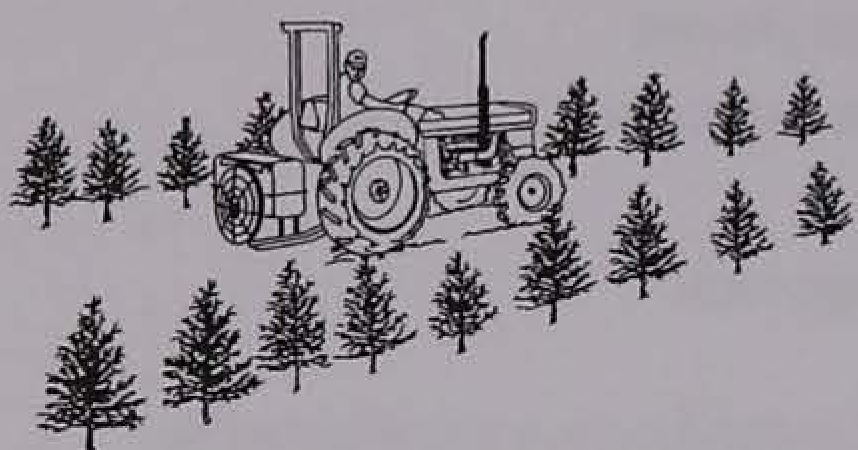

Figure 3.1. Broadcast applications are generally most effective in intensively managed areas, such as a Christmas tree plantation (David Kidd, University of California, Davis).

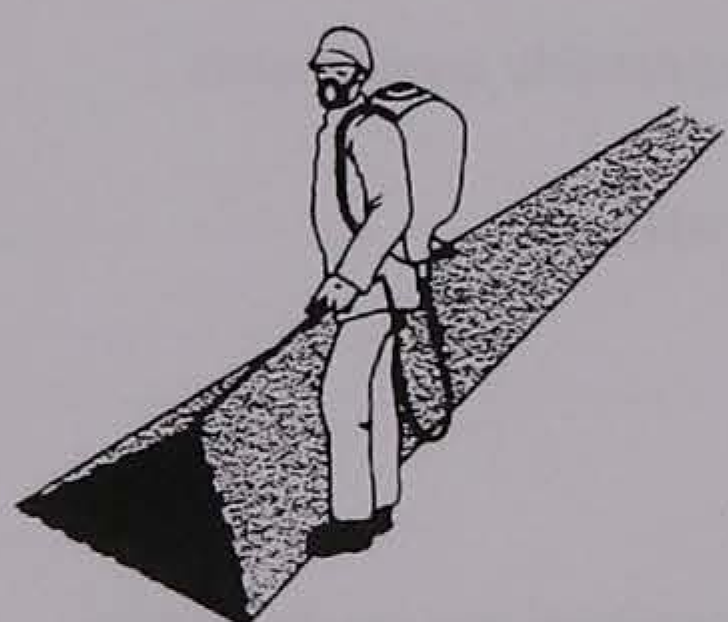

Figure 3.2. Directed sprays are a good choice for minimizing pesticide contact with the crop or with beneficial insects (David Kidd, University of California, Davis).

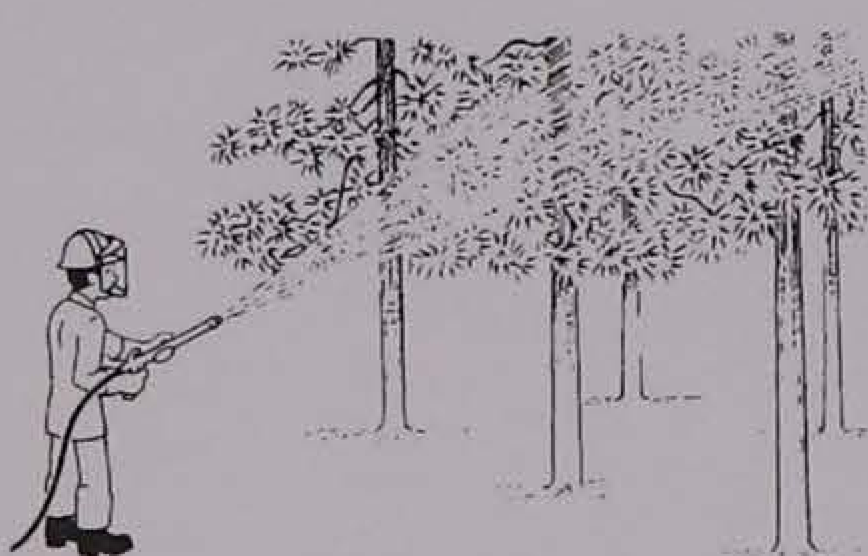

Figure 3.3. Foliar sprays can be applied from the time of spring leaf-out until first frost in the fall (David Kidd, University of California, Davis).

Application methods

The method you choose to apply a pesticide will depend on the nature and habits of the target pest, the site, the pesticide, available application equipment, and the cost and efficiency of alternative methods. Your choice is often predetermined by one or more of these factors.

General methods

Broadcast application is the uniform application of a pesticide to an entire area (Figure 3.1).

Directed spray application targets pests in a specific area (Figure 3.2).

Foliar application directs pesticide to the leafy portions of a plant (Figure 3.3). Foliage stem sprays can be applied from the time of spring leaf-out until first frost in the fall. Some herbicides, however, should be applied only in late summer or early fall. Do not treat plants that are under moisture or heat stress. Take care to avoid drift to nearby sensitive vegetation.

Soil application (Figure 3.4) places pesticide directly on or in the soil rather than on a growing plant. **Soil incorporation** is the use of tillage equipment to mix the pesticide with the soil. **Soil injection** is application of a pesticide beneath the soil surface.

Figure 3.4. Soil application is generally used for delivering systemic fungicides and insecticides to target trees (David Kidd, University of California, Davis).

Special forestry application methods for weed control

Some special application methods are used specifically in forestry applications. They are described below.

Basal sprays (Figure 3.5) are directed at the lower 18 inches (46 cm) of stems and trunks that are less than 6 inches (15 cm) in diameter. Basal treatments are usually effective on canes and thickets as well as trees. Primarily used with herbicides, basal sprays are intended to penetrate the bark and kill the tree and any basal buds that might sprout. Herbicides used for basal spraying are generally applied in oil carriers. As bark becomes rougher and thicker, this technique becomes less effective.

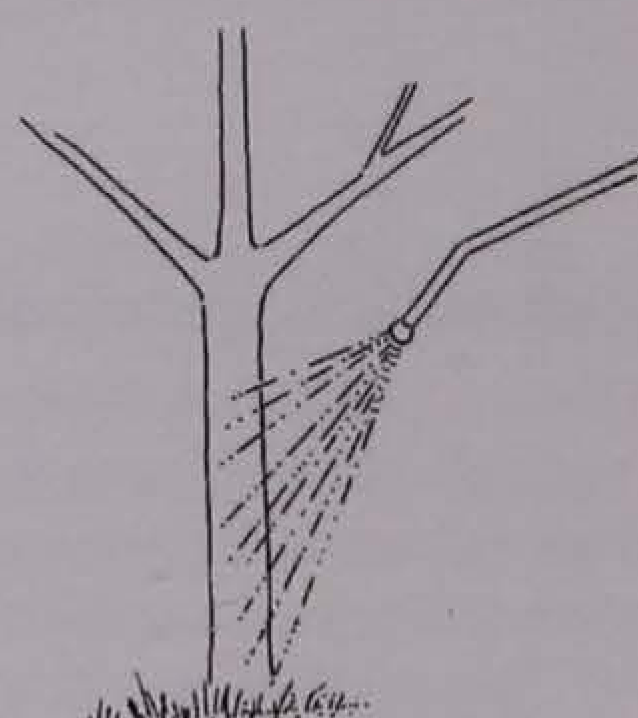

Figure 3.5. Basal sprays are directed at the lower 18 inches of stems and trunks that are less than 6 inches in diameter. (Randy Heiligmann, Ohio State University, Columbus).

Cut-stump treatments are made to the freshly cut stump surfaces. When a tree or vine is cut, there is a high probability that the stump will sprout. When this is undesirable, the sprouting can be eliminated by treating the cut stump with herbicide. Herbicides can be applied to the stump in many ways, the most common being to spray with a backpack or hand-held sprayer. Treat stump surfaces within two or three hours after cutting — drying of the cut surface reduces control. Cut-surface treatments are recommended when trees are 4 inches or more in diameter and are usually more effective than basal bark sprays on plants this size or larger.

Figure 3.6. Water-soluble herbicides applied using the cut-stump technique need only be applied to sapwood and bark of the cut stump. (adapted from Randy Heiligmann, Ohio State University, Columbus).

How much of the stump needs to be treated depends on the formulation of herbicide used. Many of the herbicides labeled for cut-stump application are water soluble. With these materials it is not necessary to treat the entire stump. The critical area of the stump that must be treated to prevent sprouting is the **sapwood** and bark of the stump's cut surface (Figure 3.6). To be effective, stump treatment with water-soluble herbicides must be done immediately after cutting the tree or vine. If treatment is delayed, adequate downward movement of the herbicide will not occur and sprouting will not be eliminated.

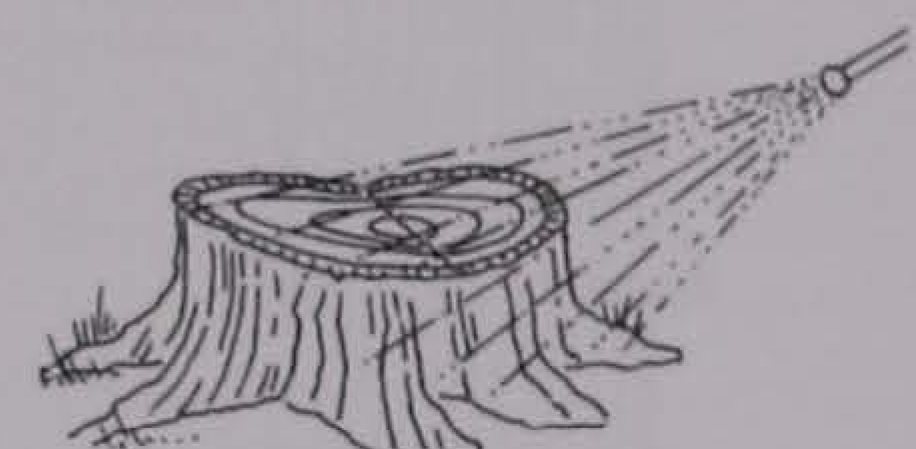

Figure 3.7. Petroleum-based herbicides applied using the cut-stump technique must be applied to the entire stump (Randy Heiligmann, Ohio State University, Columbus).

Some herbicides labeled for cut-stump application are formulated to be mixed with a petroleum product, such as diesel fuel. These materials do not move readily within the plant, but penetrate the bark. To be effective in suppressing stump sprouting, the entire stump, particularly the bark and exposed roots, must be thoroughly sprayed (Figure 3.7). Timing is less critical with these materials because they are not so dependent on movement downward from the cut surface to distribute the herbicide. In situations where immediate treatment of stumps is not possible, a herbicide in an oil carrier should be used rather than one in a water carrier.

Treatment with an oil-carried herbicide is also recommended in the spring when treating species that exhibit a spring "sap flow," such as the maples (*Acer*), grape (*Vitis*), and ironwood (*Ostrya*). Water-carried herbicides will usually not be adequately absorbed to be effective during the spring "sap flow."

Frilling and girdling methods cut the bark around the tree trunk. Herbicides may or may not be used. If one wishes to control sprouting, however, herbicides are strongly recommended. Herbicides can either be applied as a separate step or be injected simultaneously into the cut area.

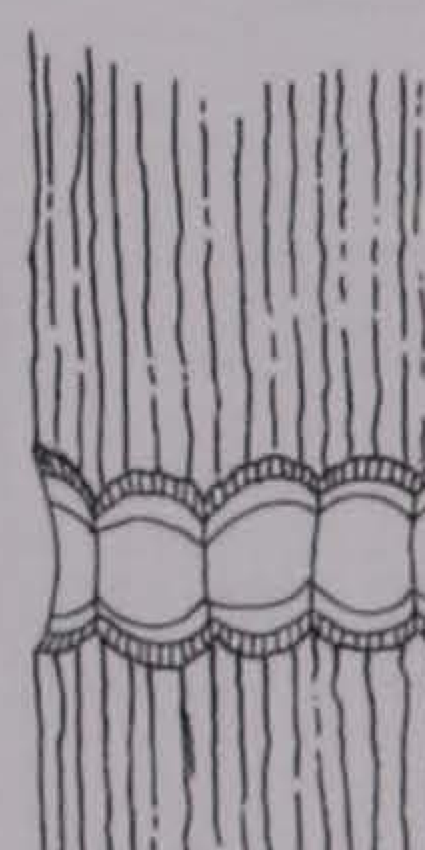

Figure 3.8. Girdling with an ax removes a notch of bark and wood (Randy Heiligmann, Ohio State University, Columbus).

Girdling can be done with an ax, hatchet, or chain saw (Figure 3.8). When done with an ax or hatchet, the girdle is made by striking from above and below along a line around the trunk so that a notch of wood and bark is removed. The width of the notch varies with the size of the tree. Effective girdles may be as narrow as 1 or 2 inches (25-50 mm) on small-diameter trees and as wide as 6 or 8 inches (152-203 mm) on large-diameter trees.

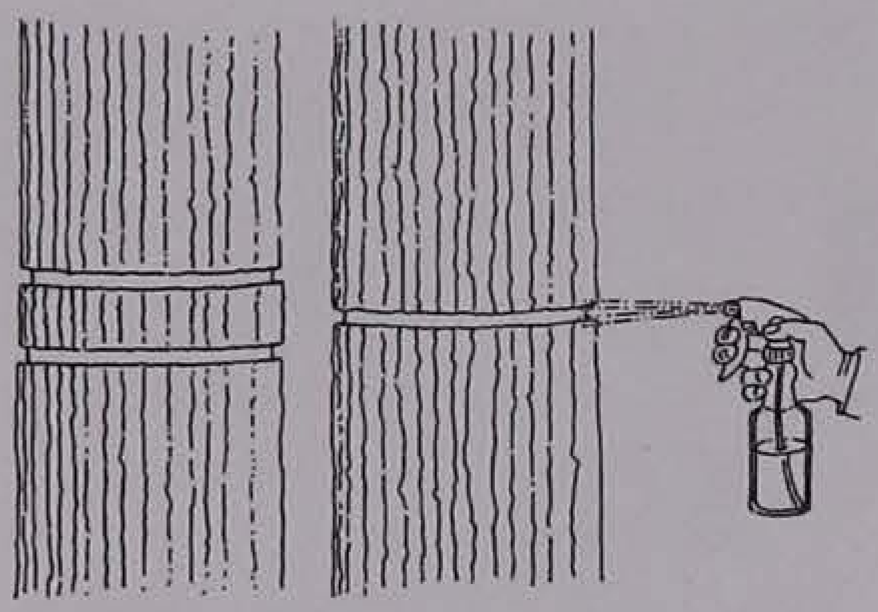

Figure 3.9a (left). Girdling with a chain saw requires two horizontal cuts completely encircling the tree when no herbicide is used. However, sprouting will still occur.

Figure 3.9b (right). To eliminate sprouting, make a single girdle and apply appropriate herbicide in the cut. (Randy Heiligmann, Ohio State University, Columbus).

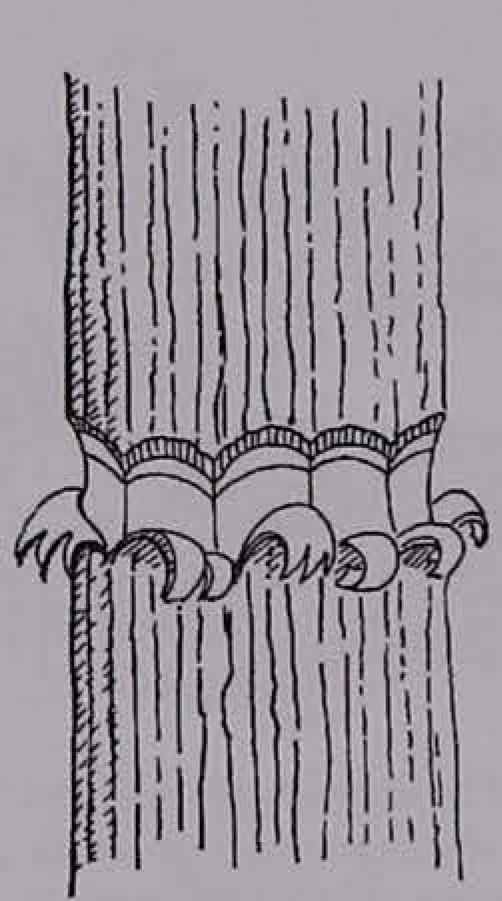

Figure 3.10. Frilling is a variation of girdling in which a series of downward-angled cuts are made completely around the tree (Randy Heiligmann, Ohio State University, Columbus).

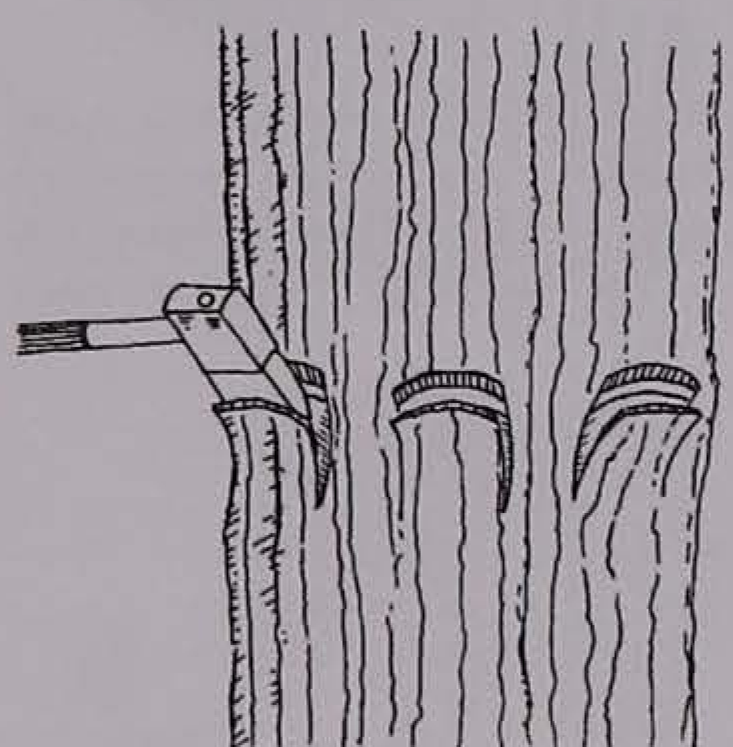

Figure 3.11. Tree injection is a discontinuous frill with a small amount of herbicide placed in each cut (Randy Heiligmann, Ohio State University, Columbus).

When a chain saw is used to girdle, two horizontal cuts between 2 and 4 vertical inches apart are usually made completely around the tree when no herbicide is used (Figure 3.9a) and one horizontal cut is made completely around the tree when herbicide is used (Figure 3.9b).

Frilling is a variation of girdling in which a series of downward-angled cuts are made completely around the tree, leaving the partially severed bark and wood anchored at the bottom (Figure 3.10). Frilling is done with an ax or hatchet.

Using herbicides can increase the effectiveness of both girdling and frilling. With frilling and girdling, water-soluble forms of herbicides are most commonly used to get maximum movement of herbicide within the plant. When using water-soluble herbicides, the herbicide/water mixture is commonly applied by squirting it on the girdle or frill until the cut surface is wet. Hand-held, pint or quart spray bottles, such as those available at local garden stores, are ideal for applying herbicide to the girdle (Figure 3.9b). Again, note that a single, rather than double chain saw girdle is needed when a water-soluble herbicide is to be used.

Exceptions to the above recommendation of using a water-soluble herbicide for girdling and frilling are the commonly used forestry herbicides that contain the ester formulation of 2,4-D + 2,4-DP. They are labeled for use with frilling in an oil carrier, and the recommendation is to fill the frill with the mixture. They are commonly applied with a backpack or hand-held, hand-pumped sprayer.

Hack-and-squirt techniques introduce a herbicide into the undesirable tree through spaced cuts made around the trunk of the tree with a hand ax, Hypo-hatchet™, or tree injector (Figure 3.11). The procedure can be visualized as a discontinuous frill with a small amount of herbicide placed in each cut. With an ax or hatchet, non-overlapping horizontal cuts penetrating into the sapwood (the outer area of lighter-colored wood in the stem cross section) are made completely around the tree. Cuts are about 2 inches (50 mm) long and are spaced with their edges 1 to 3 inches (25-76 mm) apart, depending on tree species and the specific herbicide being used. A small amount of herbicide is then placed in each cut. This can be done conveniently with a pint or quart spray bottle, such as those available at garden stores. The amount of herbicide to be placed in the cut is specified on the herbicide label, but is generally 1 to 2 milliliters. Various tree injectors can also be used, including the Hypo-hatchet™, which is a hatchet with a reservoir constructed to inject herbicide when it is struck into the tree.

Tree injection is generally more effective than mechanical girdling or frilling without herbicide because of the use of the herbicide. However, on difficult-to-control species, such as red maple, hickories and dogwoods, a continuous frill or girdle with herbicide may be necessary to obtain acceptable control. As with most of the herbicides suggested for use with girdling and frilling, the herbicides for tree injection are mostly water-soluble materials that move vertically and horizontally within the tree to complete a chemical girdle.

Microinjection is used to combat insects and disease. Insecticides, fungicides, and fertilizers can be injected into trees. Microinjection is fast acting (12 to 24 hours) and it is weatherproof because the pesticide is injected into the tree. However, this method can be costly when many trees are involved, often making the spray alternative more attractive.

Thin line application is a special form of basal bark application. It involves applying a horizontal thin line of undiluted herbicide completely around the target tree's trunk (Figure 3.12). The herbicide is usually applied near the base, but may vary depending upon the herbicide and stem size. This treatment is most effective on trees with trunk diameters of 6 inches (152 mm) or less. You may need a metered or calibrated applicator to deliver the small amounts required.

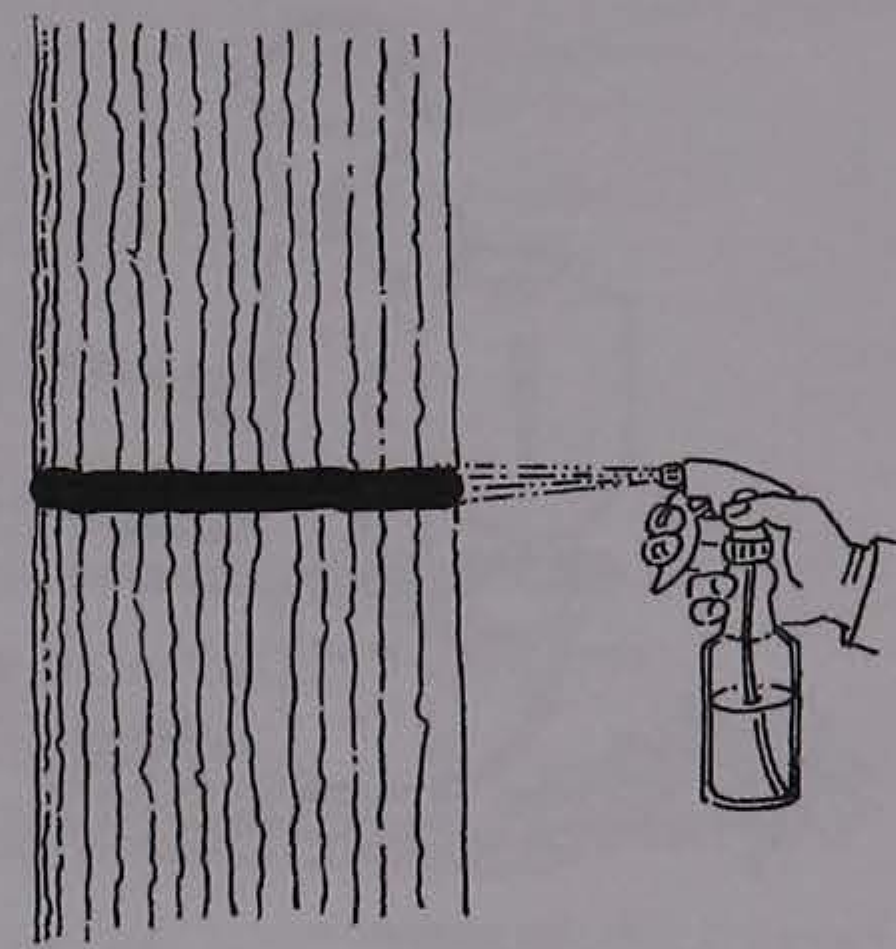

Figure 3.12. Thin line application involves applying a thin line of undiluted herbicide completely around the tree trunk (adapted from Randy Heiligmann, Ohio State University, Columbus).

