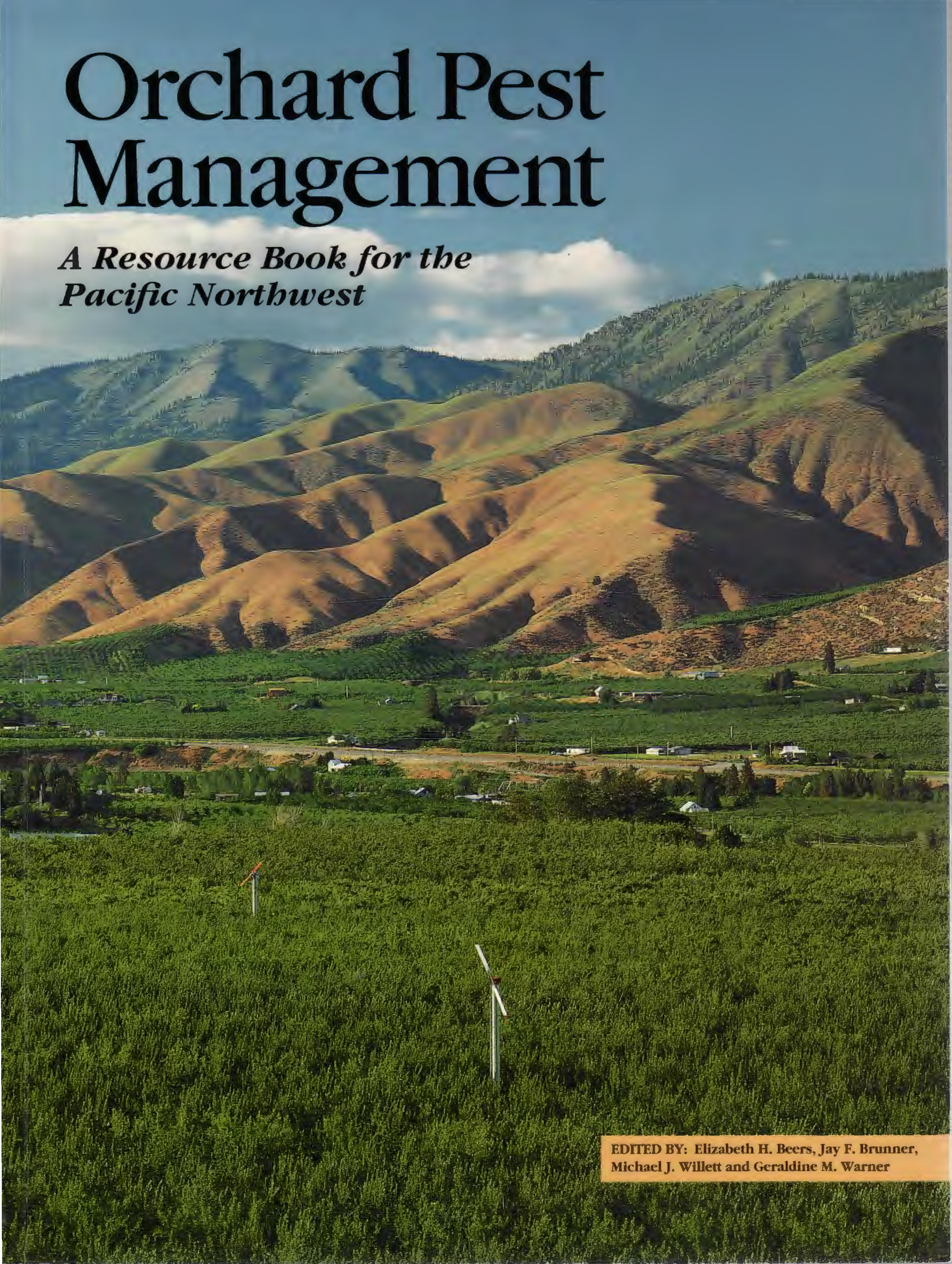
Orchard Pest Management

A Resource Book for the Pacific Northwest



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This book is dedicated, with great affection and respect, to

Dr. Stanley C. Hoyt
Dr. Everett C. Burts
and
Dr. Peter H. Westigard

whose lives and work in tree fruit pest management
have set the standard for generations to come