Application equipment

Granular applicators

Granular applicators are designed primarily for soil applications and are available in various styles and sizes. Drop-through spreaders and rotary spreaders are the most common. Shaker cans and hand distribution of pellet or gridball formulations may also be used on occasion.

Granule applicators normally consist of a hopper for the pesticide, a mechanical agitator at the base of the hopper to provide efficient and continuous feeding, and some type of metering device, usually a slit-type gate, to regulate the flow of the granules.

Drop-through spreaders are available in widths from 1½ to 3 feet (0.5 to 1 m) or more. An adjustable sliding gate opens holes in the bottom of the hopper and the granules flow out by gravity feed. Normally, a revolving agitator is activated when the spreader is in motion to ensure uniform dispensing.

Rotary spreaders distribute the granules to the front and sides of the spreader, usually by means of a spinning disc or fan. Heavy granules are thrown farther than lighter ones. A 6- to 8-foot (1.8 to 2.4 m) swath width is common. Both power and hand-driven rotary spreaders are available. The former are generally best suited for use in forests.

Sprayers

The primary function of any sprayer is to deliver the proper rate of chemical uniformly over the target area. When selecting a sprayer, be certain that its components will withstand the deteriorating effects, if any, of the chemical formulations you use. Also consider durability, cost, and convenience in filling, operating, and cleaning.

Handheld or garden sprayers are useful in applying small amounts, usually 1 milliliter, of a herbicide to a chain saw girdle or individual hacks made by a hatchet. Most sprayers will deliver about 1 milliliter per full squeeze of the trigger. It is always wise to check the delivery rate when placing a new sprayer in service and to recheck older sprayers because normal wear will affect this rate over time.

Figure 3.13. Backpack sprayer.

Figure 3.14. The hatchet injector delivers metered amounts of undiluted herbicide directly into the sapwood of the target tree. Credit: James H. Miller, USDA Forest Service, Bugwood.org.

Figure 3.15. Microinjectors deliver fungicides and insecticides directly into the vascular systems of high-value trees in urban settings either passively (top) or actively using pressure (bottom). Credits: (top) David Cappaert, Michigan State University, Bugwood.org (top, inset) J.J. Mauget Co. (bottom) Arborjet.

Backpack sprayers are useful in situations where small areas or widely dispersed individual plants require treatment. They are well suited for treating individual plants and for basal and cut-surface applications. Tanks usually hold 3 to 5 gallons. The sprayers can be fitted with a single nozzle or with a boom and up to three nozzles.

The most common backpack sprayers have a lever that is pumped during the spraying operation to activate a plunger or diaphragm pump. Initial pressure can range as high as 30 to 60 psi, but it drops continuously as the spray is applied. For this reason, it is highly desirable to either purchase sprayers equipped with a pressure regulator or retrofit your existing sprayer. Remember that a pressure gauge is not the same thing as a regulator.

Low-pressure sprayers are normally designed to deliver low to moderate volumes at low pressure — 15 to 100 pounds of pressure per square inch (psi). The spray mixture is applied through a boom equipped with nozzles. The boom usually is mounted on a tractor, truck, or trailer; the nozzle(s) also can be attached to a handheld boom.

Roller-type pumps are often used on small tank sprayers (50 to 200 gallons), but sprayers with large tanks (200 to 1,000 gallons) usually have centrifugal pumps. Low-pressure sprayers do not deliver sufficient volume to penetrate dense foliage. They are most useful in distributing dilute pesticide over large areas.

High-pressure sprayers are designed to deliver large volumes at high pressure. They are similar to low-pressure sprayers except that they have piston pumps that deliver up to 50 gallons of spray per minute at pressures up to 800 psi. A boom or handgun delivers 200 to 600 gallons per acre.

High-pressure sprayers provide thorough coverage and can penetrate dense foliage; however, these sprayers produce large numbers of fine spray droplets, which can drift. These sprayers can provide low-pressure flow when the proper pressure regulators are used.

Injectors

Tree injectors were originally two-handed devices that were designed to release an undiluted herbicide when the injector was plunged into the base of the tree. These injectors were awkward and heavy. Due to the fatigue factor, they were feasible only in areas where few trees needed to be treated.

Hatchet injectors (Figure 3.14) are lightweight and easy to use. A measured amount of the undiluted herbicide is delivered through the blade itself into the cut each time the tree trunk is struck.

Microinjectors can operate either passively by allowing the fungicide/insecticide to be taken up by normal plant translocation (Figure 3.15, top) or actively forcefully injecting the fungicide/insecticide into the tree's vascular system under pressure (Figure 3.15, bottom).

REVIEW QUESTIONS
Application Methods and Equipment

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. Which of the following methods of application mixes the pesticide into the soil using tillage equipment?
   A. Soil treatment
   B. Soil application
   C. Soil fumigation
   D. Soil incorporation

2. What are some of the factors that influence the choice of pesticide application method?

3. Water-soluble herbicides applied using the cut-stump treatment should be applied:
   A. To the entire cut surface of the stump.
   B. In a ring containing the sapwood and the bark.
   C. The entire stump; cut surface and all of the bark.
   D. Around the stump on ground cover.

4. A double girdle with a chain saw will prevent sprouting.
   A. True
   B. False

5. What is "thin lining" when applying a herbicide?

6. High-pressure sprayers:
   A. Provide low volume at low pressure.
   B. Deliver dilute pesticide over a small area.
   C. Increase spray drift.
   D. Are needed for frilling.

7. It is hardest to maintain uniform pressure when using a:
   A. Backpack sprayer
   B. High-pressure sprayer
   C. Low-pressure sprayer
   D. Hydraulic sprayer

8. Tree injectors treat several trees at the same time.
   A. True
   B. False

9. Granular applicators are designed primarily for:
   A. Foliar application
   B. Soil application
   C. Spot application
   D. Basal application

10. Microinjectors can be both passive and active application devices.
    A. True
    B. False

Learning objectives

After reading this chapter, you should be able to

- Explain how cultural, mechanical and chemical weed control are integrated for successful vegetation management.
- List the basic characteristics of herbicides and explain how they might be used in selecting a herbicide.
- List and explain the factors that influence herbicide effectiveness.
- List the more common herbicides used in tree plantings.
- List the more common herbicides used in timber stand improvement.

4
Forest Weed Management

Weeds are plants that grow out of place. Weed control practices in forests are designed to favor the growth of the desired tree species, improve visibility along forest roads, control noxious weeds, and improve wildlife habitats. The goal is to manage timber species (**crop trees**), ground vegetation (**brush**), and wildlife so that each component is maximized yet balanced. Vegetation management is a primary means to achieve a productive forest.

Goals of vegetative weed management in forestry

A forester might undertake a weed management program with one or more of the following objectives in mind:

- Remove unwanted vegetation from planting sites to favor the planted trees.
- Release more desirable species from less desirable overtopping species.
- Thin excess trees from a forest stand.
- Control vegetation along forest roads and around buildings and facilities.
- Remove exotic, invasive plants from natural and planted forests.

Integrated control

Successful vegetation management plans incorporate the right package of practices into well-planned programs that are executed on a timely basis. No single plan is best suited for every site, so careful analysis of each site is necessary. Routinely review the results obtained and modify the plans as needed to ensure satisfactory control.

Cultural control

Cultural weed control involves using practices that favor the desired tree species and make them more competitive with weeds. Examples include the following:

- Select the best-adapted species and varieties.
- Prepare site properly.
- Plant vigorous, large, healthy seedlings.
- Plant seedlings at the appropriate spacing, and replace those that die.
- Apply necessary insect, disease and rodent control measures.
- Maintain optimum stocking levels for the site at each stage of stand development.

Mechanical control

Mechanical weed control plays an important role in maintaining a productive forest. Many specialized machines and attachments are used in forest vegetation management, including brush rakes, angle blades, shearing blades, rolling brush cutters and shredders. Large offset disks and integral plows are sometimes used. In addition, chain saws, axes, brush hooks, powered brush cutters, hatchets and other hand tools can be used in weeding operations.

On gentle slopes mechanical means of site preparation and rehabilitation are generally sufficient to remove debris, control weeds, prepare seedbeds, reduce soil compaction caused by logging, and carry out minor land leveling operations.

Figure 4.1. Recently thinned upland southern red oak, Quercus falcata, stand. Credit: Brian Lockhart, USDA Forest Service, Bugwood.org.

Mechanical thinning (Figure 4.1) is sometimes practiced, especially in dense stands where clearing in regularly spaced strips is desired and no selection of individual trees is necessary. Mechanical thinning is not acceptable for release when desired small trees are hidden by taller, brushy trees or where individual tree selection is desired.

Mechanical control is not suited to all sites. The major obstacles to the use of mechanical vegetation management are unsuitable terrain, the likelihood of soil erosion, and relatively high operating costs.

Manual vegetation removal can be done in areas inaccessible to machines or to complement or replace the use of large equipment. Manual cutting is most effective when species to be cut are not too dense and do not resprout. Because conifers do not resprout, they are easily controlled by cutting. Many brush species, however, resprout readily from the trunk or established roots, and this reduces the effectiveness of cutting. Manual cutting may not always be appropriate for site preparation or release, but it can be effectively combined with herbicide treatment of stumps to remove selected trees and prevent regrowth.

Chemical control

Chemical control refers to the use of herbicides for vegetative management. The benefits of herbicides applied during site preparation and release may be evident through the life of the stand if their use is supplemented by all the other principles of good forest management. Use of herbicides is only one step in a long-term production plan. Application of herbicides should be both necessary and compatible with all other phases of the plan.

Once the weed species to be controlled have been identified, the correct herbicide, formulation, rate, water volume, method of application, and time of treatment must be determined. Before using any pesticide, read the entire label.

Evaluate the results

After using any vegetation management practice, inspect the area to evaluate the results. Keep in mind the type and species of vegetation treated, the soil type, and weather conditions during and after application. Know the objectives of the control program when evaluating the results. In some cases, suppression of treated vegetation is sufficient; in others, selective control is desired. Initial herbicide activity and possible injury to adjacent desirable vegetation can be determined two to four weeks after application. The results of vegetation control treatments should be evaluated after about two months, at the end of the season, and then for several years thereafter. The effectiveness of brush and perennial weed control measures cannot be fully evaluated for at least 12 and sometimes up to 24 months after treatment.

Evaluation must be an ongoing activity. It allows you to make adjustments in rates, products, and timing of herbicide applications, and to plan any additional control measures that may be needed.

Herbicide characteristics

Herbicides are chemicals that affect the germination, growth, and behavior of plants. To choose the appropriate herbicide for a particular situation, you need to understand some basic herbicide characteristics.

Soil applied versus foliar applied herbicides

Soil applied herbicides are applied prior to weed emergence. They may be applied to the soil surface after planting (**preemergence**) or applied prior to planting and incorporated (preplant incorporated) into the upper 1 to 2 inches of soil. For soil applied herbicides to be effective, they must receive rainfall or irrigation water after application so they are present in the soil solution and can be taken up by germinating weed seeds.

Foliar applied (**postemergence**) herbicides are applied after weed emergence to the above ground parts of established plants. Some postemergence herbicides also have soil activity and can be taken up by the roots.

Selectivity

Herbicides differ in their effectiveness on different types of vegetation. Selective herbicides may control grasses only, broadleaf plants only, or certain grasses and broadleaf plants, while not affecting desired vegetation. Nonselective herbicides kill all vegetation that they come in contact with. Some herbicides are considered nonselective but may be used selectively in certain situations. For example, some herbicides are selective in Christmas tree plantations when applied during certain periods of the year, such as before the trees begin growing in the spring, after they have hardened off in the late summer, or when they are dormant. Applied at other times of the year, the same herbicides may cause significant damage to the Christmas trees.

Movement in plant

Herbicides can be applied to the target plant's leaves or root systems and, in trees, can also be injected into the stem or applied to the cut stump.

Some herbicides kill the leaves on contact and are not mobile in the plant. Others move (**translocate**) with sugars produced in the leaves downward to sites of active plant growth (e.g. root tips,shoot meristems) or upward with the **transpiration** stream (water moving through the plant from the soil and evaporating into the atmosphere at the leaf surfaces). Herbicides that translocate in the plant are called **systemic herbicides**.

Systemic herbicides that move to actively growing sites in the plant will affect new growth first. Pigment loss, stopped growth or distorted (malformed) new growth are typical symptoms. Injury may appear in a day or take several days or weeks.

Herbicides that move upward with the transpiration stream will affect old growth first. Chlorosis (yellowing) appears first between leaf veins and along the margins, and is later followed by necrosis (browning and death) of the tissue. Herbicides that move upward with the transpiration stream also tend to have soil activity.

Contact herbicides result in rapid disruption of cell membranes and a rapid kill. Rapid destruction of cell membranes prevents translocation to other regions of the plant. Severe injury is evident hours after application, first as water-soaked areas that later turn yellow or brown. Maximum kill is attained in a week or less. Partial spray coverage of a plant results in spotting or partial control. New growth on surviving plants will be normal in appearance.

Mode of action

The "mode of action" of a herbicide is the chain of events or specific metabolic process that causes plant injury or death. Mode of action also can be defined as the mechanism by which a herbicide kills a plant. Herbicides with the same mode of action will usually have the same translocation (movement) pattern in the plant and produce similar injury symtoms. Herbicides may be classified according to mode of action, including plant growth regulators, amino acid synthesis inhibitors, pigment inhibitors, cell membrane disrupters, lipid synthesis inhibitors, photosynthetic inhibitors, and seedling growth inhibitors. The mode of action of a few herbicides is unknown.

Plant growth regulators

The synthetic auxin herbicides, also referred to as "plant growth regulators," mimic and amplify the actions of natural plant auxins causing rapid and or uncontrolled growth. When soil applied, synthetic auxin herbicides may be absorbed by seeds and roots. Leaf and stem uptake occurs when they are foliar applied. Once in the plant, synthetic auxin herbicides are translocated throughout the plant and move to the growing points of shoots and roots. An early symptom of injury to broadleaf plants is bending and twisting of leaves and stems, followed by deformities in terminal tissue. Injury also can be exhibited as strap-shaped (parallel-veined) leaves or leaf cupping. Sensitive plants can be injured with very low concentrations of growth regulator herbicides; thus, drift management is critical when using these products. A few examples of synthetic auxin herbicides include 2,4-D, dicamba, picloram, clopyralid, and triclopyr.

Amino acid synthesis inhibitors

Amino acids are the building blocks for proteins essential for plant growth. The amino acid synthesis inhibitor herbicides act on specific enzymes to prevent the production of amino acids. There are different herbicide families that inhibit amino acid synthesis.

ALS inhibitors act by inhibiting the enzyme acetolactate synthase (ALS), which is a key enzyme in the biosynthesis of branched-chain amino acids. Two main ALS inhibitor herbicide families are the imidazolinones and the sulfonylureas. A couple examples of specific ALS inhibitor herbicides include imazapyr and sulfometuron methyl. ALS inhibitor herbicides rapidly inhibit cell division in susceptible plants but typically symptoms are not visible for days, and it can sometimes take up to several weeks for plants to die. Common symptoms of injury from ALS inhibitors include stunting, yellowing, and death of tissue.

Symptoms initially appear on the new growth of affected plants. Some ALS inhibitor herbicides may persist and carryover in the soil.

Enolpyruvyl shikimate phosphate synthase (EPSPS) inhibitors interfere with amino acid synthesis by inhibiting the EPSPS enzyme. Glyphosate is the only currently available herbicide that interferes with the EPSPS enzyme. It must be applied to foliage since it tightly binds to soil colloids and has no soil activity. Once absorbed by foliage, it is readily translocated throughout the plant, making it an effective herbicide for perennial weed control. It usually takes several days for plants to show symptoms and die. Injury symptoms may first appear as wilting leaves, which then turn brown and eventually die. Affected plants also may show signs of chlorosis.

Pigment inhibitors

Herbicides in this group work by preventing the production of pigments that protect chlorophyll, the primary pigment that captures solar energy used for **photosynthesis**. Without chlorophyll, the susceptible plants appear "bleached" or white. Sometimes affected foliage is white tinged with pink or purple. Symptoms appear on new growth. An example of a pigment inhibitor herbicide is mesotrione, which is absorbed by roots and foliage.

Cell membrane disrupters

Herbicides classified as cell membrane disrupters react within the plant to form compounds that destroy cell membranes. Protoporphyrinogen oxidase (PPO) inhibitors are a type of cell membrane disrupters that interfere with chlorophyll biosynthesis. PPO inhibitors are used primarily for broadleaf weed control. Some have only contact activity, therefore, thorough coverage of the foliage is necessary for effective control. Injury symptoms usually appear as speckling or bronzing of the foliage and may appear within hours after application. More severe injury can lead to death of the terminal growing point. An example of a cell membrane disrupter is oxyfluorfen.

Lipid synthesis inhibitors

Herbicides in this mode of action class inhibit the synthesis of plant lipids (compounds consisting of fats, oils, and other substances). Acetyl CoA carboxylase (ACCase) inhibitors attack an enzyme that is involved in the synthesis of fatty acids, essential components involved in the production of cell membranes. They are primarily used for postemergence grass control and are translocated in the phloem where they kill the growing point, eventually leading to rotting of plant tissue within the stem. Leaves turn yellow, redden, and sometimes wilt. Two herbicides classified as ACCase inhibitors include fluazifop-p-butyl, and sethoxydim.

Photosynthesis inhibitors

Photosynthesis inhibitors interfere with a plant's ability to convert carbon dioxide to carbohydrates using solar energy. Plants rely on this process to grow and reproduce; therefore, any substance interrupting this process has a major effect on plant survival. Since photosynthesis relies on light, these herbicides only start working once the plants have emerged or are exposed to light. The photosystem II inhibitors (PS II), which comprise many different herbicide families, interfere with electron transfer, a process required for photosynthesis. An example of a PS II inhibitor is simazine. PS II inhibitor herbicides move upward in the transpiration stream, so when applied to the soil, injury or toxic symptoms first occur in the older leaves of plants. Symptoms of injury are chlorosis and then necrosis of the leaf tissue. Chlorosis starts between the veins in broadleaf weeds. Lower leaves will show the most severe symptoms and new leaves may be unaffected. Foliar applied PS II herbicides are absorbed into the leaf but do not readily move out of the leaf, thus, chlorosis and necrosis are localized in the treated leaves.

Seedling growth inhibitors

This mode of action refers to herbicides that disrupt new plant growth and development. Herbicides classified in this group are soil-applied and inhibit either root or shoot growth in seedlings.

Microtubule inhibitors disrupt plant growth by interfering with the production of microtubules, which serve important functions in cell division, growth, and morphology. The dinitroaniline (DNA) herbicides inhibit the formation of microtubules. Examples of DNA herbicides include pendimethalin, trifluralin, and oryzalin. These soil-applied herbicides are primarily root absorbed and, since they are not readily translocated within the plant, they have the most effect on root growth and development. Most DNA herbicides must be incorporated in the soil to reduce surface loss through photodegradation and volatilization.

Shoot inhibitors include many different herbicides. Herbicides in the amide family fit into this category as they primarily inhibit shoot growth (and to a lesser extent root growth) of germinating seedlings. Their site and mode of action has not been fully identified. They act primarily on annual grasses and small-seeded broadleaf weeds. For effective control they must be present in the early stages of weed germination and growth. They are sometimes mechanically incorporated into the soil to reduce the dependence on rainfall for moving herbicide into the weed zone. An example of a shoot inhibitor for forest weed management is s-metolachlor.

Residual herbicides

Herbicide effects vary, in part because of their residual characteristics. A herbicide is considered to have residual effect if it prevents the regrowth of vegetation or weed emergence for a period of time after application. This time period varies from a few weeks to more than a year. Application rate, soil texture (particularly clay content), soil organic matter content, soil moisture level, and herbicide solubility affect a herbicide's residual properties. Herbicides that are absorbed through foliage vary in their residual effect, with many having no residual effect. Soil-applied herbicides provide different degrees of residual activity.

Factors influencing herbicide effectiveness

To successfully control vegetation, the following factors that influence herbicide effectiveness should be understood.

Application rate

The amount of herbicide required per acre to obtain effective control depends on several variables, including herbicide formulation, soil type, and targeted vegetation. Specific application rates for various conditions are listed on the herbicide label. Follow these recommendations to obtain safe, economical and effective results.

Equipment calibration

Calibration is the process of measuring and adjusting the amount of pesticide the equipment will apply to a specific area. Proper calibration of equipment is required to obtain good results when using herbicides. Once equipment is calibrated, it is essential that the same ground speed, pump pressure and nozzle size are maintained during the actual application.

Application method

For successful results, it is essential that coverage is uniform, regardless of the method used for application. The equipment must be maintained and cleaned so that spray solutions will flow correctly. For herbicides that do not form true solutions, especially wettable powders, agitation must be maintained throughout the spray application. Failure to agitate can cause erratic application rates.

Targeted vegetation

Because of differences in anatomy and physiology, some plants are more affected by herbicides than others. Annual weeds may be controlled with preemergence products, while perennial weeds, particularly those with deep root systems, will require different control methods. Some plants, such as horsetails and sedges, are very difficult to control. Because of differences, two or more herbicides are often combined in the spray tank. The compatibility of various herbicides should be determined before preparing tank mixes to avoid interactions that may make each compound less effective or cause spray application problems. There is also a danger that an improper tank mix could damage desirable plant species. Pesticide dealers provide information regarding the compatibility of many herbicides.

Soil-site characteristics

Soils with high clay or organic matter content require a higher application rate of a soil-applied herbicide than coarse-textured sands or gravelly soils. If the amount of herbicide necessary for effective control on a heavy soil is applied to a lighter textured soil, the herbicide may injure nontarget plants. Further, some residual herbicides may persist longer on heavier soils because clay and organic particles adsorb (hold onto) more of the material.

Weather conditions

Weather factors at the time of and following application can influence herbicide effectiveness. Cool and cloudy weather following application of foliar herbicides may reduce their effectiveness. Lack of rain following soil-applied herbicides may allow weeds to grow and germinate before the herbicide moves into the soil solution. Heavy rain, however, may leach the herbicide from the upper soil profile or wash it to low-lying areas. In both cases, the herbicide is less effective and may damage nontarget plants. Weather conditions are one of the most common reasons why herbicide applications fail to control weeds.

Flashback

Flashback is the phenomenon whereby a herbicide applied to a target tree moves to nontarget trees. This movement takes place either directly through root grafts or indirectly where excessively high amounts of the chemical move into the soil and are absorbed by the roots of nontarget trees growing in the contaminated soil. Flashback injury to nontarget plants can range from mild leaf curl to death. Always read the pesticide label and apply the herbicide according to directions.

Agricultural versus specialty crop labeling

Forestry pesticide applicators need to be aware that some herbicides (as well as some insect and disease control chemicals) can have the same formulation of active and inert ingredients, and yet have two distinct labels — one for agricultural use and one for use with specialty crops. A good example is pendimethalin. It is sold as Prowl for agricultural use and as Pendulum for use with specialty crops. The big difference is price. For whatever reason, specialty crop formulations generally cost significantly more than their agricultural equivalents.

Forestry applications almost invariably fall in the specialty crop category. Applicators should not be tempted by the cheaper price of an agricultural equivalent. Using Prowl to control weeds in a new forest planting is using the product against the label. As such, if a problem were to occur with the application (e.g., poor weed control or chemical movement off-site), not only would you receive no technical assistance from the manufacturer, but you would be in violation of not following the label and subject to state civil penalties.

Weed control in tree plantings

When establishing a forest, relatively few seeds or seedlings of desired species are introduced into an environment in which an almost unlimited number of other plants exist or have the potential to become established. The immediate goal of the forest manager is species survival, which is helped by reducing the competition from weeds. Site preparation and tree release are the procedures that minimize the density and reduce the vigor of the competing vegetation in the year of, and immediately after, planting. The type and intensity of management practices depend on the vigor of the desired (planted) species and the competing species present.

The choice of a herbicide depends on four major factors: (1) the desired tree species, (2) types of weeds to be controlled, (3) the application method, and (4) the site.

Select a herbicide with specific label directions for use on the species of trees or shrubs in the planting. A herbicide recommended for one species may not be safe for another. The age of the trees and shrubs, and how long they have been planted also should be considered.

The choice between pre- and postemergence herbicides depends on the presence or absence of vegetation. Often pre- and postemergence herbicides are mixed together to control both existing vegetation and provide residual control of later germinating seeds. Most herbicides used in tree and shrub plantings are effective against a particular group of weed species. Select a herbicide that will control the major species of weeds present. Also consider the various formulations available.

Several site factors must be considered when selecting a herbicide. Preemergence herbicides are usually more effective when applied to weed-free soil. Soil type and organic matter content affect the application rate of preemergence herbicides. Generally, sandy or low-organic matter soils require less chemical than with high clay or organic matter content.

Figure 4.2. Field bindweed. Credit: Mary Ellen (Mel) Harte, Bugwood.org.

Preplant site preparation

Weed control efforts can begin before trees or shrubs are planted. This should be a standard practice when hard-to-control, perennial weeds such as bindweed (Figure 4.2) are present. Preplant weed control practices may include growing a cover crop, repeated tillage, chemical fallow with nonselective herbicides, or combinations of these methods.

Often trees and shrubs are planted in areas with established vegetation that the landowner may not want to destroy completely. In such a situation a nonselective, nonresidual herbicide should be applied in 4-foot (1.2 m)-wide strips or in 4-foot-diameter circles where the trees or shrubs are to be planted. One important advantage of preplant weed control is that certain herbicides that are very effective, but harmful to trees and shrubs, can be easily and safely applied.

Application

Proper application begins with the selection of the proper herbicide and using the correct equipment.

Precautions

1. Follow instructions for precautions and application rates.
2. Do not spray the foliage of desirable trees with postemergence herbicides.
3. Herbicide drift is a serious problem. Use drift reducing nozzles and low spray pressures, as well as watch wind speed and direction.
4. Application equipment should be in proper working condition, calibrated and free of contamination. Clean equipment immediately after use.
5. When mixing two different chemicals, be sure to determine their compatibility by checking the labels, consulting your chemical dealer, or performing a jar test.
6. Most preemergence herbicides require sufficient moisture for activation. Failure to water or incorporate according to label instructions will usually result in reduced weed control.

Application procedure

Trees are usually planted on a wide spacing, making either band or spot herbicide treatments most practical. With young trees, a band treatment should be 3 to 4 feet (0.9 to 1.2 m) wide (18 to 24 inches [46 to 61 cm] on each side of the trees). Band treatments are more efficiently applied with power spray equipment. Applying a band treatment requires less labor but more spray material than a spot application.

Spot treatments are ideally suited for small plantings with widely spaced trees or when hand or small power sprayers are used. With young trees, a spot treatment should consist of a 3- to 4-foot (0.9 to 1.2 m)-diameter circle around each tree. Directed herbicide sprays can be most safely applied with handheld sprayers. A stovepipe or other protective shield may be placed around the trees while spraying to protect them from herbicide damage.

With band and spot treatments, the weeds between treated areas must be mowed or cultivated. Mowing between tree rows is recommended where soil erosion may occur. If you are planting trees, and will make herbicide spot treatments, cross-checking the rows will make weed control within rows easier.

Commonly used herbicides in tree plantings

Some of the more common forestry herbicides used to control weeds in tree plantings are listed below. This is by no means a complete list. Further, any mention of a particular pesticide trade name is neither an explicit nor implicit endorsement of that commercial product. As always, READ AND UNDERSTAND THE LABEL before applying any pesticide

Clopyralid: A selective herbicide used for postemergence control of broadleaf weeds, especially thistles and clovers, and invasive woody species.

Dicamba: A selective, pre- and postemergence herbicide for controlling annual and perennial broadleaf weeds and some sensitive brush species.

Fluazifop-p-butyl: A selective postemergence herbicide used for control of most annual and perennial grass weeds.

Glyphosate: A broad-spectrum, nonselective systemic herbicide used for control of annual and perennial plants including grasses, sedges, broadleaf weeds, and woody plants.

Imazapic: A selective herbicide for both the pre- and postemergence control of annual and perennial grasses and broadleaf weeds.

Metolachlor: A preemergence herbicide that is used to control annual grass weeds and small-seeded broadleaf weeds.

Metsulfuron: A selective pre- and postemergence herbicide for control of broadleaf weeds and some annual grasses. It is a systemic compound with foliar and soil activity, and works rapidly after it is taken up by the plant.

Oryzalin: A selective, preemergence, soil-applied herbicide used for control of annual grasses and broadleaf weeds.

Oxyfluorfen: A selective, pre- and postemergence herbicide used to control certain annual broadleaf and grass weeds.

Pendimethalin: A selective, soil-applied herbicide used to control most annual grasses and certain broadleaf weeds. Incorporation into the soil by cultivation or irrigation is recommended within seven days following application.

Sethoxydim: A selective, postemergence herbicide used to control annual and perennial grass weeds.

Simazine: A selective herbicide used to control annual broadleaf and grass weeds.

Sulfometuron methyl: A broad-spectrum herbicide used for the pre- and postemergence control of annual and perennial grasses, broadleaf weeds and woody tree species.

Trifluralin: A selective, soil-applied herbicide used to control many annual grass and broadleaf weeds. Trifluralin should be incorporated into the soil by mechanical means within 24 hours of application.

Timber stand improvement

There are circumstances when a forested area can be improved by doing more than just allowing the trees to grow. One such circumstance would be if an area had a timber harvest in which only the most desirable mature trees were taken out and mostly inferior trees — lower value species, or damaged or diseased trees — were left to occupy the forest canopy (a practice called "high grading," Figure 4.3). Another example would be where a dense stand of young trees needed to be thinned to optimize tree health and production of fruits and timber. In situations like these, timber stand improvement (TSI) can be applied to make the most of the species and number of trees present for wildlife and timber production. TSI involves actively managing a stand of trees to improve its species composition, structure, health, and growth.

Figure 4.3. High-graded stand. Credit: Chris Schnepf, University of Idaho, Bugwood.org.

Tree selection

Trees to be enhanced through TSI must be existing or future canopy trees. Crown level is where the most intense competition for sunlight exists, so trees that are competing in the forest canopy should be examined for possible thinning. Understory trees should not normally be removed. A forest's understory provides structural diversity and food for wildlife, and it retains moisture and nutrients that benefit overstory trees.

Generally a spacing of 20 to 25 feet between crop trees is optimal, with no substantial competition between them at crown level. Trees should have growing room at crown level on at least three sides so their crowns can develop more fully.

TSI operations often are managed for high-value species such as white oak, northern red oak, and black walnut. These species are valuable for both wildlife and timber production. However, value is a personal decision and if beautiful fall foliage and maple syrup are valued, then maple might be the high-value species.

Retaining diversity and soft mast

Even in stands where noncrop species are overabundant, they should never be completely eliminated. Also, healthy and well-formed specimens of any species should normally be left in the stand.

When doing TSI, be sure to leave ample soft mast (fleshy fruit) trees. Soft mast producers are important to wildlife year-round, especially when their fruits are in season. This is usually not difficult to do, because these trees are normally not dominant trees that you would be thinning out, or they are already abundant and thinning some of them will not be detrimental.

Species such as dogwoods, sassafras, persimmon, and blackgum are soft mast trees that should be retained as part of a properly managed forest. Some hard mast trees, such as red maple, are problematic because they compete with species most often selected as crop trees. However, some of these trees should also be left in any forest stand because they also contribute to the food and cover value of woodlands.

Grape vines and invasive species

Control of harmful vines is another aspect of TSI. Wild grape vines provide excellent food and cover for many different kinds of wildlife, including deer, opossums, and a variety of birds. However, they tend to be problematic for some trees on productive sites, particularly for black walnut and white and red oaks that are being managed for timber or optimum fruit production. The weight of older grape vines can actually break out branches or entire treetops and strongly compete with crop trees for sunlight. When the crop tree dies, it becomes a safety hazard because it cannot fall freely to the ground.

Not all grape vines are bad. They should be left alone in noncrop trees and cull trees, and other native plant vines should normally be left to grow undisturbed.

Some woodlands have other competition problems with exotic invasive plants. Bush honeysuckle and autumn-olive can choke out native understory species and prevent natural regeneration of main canopy species. In these cases, intensive manual removal or timely application of foliar herbicides may be needed.

Limitations to TSI

There are limits to the effectiveness of thinning a stand of trees. Usually, trees must be relatively young to benefit from thinning. Trees that are 10 to 30 years old will often grow taller, produce greater crowns and yield more fruit as a result of being released from competition, but trees that are 50 or more years old may not respond to a thinning. Also, the site and soil types in an area will largely dictate the growth potential of a forest stand. TSI on poor-quality sites may not be practicable because the returns will be minimal.

TSI and herbicides

Unless it is desired that a deadened tree sprout, as in the case of a high-value white or red oak, TSI is a wasted effort without the use of herbicides. Most plant species will produce multiple sprouts, so unless herbicides are used, there will be increased competition rather than a reduction.

Timing of TSI

TSI can be done year-round, but some seasons are better than others for obtaining effective control. Generally, it is best to avoid doing TSI during spring (April 1 through June 30) when trees are growing most rapidly; they will more likely seal over wounds and metabolize herbicides faster during that period.

The hottest part of summer can be a good time to perform TSI, but many landowners prefer to avoid that time of year because of heat, insects and thick understory vegetation. Fall and winter are when most TSI is completed because of the more comfortable conditions of working outside, and because visibility in the woods is better.

Commonly used TSI herbicides

Some of the more common forestry herbicides used for TSI are listed below. This is not a complete list, and any mention of a particular pesticide trade name is neither an explicit nor implicit endorsement of that commercial product. As always, READ AND UNDERSTAND THE LABEL before applying any pesticide.

2,4-D: A systemic herbicide most effectively applied to a complete girdle or cut stump. Little lateral movement makes it less effective if injected unless the injections are made edge to edge. 2,4-D is commonly found in combination with other herbicides. As a sole active ingredient, 2,4-D may also be used to control many types of broadleaf weeds in tree plantings.

2,4-D + dicamba: This mixture is most effective when applied to complete girdles or cut stumps.

2,4-D + picloram: This herbicide mixture is sold as ready-to-use products and is most effective when applied to complete girdles or cut stumps.

2,4-D + triclopyr: When mixed with diesel fuel, this mixture is useful as a cut stump spray and basal bark treatment.

Special note: While it is commonly assumed among many practicing foresters that combinations of 2,4-D, and triclopyr can be used in TSI applications, the general information on the product's label specifically states, "For use on plants in noncrop and nontimber areas only. Not for use on crops, timber or other plants being grown for sale or other commercial use, or for commercial seed production, or for research purposes." ALWAYS READ THE LABEL.

Fosamine: A selective, postemergence herbicide for controlling woody shrubs (as a foliar spray) or trees (as a cut stump application). It is very useful in areas adjacent to bodies of water.

Figure 4.4. Amur honeysuckle infestation, W. Lafayette, IN. Credit: James H. Miller, USDA Forest Service, Bugwood.org.

Glyphosate: A nonselective herbicide that can be used as a foliar spray to control invasive understory shrubs, such as bush honeysuckle (Figure 4.4). However, because it is nonselective, there is a high risk of killing desirable understory species. For trees, it is most effective when applied to complete girdles or cut stumps. But, there are more effective herbicides than glyphosate in TSI applications.

Hexazinone: A broad-spectrum, nonselective herbicide used against many annual, biennial, and perennial weeds including woody species. Its primary TSI application is pine release in pine-hardwood stands.

Imazapyr: A broad-spectrum, nonselective herbicide that can be used as a foliar spray, injection treatment, cut stump spray, or basal bark treatment. Its effective lateral movement in the wood makes it well suited for injection application. Because imazapyr does not readily degrade and is highly mobile in groundwater, extreme care is recommended when using this herbicide.

Picloram: A systemic herbicide used for control of woody plants. It is usually found in combination with other herbicides. Picloram is a persistent, highly mobile herbicide that should not be used in areas where runoff water may contaminate surface water or groundwater.

Picloram + triclopyr: This mixture is effective as a basal bark or thin-line treatment and is mixed with diesel fuel, kerosene, or other approved penetrant before application.

Triclopyr: A selective systemic herbicide. The amine formulation can be applied as a foliar spray, stem injection, or stump spray. The ester formulation may be mixed with diesel fuel or other petroleum-based solvent for basal bark treatment, thin-line, or stump spray.

REVIEW QUESTIONS
Forest Weed Management

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1-5. Match the following types of weed control to the appropriate description.

A. Cultural control

B. Mechanical control

C. Chemical control

_____ 1. Plant seedlings at the appropriate spacing and replace those that die.

_____ 2. Manual cutting of species that are not too dense and do not resprout.

_____ 3. Use of herbicides during site preparation.

_____ 4. Select the best-adapted species and varieties for planting.

_____ 5. Preparing or rehabilitating the site with specialized equipment.

6. What does selectivity mean in reference to herbicides?

7. What does preemergence control by a herbicide refer to?

A. Controls weeds as the seeds germinate.

B. It kills weeds only when directly applied to the foliage.

C. It kills all vegetation that it comes in contact with.

D. It kills only the portion of the plant to which it is applied.

8. How is herbicide effectiveness influenced by:

A. Application rate?

B. Equipment calibration?

C. Application method?

D. Targeted vegetation?

E. Soil-site characteristics?

F. Weather conditions?

9. Perennial grasses and weeds are more easily controlled than annual weeds and grasses with preemergence herbicides.

A. True

B. False

10. Generally speaking, during which season will TSI herbicides be least effective?

A. Winter

B. Spring

C. Summer

D. Fall

5
Forest Disease Management

Plant pathogens play a significant role in our forests. The chestnut blight fungus brought to this country from Asia literally wiped out the American chestnuts, which at one time dominated the great eastern forests of the United States. More recently, Dutch elm disease threatens to exterminate the American elms, as it has destroyed trees in many parts of Europe. Various plant diseases of less significance prevail in our forests today. Yet, even though they might not have the widespread impact of the pathogens mentioned above, in some instances, their effects on the local or regional landscape can be severe.

Learning objectives

After reading this chapter, you should be able to

- Explain the plant disease triangle.
- List the basic types of plant pathogens.
- Distinguish between symptoms and signs of plant disease.
- Outline the signs and symptoms of the more common forest diseases.
- List the more common fungicides used to control the above forest pathogens.

The plant disease triangle

Disease can be defined as any harmful deviation, caused by a persistent agent, in the normal function of an organism. The **disease triangle** is a basic concept in plant pathology (Figure 5.1). It illustrates the combination of three factors needed for a disease to occur and develop:

- a *susceptible* host
- an *infective* pathogen
- a *favorable* environment

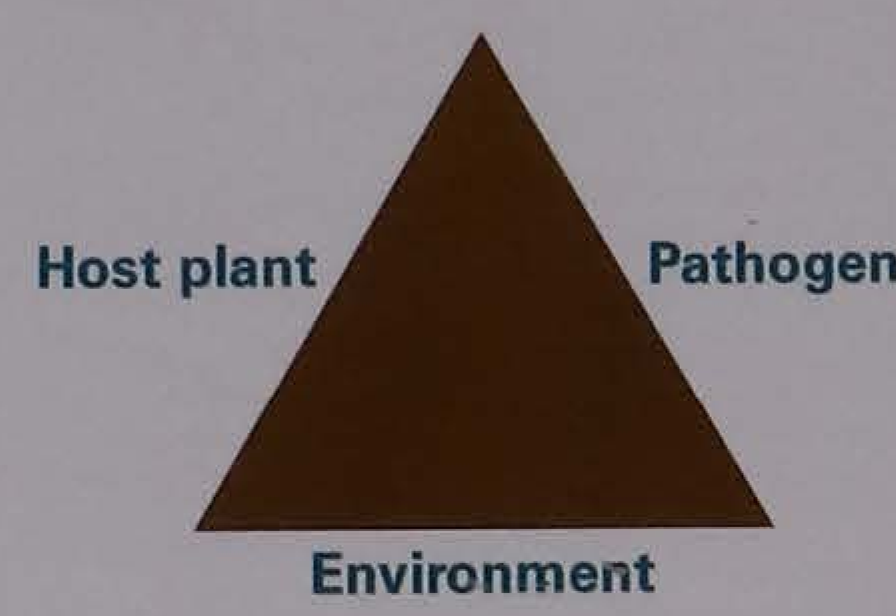

Figure 5.1. The plant disease triangle consists of the a susceptible host, and infective pathogen and a favorable environment.

Susceptible host

For disease to occur, the host plant must be at a stage of development that allows it to be susceptible to infection and then allows the pathogen to develop, thereby creating the disease complex.

The genetic defense against a pathogen is called disease resistance. This resistance can be physical (e.g., fuzzy or waxy leaf surfaces), chemical (e.g., enzymes that kill pathogens), or morphological (ability to block off diseased tissue or outgrow damage).

It is important to remember that plants labeled as disease-resistant are resistant only to a particular disease. They are not resistant to all diseases. Resistance does not mean immunity. Under extreme circumstances, resistant plants may be infected by the disease to which they have resistance.

Infective pathogen

Pathogens are microorganisms that cause disease. Because they are living, they are called biotic agents or causes. Pathogens can be fungi, bacteria, viruses, mycoplasmas, or nematodes. Each has a different life cycle, which includes an infectious stage. **Inoculum** is the pathogen or its parts.

Favorable environment

Certain environmental conditions must exist for disease pathogens to cause infection. The specific conditions vary for different pathogens. High moisture and specific temperature ranges, for example, are necessary for many fungal diseases. These conditions must continue for a critical period of time while the pathogen is in contact with the host for infection to occur.

Moisture, temperature, wind, sunlight, nutrition, and soil quality affect plant growth. If one of these factors is out of balance for the culture of a specific plant, that plant may have a greater tendency to become diseased.

Environmental conditions also affect the growth and spread of disease pathogens. Both dry and wet weather are associated with corresponding sets of diseases that thrive under these conditions. A change in any environmental factor may favor the host or the pathogen or both, and the expression of disease will be affected accordingly. Factors like temperature, moisture, wind, light, soil pH, and host-plant nutrition all interact to affect how a disease develops.

Symptoms and signs

To understand plant diseases, it is important to know the difference between symptoms and signs. **Symptoms** are the visible responses of the host to a causal agent over time. Examples of symptoms include:

- chlorotic (yellow) leaves
- necrotic (dead) leaves
- wilted leaves
- blighted (wilted or dead) shoots
- cankers
- witches' brooms
- lesions
- bark splits
- decay

Signs are physical structures produced by the causal agent of that disease. They are more specific than symptoms and are more useful in the accurate diagnosis of a disease. Signs are usually very small. Examples include:

- white, fungal mats on the surface of a leaf or under the bark
- small, black, spore-emitting structures erupting through leaf or needle surfaces

Timing of disease control measures

When application of chemical disease control is economically feasible, as in the case of Christmas trees or forest nursery stock, the pest manager must understand the life cycle of the disease to be controlled. For many diseases, only one short window of control may be available in a calendar year, or the control spray may have to be applied preventively — before any signs or symptoms of disease are present. Chemical control measures must be applied when infection is most likely to occur or it will be a waste of time, effort, and money. Understanding the life cycle of the disease organism enables you to make proper and timely management decisions.

Forest disease management

The most important principle in forest protection is that preventing attack by an insect or disease pest or preventing further development of the pest problem is far more effective than attempting to stop the damage after it is under way. The wise application of forest management practices ultimately has more enduring and less expensive results than more direct methods of protection.

Most forest disease control can be achieved through sound forest management practices:

- Prevent damage to crop trees during intermediate harvests.
- Maintain vigorous tree growth by conducting timber stand improvement operations.
- Salvage dead or dying trees.

Planted stands are particularly liable to disease. The impact of disease will become increasingly important as more planting is done and as plantations become older. The critical period for most stands is from about 20 to 40 years of age, the period when the stands make the greatest demands on the site. Vigorous early growth is no assurance of satisfactory long-term development. The major effort toward disease control in plantations is through avoidance. Selecting a site with favorable growing conditions and then a species suited to that site is of primary importance. Planting stock must be free of disease. In choosing a species, consider the risks entailed by introducing exotics or extending the range of a species; also select a seed source that is adaptable to the region. Pure stands are at more risk than mixed stands, as are large areas of even-aged trees. Spacing, thinning, and weed control are also important for maintaining stand vigor.

Common diseases

Foliar diseases

Anthracnose is the name given to a fungal disease characterized by leaf spots on several tree species. Caused by several related species of fungi, the disease occurs most commonly and severely on sycamore, maple, and walnut. Other host trees, such as ash, linden (basswood), and yellow poplar, are usually only slightly affected.

Anthracnose-causing fungi have similar life cycles but require slightly different moisture and temperature conditions for infection. Because the fungi are different and the host tree species are different, symptoms vary. Generally, the disease is characterized by circular to irregular brown spots on the leaves (Figure 5.2). Severe defoliations, particularly on sycamore and maple, can occur following unusually cool, wet weather during spring bud break. In certain susceptible trees, such as sycamore, twig infections also may occur with serious consequences, especially to young trees.

Figure 5.2. Irregular necrotic spot on a sycamore leaf is a telltale symptom of anthracnose. Credit: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org.

Control anthracnose and other leaf-spotting tree diseases with preventive measures that help reduce the attacks. Practice sanitation measures, including collecting and destroying fallen leaves and dead twigs. Pruning infected branches reduces the potential for infection. Also, prune to increase air circulation and faster drying.

Chemical control may be necessary if anthracnose appears to cause serious leaf injury and defoliation on a year-to-year basis. Growth of nursery trees will be reduced substantially by defoliation. You may hand spray young trees; however, larger trees require high-pressure spraying equipment.

Needle diseases of conifers

Several needle diseases threaten coniferous species in the north central United States. This chapter discusses five potentially damaging needle diseases: brown spot needle blight, Diplodia tip blight, Dothistroma needle blight, Lophodermium needle disease, and Phomopsis needle blight of junipers.

Some, like brown spot needle blight, have been causing damage to Scots pine Christmas tree plantations in the Midwest for years. Others, like Phomopsis needle blight, can present serious problems to managers of forest seedling nurseries.

Common features

The needle diseases of conifers are caused by different fungi. They are also called needlecast diseases because the trees cast, or drop, infected needles prematurely. There are some commonalities among the diseases, most notably the infecting spore, disease progression, symptoms, and control measures. It takes a trained pathologist to definitively distinguish one needlecast disease from another.

Figure 5.3. Pycnidia of the fungus *Diplodia pinea* on Austrian pine cone scales. The resulting disease is Diplodia tip blight. Credit: Petr Kapitola, State Phytosanitary Administration, Bugwood.org.

The primary sign associated with fungi causing needlecast diseases is the small, black fruiting structures that produce the infecting spores called **conidia**. Conidia may be produced in minute, flask-shaped **pycnidia** or tiny, cushionlike **acervuli**. To the unaided eye, both fungal structures resemble black pepper spots erupting through the plant tissue (Figure 5.3). However, the kind of conidia will tell trained pathologists whether they are dealing with brown spot or Dothistroma needle blight.