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Contributors

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Beers, Elizabeth H.	White apple leafhopper, rose leafhopper, campylomma, European red mite, twospotted spider mite, McDaniel spider mite, yellow spider mite, apple rust mite, prunus rust mites, *Anagrus* sp., *Aphelopus typhlocyba* woolly apple aphid, green apple aphid, *Aphelinus mali*, tenlined June beetle, cherry bark tortrix, western tentiform leafminer, stunk bugs, dock sawfly, pearleaf blister mite, IPM overview, insect growth & development
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Brunner, Jay F.	Mating disruption, codling moth, oriental fruit moth, eyespotted budmoth, leafrollers, apple maggot, western tentiform leafminer, redhumped caterpillar, yellownecked caterpillar, peachtree borer, peach twig borer, fall webworm, tent caterpillars, parasitic wasps, IPM overview, degree day models, sampling.
Burgett, Michael	Honeybee
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Dennehy, Timothy J.	Pesticide resistance management
Elsner, Erwin A.	White apple leafhopper, rose leafhopper, *Anagrus sp., Aphelopus typhlocyba*
Gut, Larry L.	IPM overview, predatory bugs, predatory flies, lacewings.
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Howell, J. Franklin	Green fruitworms and cutworms
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Foreword

Although a book of this type has been on the agenda for many years, its realization was given impetus by the increased concern over the environmental and human health effects of pesticides. When CBS aired the *60 Minutes* episode about the plant growth regulator Alar, the tree fruit industry was surprised and dismayed by the onslaught of negative publicity. Not since Rachel Carson's *Silent Spring* was published in 1962 has public consciousness of the potential undesirable side effects of pesticides been so high. Although not so widely publicized, the response of the Pacific Northwest tree fruit industry has been laudatory: it has redoubled its ongoing efforts to develop and implement Integrated Pest Management (IPM) programs. This book represents one component of that effort.

The purpose of this book is to provide both a reference for practical use, and to educate and inform the user. Our intent is that the reader gain a broader appreciation of entomology in general, and tree fruit IPM in particular. To this end, we have made it as comprehensive as possible. Some of the pests which are currently rare in commercial orchards may resurface as we move towards more selective IPM programs. Happily, many of the natural enemies we seldom see may become commonplace under these programs.

A person desiring specific information can readily locate it, because of indexing, standardized format, and the variety of photographs and summary graphics. Some redundancy occurs in different sections so that the reader can find the desired information, without referring to multiple sections. This is especially apparent in sections where several pests have a similar life cycle (e.g., mites), or between biological control and management sections under the pest, and information given under its predators or parasites. Where appropriate, related information has been cross-referenced in the text. Occasionally, the authors have referred to what is *not* known, but may be relevant to IPM. Delimiting the scope of our knowledge is in some cases just as enlightening as providing the information that we have at our disposal.

This book was written in such a way that it should be useful to a broad cross-section of readers. Some of the more detailed information on biology and management will be of interest to only a small proportion of the readers, while the photographs, life history charts, and general information should be universally useful.

The use of specific pesticide names throughout most of the book has been deliberately avoided. The 1988 amendments to FIFRA (Federal Insecticide, Fungicide and Rodenticide Act) have accelerated the loss of materials available to the industry, while new registrations have slowed to a trickle. Any specific recommendations on a pesticide may soon be outdated. This book is intended to complement, not replace, the annually revised pest control guides published by the various fruit-growing regions. These guides contain specific recommendations for pesticide use, and even their annual revision format cannot entirely keep pace with the changes in labeled uses. The information on basic biology, identification, life history, and principles of management hopefully will stand the test of time.

This book could not have been completed without efforts of the research and extension personnel from throughout the Pacific Northwest and the nation, whose names appear in the list of contributors. Each section was written by a person with expertise in that field, with supporting information and review by colleagues. These sections represent the current state of knowledge, and many lifetimes of research and field experience. Each person, in his or her turn, has built on the information gleaned by predecessors, and thus, slowly and steadily, we build our base of knowledge.

Elizabeth H. Beers

Wenatchee, Washington

August, 1993

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Part II: Direct pests

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Integrated Pest Management Overview

What is IPM?