The disease cycle begins in mid to late spring with the primary inoculum consisting of conidia that have overwintered in acervuli or pycnidia produced the previous year in infected plant tissues. These fungal spores are produced in a sticky, water-soluble medium and are disseminated primarily by splashing rain.

This means of dissemination is of little consequence in long-distance spread of the disease but plays a major role in intensifying the disease within a given tree and between neighboring seedlings in nursery beds or in Christmas tree plantations. In conjunction with the humid microclimate that is created, it also explains why these diseases progress from the bottom of the tree upward and appear to be more severe on the north side of the tree.

Secondary infections may occur throughout the growing season as long as conditions are favorable for spore dissemination and germination.

Symptom expression may follow soon after infection or may be delayed. But, eventually characteristic brown spots appear at the infection points, followed by a brown band encircling the needle. The tips of the infected needles turn tan, then **necrotic**, while the base of the needles remains green (Figure 5.4). Later, the base turns brown. The dead needle may or may not be cast from the tree.

Figure 5.4. Necrotic spots on Scots pine needles infected with the *Mycosphaerella pini fungus.* Note also the small, black acervuli that produce conidia. Credit: Andrej Kunca, National Forest Centre - Slovakia, Bugwood.org.

To control needle diseases through cultural practices, managers should (1) plant healthy, resistant nursery stock, (2) avoid planting pine seedlings next to older pine plantings, (3) cut and immediately remove small pockets (one to five trees) of infected trees, (4) avoid leaving live branches on stumps when harvesting trees, especially in infected plantations, and (5) avoid shearing infected trees or plantations during wet weather.

Fungicidal sprays, such as benomyl, a Bordeaux mixture or chlorothalonil, can help control these diseases. These are protectant fungicidal applications and are most effective before dissemination of the primary inocula in the spring. Some diseases require more than one application, and in all cases, if it rains then additional treatments will be required.

Brown spot needle blight

Brown spot needle blight (Figure 5.5) is caused by the fungus *Mycosphaerella dearnessii.* More than 20 species of pine are susceptible to the fungus; the Scots pine is the most notable of these species in the Midwest.

Figure 5.5. Brown spot on longleaf pine, Pinus palustris. Credit: Paul A. Mistretta, USDA Forest Service – Region 8 Archive, Bugwood.org.

The fungal spores are produced in acervuli of dead needles. Symptoms may be confused with those caused by Dothistroma needle blight. Positive identification should be made in the laboratory.

Diplodia tip blight

Diplodia tip blight is caused by the fungus *Diplodia pinea.* This disease is most commonly seen on Austrian and black pines and some of the other two- and three-needle pines such as mugo pine and Scots pine.

The fungus commonly attacks mature trees that have been under stress from drought, root restriction, or other planting site problems. Although initial infections do not result in sudden death of the trees, reinfection and subsequent development can cause tree mortality over a period of several years. Damage to pines more than 30 years old has been so extensive in the Midwest that the beauty of many trees in residential and park plantings has been marred. It can also be a problem in young, rapidly growing nursery or Christmas tree plantings.

The fungus produces pycnidia at the base of necrotic needles, needle sheaths, stems, and cones.

Dothistroma needle blight

Dothistroma needle blight is caused by the fungus *Mycosphaerella pini* (formerly *Dothistroma septospora*). The disease is common and serious on Austrian and ponderosa pines planted for windbreak and ornamental purposes. Mugo pine also is susceptible to the disease, but Scots pine is considered more resistant.

As with the other needlecast diseases, infections occur in late spring when the inoculum levels are the highest. Conidia are produced in pycnidia on dead needles and are passively disseminated by splashing raindrops.

Lophodermium needlecast

Lophodermium needlecast is caused by the fungus *Lophodermium seditiosum* and may attack all two- and three-needle pines as well as a few five-needle pines. Scots, Austrian, and red pines are among the more susceptible species.

Figure 5.6. Lophodermium needlecast on Scots pine. Credit: USDA Forest Service – North Central Research Station Archive, USDA Forest Service, Bugwood.org.

Unlike the other needlecast diseases discussed so far, this disease progression occurs later in the growing season. In mid to late summer, minute, black, football-shaped fruiting bodies form on the recently killed needles, and these fruiting bodies release spores after they are moistened. The spores are shot out of the fruiting bodies and up into the air where they are carried by the wind to new sites of infection on the current year's needles. If weather conditions are favorable, once a spore lands on a needle it will germinate and cause infection; however, needle infection will not be noticed until the following spring when trees begin to brown and drop needles.

The browning of needles on lower branches first appears in early spring (April-May, Figure 5.6). Because the most common cause of brown foliage in spring is winter burn, carefully examine the affected trees before reaching conclusions about the cause of the damage.

Phomopsis needle blight

Phomopsis needle blight, caused by the fungus *Phomopsis juniperovora*, is a problem on both eastern redcedar and Rocky Mountain juniper.

Figure 5.7. Shoot blight is a common symptom of redcedar trees infected with the Phomopsis blight fungus, *Phomopsis juniperovora*. Credit: Robert L. Anderson, USDA Forest Service, Bugwood.org.

Small yellow spots appear on young needles within three to five days after infection. The fungus ramifies within infected needles and rapidly invades and girdles young branches and stems. The portion above the girdled area then dies (Figure 5.7). At first, infected tissues turn light green; but they rapidly change to the characteristic red-brown color of dead shoots, which finally turn ashen gray. Lesions on larger stems frequently develop into cankers, but the stems are not girdled. The fungus does not spread far below cankers. Survival of even lightly blighted nursery stock in outplanting sites is poor because new shoots continue to be infected by spores produced on old, infected tissues.

When junipers in landscape plantings become infected, they may become unsightly because of numerous dead branch tips. The disease seldom kills older trees, because only small-diameter stems are girdled. For this reason, Phomopsis blight does not cause significant damage in natural stands of junipers.

Damage from drought may be confused with Phomopsis blight. In both cases, tips of branches may be killed. However, the demarcation between green and dead tissues is sharp in Phomopsis-blighted seedlings and gradual in seedlings affected by drought.

Spores produced in pycnidia formed on leaves and stems of seedlings infected the previous year are the most important source of inoculum early in the growing season. These spores are most commonly found on tissues that have turned ashen gray. The pycnidia are at first embedded in needles and stems, but then partially erupt through the epidermis. The fungus can produce spores for as long as two years in dead parts of infected plants.

Spores are dispersed primarily by rain splash. Newly developing needles are especially susceptible while they are still in the yellowish green stage; after needles become a normal deep green, they are no longer susceptible.

Because susceptible new foliage and viable fungus spores are present throughout the growing season in juniper seedling beds, protective fungicides need to be applied regularly during this season. The fungicides labeled for controlling Phomopsis blight include Bordeaux mixture, fixed coppers, mancozeb, and thiophanate-methyl. One of these chemicals applied at 7- to 21-day intervals, combined with a vigorous schedule of roguing infected seedlings over the same interval, will give excellent control of Phomopsis blight.

Other actions can be taken to reduce losses. Sowing juniper seed adjacent to beds containing juniper stock should be avoided if possible. Poorly drained areas should be avoided because losses are often greater where water tends to stand. If overhead sprinklers are used, seedlings should be irrigated so that water on seedlings dries before nightfall. Junipers or other hosts of this fungus should not be used in nursery windbreaks or in landscape plantings on nursery grounds because they may be a source of inoculum for nursery stock. Such trees are more likely to be extensively infected if pruning results in the development of juvenile foliage.

Cankers

Cankers weaken branches and main stems. Multiple cankers girdle trees, causing top dieback, breakage, and tree death. Secondary organisms enter trees through cankers, causing stain and decay.

Septoria canker is caused by the fungus *Septoria musiva*. The fungus produces cankers on native cottonwood and a wide range of hybrid poplars.

Cankers are formed on the main stem and branches of the current season's growth, usually within 5 feet (1.5 m) of the ground. Cankers are often flat-faced or have a swollen marginal callus (Figure 5.8). The bark of young cankers is dark brown or black and depressed. Infected cambium is killed, and small black pycnidia may develop in bark in the ashy-white central area of the canker. Continued development of cankers may result in girdling and death of affected stems during late summer.

Figure 5.8. Septoria cankers on cottonwood are often flat-faced or have a swollen marginal callus. Credit: T.H. Filer Jr., USDA, Bugwood.org.

The fungus overwinters on fallen infected leaves and in the bark of cankers. In the spring, sexual ascospores and asexual conidia are discharged during wet weather. These spores are dispersed by wind and washed by rain to infect leaves and stems. Infections may occur through stipules, buds, lenticels, or wounds. The fungus can also infect unwounded leaves and stems.

Leaf infection usually precedes stem infection. Leaf spots appear soon after leaves develop, and the fungus spreads to stems and branches to form cankers. Conidia from pycnidia in leaf spots and cankers cause secondary infections. Disease development is enhanced by warm temperatures and long periods of high humidity.

Control is primarily through the use of resistant cultivars. Fungicides containing captan or benomyl may also be used to reduce damage. Cultural treatments, such as cultivation or raking in the fall to remove leaf litter containing fungal inoculum, will minimize primary infections in the spring if inocula from adjacent trees are not a factor.

Wilts

Oak wilt

Oak wilt is caused by the fungus *Ceratocystis fagacearum*. It is a lethal disease in oaks belonging to the red or black oak group (red oak, black oak, pin oak, shingle oak, etc.) and often kills trees within a few weeks of infection. Members of the white oak group (white oak, post oak, bur oak, etc.) are quite resistant to the disease and sometimes recover from infection.

Figure 5.9. Beetles are attracted to spore masses of the fungus *Ceratocystis fagacearum* formed under the bark of dying trees in red oak group. Credit: Joseph O'Brien, USDA Forest Service, Bugwood.org.

Once in a forested area, the disease can spread through root grafts to oaks up to 50 feet away from the infected tree.

The disease is spread to separate areas by beetles. These beetles are attracted to spore masses of the fungus formed under the bark of dying oaks in the red oak group (Figure 5.9). These spore mats emit a strong fruity odor that attracts the beetles. The beetles feed on the sap at these wounds and transport the fungal spores to new infection sites on healthy trees. Beetle-vectored infections occur in the spring and early summer.

Figure 5.10. Symptomatic oak wilt leaves may either turn brown at the margins or take on a bronze coloration, or both, before dying. Credit: Minnesota Department of Natural Resources Archive, Minnesota Department of Natural Resources, Bugwood.org.

Branches at the top of the tree usually wilt first. Lower branches often are the last affected. Leaves may either turn brown at the margins or take on a bronze cast, or both, before dying (Figure 5.10). The disease causes brown streaking in the sapwood that can be seen by peeling back the bark and slicing into the sapwood, but a positive diagnosis requires culturing the fungal pathogen from affected wood in a laboratory. Positive diagnosis usually takes only two to three weeks, and other pathogens may cause vascular discoloration. Control measures are expensive, so waiting to see what a clinic finds may be a good decision.

Control depends on avoiding unnecessary wounding of oak trees in the spring and early summer, promptly painting wounds that occur in the spring and summer with latex tree paint, severing root grafts between oaks that are within 50 feet of one another, and removing and destroying infected trees. Root grafts between affected trees and apparently healthy trees should be severed *before* the affected tree is cut. Cutting the affected tree before severing the root grafts hastens the transmission of the disease through the roots to unaffected trees.

Before severing root grafts, know the location of underground utility lines. Locate the cut midway between trees. It is also important to sever the root grafts between the apparently healthy trees surrounding the affected tree and the healthy trees beyond the first line of trees, because a tree may be infected and pass on the disease to other trees before it shows any visible symptoms. Root grafts are best severed with a vibratory plow equipped with a five-foot blade. The tractor that pulls the plow should have balloon tires to minimize soil compaction in the root zone.

Fungicides containing propiconazole may be applied to healthy oak trees as a preventive measure. But the fungicides are apparently unable to prevent the death of an infected oak tree. Such treatments create their own problems, including the necessity of wounding the tree to inject the fungicide.

Dutch elm disease

At one time, the American elm was considered to be an ideal street tree because it was graceful, long-lived, fast growing, and tolerant of compacted soils and air pollution. Then Dutch elm disease (DED) was introduced and began devastating the elm population.

DED can be caused by either of two closely related species of fungi: *Ophiostoma ulmi* (formerly called *Ceratocystis ulmi*) and *Ophiostoma novo-ulmi*. The latter, which is more aggressive in causing disease, was recently recognized as being a separate species. The DED fungus was first introduced to the United States on diseased elm logs from Europe before 1930. It is unknown when the more aggressive species became established in the United States; however, it was possibly present as early as the 1940s to 1950s, and most likely caused much of the devastating mortality through the 1970s. The less aggressive species is becoming increasingly rare in nature, and the aggressive species is thought to be responsible for most of the current mortality.

Although some local resurgence of DED has been observed, there is no evidence that it is due to a change in the pathogen. Localized resurgence is more likely due to the following conditions: (1) a decrease in vigilance in monitoring and sanitation, (2) a buildup in populations of the insect vectors, (3) ingrowth of susceptible host trees in the wild, and (4) confusion of DED with pathogens that cause similar symptoms.

Spread by elm bark beetles. Overland spread of DED is closely linked to the life cycles of the native elm bark beetle (*Hylurgopinus rufipes*) and the smaller European elm bark beetle (*Scolytus multistriatus*). Both beetles are attracted to stressed, dying or dead elm wood to complete the breeding stage of their life cycle. The adult beetles tunnel into the bark and lay their eggs in tunnels (called galleries) in the inner bark. The eggs hatch and the larvae feed in the inner bark and sapwood. The larvae mature into adults and emerge from the elm wood.

If the DED fungus was present in the wood that the beetles infested, the fungus produces sticky spores in the beetle galleries. Spores of the DED fungus are eaten by, or stick to, the adult beetles as they emerge from diseased trees. Adult beetles then visit healthy trees, feed in twig crotches or branch inner bark, and introduce the fungus into or near severed wood vessels as they feed.

Once the DED fungus is introduced into the upper crown of healthy elms by bark beetles, it slowly moves downward, killing the branch as it goes. Disease progression may occur rapidly, killing the tree by the end of the growing season, or may progress gradually over a period of two or more years. It is also possible that the tree may recover. The rate of progression within the tree depends on tree size, time, and location of infection in the tree, climatic conditions, and response of the host tree.

Spread through grafted roots. Roots of the same or closely related tree species growing near each other often cross each other in the soil and eventually fuse (**root graft**) to each other.

The DED fungus can move from infected trees to adjacent trees through these grafted roots. Infections that occur through root grafts can spread rapidly throughout the tree, as the fungus is carried upward in the sapstream. Root graft spread of DED is a significant cause of tree death in urban areas where elms are closely spaced.

Figure 5.11. Blighted leaves infected with the fungus *Ophiostroma ulmi*, which causes Dutch elm disease. Credit: Minnesota Department of .Natural Resources Archive, Minnesota Department of Natural Resources, Bugwood.org.

Symptoms of DED begin as wilting of leaves and proceed to yellowing and browning (Figure 5.11). The pattern of symptom progression within the crown varies depending on where the fungus is introduced to the tree. If the fungus enters the tree through roots grafted to infected trees, the symptoms may begin in the lower crown on the side nearest the graft and the entire crown may be affected rapidly. If infection begins in the upper crown, symptoms often first appear at the end of an individual branch (called flagging) and progress downward in the crown.

Branches and stems of elms infected by the DED fungus typically develop dark streaks of discoloration. To detect discoloration, cut through and peel off the bark of a dying branch to expose the outer rings of wood. In newly infected branches, brown streaks characteristically appear in the sapwood of the current year (Figure 5.12).

Figure 5.12. Brown streaks characteristically appear in the current-year sapwood of trees infected with the Dutch elm fungus. Credit: William Jacobi, Colorado State University, Bugwood.org.

DED is managed by interrupting the disease cycle. The most effective means of breaking the cycle is early and thorough sanitation to limit the population of the insects that transmit the fungus from tree to tree. Other useful means of affecting the disease cycle include using insecticides to kill the insect vectors, breaking root grafts between trees, injecting individual trees with fungicides to prevent or halt the fungus, pruning out early infections, and planting DED-tolerant or DED-resistant elm cultivars or other tree species.

Certain fungicides, when properly injected, are effective in protecting elm trees from infection transmitted by beetles. This treatment is expensive and must be repeated every one to three seasons. Thus, it is appropriate only for high-value or historically important trees. The treatment itself also may pose risks to the health of the tree.

There are several chemicals in various formulations registered for injection to manage DED. To be effective, the fungicide must be present at adequate concentration at all potential points of infection. Thus, the dosage and means of application are critical to success. The injection of chemical into root flares in large volumes of water (macroinjection) provides thorough distribution of chemical in the crown. Microinjection is also an option, although its efficacy compared with that of macroinjection has not been thoroughly researched. Preferably, injections should be done soon after the earliest leaves have fully expanded, but may be done from then to the end of the growing season. Label rates of concentration for chemical application are updated to reflect the most recent findings on effectiveness; always follow the current label.

Pine wilt disease

The pine wood nematode *Bursaphelenchus xylophilus* causes pine wilt. This nematode is unusual because it is a pathogen in aboveground parts of trees. It is transmitted by insects and does not enter the soil. It was not recognized as a potential pathogen in the United States until 1979, when it was found associated with dying Scots and Austrian pines in Columbia, Missouri. More than 20 pine tree species serve as a suitable host for the nematode.

The first symptom of pine wilt is a marked reduction in flow of oleoresin that occurs before external symptoms are apparent. Transpiration from foliage decreases, then stops three to four weeks after infection. Foliage rapidly yellows and browns as sapwood moisture decreases. Needles show definite wilt only in long, soft-needled species, such as white pine (Figure 5.13). Foliar symptoms may progress uniformly through the tree or branch-by-branch, largely depending on the size of the tree and the season of death. Trees may die from midsummer to late fall or from late winter to late spring. The rapid death contrasts with the slow decline caused by pathogenic fungi associated with needlecast diseases.

Figure 5.13. Soft-needled white pines easily exhibit whole-tree wilt caused by the pine wilt nematode. Credit: USDA Forest Service - North Central Research Station Archive, USDA Forest Service, Bugwood.org.

Several *Monochamus* spp. (longhorned) beetles are responsible for transmitting the pine wood nematode. Adult beetles infested with *B. xylophilus* emerge from dead pines in May and June, fly to healthy pine trees, and begin maturation feeding on phloem of young pine shoots. Immature nematodes leave the beetle, enter feeding wounds, molt to the adult stage and mate, and reproduce rapidly in the resin canals of the pine host during the propagation phase of the nematode life cycle. Under optimum conditions, growth of nematodes from eggs to adults is completed in five days. Within four to five weeks, infected pines exhibit reduced oleoresin flow and transpiration, and large numbers of nematodes are present throughout trees as wilting and yellowing of foliage become noticeable. Trees die within three months after becoming infected.

Currently, the only effective control of pine wilt disease is to remove and destroy affected trees, which can be a source of infection for healthy trees nearby.

Root rots

Armillaria root rot is caused by several fungi in the genus *Armillaria*, of which *A. ostoyae* and *A. mellea* are the most pathogenic. It is one of many microorganisms that cause natural decay of tree stumps and roots. While growing on a dead stump, the fungus produces rootlike structures called rhizomorphs, which can grow out into the soil away from the infected stump for distances of up to 60 feet (18 m). Fruiting bodies may be attached to the base of the tree trunk or as lone clumps on the forest floor, seemingly detached from their host (Figure 5.14).

Figure 5.14. Fruiting body of *Armillaria ostoyae.* Credit: John H. Ghent, USDA Forest Service, Bugwood.org.

But *Armillaria* species can also attack living trees. Where rhizomorphs contact the root system of a suitable host, they may be able to infect those roots, causing a reduction in growth or a girdling of the tree.

Large trees may be able to confine the fungus in infected roots and thereby survive for years, but they grow progressively weaker as roots are killed and eventually become subject to windthrow. Smaller trees may be killed much more quickly.

Figure 5.15. The dense, white "mat" of fungal tissue growing beneath the root bark is a reliable sign of Armillaria root rot. Credit: Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org.

To check for Armillaria root rot, gently remove the bark from the root collar area of a suspicious-looking tree. Look for a dense, white "fan" of fungal tissue growing between the bark and the wood (Figure 5.15). Armillaria is not likely to be the culprit if the mat is not present.

No chemical treatments are available for use in controlling Armillaria root rot. Often, trees killed by this fungus have first been weakened by other agents such as insects or other pathogens, so anything you can do to prevent stress on the trees should help prevent Armillaria from gaining a foothold.

Decline

Oak decline is a complex of disorders and diseases that threaten these mighty trees. Although some oak problems are caused by the action of a single pathogen, insect, or environmental agent, some conditions leading to decline are not easily explained. Various stresses are responsible for reduced tree vigor. This allows secondary diseases and insects to cause further decline or death of branches and sometimes entire trees.

Oaks, like other tree species, have favored environments. They prefer deep, fertile soils with abundant moisture and slightly acidic conditions. They grow best in undisturbed and stable areas. Unfortunately, many oaks in the Midwest are growing in less-than-ideal sites. Also, weather patterns can cause serious stress. Drought conditions followed by severe winters, such as those that occurred between 1978 and 1980, or flood conditions, such those as in 1993 and 2008, are hard on oaks.

Oaks are intolerant of site disturbances associated with the activities of people. Oaks in recreational areas are subject to soil compaction and frequent wounding. Oaks also are intolerant of the activities around construction sites due to the destruction of feeder roots by heavy equipment and smothering of root systems by extra layers of soil.

Oaks often are defoliated by insects: for example, the looper complex and gypsy moth. Leaf diseases, such as anthracnose, contribute to a shorter productive leaf life. When the "factories" are destroyed, the "industry" is stressed.

Numerous secondary fungal organisms attack stressed oaks. The shoestring fungus, *Armillaria mellea*, infects the roots of stressed trees. Oak wilt and other serious diseases also make up the picture of oak decline and death. Certain insects are attracted to stressed trees and sometimes can act as vectors for pathogens.

Leaf scorch, late spring flush, interveinal necrosis, decreased twig growth, early fall coloration, premature leaf drop, and twig dieback are early symptoms indicating that a tree is under stress. If the situation is not improved, dieback of branches begins and root infections occur. Dieback of larger branches increases progressively with stress. In severe cases, trees may begin to sprout from the lower trunk.

Emerging forest diseases

Whether or not the global economy is the cause, new pests are being discovered on a routine basis across the United States. Some pose immediate threats while others may or may not depend on the right combination of susceptible hosts, infective pathogens, and a favorable environment for disease to develop.

The first of these emerging diseases discussed here is ominously making its presence known in black walnut plantations in the West and has also been found in Tennessee forests. The second disease may be held in check in the Midwest by unfavorable environmental conditions. Still, it bears watching and is worthy of discussion here.

Figure 5.16. Black walnut in end stage of thousand cankers. Credit: Whitney Cranshaw, Colorado State University, Bugwood.org.

Thousand cankers disease

Within the past decade an unusual decline of eastern black walnut (*Juglans nigra*) has been observed in several western states. Initial symptoms involve a yellowing and thinning of the upper crown, which progresses to include death of progressively larger branches (Figure 5.16). In the final stages, large areas of foliage may rapidly wilt. Trees often are killed within three years after initial symptoms are noted.

Tree mortality is the result of attack by the walnut twig beetle (*Pityophthorus juglandis*) and subsequent canker development around beetle galleries caused by a fungal associate (*Geosmithia* sp.) of the beetle. A second fungus (*Fusarium solani*) is also associated with canker formation on the trunk and scaffold branches. The proposed name for this disease complex is thousand cankers.