Integrated pest management (IPM) is a philosophy of pest control founded on the principles of ecology. In practice, it involves using several control tactics based on a knowledge of the crop, pests and associated natural enemies to avoid crop loss and minimize harmful effects on the environment. Implementing IPM requires an understanding not only of insect and mite biology and ecology, but of the entire orchard system. This includes the plants and animals that comprise the orchard community, as well as consideration of contributions from the surrounding habitat. The orchard system also takes into account financial, physical and human aspects of orchard operations.

IPM requires a more tolerant approach to pest control than traditional insecticide-based programs. Eliminating all insects and mites from the orchard is not the objective of IPM. Natural enemies are to be conserved as much as possible and some damage, especially to foliage, is tolerated. For example, pests that attack the foliage can usually be allowed to build to levels higher than those that attack the fruit.

There are both positive and negative impacts associated with the reduced insecticide use that usually accompanies the adoption of an IPM approach. Benefits of IPM include greater survival of natural enemies, slower development of resistance, less pest resurgence, fewer outbreaks of secondary pests, less negative impact on the environment, and greater worker safety. On the negative side, potential pests that are coincidentally controlled by insecticides used to control key pests may be released from all but natural controls. Natural

An IPM program involves:

- Identifying pests, which requires knowledge of their biology and the damage they inflict.
- Identifying the natural enemies of pests.
- Understanding the biological and environmental factors that affect the abundance and distribution of pests and natural enemies.
- Monitoring both pests and natural enemies to determine potential for damage and biological control.
- Tolerating higher levels of pests, particularly foliage feeders.
- Using a treatment threshold to decide when control is needed.
- Knowing the efficacy of available control tactics, as well as their potential impact on non-target pests and natural enemies.
- Building flexibility into the control program to allow for variations from block to block or year to year.
- Follow-up to see how well control measures work and if further action is needed.

controls will be effective for some. For others, however, the release from insecticidal control will result in population levels that are sometimes damaging. The transition to more intensive IPM programs in orchards will require knowledge and patience — knowledge of pest and natural enemy biology and patience to allow natural enemy build-up. Selective controls will have to be used for pests that are not maintained at acceptable levels by natural controls.

History

The advent of synthetic insecticides after World War II launched a new era of pest control. The number of registered pesticides rose from about 30 in 1936 to more than 900 in 1972. The new chemicals were effective, easy to use and inexpensive. For several years it appeared that broad-spectrum pesticides could eliminate most pest problems. Sprays were often used on a routine, preventive basis, providing protection for the crop whether the insect was there in damaging numbers or not.

Soon, however, insects began to develop resistance to insecticides and new problems arose because natural enemies were eliminated. Some insects that previous to broad-spectrum insecticides had been kept in check by their natural enemies now reached pest status. In the absence of natural enemies, growers often applied more toxic products in an effort to control these secondary pests, as well as resurging populations of the insecticide-resistant target pest. Orchardists became trapped in a cycle of using more insecticides to cure one pest problem which resulted in the worsening of another pest problem. The cost of control increased while the degree of control often declined and the harmful effect on the environment escalated.

The inability to control mites during the 1950s and 1960s was a major impetus in the development of integrated mite control in apple orchards. Mites were quickly developing resistance to miticides. Scientists found that predatory mites had developed resistance to some organophosphate insecticides and, if these were used at selective rates and properly timed, biological control of mites could be integrated with chemical control of other insects. It meant tolerating some mites in the orchard until predators gained control, and at first was a difficult concept for growers to accept. But integrated mite control became so successful that many orchardists in the Pacific Northwest have not had to apply chemicals to control mites since the 1960s.

Although integrated mite management was widely adopted in the early 1970s, growers have continued to rely almost exclusively on insecticides for control of other pests. Insecticides have been effective and in the absence of any crisis, as was experienced with mites, IPM was a less attractive alternative. Recently, however, the pace toward widespread implementation of IPM for the entire complement of orchard pests has been quickening. A number of factors are responsible for the renewed interest in IPM. Those most evident are:

- A decline in the number of insecticides available because of the EPA's reregistration of old pesticides;
- A lack of new registrations because of development costs and regulatory requirements; and
- A reduction in the effectiveness of registered products because of pest resistance.

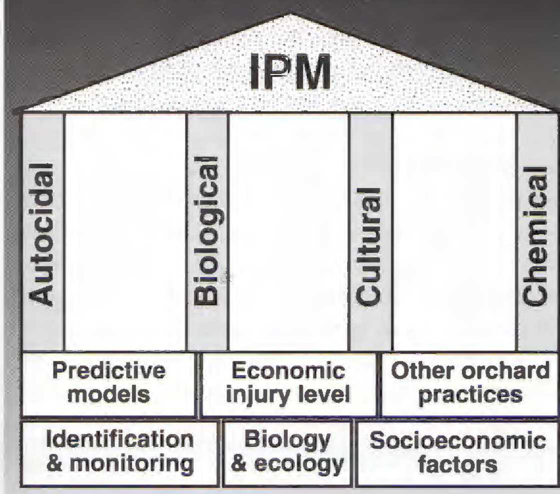
The public's concern over insecticide residues on food, contamination of the environment, and exposure of farm workers to insecticide residues during thinning, tree training, and harvesting operations are issues of increasing importance. IPM addresses each of these concerns. Moreover, IPM has the capacity to evolve to accommodate new pests and control techniques.

Integrating management tactics

A successful IPM program incorporates a variety of compatible tactics such as biological control, cultural control, judicious use of insecticides, and autocidal techniques such as mating disruption. It does not preclude the use of insecticides but attempts to use them as a last line of defense against pests, not as the first option for control. IPM recognizes that insecticides are one of many tools available for managing pests and the more tools that are included in a management program, the stronger it will be (*Figure 1*).

For example, where mating disruption is used to control codling moth, supplemental treatment with insecticides may be needed to reduce pest pressure on orchard borders to prevent damage resulting from

Foundations and Structure of an IPM Program



Knowledge of the identity, abundance and dynamics of pest populations and their relationships with other insects and the environment are the foundations of an IPM program. An IPM program is built on all compatible control tactics: biological, cultural, chemical and autocidal. The more of those elements that are included in the program, the stronger it will be.

Figure 1

mated moths immigrating from adjacent sources.

Conflicts often arise when attempting to integrate insecticidal and biological controls. However, these problems can be reduced by using insecticides that are selective, that is, those that control the pest but are less toxic to natural enemies. Applying insecticides only where needed and timing applications when the pest is most vulnerable will maximize benefits of the chemical control while reducing the impact on natural enemies. Delaying treatments as long as possible to allow predator and parasitoid populations to build up or using chemical controls during the dormant period before natural enemies are active are strategies that will help encourage biological controls.

In an IPM program, pests are not treated in isolation. It is important to consider their relationships with other insects and with their environment. The distribution and abundance of pests is influenced by their natural enemies, by weather, by orchard practices including pruning, fertilization and cover crop management, and by habitats surrounding the orchard that may provide alternate hosts for pests and their natural enemies. Understanding that these factors influence pest populations is a key to successful pest management.

Similarly, decisions that affect the biological components of the orchard system are not made without considering the larger social system of which they are a part. The tree fruit industry is well aware of how pesticide laws and the concerns of consumers can dramatically impact production and marketing programs. IPM should provide the platform for developing a more harmonious relationship between the agricultural community and social and environmental action groups.

Components of an IPM program

Pest identification

The use of broad-spectrum insecticides reduces the need to know specifically what pest is causing what damage. Treatment decisions are often prevention-based and several target pests are killed with the same treatment. As more selective controls are incorporated into a management program, it becomes increasingly important to know more about the target pest in order to achieve control. The effectiveness of selective controls often depends on very accurate timing of applications.

Damage in an orchard may not necessarily be due to the most abundant insect present at the time observations are made. An incorrect diagnosis can lead to unnecessary sprays. Many insects found in the orchard are not pests but only incidental visitors, while others are beneficial, acting as biological controls for pests. Some pest and beneficial species look similar. For example, many stink bugs are potential pests, but a *Brochymena* species is predaceous and a natural enemy of soft-bodied pests in orchards.

Several kinds of information are helpful when identifying an insect in the field. Physical appearance (including color, size and shape) is usually of primary importance. However, since many pests restrict their feeding to only certain plant parts, knowing where they are most likely to be found helps narrow the possibilities when making field identifications. Similarly, many insects leave characteristic feeding damage that provides a clue to their identity. Descriptions and pictures of the most common insect and mite pests, their natural enemies, and typical damage caused by pests are presented in this manual.