Before 2002, walnut twig beetle was not associated with any significant *Juglans* mortality. In most areas where the die-offs of black walnut have occurred, drought was originally suspected as the cause of the decline and death of trees, while the beetle was regarded as a secondary pest. However, the following circumstances suggest an alternate underlying cause:

- The widespread area across which a die-off of *Juglans* spp. has been recently reported.
- The documented presence of an associated canker-producing fungal pathogen carried by the twig beetle.
- The occurrence of black walnut death in irrigated sites not sustaining drought.

Figure 5.17. Canker produced following introduction of *Geosmithia* (isolate 12 - 181) into northern California walnut seedling. Associated with walnut twig beetle. Credit: Curtis Utley, Colorado State University Extension, Bugwood.org.

Two different types of cankers have been observed on declining walnut trees. Small, diffuse, dark brown to black cankers, caused by an unnamed fungus in the genus *Geosmithia* (Figure 5.17), initially develop around the nuptial chambers of the walnut twig beetle in small twigs, branches, and even the trunk. *Geosmithia* species are associates of bark beetles of hardwood and conifer trees but have not previously been reported as pathogens of *Juglans*. Branch cankers may not be visible until the outer bark is shaved from the entrance to the nuptial chamber; although a dark amber stain may form on the bark surface in association with the cankers. Cankers expand rapidly and develop more expansively lengthwise than circumferentially along the stem. On thick-barked branches, cankers may at first be localized in outer bark tissue and extend into the cambium only after extensive bark discoloration has occurred. Eventually multiple cankers coalesce and girdle twigs and branches, resulting in branch dieback. The number of cankers that are formed on branches and the trunk is enormous; hence the name thousand cankers to describe the disease.

A second canker type caused by the fungus *Fusarium solani* may occur on black walnut trees in advanced stages of decline. These diffuse cankers are much larger than those caused by *Geosmithia* and often exceed 6 feet (1.8 m) in length, extend from the ground into the scaffold branches, and may encompass more than half the circumference of the trunk. Trunk cankers are not readily visible without removal of the outer bark. However, a dark brown to black stain on the bark surface or in bark cracks often indicates the presence of a canker. The inner bark and cambium below the bark surface on the canker face is macerated, water-soaked, and stained dark brown to black. *Fusarium solani* has not been isolated from cankers surrounding walnut twig beetle galleries or directly from beetles.

Controls for thousand cankers disease have not yet been identified, and their development will require better understanding of the biology of the walnut twig beetle and the canker-producing *Geosmithia* species. Because of the extended period when adult beetles are active, insecticide spray applications are likely to have only limited effectiveness. Furthermore, colonization of the bark and cambium by *Geosmithia* may continue even if adult beetles or larvae are killed by the insecticide. This will probably limit the ability of systemic insecticides to control transmission of the fungus to new hosts before substantial infection occurs. Rapid detection and removal of infected trees currently remains the primary means of managing thousand cankers disease.

Sudden oak death

A phenomenon known as sudden oak death was first reported in 1995 in central coastal California. Since then, tens of thousands of tanoaks, coast live oaks, and California black oaks have been killed by a newly identified fungus, *Phytophthora ramorum*. On these hosts, the fungus causes a bleeding canker on the stem. The pathogen also infects *Rhododendron* spp. (Figure 5.18), huckleberry, bay laurel, madrone, bigleaf maple, manzanita, and California buckeye. On these hosts the fungus causes leaf spot and twig dieback.

Figure 5.18. *Phytophthora ramorum* symptoms on rhododendron in central California. Credit: Joseph O'Brien, USDA Forest Service, Bugwood.org

On oaks and tanoak, cankers are formed on the stems. Cankered trees may survive for one to several years, but once crown dieback begins, leaves turn from green to pale yellow to brown within a few weeks. A black or reddish ooze often bleeds from the cankers (Figure 5.19), staining the surface of the bark and the lichens that grow on it. Bleeding ooze may be difficult to see if it has dried or has been washed off by rain, although remnant dark staining is usually present.

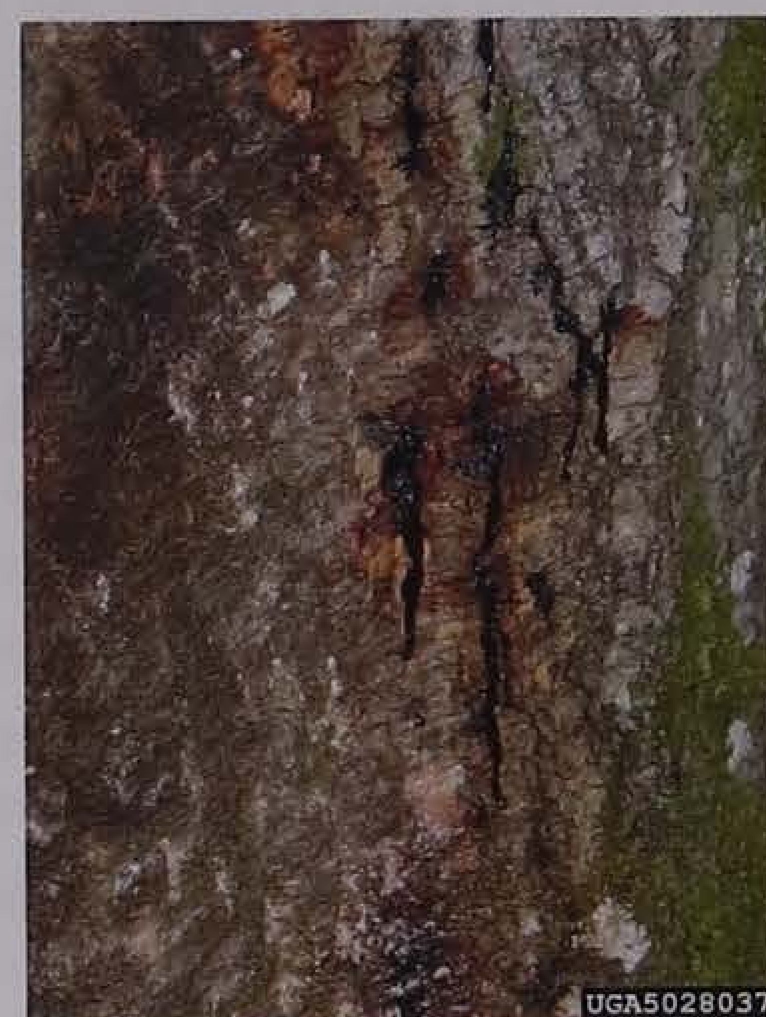

Figure 5.19. Sudden oak death canker ooze symptom on oak. Credit: Bruce Moltzan, Missouri Department of Conservation, Bugwood.org.

Necrotic bark tissues surrounded by black zone lines are usually present under affected bark. Because these symptoms can also be caused by other *Phytophthora* species, laboratory tests must confirm pathogen identity.

In the eastern United States, other disorders of oaks have similar symptoms. Canker rots, slime flux, leaf scorch, root diseases, freeze damage, herbicide injury, and other ailments may cause symptoms similar to those caused by *P. ramorum*. Oak wilt, oak decline, and red oak borer damage are potentially the most confusing. If unusual oak mortality occurs and symptoms do not match these regional disorders, evaluate affected trees for *Phytophthora ramorum*.

In the United States, sudden oak death is known to occur only along the West Coast. However, the fact that widely traded rhododendron ornamentals can be infected with the pathogen and the demonstrated susceptibility of some important eastern oaks make introduction to eastern hardwood forests a significant risk. Early detection will be important for successful eradication.

Commonly used forest fungicides

Some of the more common fungicides used for controlling the causal agents that lead to forest disease are listed below. It is by no means a complete list. Further, any mention of a particular pesticide trade name is neither an explicit nor implicit endorsement of that commercial product. As always, READ AND UNDERSTAND THE LABEL before applying any pesticide.

Benomyl

Benomyl is a **systemic fungicide** that is selectively toxic to microorganisms and to invertebrates, especially earthworms. It is used against a wide range of fungal diseases.

Bordeaux mixture

Bordeaux mixture is a combination of hydrated lime and copper sulfate. Copper sulfate is a fungicide used to control bacterial and fungal diseases of fruit, vegetable, nut, and field crops and when mixed with hydrated lime it serves as a protective fungicide for leaf application and seed treatment.

Captan

Captan is a nonsystemic, broad-spectrum fungicide. Captan may be found in formulations with a wide range of other pesticides.

Chlorothalonil

Chlorothalonil is a broad-spectrum fungicide. The compound can be found in formulations with many other pesticide compounds

Fixed coppers

Fixed coppers are relatively insoluble copper compounds that are less injurious to plant tissues (phytotoxic) than Bordeaux mixture. Limited use due to some phytotoxicity and incompatibility with other pesticides.

Iprodione

Iprodione is a **contact fungicide** used to control a wide variety of crop diseases. The compound is used in formulations with numerous other fungicides.

Mancozeb

Mancozeb is a nonsystemic, broad-spectrum fungicide used to protect many fruit, nut, and foliar crops.

Propiconazole

Propiconazole is a systemic foliar fungicide with a broad range of activity. It is also formulated with other pesticides.

Thiophanate-methyl

Thiophanate-methyl is a systemic fungicide that controls a variety of diseases on woody and herbaceous ornamentals.

REVIEW QUESTIONS
Forest Disease Management

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. What three elements make up the plant disease triangle?

2. A plant that is resistant to one pathogen is resistant to all pathogens.
   A. True
   B. False

3. Explain the difference between the terms "symptom" and "sign."

4. The majority of forest tree diseases are caused by:
   A. Fungi
   B. Bacteria
   C. Viruses
   D. Mycoplasmas
   E. Nematodes

5. Many forest disease can be controlled:
   A. Any time of the year
   B. Before infection starts
   C. After symptoms appear
   D. After signs appear

6. The primary sign associated with fungi-causing pine needlecast diseases is:
   A. Chlorotic spots
   B. Necrotic regions distal to the infection point
   C. Small black fruiting structure bearing conidia
   D. Premature shedding of needles

7. Canker diseases not only disfigure a tree, they also create entry points for:
   A. Lightning strikes
   B. Wood decay
   C. Leaf-spotting organisms
   D. Beneficial insects

8. Which is NOT true concerning oak wilt?
   A. It kills trees by plugging water-conducting cells.
   B. Spread by insects is most serious in late spring and early summer.
   C. Once established, the disease spreads quickly via root grafts.
   D. White and bur oaks are more susceptible than red or black oaks.

9. Which management strategy is NOT suitable for planted forest stands?
   A. Plant disease-free seedlings.
   B. Plant stands of mixed species.
   C. Plant fast-growing, nonnative seedlings.
   D. Match the species to site conditions.

10. What are the diagnostic symptoms of Dutch elm disease?

Learning objectives

After reading this chapter, you should be able to

- Explain what is meant by natural, regulatory, mechanical, cultural, biological, and chemical control measures.
- Outline the more common forest insect pests, the type of damage they cause, their basic life cycle, and management strategy.
- List the more common insecticides used to control the above forest insect pests.

6 Forest Insect Management

All species of trees are affected by a complex of insects. Not all insects are pests; in fact, only a small percentage cause damage to trees. Most forest insects play important roles in forest ecosystems. Still, insects can injure forest trees in the following ways:

- Chewing on the leaves, buds, fruits, seeds, twigs, roots, or bark.
- Tunneling in the stems or actually severing twigs and small limbs from the tree.
- Sucking sap from the leaves, flowers, fruits, stems, or roots.
- Initiating the formation of abnormal growths (galls) on leaves and twigs.
- Damaging trees during the process of egg laying.
- Transmitting plant pathogens.

Every part of a tree — its roots, trunk, branches, twigs, buds, leaves, needles, cones, and seeds — may be fed upon by insects. Insects may attack trees of any age. The types of insect pests affecting a specific tree will depend on the age, vigor, location, and susceptibility of the tree.

Stressed trees are often more susceptible to insect attack than healthy trees. Stunting, distortion, weakening, or death of a tree is frequently caused by some combination of adverse environmental factors with insect or plant pathogen attack. For example, severe drought stress followed by twolined chestnut borer infestation may eventually kill an oak tree.

Managing forest insect pests

Because of environmental issues and the relatively high cost of insecticides, we often rely on nonchemical alternatives for managing forest insect pests. As with any good integrated pest management program, a combination of control measures is usually the best approach for mitigating a forest insect problem.

Natural controls

The term "natural control" implies that we are not directly involved in the regulation of insect numbers. The environment applies many pressures that usually keep insect populations from reaching damaging levels. Such environmental factors that limit the abundance or distribution of pest species include biotic (living) and abiotic (nonliving) factors.

Biotic factors

- Insectivorous vertebrates such as rodents, skunks, and birds.
- Predaceous insects such as ladybird beetles, ground beetles, ants, and lacewings.
- Parasitic wasps and flies.
- Insect diseases caused by microorganisms such as viruses, bacteria, and fungi.
- Density and diversity of tree stand.

Abiotic factors

- Climatic factors, including heat, cold, and too much or too little moisture.
- Topographic barriers such as mountain ranges and bodies of water.
- Soil conditions, such as compaction, physical makeup, and moisture content.
- Disturbances such as wildfire.

Any method used by managers to reduce insect numbers is considered to be applied control.

Regulatory controls

Regulatory controls are used by governmental agencies to keep pest problems from spreading. Objectives include preventing foreign pest species from entering this country, eradicating newly introduced pests, and containing pest species within defined boundaries. Specific actions include inspecting plant materials, monitoring survey and detection traps, destroying or fumigating infested materials, and establishing and enforcing quarantines.

Figure 6.1. Sticky bands on trees for monitoring and control. Credit: G. Keith Douce, University of Georgia, Bugwood.org.

Mechanical controls

Mechanical controls include devices to trap, kill or prevent free movement of insects. An example is placing sticky bands on trees to trap **larvae** (Figure 6.1).

Cultural controls

Cultural controls make the environment less favorable for pest activity by modifying cultural practices. Proper site selection, for example, results in a favorable habitat for the tree, more vigorous growth, and fewer insect problems from secondary pests that attack only stressed trees. Stand management, including proper species selection, proper thinning, and adjustment of harvest age, can reduce problems caused by some insects such as jack pine budworm. Sanitation is the removal of breeding material, a practice used in control of some bark beetle species.

Biological controls

Biological control measures use living organisms or their products to achieve pest control. The results are similar to biotic natural control, but here we are directly involved in the application of the controls. The major groups of beneficial organisms used are predaceous and parasitic insects and disease organisms affecting insects. Methods include introducing new natural enemies from the original home of a foreign pest species; rearing and releasing beneficial predator and parasitoid species; and conservation of natural enemy populations by providing food, overwintering habitat, alternative prey, or other resources for beneficial species, or by minimizing the use of broad-spectrum insecticides that would kill beneficial insects.

Chemical controls

Chemical control is used for several reasons: it is often more effective than alternative methods; its effects are immediate and predictable; it can rapidly reduce damaging populations; and it can be used where needed. Chemical controls are used more commonly in Christmas tree plantations and forest nurseries because of the high value and the short rotation age of the crop.

Insecticide applications are limited in forest situations because of their relatively high cost of application, the low value of the individual trees, and the high risk to humans, pollinating insects, and the environment.

Pest resistance to insecticides

The insects left alive after a pesticide application may be better able to tolerate future applications of that pesticide, and, over time, the insect population can evolve genetic resistance to the pesticide. Insects can also develop cross-resistance. Cross-resistance occurs when an insect population that has developed resistance to a certain pesticide also develops resistance to other related or unrelated pesticide compounds to which it has never been exposed.

Resistance to insecticides can be prevented or postponed indefinitely by following label directions and these guidelines:

- Use integrated control strategies.
- Limit the use of pesticides as much as possible.
- Rotate different modes of action of insecticides.

Common forest insect pests

In this chapter, we cannot discuss all of the major insect forest pests in the Midwest. A few important and representative pests have been chosen to serve as useful examples of diagnosis and management.

Defoliators

Insects have been responsible for the defoliation of forest trees in certain areas of midwestern states in the past and, in all probability, will cause similar defoliation in the future. Deciduous forest trees in select locations can withstand complete defoliation for two or three years in succession, providing the defoliation takes place late in the growing season (late August or September). By late summer or early fall, trees have completed most of their growth for the year and have set leaf and flower buds for the following season. If complete defoliation occurs for three or four consecutive seasons, even if it occurs late in the year, there is a good chance that some limbs will die and tree growth will decrease. One total defoliation event can kill evergreen trees.

Spring hardwood defoliators

Eastern tent caterpillar (*Malacosoma americanum*)

The favorite hosts of the eastern tent caterpillar are wild cherry, apple, and crabapple. Occasionally, this defoliating pest feeds on ash, birch, blackgum, redgum, willow, witch hazel, maple, oak, poplar, peach, and plum.

These insects overwinter as eggs, which are laid in distinctive masses containing 150 to 300 eggs and appear varnished.

Larvae hatch from eggs in the spring, and the young caterpillars quickly gather at a major branch or crotch and begin to build a web, which they leave to feed on newly opened leaves (Figure 6.2). Larvae spin a fine strand of silk wherever they go. As the caterpillars grow, so does the size of the tent. When populations are large, whole branches or trees become covered with webbing, and all leaves are devoured.

The fully grown caterpillars generally are black with a white stripe down the back and a series of bright blue spots between longitudinal yellow lines (Figure 6.3). It is at this stage that the larvae leave the host tree and search for a place to spin white cocoons. Within the cocoon they transform into **pupae**, then into reddish brown moths with two whitish stripes running obliquely across each forewing. The adults emerge in early summer. One generation occurs each year.

Damage due to eastern tent caterpillars can be reduced on small trees by getting rid of the egg masses during the winter or by clipping and destroying the tents and their occupants on rainy, cool days when they are still small (Larvae do not venture out of their tents to feed during inclement weather.) Chemical controls include *Bacillus thuringiensis*, carbaryl, and chlorpyrifos).

Figure 6.2. Eastern tent caterpillars in tent. Credit: Robert L. Anderson, USDA Forest Service, Bugwood.org.

Figure 6.3. Spring defoliators like the eastern tent caterpillar are potentially more damaging than fall defoliators because they destroy the tree's photosynthetic ability. Credit: David Cappaert, Michigan State University, Bugwood.org.

Cankerworms (Fall: *Alsophila pometaria*, Spring: *Paleacrita vernata*)

Also known as inchworms, cankerworms have a wide host range, but prefer elm, hackberry, and honeylocust.

Two species of cankerworms occur: spring cankerworm and fall cankerworm. Both feed on host trees early in the spring just as the leaves are beginning to appear, or they sometimes attack the buds before the leaves open.

Adult females of both species are wingless moths (Figure 6.4). The fall cankerworm adult emerges in October and November, whereas the spring cankerworm adult does not emerge until late February and March. The females of both species crawl up the trunk of the tree to deposit eggs. Eggs of both species hatch in April or early May and the young devour the developing leaves. Dispersal is accomplished when the small caterpillars are blown from one tree to another. Large numbers of larvae may annoy passersby because they often hang from a strand of silk. Upon maturity, larvae descend from the tree on a silk thread and then burrow into the ground, spin a cocoon, and pupate.

Figure 6.4. Fall cankerworm female laying eggs. Credit: John H. Ghent, USDA Forest Service, Bugwood.org.

The spring cankerworm larvae vary in color from reddish to yellowish brown or yellowish green and may even be black. Usually there is a yellowish stripe on the side of the body though this may be missing. Fall cankerworm larvae color ranges from light green to dark brownish green with a wide, dull, dark longitudinal stripe down the center of the back. Fall cankerworm has three pairs of prolegs, whereas the spring cankerworm has only two.

Both species have one generation per year. Defoliation is often not readily apparent, although trees may appear dead because they are late in leafing out. Caterpillars begin chewing small holes in leaves, then progress to free feeding as they get bigger.

Applying bands of sticky material to the trunks of individual trees to catch the wingless females as they crawl upward to lay their eggs is an old technique that is worthy of more frequent use. This technique has failed in the past because people did not understand that there are two species of cankerworms and they crawl up the trees in different seasons; the fall cankerworms in October and November and the spring cankerworm in late February and March. In addition, they failed to realize that sticky bands exposed to changing temperatures, blowing dust, etc., lose their stickiness and become ineffective.

Sticky bands should be made from materials that are nontoxic to the tree. Sticky material is sold under various trade names, including "Tanglefoot," "Stickem," and "Tack Trap." Apply a band about 4 to 6 inches (102-152 mm) wide evenly around the trunk, preferably 6 to 7 feet (1.8-2.1 m) high, but lower if the tree branches are below this height. Do not scrape the rough bark to make a smooth surface. This may expose living tissue that can be injured. The sticky material may also be applied to a strip of paper, cloth, or burlap that is tacked to the trunk, so it can be removed after the cankerworm season. Make sure all crevices in the bark under the paper or cloth are plugged to prevent females from crawling under. Heavy greases or other crude petroleum products should *not* be used on trees, because they will kill the tree.

Insecticide applications including those containing *Bacillus thuringiensis* are quite effective if applied when the larvae are small. Other effective insecticides include acephate, carbaryl, cyfluthrin, and malathion.

Summer hardwood defoliators

Walnut caterpillar (*Datana integerrima*)

Forest trees like walnut, hickory, and pecan are readily defoliated by the walnut caterpillar, but oaks are only occasionally attacked by this forest pest. Frequently, the trees are completely defoliated during July and August. Young trees can be stunted and older trees seriously damaged when defoliation occurs in consecutive years.

The walnut caterpillar overwinters as a dark-brown pupa about 1 inch (25 mm) in length located about 4 to 6 inches (102-152 mm) below the soil surface. The adult moth, with a wingspread of from 1½ to 2 inches (38 to 50 mm), emerges in June and July. The wings are light brown in color with dark-brown, wavy lines across them. The female moth deposits the eggs in masses of 200 to 300 on the underside of leaves on the host plant.

Small, reddish larvae with white stripes hatch from the eggs in about two weeks and begin to feed on the leaves. The larvae feed in groups and increase in size. The entire mass moves to a spot, usually the trunk of the tree. They shed their skins, then return to feed on more leaves. The mature black larvae, with long, shaggy, white hair, measure nearly 2 inches (51 mm) in length (Figure 6.5). They then leave the tree, enter the soil, and change to the pupae. There is only one generation per season in the Midwest.

Figure 6.5. The walnut caterpillar is a summer defoliator that, while unsightly, causes less damage than spring defoliators. Credit: Lacy L. Hyche, Auburn University, Bugwood.org.

Insecticidal control measures for the walnut caterpillar are seldom recommended for forest plantings, but may be necessary for individual trees in the border areas as well as individual trees in nut-producing groves. Effective insecticides include those containing *Bacillus thuringiensis* for young larvae and also those containing carbaryl, chlorpyrifos, or cyfluthrin.

Figure 6.6. Fall webworm on crabapple. Credit: Mark H. Shour, Iowa State University.

Fall webworm (*Hyphantria cunea*)

The unsightly webs of the fall webworm (Figure 6.6) cause concern when they appear in rather large numbers on cherry, walnut, pecan, hickory, apple, and persimmon in late summer. Although the webs may be numerous and defoliation moderate to severe, actual damage to the infested trees is of little importance.

The adults have a wingspan of about 1¼ inches (32 mm). Emergence begins in late May and continues for about a month. Clusters of eggs are deposited on the leaves of trees.

The larvae, or caterpillars, are pale yellow, black spotted, and hairy. They measure about 1 inch (25 mm) in length when mature. They feed on leaves enclosed in large webs. Two generations of this pest exist in the Midwest.

To control fall webworm, prune and destroy infested limbs. Several effective control agents exist, including the egg parasite *Telenomus bifidus* Riley. An important parasitoid of the caterpillar is *Meteorus hyphantriae* Riley. Chemical control is rarely recommended.

Variable oakleaf caterpillar (*Heterocampa manteo*)

The variable oakleaf caterpillar is a periodic pest in the Midwest because it can build up in great numbers to cause complete defoliation of oak trees for two or three consecutive years. Defoliation usually occurs in late August and early September, so serious damage to trees usually is minimal.

The moth is ash gray with a wingspread between 1½ and 1¾ inches (38 to 44 mm). The wings vary from light to dark gray with darker shading.

Figure 6.7. Variable oakleaf caterpillar. Credit: James B. Hanson, USDA Forest Service, Bugwood.org.

They deposit eggs in clusters on the underside of oak, basswood, and birch leaves. The larvae vary in color. The body is smooth yellowish green with a pale middorsal longitudinal line, and reddish brown markings on the sides are commonly bordered by creamy-yellow stripes (Figure 6.7). The full-grown larvae are about 1½ inches (38 mm) long. The mature larvae drop from the trees, enter the soil, and remain during winter. Some larvae may remain in the soil for two years. Pupation takes place in July.

In years following large infestations, egg parasitoids may kill 90 percent of the eggs. Nearly all egg masses have some parasitized eggs; only the eggs concealed within a cluster escape. This high parasitism rate and the failure of many prepupae to complete development are the major reasons for lack of consecutive heavy defoliations. In addition, there are at least seven species of larval parasitoids that attack variable oakleaf caterpillar larvae. Finally, there are two large ground beetles that feed on the adult caterpillars. With all of these natural control mechanisms, chemical control is generally neither necessary nor recommended over large areas. However, localized treatments using pesticides may be necessary in residential or recreation areas.

Figure 6.8. Introduced pine sawfly female laying eggs in a pine needle. Credit: Gyorgy Csoka, Hungary Forest Research Institute, Bugwood.org.

Softwood defoliators

Pine sawflies

Several species of conifer-feeding sawflies feed on foliage, mine buds, or bore into the pith of shoots. Sawflies are not flies at all, but nonstinging wasps. The females of these economically important species have a sawlike apparatus at the tip of their abdomens. The "saw" is used to split or cut plant tissue and aids in the insertion of eggs into these slits (Figure 6.8). Some species feed only on the old needles, some feed only on the new, and still others (e.g., redheaded pine sawfly) feed on old needles in their spring generation and on new needles in a later generation. The larvae of typical defoliating sawflies look much like the caterpillars of moths and butterflies but can be differentiated by the number of **prolegs** on the abdomen. Sawfly larvae have more than five pairs (Figure 6.9), each of which lacks the hooked spines (crochets) typical of caterpillar larvae. Caterpillars have two to five pairs.

Figure 6.9. Pine sawfly larvae can be distinguished from other caterpillar larvae in that they have more than five pairs of prolegs along their abdomen. Credit: Gerald J. Lenhard, Bugwood.org.

The life cycle of the redheaded pine sawfly, *Neodiprion lecontei*, is typical of most sawflies. This species attacks a variety of two- and three-needle pines. It also may attack five-needle pines if these trees are growing among other, preferred hosts.

Larvae hatch from the eggs after about a month and feed for another month or so before dropping from the host tree to the ground to spin their tough, brown cocoons. Several generations may occur in the Midwest.

If infestations of pine sawfly are localized, handpicking of sawfly colonies may control the problem. Apply insecticides when the larvae are young (first and second **instar**) to minimize seedling damage. Several insecticides are available for pine sawfly control: acephate, bifenthrin, carbaryl, malathion, and permethrin.

Borers

Several insects bore into the stems, roots, and twigs of forest trees. A few of these insects attack healthy trees, and many attack stressed trees, while others attack only dead or dying trees. These borers frequently attack trees damaged by fire, winter injury, ice, winds, defoliating insects, and plant diseases. The following section provides more detailed information about several of the more important species that occur in the Midwest.

It is seldom practical or cost effective to apply insecticides to control these insects. Usually, the borers are inside the trees and therefore can't be controlled with contact insecticides. Further, the translocation of systemic insecticides is often hindered by prior injuries to the vascular system of older trees. Cultural control methods usually are most feasible in minimizing damage caused by these pests. These include removing seriously damaged as well as dead and dying trees and keeping trees in a vigorous state.

Twolined chestnut borer (*Agrilus bilineatus*)

The twolined chestnut borer is a pest of oak and chestnut species with a few reports of injury to species of beech. Research has shown that healthy as well as stressed oaks are susceptible to attack by this pest. Large and seriously injurious populations of the borer almost always follow outbreaks of defoliating insects. If a tree weakened from any cause supports these borers for two to three years in a row, gradual death occurs from the top down. Infested trees can be recognized by sparse, small and discolored foliage, and branch dieback.

Adult borers (Figure 6.10) begin to appear in late spring and may be found through the summer. The eggs are laid in cracks and crevices in the trunk bark, usually in sections exposed to sunlight. Beetles are sun-loving and feed on the leaves of many hardwood-tree species. Newly hatched larvae bore directly into the bark and establish themselves primarily in the **phloem**, making winding, zigzagging tunnels filled with frass. The cream-colored larvae are legless; they have flat heads and an elongate, rather delicate body. Spring pupation takes place in the outer bark. The adult chews a D-shaped exit hole in the bark. The twolined chestnut borer usually produces one generation of offspring each year.

Figure 6.10. Twolined chestnut borer, *Agrilus bilineatus.* Credit: Mike Quinn, www.TexasEnto.net.

Red oak borer (*Enaphalodes rufulus*)

The red oak borer (Figure 6.11) is native to North America and has been found in many oak species. Economic loss occurs when borer tunnels and subsequent wood overgrowths in attacked trees are distributed on the grading surfaces of boards and veneer. Wood-inhabiting insects such as carpenterworms, timberworms, and carpenter ants use red oak borer tunnels to gain entry into oaks. These other pests extend and increase the damage begun by the red oak borer. Decay organisms also gain entry into oak **heartwood** through borer tunnels.

Figure 6.11. The adult red oak borer is one of the key players in oak decline. Credit: Gerald J. Lenhard, Bugwood.org.

The adults are nocturnal and can be found from mid-June to mid-August. Mating takes place on the host tree, and the female lays an average of 110 eggs. The eggs are attached with an adhesive in cracks, and under lichen patches and vines on host trees. The young larvae begin boring directly through the bark and spend their first year in the phloem and **sapwood** making small (2 by 3 by ½ in.) (51 by 76 by 13 mm) tunnels. The two-year-old larvae (Figure 6.12) make larger mines (7 by 3 by ½ in.) (178 by 76 by 13 mm) and tunnel into the **xylem** and the heartwood to construct a pupal cell. The adult emerges near the original oviposition site by gnawing an oval hole through the bark.

Figure 6.12. Red oak borer larva. Credit: James B. Hanson, USDA Forest Service, Bugwood.org.

Certain specific external signs indicate internal red oak borer damage in host trees. Fine larval frass is found during the first fall and winter after eggs hatch. Wet spots and medium-sized larval frass can be found during the first spring and early summer. Discolored bark patches and large quantities of larval frass occur in the second fall and winter. Wood slivers are extruded in the spring and early summer just before the adult emerges.

Carpenterworm (*Prionoxystus robiniae*)

Carpenterworms are found across the Midwest. Shade trees such as ash, elm, maple, oak, poplar, and willow are commonly infested. White oaks appear to be a favored host tree. Carpenterworms bore into the heartwood of trunks and limbs. They seldom kill trees outright, but small, heavily infested trees may break off in high winds. The greatest commercial damage results from degradation of lumber cut from infested trees. Yard trees or trees growing on poor sites such as dry ridge tops or ridge slopes seem to be particularly likely to be infested. Greater damage occurs when carpenter ants and wood knot fungi invade the tunnels.

Figure 6.13. Adult female carpenterworm, *Prionoxystus robinae.* Credit: James Solomon, USDA Forest Service, Bugwood.org.

Carpenterworm moths (Figure 6.13) are dark and slightly mottled and have stout bodies. Females (wingspan of about 3 inches; 76 mm) are considerably larger than males. Male moths are dark and their hindwings have a large yellowish to orange spot with a black border. The egg is olive green, oblong and slightly larger than the head of a sewing pin. The surface of the egg has a minute network of ridges and shallow pits. Carpenterworms (larvae) are pink to greenish white and grow to 2.5 inches (63 mm) long (Figure 6.14). The pupae are dark brown and up to 2 inches (51 mm) long.

Figure 6.14. Carpenterworms favor white oak but also attack ash, elm, maple and poplar. Credit: William H. Hoffard, USDA Forest Service, Bugwood.org.

The eggs are laid singly or in groups of two to six and hatch in 10 to 14 days. Newly hatched larvae feed for a short while on the empty egg shells, but within a few hours begin penetrating bark or entering tree wounds. The number of larval instars (stages) varies from 8 to 15. Young larvae feed on the inner bark until about half grown. Then they bore into the wood, making tunnels that angle upward in the sapwood and turn straight upward in the heartwood. Tunnels are kept open and enlarged by the growing carpenterworms. Eventually the tunnels may reach a diameter of ⅝ inch (16 mm) with a length of 12 inches (30 cm).

Mature larvae line their tunnels with loose, silky, yellowish brown webs. Pupation (duration of 17 to 19 days) occurs at the upper end of the tunnel. Mature pupae wiggle to the opening of the tunnel and protrude from the trunk. The adult soon emerges. The thin, brown pupal skin remains protruding from the trunk until it weathers away.

Bark beetles

Elm bark beetles are primarily responsible for the long-distance spread of Dutch elm disease (see Chapter 5). The European elm bark beetle is more important than the native elm bark beetle as a vector of Dutch elm disease because of its breeding dominance over the native species.

Proper sanitation is the basis for elm bark beetle management programs. Prompt removal and disposal of dead and dying elms, debarking cut elm wood and stumps, as well as pruning dead branches is essential to reducing bark beetle breeding sites. If barked elm wood can't be immediately buried, burned, chipped or debarked, the material can be treated with 0.5 percent chlorpyrifos until disposal takes place.

The use of insecticides to suppress early beetle populations has diminished in recent years. See Chapter 5 for the use of fungicides to control the fungus responsible for the Dutch elm disease.

Figure 6.15. Smaller European elm bark beetle, *Scolytus multistriatus*.Credit: Natasha Wright, Florida Department of Agriculture and Consumer Sciences, Bugwood.org.

European elm bark beetle (*Scolytus multistriatus*)

The European species overwinters as a full-grown larva in the inner bark of elm trees. Larvae are small, white, and grublike and are found under the bark of dying or dead elms. Pupal development is completed in the spring.

Adults (Figure 6.15) are dark reddish brown, shiny, and about ⅛ inch (3 mm) long. They emerge through small holes chewed in the bark. Emergence continues for several weeks beginning in the middle of May. Adult beetles feed on young bark, usually in twig crotches, where they inoculate elms with the spores of Dutch elm disease. The spores are present in their brood galleries and on their body parts.

Figure 6.16. The egg-laying gallery of the European elm bark beetle that is a key vector for Dutch elm disease is oriented parallel to the wood grain. Credit: James Solomon, USDA Forest Service, Bugwood.org.

Unhealthy or recently killed elm trees are chosen for egg laying. The egg-laying gallery is oriented parallel to the wood grain (Figure 6.16). As the eggs hatch, each larva chews a short tunnel (larval gallery) radiating away from the egg-laying gallery. Pupation occurs at the end of the larval gallery when the larva is mature.

Native elm bark beetle (*Hylurgopinus rufipes*)

The native elm bark beetle overwinters either as a fully grown larva or as an adult. The life cycle is similar to that of the European elm bark beetle. However, the egg-laying galleries run perpendicular to the wood grain, and the subsequent larval galleries run parallel to the grain.

Eastern ash bark beetle (*Hylesinus aculeatus*)

The eastern ash bark beetle is commonly found on declining and recently felled ash (*Fraxinus* spp.) trees. Adults have light brown and white scales on a dark brown body; they are 0.1 to 0.2 inch (2 to 3 mm) long. White, legless larvae with brown heads feed in galleries perpendicular to the wood grain. Beetles emerge from galleries under the bark by chewing 1mm diameter round exit holes. There are one to two generations in Iowa each year, with activity starting late spring. Adult beetles overwinter in small holes in the inner bark of host trees.

Ips bark beetles (*Coleoptera: Scolytidae*)

Ips beetles are commonly found throughout the South. In Iowa they can create problems in Scots pine. They usually attack injured or stressed trees, freshly felled trees or logging slash. Infestations are frequently initiated in trees stressed by lightning, logging injury or fire damage. *Ips* beetles usually

Figure 6.17a. Eastern fivespined Ips, Ips *grandicollis*. Note the scooped out area of the rear end and the spines on each side. Credit: Natasha Wright, Florida Department of Agriculture and Consumer Sciences, Bugwood.org.

Figure 6.17b. Eastern fivespined Ips, Ips *grandicollis*. Spines also are visible in this side view. Credit: Natasha Wright, Florida Department of Agriculture and Consumer Sciences, Bugwood.org.

attack and kill only one or a few trees in a location. However, in areas in which trees have undergone severe drought stress or damage by ice, wind, or hail, they frequently build up large populations and may kill large numbers of trees.

The rear end of adult *Ips* beetles are concave (scooped out in appearance) with four to six pairs of spines on either side of the concaved areas (Figure 6.17a and b). Adults are cylindrical in shape, usually dark brown to black, and range in length from 0.1 to 0.3 inch (2 to 7 mm).

Depending upon which of the four *Ips* species are involved, an infestation is initiated by adults attacking the tree trunk, the trunk and primary limbs or only primary limbs. Often, the first recognized sign of attack is yellowing or reddening of needles in tree crowns. These color changes can occur in two to four weeks in warm weather, but may take several months during cooler periods of the year. Unfortunately, by this time most of the beetles have completed their life cycle (from about 21 days to several months, depending on temperature) and emerged from the tree.

Other signs of attack include the accumulation of reddish brown boring dust on the bark, nearby cobwebs, or understory foliage. If there is sufficient resin pressure within the host, attacked trees will exhibit dime-sized, whitish, or reddish brown globs of resin and boring dust called "pitch tubes" on the bark at each point of beetle attack. Unlike those of the southern pine beetle, *Ips* pitch tubes are more commonly seen on the surface of bark plates than in bark crevices. After beetles emerge from the tree, scattered circular emergence holes (1 to 3 mm diameter) can be observed on the outer bark. By removing a section of the outer bark, the characteristic Y-, I- or H-shaped galleries may be observed in the phloem or engraved on the outer sapwood.

The strategies for preventing damage and controlling the spread of *Ips* beetles essentially involve promoting tree vigor and reducing the amount of vulnerable host material within the stand. Preventive strategies in forest stands include (1) planting species that are appropriate to the site, (2) thinning dense, overstocked stands, (3) conducting prescribed burns or other treatments to control competing understory vegetation, (4) removing or salvaging damaged, declining, or recently-dead trees, (5) avoiding damage to residual stands when conducting management operations, and (6) lopping and scattering or removing logging slash.

There is no effective way to save an individual tree once it has been successfully colonized by *Ips* beetles. When *Ips* infestations are small or sparsely scattered throughout a stand, the best course of action is often to let them die out on their own. Cutting and removal of isolated infested trees or small "spot" infestations with buffer strips is not recommended. In fact, it may increase the likelihood of *Ips* problems by producing fresh host odors, logging slash, and additional stress or injury to the residual stand. If scattered mortality is progressing to unacceptable levels, a stand-level clearcut or a contiguous block removal of a generally infested area may be preferable to single-tree harvests.

Acorn weevils

There are 27 *Curculio* species in North America and Mexico called "acorn weevils." They feed on many hosts in the beech, walnut, and birch families. Adults are brown to black in color, have a robust body ⅜ inch (9.5 mm) long, and have a long slender snout. There are two elbowed antennae midway down the snout and fine chewing mouthparts at the tip. Adults feed on acorn nutmeat using this snout, and females chew deeper and deposit two or more eggs in the hole. White grub-like, legless larvae with brown heads feed on the acorn nutmeat (Figure 6.18). Once the acorn drops off the tree, the larvae chew out of the acorn, burrow into the soil, and transform to the pupal stage. The insect will stay up to five years in the soil before it emerges as an adult during the summer. Although numerous at times, acorn weevil control is not cost effective.

Figure 6.18. Acorn weevil larva that emerged from an infested northern pin oak acorn. Note exit hole and internal damage to acorn. Credit: Steven Katovich, USDA Forest Service, Bugwood.org.

Nut weevils

Nut weevils can be serious pests of both native and nonnative nut trees. These damaging insects begin to attack the kernels in the developing nuts while the nuts are still on the tree. However, problems often are not noticed until the nuts are harvested and opened. Occasionally, these weevil grubs are found in homes or other places where nuts are stored.

Pecan weevil (*Curculio caryae*)

The pecan weevil is a serious late-season pest of hickory and pecan trees. The greatest damage is caused by the grub that feeds directly on the developing kernel.

Adults are reddish brown and densely covered with olive-brown hairs and scales (Figure 6.19). Body length is about ⅜ inch (9 mm), exclusive of the snout. The female has a snout as long as her body, while the male's is about half that long.

Figure 6.19. Pecan weevil, *Curculio caryae*, side view. Note long snout and elbowed antenna on the snout. Credit: Natasha Wright, Florida Department of Agriculture and Consumer Sciences, Bugwood.org.

Two types of damage are caused by this insect; midseason adult feeding on young nuts causing premature nut drop, and grub damage to the kernels that usually occurs after shell hardening.

Adult weevils emerge from the ground in late August through September, about the time nuts begin to harden. Peak periods of adult emergence usually follow heavy rains. After the nut kernels have hardened, the female uses her long snout to chew a hole in the side of the nut; she then deposits eggs in little pockets made in the nut. Creamy white grubs with reddish brown heads hatch and feed inside the nuts during the fall, reaching ⅝ inch (16 mm) in length.

When mature, the grub chews a perfectly round ⅛-inch (3 mm) hole in the side of the nut and falls to the ground in late fall or early winter, usually between late September and December. The grubs make earthen cells in the ground, where they remain as grubs for one to two years. Most of the grubs will pupate the following fall. Some, however, do not pupate until the fall of the next year. Adults emerge during the summer following pupation. The entire life cycle requires two to three years to complete, most of it in the soil.

Weevils usually move only a short distance after emerging and often attack nuts on the same trees year after year, so long as there is a crop of nuts. Weevils apparently prefer trees growing in low areas or those near hickory trees. Early-maturing varieties of pecan are most susceptible to the weevils. Hickory nuts are attacked by the pecan weevil as well.

Trees can be jarred beginning in mid-August to determine when to apply insecticides. Place a large harvesting sheet under the trees and jar the limbs with a padded pole. The adult weevils will fall onto the sheet and remain motionless for a short period. When three or more weevils are jarred per tree, insecticide applications should begin. Peak emergence usually follows rains. Otherwise spray applications should begin when shell hardening begins and should be repeated at 10- to 14-day intervals. Carbaryl, esfenvalerate, and phosmet can be used to control pecan weevils on pecan.

Galls

Galls are abnormal plant growth or swellings consisting of plant tissue. Galls are usually found on foliage or twigs. These unusual deformities are caused by plant growth-regulating chemicals or stimuli produced by an insect or other arthropod pest species. The chemicals produced by these causal organisms interfere with normal plant cell growth.

Figure 6.20. The horned oak gall wasp produces an abnormal growth that, while unsightly. does not significantly affect tree growth. Credit: USDA Forest Service - Northeastern Area Archive, USDA Forest Service, Bugwood.org.

There are a variety of gall-forming species of small wasps that commonly infest oak trees in the Midwest. Most leaf galls on oak cause little or no harm to the health of a tree. However, twig or branch galls may cause injury or even death to a heavily infested tree. Two common species of twig gall-producing insects are the horned oak gall wasp (*Callirhytis cornigera*) and the gouty oak gall wasp (*C. quercuspunctata*). Galls caused by these insects can be diagnosed by their characteristic size, shape, and color.

Both the horned oak gall wasp and the gouty gall wasp attacks the twigs of pin, shingle, black, and blackjack oaks. These two woody twig galls on oak have a similar appearance, but the horned oak gall has small horns that protrude from around the circumference of the gall (Figure 6.20). One adult gall wasp emerges from each of these horns.

The life cycles of the various gall-forming wasps are highly variable. Two or more years are required for gall wasps that develop in woody twig galls to reach maturity. Many gall-forming wasps overwinter as adults in protected places away from the host tree. As the buds break in the spring and the leaves begin to expand, these small wasps start to lay their eggs in expanding plant tissue. During the egg-laying process or early larval-feeding period, specialized body glands secrete growth-regulating chemicals that interact with certain plant chemicals to produce these abnormal growths. After a brief period of cell growth, gall development stops completely. The insect is confined within "its house" and feeds only on gall tissue during the remainder of its development. Once these galls are formed, they do not continue to use nutrients from the host plant.

In general, most leaf galls on oak in the Midwest do not affect the health of the host tree. A few can cause leaves to drop prematurely, or distort them so that photosynthesis (the plant's food-making process) is interrupted. Galls (Figure 6.21) generally are aesthetically objectionable to homeowners, who often find them unattractive and fear that galls will damage the health of their oak trees.

Figure 6.21. Vein pocket gall on pin oak. Close-up of galling along the midrib and major veins. Credit: Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org.

Chemical control is seldom suggested for management of galls on oak. Cultural methods of control may be effective in reducing the impact of these insects. Some fallen leaves may harbor various life stages of gall-producing pests. Therefore, it may be useful to collect and destroy all infested leaves. Some of these pests overwinter in twigs and branches of oak. Where such woody galls are detected, prune and destroy the infested plant material when the galls are small and have just started to develop.

Once a gall begins to develop, it is almost impossible to stop or reverse its development. Unless registered insecticides can be applied when gall wasps are flying, they offer little or no effective measure of control. Lack of serious plant damage from leaf galls and the difficulty in proper timing of insecticide applications pose a strong argument against the use of insecticides to reduce galls on oak.

Sucking insects

Various insects feed on forest trees by piercing the plant tissue (leaves, flowers, fruit, woody stems, and roots) and ingest the sap through specialized mouthparts. Examples of sucking pests include: 1) aphids, 2) cicadas, 3) lace bugs, 4) plant hoppers, 5) tree hoppers, and 6) scale insects.

These pests often feed in high numbers on a host and can: 1) distort plant tissues, 2) extract significant amount of chlorophyll producing chlorotic leaves, 3) inject toxic salivary secretions, 4) deposit eggs in plant tissues, 5) create swollen areas (galls), and/or 6) vector viruses resulting in plant disease. Although high pest populations can kill branches or trees, sucking pests generally are not problematic and treatment is not warranted. In closely managed areas (Christmas trees, forestry nursery) with high pest numbers, systemic insecticides would have better control potential than contact products.

Spider mites

Spider mites can affect all Christmas tree species. They suck the juices from needles, causing bronzing or grayish discoloration of needles. Fine webbing may also be present. Injury can become severe, especially after hot, dry weather, or where an improper pesticide application has killed the natural enemies of the mites. Spider mites are tiny and difficult to see. An easy way to check for their presence is to hold a white sheet of paper beneath the suspect branch, tap the branch, and then look for "moving specks" on the paper. Spruce spider mites are dark red or purple, while twospotted spider mites are clear with two dark spots. Beneficial mites are brown and much larger than these two pest species.

Spherical eggs overwinter at the bases of needles. Hatch occurs in early summer. In favorable weather, it may take only two to five weeks to complete a life cycle. Several generations can occur in one growing season. Eggs are laid in fall and overwinter.

An effective control strategy is to scout last year's damage in early June, checking older needles near the main stem. Abundance of viable eggs, webbing, or live mites will determine if a miticide application is necessary. Selective products that control spider mites but do not harm predatory mites are available.

Emerging forest insect pests

Emerald ash borer (*Agrilus planipennis*)

This beetle from Asia was identified in July 2002 as the cause of widespread ash (*Fraxinus* spp.) tree decline and mortality in southeastern Michigan and Windsor, Ontario, Canada. Since its original detection, it has been found throughout Michigan, across much of Ohio and Indiana, and in parts of Illinois, Iowa, Kentucky, Maryland, Minnesota, Missouri, New York, Pennsylvania, Virginia, West Virginia, and Wisconsin. Infestations have also been found in more areas of Ontario and in the province of Quebec. The insect will be found in additional areas as detection surveys continue.Tens of millions of ash trees in forest, rural, and urban areas have already been killed or are heavily infested by this pest. Evidence suggests that the insect is generally established in an area for several years before it is detected.

The broad distribution of this pest in the United States and Canada is primarily due to people inadvertently transporting infested ash nursery stock, unprocessed logs, firewood, and other ash commodities. Federal and state quarantines in infested states now regulate transport of these products.

Figure 6.22. The emerald ash borer has a distinctive color (left). Larvae are white to cream-colored and have bell-shaped segments (right). Credits: (left) Howard Russell, Michigan State University, Bugwood.org; (right) David Cappaert, Michigan State University, Bugwood.org.

Adults are slender, elongate, and about ¼ to ¾ inch (7.5 to 13.5 mm) long. The body is brassy or golden green overall, with darker, metallic emerald green wing covers (Figure 6.22, left). The dorsal side of the abdomen is metallic purplish red and can be seen when the wings are spread.

Larvae reach a length of 1 to 1 ¼ inch (26 to 32 mm) and are white to cream-colored and dorsoventrally flattened. The brown head is mostly retracted and only the mouthparts are visible. The abdomen has 10 bell-shaped segments, the last of which has a pair of brown, pincerlike appendages (Figure 6.22, right).

Adult beetles begin emerging in early April in the southern Midwest. Beetle activity peaks between mid-May and early June and continues into August. Throughout their lives beetles feed on ash foliage, usually leaving small, irregularly shaped patches along the leaf margins. Leaf feeding has minimal effect on tree health, especially when compared with the damage caused by larval tunneling.

After mating, the females deposit eggs in bark crevices or under bark flaps on the trunk or branches. After hatching, the larvae chew through the bark and into the cambial region, where they feed on phloem and outer sapwood for several weeks. This feeding activity results in distinctive S-shaped galleries (Figure 6.23, left). After overwintering under the bark, the larvae pupate and the adults emerge headfirst through a D-shaped exit hole that is about ⅛ inch (3 to 4 mm) in diameter (Figure 6.23, right).

Figure 6.23. Emerald ash borer larvae produce distinctive serpentine, S-shaped galleries (left). The adult produces a D-shaped exit hole when it emerges in the spring (right). Credits: (left) Art Wagner, USDA APHIS PPQ, Bugwood.org; (right) David Cappaert, Michigan State University, Bugwood.org.

It is difficult to detect the emerald ash borer in newly infested trees because they 1) first attack the top of the trees, and 2) exhibit few, if any, external symptoms. Small jagged holes excavated by woodpeckers feeding on late-instar or prepupal larvae, along with the lighter bark color where woodpeckers have chipped off outer bark scales, may be the first sign that a tree is infested. D-shaped exit holes left by emerging adult beetles may be seen on branches or the trunk, especially on trees with smooth bark. Bark may split vertically over larval feeding galleries. When the bark is removed from infested trees, the distinct, frass-filled larval galleries that etch the outer sapwood and phloem are readily visible.

As insect densities build, foliage wilts, branches die, and the tree canopy becomes increasingly thin. Many trees appear to lose about 30 to 50 percent of the canopy after only a few years of infestation. Trees may die after three to four years of heavy infestation. Epicormic shoots may arise on the trunk or branches of the tree, often at the margin of live and dead tissue. Dense root sprouting sometimes occurs after trees die.

Emerald ash larvae have developed in branches and trunks ranging from 1 inch (2.5 cm) to 55 inches (140 cm) in diameter. Although stressed trees are initially more attractive to *A. planipennis* than healthy trees are, in many areas all or nearly all ash trees greater than about 1¼ inches (3 cm) in diameter have been attacked.

The following steps will help reduce emerald ash borer infestations and lessen their impact:

- Purchase firewood at or near the campsite.
- Do not bring firewood back home after a camping trip.
- Know the signs and symptoms of the borer. The quicker it is detected, the better chance there is to slow its spread to new areas.
- Avoid planting ash trees.

Asian longhorned beetle (*Anoplophora glabripennis*)

The Asian longhorned beetle has been discovered attacking trees in several locations in the United States (Figure 6.24). Tunneling by beetle larvae girdles tree stems and branches. Repeated attacks lead to dieback of the tree crown and, eventually, death of the tree. This pest probably traveled to the United States inside solid wood packing material from China. The beetle has been intercepted at ports and found in warehouses throughout the United States.

Figure 6.24. The Asian longhorned beetle is a serious pest that has been recently introduced into the United States and kills maple, elm, horsechestnut, and willows, just to name a few. Credit: Kenneth R. Law, USDA APHIS PPQ, Bugwood.org.

This beetle is a serious pest in China, where it kills hardwood trees in roadside plantings, shelterbelts, and plantations. In the United States the beetle prefers maple species (*Acer* spp.), including boxelder, Norway, red, silver, and sugar maples. Other preferred hosts are birches, Ohio buckeye, elms, horsechestnut, and willows. Occasional to rare hosts include ashes, European mountain ash, London planetree, mimosa, and poplars. A complete list of host trees in the United States has not been determined.

Currently, the only effective way to eliminate infestations of Asian longhorned beetle is to remove infested trees and destroy them by chipping or burning. To prevent further spread of the insect, quarantines are established to avoid transporting infested trees and branches from the area. Early detection of infestations and rapid treatment response are crucial to eradication of the beetle.

Sirex woodwasp (*Sirex noctilio*)

Sirex woodwasp has been the most common species of exotic woodwasp detected at U.S. ports of entry associated with solid wood packing materials. Recent detections of Sirex woodwasp outside of port areas in the United States have raised concerns because this insect has the potential to cause significant mortality of pines. Awareness of the symptoms and signs of a Sirex woodwasp infestation increases the chance of early detection and the rapid response needed to contain and manage this exotic forest pest.

Figure 6.25. Recent detection of the Sirex woodwasp outside of U.S. port areas has raised concern because unlike native woodwasps, this one can attack living pines. Credit: David R. Lance, USDA APHIS PPQ, Bugwood.org.

Key characteristics of the Sirex woodwasp (Figure 6.25) include the following:

- Body dark metallic blue or black; abdomen of males black at base and tail end, with middle segments orange.
- Legs reddish yellow; feet (tarsi) black; males with black hind legs.
- Antennae entirely black.

Positive identification of *S. noctilio* needs to be confirmed by an insect taxonomist. Therefore, collect and submit any suspect woodwasps to your county extension or state Department of Agriculture office.

Sirex woodwasp can attack living pines, while native woodwasps attack only dead and dying trees. At low populations, Sirex woodwasp selects suppressed, stressed, and injured trees for egg laying. Foliage of infested trees initially wilts and then changes color from dark green to light green, to yellow, and finally to red, during the three to six months following attack. Infested trees may have resin beads or dribbles at the egg laying sites, which are more common at the mid-bole level. Larval galleries are tightly packed with very fine sawdust. As adults emerge, they chew round exit holes that vary from ⅛ to ⅜ inch (3 to 9 mm) in diameter.

Sirex woodwasp has been successfully managed using biological control agents. The key agent is a parasitic nematode, *Deladenus siricidicola*, which infects Sirex woodwasp larvae, and ultimately sterilizes the adult females. These infected females emerge and lay infertile eggs that are filled with nematodes, which sustain and spread the nematode population. The nematodes effectively regulate the woodwasp population below damaging levels. As Sirex woodwasp establishes in new areas, this nematode can be easily mass-reared in the laboratory and introduced by inoculation into infested trees.

Gypsy moth (*Lymantria dispar*)

Gypsy moth will be the major threat to midwestern trees and forests when it arrives. Its impact easily could surpass any other insect threat the region will face in the next century. A gypsy moth infestation would mean many things: the loss of trees in yards, parks, and large forested areas; personal distress; lower private and commercial land values; reduced tourism; fewer wood products; lost ground cover, which causes erosion; degraded water quality; and poor ecological stability, harming other plants and wildlife.

The oak is a preferred food of the gypsy moth. Infested states have seen mortality range from 25 percent to 63 percent, with up to 84 percent mortality among preferred white oaks. Other susceptible trees are apple, alder, aspen, basswood, hawthorn, willow, and gray and river birch.

Some of the less-susceptible trees are other birches, beech, cherry, black gum, hemlock, hickory, hornbeam, larch, maple, pine, sassafras, and spruce.

Gypsy moth larvae (Figure 6.26) hatch and begin feeding on susceptible trees, and, as they grow larger and all of the leaves are eaten off susceptible trees, they attack less susceptible trees. Less susceptible evergreens, such as pines and spruce, will die soon after they are defoliated.

Figure 6.26. While not in the Midwest yet, the gypsy moth is continuing its westward march. Vigilant monitoring keeps tabs on this pest, which likes to hitchhike on camper trailers returning from infested areas in the eastern United States. Credit: Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org.

Gypsy moth is established in 16 northeastern states and the District of Columbia. This large population is slowly migrating westward and is as close as western Illinois and Wisconsin. Unfortunately, midwestern states are in immediate danger of gypsy moth infestations from hitchhiking egg masses. Female gypsy moths do not fly, and they will lay eggs on any available surface. This means that trains, vehicles, equipment, and other outdoor items coming into the Midwest could be the source of an infestation.

Our defense against this pest is early detection through the use of **pheromone** traps. A coordinated trapping program among the U.S. Department of Agriculture, Iowa Department of Agriculture and Land Stewardship, and Iowa Department of Natural Resources helps set traps. The traps are brown, green, or orange, and triangular shaped (Figure 6.27). The pheromone tricks the male gypsy moth into thinking a female is in the trap. If any gypsy moths are caught, an infestation may be in the vicinity. The area around each gypsy moth capture is surveyed for signs of an infestation, and additional traps are concentrated in that area the next year. Because people move the gypsy moth, most traps are placed where anything people transport from the Northeast could come together with midwestern trees and forests.

Figure 6.27. Delta traps for monitoring gypsy moth activity. Males are lured into the sticky trap by pheromones. Credit:Terry Price, Georgia Forestry Commission, Bugwood.org.

Commonly used forest insecticides

Some of the more common insecticides used for controlling forest insects are listed below. It is by no means a complete list. Further, any mention of a particular pesticide trade name is neither an explicit nor implicit endorsement of that commercial product. As always, READ AND UNDERSTAND THE LABEL before applying any pesticide.

Bacillus thuringiensis (commonly called Bt)

Spores produced by bacterium *Bacillus thuringiensis* have been used to control insect pests since the 1920s. Because of its specificity to caterpillars, some beetles, and mosquitoes, this bacterium is regarded as environmentally friendly, with little or no effect on humans, wildlife, pollinators, and most other beneficial insects.

Carbaryl

Carbaryl is a wide-spectrum carbamate insecticide that controls more than 100 species of insects. Carbaryl works whether it is ingested into the stomach of the pest or absorbed through direct contact.

Chlorpyrifos

Chlorpyrifos is a broad-spectrum organophosphate insecticide. Chlorpyrifos acts on pests primarily as a contact poison, with some action as a stomach poison.

Cyfluthrin

Cyfluthrin is a nonsystemic, synthetic pyrethroid insecticide that has both contact and stomach poison action. Its primary agricultural uses have been for control of chewing and sucking insects.

Diazinon

Diazinon is a nonsystemic organophosphate insecticide used to control soil and foliage insects and pests on a variety nut and tree crops.

Esfenvalerate

Esfenvalerate is a pyrethroid insecticide that is used on a wide range of insect pests to protect tree fruit and nut crops. It may be mixed with several organophosphate and carbamate pesticides.

Imidacloprid

Imidacloprid is a systemic insecticide with soil, seed, and foliar uses for the control of sucking insects.

Malathion

Malathion is a nonsystemic, wide-spectrum organophosphate insecticide. It was one of the earliest organophosphate insecticides developed (introduced in 1950). Malathion is suited for the control of sucking and chewing insects. Malathion may also be found in formulations with many other pesticides.

Phosmet

Phosmet is a non-systemic organophosphate insecticide used on a wide range of fruit crops, ornamentals, and vines for the control of sucking insects, mites, and fruit flies.

REVIEW QUESTIONS
Forest Insect Management

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. The environment applies many pressures — i.e., natural controls — that limit the abundance or distribution of pest species.
   A. True
   B. False

2. Give an example of a natural biotic control that could lessen the effects of a forest insect pest.

3. Give an example of a cultural control that could lessen the effects of a forest insect pest.

4. What symptom or sign is not associated with the emerald ash borer?
   A. Adults are a metallic green, slender, and longer than the width of a penny.
   B. Larval galleries have a serpentine S-shape pattern.
   C. Larvae are white to cream-colored and their abdomens have 10 bell-shaped segments.
   D. The adults emerging from the ash tree leave a distinctive D-shaped exits hole.

5. Name the vector of Dutch elm disease.
   A. Emerald ash borer
   B. European elm bark beetle
   C. Red oak borer
   D. Pecan weevil

6-10. Match the following forest insect pests to the appropriate description.

A. Eastern tent caterpillar
B. Fall webworm
C. Pine sawfly
D. Twolined chestnut borer
E. Carpenterworm
F. European elm bark beetle
G. *Ips* bark beetle
H. Horned oak gall

_____ 6. Small, pointed protrusions from swollen twig tissue.

_____ 7. Unsightly webs enclosing host foliage.

_____ 8. Adult beetles emerge from D-shaped holes in the bark of low-vigor oak trees from late May to mid-September.

_____ 9. Have more than five pairs of prolegs as opposed to other caterpillars that have two to five pairs.

_____ 10. Typical symptom includes the presence dime-sized, whitish or reddish brown globs of resin and boring dust called "pitch tubes."

Learning objectives

After reading this chapter, you should be able to

- List the mechanisms by which pesticides are degraded.
- Explain what is meant by the terms soil half-life and sorption coefficient and how they are used to determine the groundwater ubiquity score (GUS).
- Distinguish between the terms LD_{50} and LC_{50}.
- Explain how to find information on a pesticide's environmental chemistry and toxicity.

7
Environmental Fate and Toxicity of Commonly Used Forestry Pesticides

Environmental fate

A pesticide's fate is described by how and where it enters the environment, how long it lasts, and where it goes.

Application

Knowing how a pesticide enters the environment is the first step in determining its fate. Initial distribution is determined by the method of application, the amount, timing, frequency, and placement. Weather conditions during application can also affect initial distribution. Land form (topography), vegetation type and density, soil conditions, and the proximity of water bodies also are important. Together, these factors help determine how much pesticide is distributed to the air, soil, water, plants, and animals

Degradation

Like most other organic materials, pesticides are not stable in soil and they can be degraded. Degradation typically detoxifies a pesticide and therefore is a desirable process from the perspective of environmental safety. However, fast degradation can render a pesticide ineffective for pest control.

There are many ways that pesticides can be degraded. Most often they react with oxygen (**oxidation**) or water (**hydrolysis**). In addition, all pesticides are subject to breakdown in the presence of sunlight. In soil and sediments, microorganisms (bacteria, fungi, etc.) are primarily responsible for pesticide breakdown. Some pesticides may enter plant roots or foliage and break down through plant metabolism.

In the atmosphere, most pesticides break down rapidly by reaction with oxygen or free radicals, catalyzed by sunlight (indirect photolysis). Some pesticides break down by directly absorbing sunlight (**photolysis**). Pesticides are also susceptible to photolysis on soil and foliar surfaces. In water, breakdown is usually by hydrolysis.

The predominant degradation pathway in soil and aquatic sediments is microbial degradation, although for some pesticides chemical degradation is important. Pesticides break down in plants or animals (including microorganisms) by metabolism. Metabolic reactions are catalyzed by enzymes.

Environmental conditions can influence reaction rate and therefore how fast pesticides break down. For air, these conditions include temperature, moisture, sunlight intensity, and free radicals. For water, conditions include temperature, pH, sunlight intensity, and sediment microbial activity. For soil, conditions include temperature, soil type, organic matter, moisture, pH, aeration, and microbial activity. For plants and animals, conditions include rates of uptake, metabolism, and elimination. Metabolism may be temperature dependent.

Persistence

The **soil half-life** (DT_{50}) is a measure of the persistence of a pesticide in soil. It is determined by measuring the time it takes for the concentration of a pesticide in the soil to decrease to half of the original concentration.

Pesticides can be categorized on the basis of their half-life as nonpersistent, degrading to half the original concentration in less than 30 days; moderately persistent, degrading to half the original concentration in 30 to 100 days; or persistent, taking longer than 100 days to degrade to half the original concentration.

A "typical soil half-life" value is an approximation and may vary greatly because persistence is sensitive to the properties of the pesticide itself as well as variations in site, soil, and climate. Because half-life values can vary considerably, they are often reported as a range.

The longer the persistence, the higher will be the probability that a pesticide will move from where it was originally applied.

Pesticide movement

Pesticides can move from their initial distribution site by a number of processes. In air and water (including air and water in soil) pesticides move only short distances by diffusion. To travel longer distances pesticides move by mass transfer, usually in moving air or water.

A pesticide's tendency to move in air or water is determined by how strongly it is retained by the surfaces on which it was deposited. Pesticides may attach to soil, vegetation, or other surfaces. The strength of the attachment often determines a pesticide's availability for mass transfer.

Pesticide movement in air

Transfer from water, soil or plant surfaces to air is called volatilization. **Volatilization** occurs when pesticide surface residues change from solid or liquid to a gas. The pesticide vapors diffuse a very short distance and then are swept away with the air current.

Each pesticide has a characteristic tendency to become a gas, which is called its vapor pressure. The more tightly a pesticide is attached (adsorbed) to a soil particle or plant surface, the lower is its vapor pressure. In determining the tendency to move from water to air, for pesticides with similar vapor pressure, those with higher water solubility will have lower volatility.

Pesticide movement in ground and surface water

Water solubility and adsorption to soil are important in determining a pesticide's tendency to move through the soil profile with infiltrating water, and over the soil with runoff.

Water solubility describes the amount of pesticide that will dissolve in a known amount of water. Most reported values are determined at room temperature (20°C or 25°C). The higher the solubility value, the more soluble the pesticide. Highly soluble pesticides are more likely to be removed from the soil by runoff or by moving below the root zone with excess water.

A good rule of thumb to remember is that acid and amine salt formulations of a pesticide are more soluble in water than ester formulations. Esters are better able to penetrate waxy leaf surfaces than amines, while amines are more easily moved into the soil by rainfall for root uptake (an important characteristic in certain brush-control applications).

The **sorption coefficient** (K_{OC}) describes the tendency of a pesticide to adsorb (bind) to soil particles. The higher a pesticide's K_{OC}, the more tightly it is bound to the soil particle. Pesticides adsorbed to soil will not be lost to infiltration or runoff. However, if runoff results in soil erosion, pesticides adsorbed to surface soil will move with the displaced soil.

Another consequence of a pesticide's high K_{OC} could be increased persistence because the pesticide may be protected from degradation. Typically, the adsorption of a pesticide in soil decreases as its water solubility increases simply because water-soluble pesticides tend to stay in the soil solution. Pesticide adsorption is also a function of soil features; increasing as clay and organic matter content increase.

The importance of adsorption and persistence can be illustrated through the **groundwater ubiquity score** (GUS) index. GUS is calculated using the following simple equation:

$$GUS = log(DT_{50}) \times (4 - log[K_{OC}])$$

This equation incorporates only the properties of pesticides, and no information from the soil. Therefore, GUS indicates the intrinsic mobility of pesticides and their *potential* to move toward groundwater.

Movement ratings range from extremely low to very high. Pesticides with a GUS less than 0.1 are considered to have an extremely low potential to move toward groundwater. Values of 1.0 to 2.0 are low, 2.0 to 3.0 are moderate, 3.0 to 4.0 are high, and values greater than 4.0 have a very high potential to move toward groundwater.

Table 1 shows the soil half-life range, sorption coefficient, and calculated groundwater ubiquity score of the more commonly used forestry pesticides. Remember that the soil half-life value (DT_{50}) represents a typical value from the scientific literature and that it will vary with differences in soil texture and chemical properties (e.g., pH). Similarly, the K_{OC} value represents the adsorption of the pesticide on the soil normalized by the organic matter to provide a single representation of a particular pesticide for all soils. As a result, these numbers are useful for comparing relative differences among pesticides and should not be construed as absolute values.

There are three things to note in Table 1. First, K_{OC} values greater than 10,000 will result in a negative GUS because of the equation $GUS = log(DT_{50}) \times (4 - log[K_{OC}])$. Second, the formulation of the pesticide can affect its GUS. For example, the water-soluble amine salt form of triclopyr, with its low K_{OC}, results in high GUS; while the petroleum-soluble ester form results in a low GUS. Lastly, some pesticides do not fit into nice, neat environmental fate parameters. For example, Bordeaux fungicide is a mixture of copper sulfate and lime. As a metal, it is highly persistent, but because of copper's high binding capacity, its leaching potential is low in all but sandy soils.

Table 1. Soil half-life, sorption coefficient, and GUS values for commonly used forestry pesticides.

Pesticide common name	Average soil half-life, DT_{50} (days)	Soil sorption coefficient (K_{OC})	Groundwater ubiquity score (GUS)	Pesticide movement rating (based on GUS)
Herbicides				
2,4-D	10	20	2.7	Moderate
clopyralid	40	6	5.2	Very high
dicamba	14	2	4.2	Very high
fluazifop-p-butyl	7	5,700	0.2	Very low
fosamine	14	10	2.5	Moderate
glyphosate	47	24,000	-0.6	Extremely low
hexazinone	90	54	4.4	Very high
imazapic	130	206	3.6	High
imazapyr	90	100	3.9	High
metsulfuron-methyl	7	180	1.5	Low
oryzalin	20	600	1.6	Low
oxyfluorfen	35	100,000	-1.5	Extremely low
pendimethalin	90	5,000	0.6	Very low
picloram	90	16	5.5	Very high
sethoxydim	5	100	1.4	Low
simazine	60	130	3.4	High
sulfometuron	20	78	2.7	Moderate
triclopyr (amine)	46	20	4.5	Very high
triclopyr (ester)	46	780	1.8	Low
trifluralin	60	8,000	0.2	Very low
Fungicides				
benomyl	67	1,900	1.3	Low
Bordeaux mixture[1]	not available	not available	not available	not available
captafol	5	not available	not available	not available
captan	3	200	0.8	Very low
chlorothalonil	30	1,380	1.3	Low
iprodione	45	426	2.3	Moderate
propiconazole	100	229	4.7	Very high
thiophanate methyl	45	225	2.7	Moderate
Insecticides				
acephate	4	0.48	2.1	Moderate
Bacillus thuringiensis	not available	not available	not available	not available
bifenthrin	7	1,000,000	-1.7	Extremely low
carbaryl	10	300	1.5	Low
chlorpyrifos	30	6,070	0.3	Very low
cyfluthrin	2	5.62	1.0	Low
diazinon	40	1,000	1.6	Low
esfenvalerate	45	5,300	0.5	Very low
imidacloprid	520	200	4.6	Very high
malathion	1	1,800	0.0	Extremely low
permethrin	34	100,000	-1.5	Extremely low
phosmet	12	820	1.2	Low

[1] Because copper sulfate is highly water soluble, it is considered one of the more mobile metals in soils. However, because of its binding capacity, its leaching potential is low in all but sandy soils.

Note: The parameter values for DT_{50} and K_{OC} rely heavily on the SCS/ARS/CES Pesticide Properties Database for Environmental Decision Making. The values for the pesticides that were not listed in the SCS/ARS/CES database were researched by MU Forestry Extension personnel.

Toxicity

Studies on mammalian species (usually rats) are carried out to determine the potential toxicity of substances to humans. The toxicity of a pesticide is expressed through the terms "oral" and "dermal" LD_{50}, short for "lethal dose, 50%" or "median lethal dose." **LD_{50}** is the dosage of poison that kills 50 percent of the test animals with a single application of the "pure" pesticide for a given weight of animal (mg/kg of weight). The lower the LD_{50} value, the more toxic the material. Oral LD_{50} is the measure of the toxicity of pure pesticide when administered internally to test animals. Dermal LD_{50} is the measure of the toxicity of pure pesticide when applied to the skin of test animals.

Avian and aquatic species are studied primarily to assess the environmental impact on the ecosystem. Mallard ducks and bobwhite quail are the most frequently used avian species for toxicological studies; trout (brown and rainbow) and bluegill are among the more often cited aquatic species.

Avian toxicity ratings may be based on either a single-dose oral LD_{50}, as in mammalian studies, or a dietary LC_{50}. LC stands for "lethal concentration." In the dietary studies, a series of concentrations are incorporated into standard feed and fed to the subjects over a period of days. Fish toxicity ratings are usually stated in 96-hour LC_{50} values.

Table 2 shows the relative toxicities of the more commonly used forestry pesticides. Values were obtained from pesticide information profiles available on the Extension Toxicology Network (EXTOXNET). Remember that these toxicological data represent a typical value from the scientific literature and they will vary depending on the specific formulation of the pesticide evaluated. You should always refer to the pesticide's Material Safety Data Sheet (MSDS) for the latest information.

Where to find environmental fate and toxicological information

There are many ways to obtain pesticide environmental fate and toxicological information both in print and electronically. Here are a few of the more common sources used in the forestry community.

Material Safety Data Sheet

First and foremost, the Material Safety Data Sheet (MSDS) is your best source of up-to-date environmental and toxicological information. Chemical properties, such as vapor pressure and water solubility, are given in Section 9; toxicological information in Section 11; and ecological information in Section 12. MSDS should accompany the delivery of each pesticide purchased; ask your supplier for the MSDS if it is initially not provided. MSDS documents are also available online.

Commercial Web sites

Another useful source of information can be found online at the Crop Data Management Systems' (CDMS) Web site (*www.cdms.net/LabelsMsds/LMDefault.aspx*). In addition to a pesticide's MSDS, you will also be able to download current product label information and any restrictions or special use permits that may be in place.

Extension Web sites

The EXtension TOXicology NETwork (EXTOXNET) is an effort of University of California, Davis, Oregon State University, Michigan State University, Cornell University, and the University of Idaho. EXTOXNET seeks to stimulate dialog on toxicology issues, develop and make available information relevant to extension toxicology, and facilitate the exchange of toxicology-related information in electronic form, accessible to all with access to the Internet. The EXTOXNET InfoBase is accessible online at *extoxnet.orst.edu*.

Table 2. Relative toxicities of the more commonly used forestry pesticides. Values were obtained from pesticide information profiles available on the Extension Toxicological Network (EXTOXNET).

Pesticide common name	Mammalian toxicity			Avian toxicity		Aquatic toxicity		Risk to bees
	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)		5- to 8-day dietary LC_{50} (mg/L)		96-hour LC_{50} (mg/L)		
	Rat	Rabbit	Rat	Mallard duck	Bobwhite quail	Bluegill	Trout	
Herbicides								
2,4-D	375-666	1,400		1,000	668		1 – 100(H-VH)	high
clopyralid	>4,300	>5,000		>2,000	>2,000	125	104(ML)	no
dicamba	757-1,707	>2,000		>10,000	>10,000	135	135(ML)	no
fluazifop-p-butyl	>4,000	>2,400		>4,300	>4,600	0.53	1.37 (H)	low
fosamine	>5,000	>2,000		>5,000	>5,000	>650	>1,000 (VL)	no
glyphosate	5,600	>5,000		>4,500	>4,500	120	86 (ML)	no
hexazinone	1,690	>6,000			2,258	370	320(L)	no
imazapic	>5,000	>5,000			>2,000	>100	>100(M)	no
imazapyr	>5,000	>2,000		>2,100	>2,100	>100	>100(M)	no
metsulfuron-methyl	>5,000	>2,000		>5,600	>5,600	>150	>150(M)	low
oryzalin	>5,000	>2,000		>5,000	>5,000	2.85	3.26(H)	no
oxyfluorfen	>5,000	>5,000		>4,000	>2,200	0.2	0.4 (H)	no
pendimethalin	>5,000	>2,000		>10,000	>3,000	0.2	0.14 (H)	no
picloram	>5,000	>4,000		>2,500	>2,500	14.5	19.3(MH)	no
sethoxydim	>2,500	>5,000		>2,500	>5,000	100	32(MH)	no
simazine	>5,000	>10,000		>4,600	>4,600	100	>100 (M)	no
sulfometuron	>5,000	>8,000		>5,000	>5,000	>12.5	>12.5(MH)	no
triclopyr (amine)	>1,500	>2,000		>2,000		240	450(L)	no
triclopyr (ester)	>1,000	>2,000			750	<1.0	<1.0(H)	no
trifuralin	>10,000	>2,000		>5,000	>2,000	0.02	0.05(H)	no
Fungicides								
benomyl	>10,000	>3,400	>10,000	>10,000	>10,000		0.05-14 (H)	low
Bordeaux mixture	not available	not available		>2,000	not available	not available	not available	moderate
captafol	6,780	15,400		>100,000	>5,600	0.15	0.5 (H)	no
captan	>8,400	>10,000		>5,000	>2,000	0.07	0.06 (H)	no
chlorothalonil	>10,000	10,000	10,000	5,000		0.3	0.25 (H)	no
iprodione	3,500	2,500	1,000		930	2.25	6.7 (MH)	no
propiconazole	1,517	>4,000		>2,510	2,825	1.3	0.9 (H)	not available
thiophanate methyl	>5,000	>2,000			>5,000	38.3	11.4 (MH)	no
Insecticides								
acephate	866	2,000		>5,000	1,280	>1,000	>1,000 (VL)	high
Bacillus thuringiensis	>13,000	>7,200		>10,000	>10,000	>1,000	>560 (L)	no
bifenthrin	54	>2,000		1,280	4,450	0.00035	0.00015 (VH)	high
carbaryl	250-850	>2,000		>2,000	2,230	10	1.3 (H)	high
chlorpyrifos	95-270	1,000-2,000	>2,000	112	108	0.01	0.098 (VH)	high
cyfluthrin	869-1,271		>5,000	>5,000	>2,000	0.0015	0.00068 (VH)	high
diazinon	300-400	3,600		2.75-40.8			2.6-3.2 (H)	high
esfenvalerate	458	2,500		>5,500	>10,000	0.0003	0.0003 (VH)	high
imidacloprid	450		>5,000	>4,797	1,536		211 (ML)	high
malathion	>10,000		>4,000		>3,000		0.1 (H)	high
permethrin	430-4,000	>2,000		>9,900	>15,500	0.0078	0.0078 (VH)	high
phosmet	160	3,160		>2,000	501	1.0	1.0 (H)	high

REVIEW QUESTIONS
Environmental Fate and Toxicity of Commony Used Forestry Pesticides

Write the answers to the following questions and then check your answers with those in the back of the manual (Appendix A).

1. What three things determine a pesticide's environmental fate?

2. The predominant degradation pathway in soil and aquatic sediments is
   A. Oxidation
   B. Microbial
   C. Hydrolysis
   D. Photolysis

3. Soil half-life, DT_{50}, measures ____________ of a pesticide in soil.
   A. Solubility
   B. Adsorption
   C. Persistence
   D. Toxicity

4. A pesticide's soil half-life can be affected by:
   A. Its formulation
   B. Soil structure
   C. Climate
   D. All of the above

5. The higher the water solubility value, the more soluble the pesticide.
   A. True
   B. False

6. The adsorption of a pesticide in soil ________ as its solubility increases.
   A. Decreases
   B. Increases
   C. Remains constant

7. The groundwater ubiquity score (GUS) is a function of:
   A. Vapor pressure and solubility
   B. Solubility and soil half-life
   C. Solubility and sorption coefficient
   D. Soil half-life and sorption coefficient

8. A pesticide with a low GUS will have a _____ potential to move toward groundwater.
   A. Low
   B. High

9. What is the LD_{50} of a pesticide?

10. The longer the persistence, the better the possibility for a pesticide to move from where it was applied.
    A. True
    B. False

Glossary

Abiotic. Not associated with or derived from living organisms. Abiotic factors in an environment include such conditions as sunlight, temperature, wind patterns, and precipitation.

Acervuli. Fruiting bodies produced by fungi in a saucer-shaped, depressed structure consisting of a layer of stalklike filaments that bear at their tips nonsexual spores in a cushionlike mass.

Active ingredient. The chemical in a pesticide formulation primarily responsible for its activity against pests. It is identified on the ingredients statement of the product label.

Biotic. Associated with or derived from living organisms.

Brush. Woody plants, such as brambles, shrubs, and vines that are less than 10 feet in height at maturity.

Calibration. Measurement of application equipment's delivery rate.

Conidia. Fungal spores formed by being pinched off or cut off from the tip of a specialized, erect, aerial filament.

Contact fungicide. A pesticide that kills when it touches or is touched by a pest.

Contact herbicide. A herbicide that causes localized injury to plant tissue wherever the plant and the herbicide come into contact.

Crop trees. Trees that produce, or have the potential to produce, desired benefits for the landowner.

Disease triangle. The combination of three factors necessary for disease development: a susceptible host, an infective pathogen, and a favorable environment.

Flashback. A herbicide that has been applied to target trees can move to nontarget trees by a process called flashback. This movement takes place either directly through root grafts or indirectly where excessively applied amounts of the chemical move into the soil and are absorbed by the roots of nontarget trees growing in the contaminated soil.

Groundwater ubiquity score (GUS). A calculated value that indicates the intrinsic mobility of pesticides and their potential to move toward groundwater.
$GUS = \log (DT_{50}) \times (4 - \log [K_{oc}])$

Herbaceous weed. A vascular plant that does not develop woody tissue above ground.

Heartwood. The central cylinder of nonfunctional xylem in a woody stem.

Hydrolysis. Decomposition of a chemical by reaction with water.

Inoculum. The pathogen or its parts that can cause disease.

Instar. The stage of an insect between molts.

Larva. An immature stage between egg and pupa of an insect with complete metamorphosis. Caterpillars, maggots, and grubs are examples.

LD_{50}. The dosage of poison that kills 50 percent of the test animals with a single application of the "pure" pesticide for a given weight of animal (mg/kg of weight).

Necrotic. Refers to nonliving cells (darkened in coloration) in living plant tissue.

Nematode. A nonsegmented roundworm that can be parasitic on plants or animals or free living in the soil or water.

Oxidation. The chemical combination of a substance with oxygen.

Pathogens. Microorganisms that cause disease.

Pheromone. A biochemical substance produced by insects to communicate with the same species through the sense of smell.

Phloem. Plant tissue that functions to translocate solutes within the plant.

Photolysis. Chemical decomposition induced by light.

Photosynthesis. The biological production of organic substances, chiefly sugars, occurring in green plant cells in the presence of light.

Postemergence herbicide. A herbicide applied after emergence of a specified weed or crop.

Preemergence herbicide. A herbicide applied to the soil before emergence of a specified weed or crop.

Prolegs. Fleshy abdominal legs of certain insect larvae.

Pupa. A resting stage of an insect; the stage between the larva and the adult in insects with complete metamorphosis.

Pycnidia. Flasklike, fungus fruiting bodies containing nonsexual spores.

Residual herbicide. A herbicide that persists in the soil and injures or kills plants for an extended period of time (several weeks to several months, depending on the herbicide).

Root graft. Roots of the same or closely related tree species growing near each other often cross each other in the soil and eventually fuse (become grafted) to each other.

Sapwood. The physiologically active zone of wood contiguous to cambium.

Scouting. Periodic inspections of natural forests or plantations for pests.

Sign. Physical evidence of a disease or insect attack from direct observation of the causative agent or its parts. Examples include fungal mats, spores, nematodes, cast skins, frass, or actual insects.

Soil half-life (DT_{50}). The measure of a pesticide's persistence in soil. It is determined by measuring the time it takes for the concentration of a pesticide in the soil to decrease to half of the original concentration.

Soil incorporation. The use of tillage equipment to mix a pesticide with the soil.

Soil injection. Application of a pesticide beneath the soil surface.

Sorption coefficient (K_{OC}). The measure of a pesticide's ability to adsorb (bind) to soil particles.

Symptom. The changes in the appearance or growth of a host in response to some causal agent. Examples include chlorotic leaves, cankers, bark splits, exit holes, galls, rot, or stunted growth.

Systemic fungicide. A fungicide that is absorbed into plant tissue. May be locally systemic or move within the plant. May have protective or curative (after-infection) activity.

Systemic herbicide. A herbicide that is absorbed and moved to other plant tissue.

Threshold level. The point at which the pest or its damage becomes unacceptable.

Translocation. The movement of dissolved substances within a plant, usually from the site of production to the center of growth or storage areas.

Transpiration. The loss of water from aerial portions of plants by evaporation and diffusion of water vapor into the air.

Vertebrates. Animals that have a backbone or spinal column.

Volatilization. Transfer of pesticide particles to change from solid or liquid to a gas.

Water solubility. The amount of pesticide that will dissolve in a known amount of water.

Weeds. Plants that grow out of place.

Xylem. Plant tissue that functions for the conduction of water.

Appendix A

Answers to Review Questions

Chapter 1: Worker Protection Standard

1. B. False. WPS applies to both handlers of pesticides and persons working in areas where pesticides have been applied

2. B. False. General-use pesticides are covered by the WPS.

3. *How to Comply with the Worker Protection Standard for Agricultural Pesticides.*

4. C. Even if they do not handle, load, mix, or apply the pesticide, if they enter a greenhouse or other enclosed area after application and before the inhalation exposure level listed on the product label has been reached or one of the WPS ventilation criteria have been met, then they are considered a handler.

5. (1) EPA WPS safety poster, (2) name, address, and telephone number of the nearest medical facility, and (3) specific information about each pesticide application from the time the application begins until 30 days after the restricted-entry interval (REI)

6. If the workplace is a forest, you may display the information near the forest. It must be in a location where workers and handlers can easily see and read it and where they are likely to gather or pass by. For example, you might display the information with the decontamination supplies or at the equipment storage shed.

7. B. WPS worker training materials cannot be used to train handlers. Training materials specifically designed for handlers must be used to train handlers.

8. A. Decontamination supplies must be located within ¼ mile of all workers and handlers.

9. If the workplace is a forest and the tasks are performed more than ¼ mile from the nearest point reachable by vehicles, the decontamination supplies may be at the access point.

10. In case of a suspected unsafe exposure to a pesticide, the following information should be provided to the victim and medical personnel: (1) product name, EPA registration number, and active ingredient, (2) all first aid and medical information from the label, (3) description of how the pesticide was used, and (4) information about the victim's exposure.

Chapter 2: Principles of Pest Management

1. Many factors — such as crop value, pest biology, degree of damage, and possible effects on the environment — must be considered and prioritized before choosing a control strategy.

2. C. If you search for a single pest during an inspection, you may miss an emerging problem.

3. B. Identify the organism.

4. Collect a sample of the pest and look at it under magnification. Check it against a book with pictures and descriptions. If you are still uncertain, submit the sample to your local extension center for identification.

5. The threshold level is the point at which the pest or its damage becomes unacceptable.

6. D. Cultural management.

7. A. Biological management.

8. B. False. Biological control organisms are also sensitive to pesticides.

9. D. All of the above.

10. To determine if the strategies were effective.

Chapter 3: Application Methods and Equipment

1. D. Soil incorporation

2. Nature and habits of the target pest, the site, the pesticide, available equipment, cost, efficiency.

3. B. In a ring containing the sapwood and the bark.

4. B. False. The only way to ensure no sprouting is to apply a herbicide.

5. "Thin lining" involves applying a horizontal thin line of undiluted herbicide completely around the target tree's trunk, usually at breast height (4.5 feet or 1.4 m above the ground).

6. C. Increase spray drift.

7. A. Backpack sprayer.

8. B. False. Tree injectors treat one tree at a time.

9. B. Soil application.

10. A. True. Microinjectors can be both passive and active application devices.

Chapter 4: Forest Weed Management

1. A. Cultural control

2. B. Mechanical control

3. C. Chemical control

4. A. Cultural control

5. B. Mechanical control

6. Herbicide selectivity refers to choosing a product to meet the specific type of weed(s) you must control. Some herbicides only control grasses, others only broadleaved plants, and others are nonselective, meaning they will kill all vegetation they contact.

7. A. It continues to kill weeds as they germinate.

8. *Application rate* —the amount of herbicide required per acre to obtain effective control. Too little will result in lack of control; too much will result in environmental or plant damage.

   Equipment calibration — equipment must be properly calibrated to ensure the proper application rate.

   Application method — must be considered to ensure uniform coverage.

   Targeted vegetation —because of differences in anatomy and physiology, some plants are more affected by herbicides than others.

   Soil-site characteristics — soils with high clay or organic matter contents require a heavier application rate of residual herbicide than coarse-textured sands or gravelly soils.

   Weather conditions — cool and cloudy weather following application of foliar herbicides will reduce their effectiveness. Lack of rain following soil-application of herbicides may allow weeds to grow and germinate before the herbicide moves into the soil solution. Heavy rain, however, may leach the herbicide from the upper soil or wash it to low-lying areas. In both cases the herbicide is less effective and may damage nontarget plants.

9. False. Annual weeds and grasses are easily controlled with preemergence products; perennial grasses and weeds, particularly those with deep root systems, are more difficult to control chemically.

10. B. Herbicides are least effective in the spring because sap flow tends to prevent the herbicide from entering the tree's vascular system.

Chapter 5: Forest Disease Management

1. The plant disease triangle is composed of (1) a susceptible host, (2) an infective pathogen, and (3) a favorable environment.

2. B. False. A plant that is resistant to one particular plant pathogen does not mean it is resistant to all pathogens.

3. Symptom: a visible response of the host to a causal agent over time.
   Sign: a physical structure produced by the causal agent of the disease.

4. A. Fungi

5. B. Before infection occurs.

6. C. Small black fruiting structure bearing conidia.

7. B. Wood decay.

8. D. Red and black oaks are more susceptible to the fungus causing oak wilt than white and bur oaks.

9. C. Planting of fast-growing, nonnative seedlings is not recommended because they might be susceptible to local pathogens.

10. Diagnostic symptoms include wilting, yellowing, and then browning of leaves, and drying up of foliage on affected portions of the crown. Diseased branches develop brown streaking in the wood that is evident when the bark is peeled back. Vectors breed only in weakened, dying, or dead elms with tight bark.

Chapter 6: Forest Insect Management

1. A. True.

2. Any one of the following:

   - Insectivorous vertebrates such as rodents, skunks, and birds.
   - Predaceous insects such as ladybird beetles, ground beetles, ants, and lacewings.
   - Parasitic wasps and flies.
   - Insect diseases caused by microorganisms such as viruses, bacteria, and fungi.

3. Any one of the following:

    - Proper site selection that ensure vigorous tree growth
    - Proper species selection
    - Proper thinning
    - Adjustment of harvest age
    - Sanitation removal of dead and dying trees

4. A. Adults are metallic green and slender, but they are smaller than the width of a penny.

5. B. The European elm bark beetle is the primary vector of Dutch elm disease.

6. H. Horned oak gall

7. B. Fall webworm; possibly A. Eastern tent caterpillar with large populations.

8. D. Twolined chestnut borer

9. C. Pine sawfly

10. G. *Ips* bark beetle

Chapter 7: Environmental Fate and Toxicity of Commonly Used Forestry Pesticides

1. (1) How and where it enters the environment, (2) how long it lasts, and (3) where it goes.

2. B. Microbial

3. C. Persistence

4. D. All of the above

5. A. True

6. A. Decreases

7. D. GUS is a function of the pesticide's soil half-life and sorption coefficient.

8. A. Low

9. The LD_{50} is the dosage of a poison that kills 50 percent of the test animals with a single application of the "pure" pesticide for a given weight of the named animal.

10. A. True

Appendix B

References and Resources

References

Johnson, W.T., and H.H. Lyon. 1991. *Insects That Feed on Trees and Shrubs.* 2nd edition. Cornell University Press, Ithaca, NY

Sinclair, W., and H.H. Lyon. 2005. *Diseases of Trees and Shrubs.* 2nd edition. Cornell University Press, Ithaca, NY

Wax, L.M., R.S. Fawcett, and D. Isley. 1981. *Weeds of the North Central States.* North Central Regional Research Publication No. 281 (Bulletin 772) University of Illinois at Urbana-Champaign. Available for purchase at: ***https://www.extension.iastate.edu/store/ItemDetail.aspx?ProductID=3053&SeriesCode=&CategoryID=&Keyword=CR%20281***

Web site resources

Forest Insect and Disease Leaflets, U.S. Department of Agriculture, Forest Service
http://www.fs.fed.us/r6/nr/fid/wo-fidls/

Forest Pests
http://www.forestpests.org/

Identification of Common Trees of Iowa, Iowa State University Extension Forestry
http://www.extension.iastate.edu/Pages/tree/

Iowa Department of Agriculture and Land Stewardship, Pesticide Bureau
http://www.iowaagriculture.gov/pesticides.asp

Iowa Tree Pests
http://www.iowatreepests.com/

Pest Management and the Environment
http://www.extension.iastate.edu/pme/

Plant and Insect Diagnostic Clinic
http://www.plantpath.iastate.edu/pdc/

U.S. Department of Agriculture Forest Service
http://www.fs.fed.us/

Plant and Animal Health Inspection Service
http://www.aphis.usda.gov/

Cover Images

Oak rough bulletgall on bur oak
Whitney Cranshaw, Colorado State University, *Bugwood.org*

Bur oak bark
Paul Wray, Iowa State University, *Bugwood.org*

Oak wilt leaf symptoms
D.W. French, University of Minnesota, *Bugwood.org*

Garlic mustard in flower
David Cappaert, Michigan State University, *Bugwood.org*

Dutch elm disease symptoms
Joseph O'Brien, USDA Forest Service, *Bugwood.org*

Twolined chestnut borer larvae
David Cappaert, Michigan State University, *Bugwood.org*

Young maple stand
Joseph O'Brien, USDA Forest Service, *Bugwood.org*

Pine wilt nematode bluestain fungi
L.D. Dwinell, USDA Forest Service, *Bugwood.org*

Pine engraver, *Ips pini*
Pennsylvania Department of Conservation and Natural Resources – Natural Resources, *Bugwood.org*

Austrian pine foliage
Howard F. Schwartz, Colorado State University, *Bugwood.org*

Walnut caterpillars on black walnut
Lacy L. Hyche, Auburn University, *Bugwood.org*

Shrubby lespedeza
David J. Moorhead, University of Georgia, *Bugwood.org*

Eutypella canker on sugar maple
Joseph O'Brien, USDA Forest Service, *Bugwood.org*

Emergency Telephone Numbers

Regional Poison Center **1-800-222-1222**

For pesticide emergencies, state poison centers provide service that is free of charge to the public and is available 24 hours a day, seven days a week

Environmental Emergency Response

For pesticide spill emergencies

Iowa – Iowa Department of Natural Resources.............................. (515) 281-8694

Kansas – Department of Public Health Protection,
Bureau of Environmental Remediation.. (785) 296-1503

Missouri – Department of Natural Resources................................ (573) 634-2436

Nebraska – Department of Environmental Quality........................... (402) 471-2166

National Pesticide Safety Team Network (Chemtrec) **1-800-424-9300**

The National Agricultural Chemicals Association has a telephone network. This network can tell the applicator the correct contamination procedures to use to send a local safety team to clean up the soil. An applicator can call the network toll-free at any time.

National Pesticide Information Center........................ **1-800-858-PEST**

Call the NPIC network toll-free

U.S. Environmental Protection Agency (EPA).................... **913-281-0991**

All major pesticide spills must by law be reported immediately to the U.S. Environmental Protection Agency, Region VII Office, 901 N. 5th Street, Kansas City, KS 66101. The following information should be reported:

1. Name, address, and telephone number of the person reporting
2. Exact location of spill
3. Name of company involved and location. Specific pesticide spilled
4. Estimated quantity of pesticide spilled
5. Source of spill
6. Cause of spill
7. Name of body of water involved, or nearest body of water to the spill area
8. Action taken for containment and clean-up