Monitoring

Monitoring is the most fundamental yet the most often neglected activity in an IPM program. Both the need for control and the effectiveness of any action taken are determined by monitoring pest and natural enemy populations. Since it is impossible to count all the insects only a portion, a sample, is counted. Information obtained from the sample is used to make inferences about an insect's density in the entire orchard. To decide if a control is required, pest density must be related to the potential damage and balanced against how likely it is that the pest's natural enemies will be able to keep it below damaging levels. Even if treatment thresholds are unknown, sampling provides information on the insect's stage of development, population densities and the ratio of pests to natural enemies, all of which form a sound basis for decision making. Management in the absence of sampling usually leads to an overuse of insecticides.

It is important to know how a pest develops, i.e., its life history, because different life stages may be monitored and managed in different ways. For example, you would sample foliage to look for leafroller larvae, which feed on leaves and fruit, but use pheromone traps to monitor adults. Control decisions may be based on either of these monitoring methods at different times during the season (see Leafrollers in Part II, Direct Pests).

Different sampling methods are used, depending on the type of pest and monitoring objective. Since all methods only estimate the number of individuals in the actual population, there is always variation from one sample to the next. This variation is kept within acceptable limits by guidelines that specify how, when, and where to sample. Detailed sampling guidelines for many orchard pests are presented in this manual. Some general methods of monitoring orchard pests and their natural enemies are outlined here.

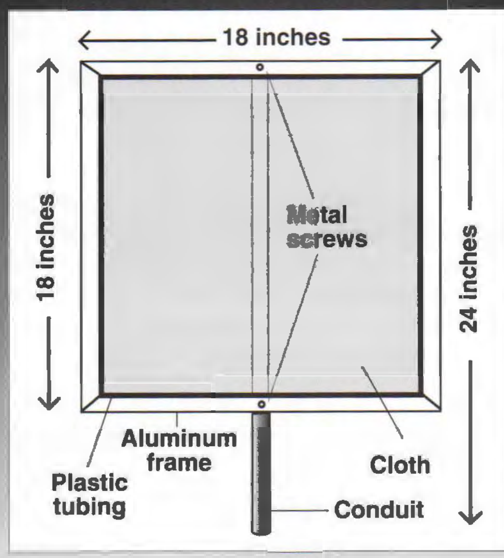
Visual counts

Caterpillars, leafminers, leafhoppers, aphids, mites and many of their natural enemies can be sampled simply by counting them on leaves, shoots or fruit. A 10-power hand lens is an essential tool. It makes sampling smaller insects easier and is necessary when evaluating parasitism of leafminers.

Leaf brushing

Leaf brushing is the standard method for counting mites and can be used to estimate psylla densities. A machine is used to brush mites or immature pear psylla off leaves and onto a glass plate placed over a grid (Appendix 4) to make counting easier. See the appropriate pest section for the kind and number of leaves to be sampled and subsequently brushed.

Building a Beating Tray



An economical beating tray frame can be made from aluminum window screen framing. Lightweight white or black cloth is stretched over it and held in place by narrow plastic tubing that presses snugly into a groove in the framing. A piece of 1/2-inch or 3/4-inch electrical conduit is fastened across the bottom of the frame as a handle. Materials are generally available from glass suppliers.

Figure 2

Beating tray

Insects such as adult pear psylla, plant bugs, older caterpillars, and predators of pear psylla and aphids can be monitored by jarring them from limbs onto a cloth tray. A white cloth provides a good background for counting most insects. However, light colored pests such as campylomma are more easily detected against a black cloth. Instructions for making a beating tray are given in *Figure 2*. The tray is held under an almost horizontal section of limb that is ¾ inch to 1½ inches in diameter with an average complement of branches and spurs (*Figure 83*). The limb is firmly tapped three times with a l-foot length of stiff rubber hose. Old spray hose works well. Insects jarred from the tree cling to the cloth and can easily be counted. Insects and debris are removed from the tray by turning it upright and tapping it lightly with the hose.

Beating tray counts should be taken at random throughout a block. The number of tray samples required to make a management decision varies and is discussed in the specific pest sections. When sampling for parasitic wasps or other minute insects, an aspirator can be used to collect the specimens for later identification (*Figure 3*).

Traps

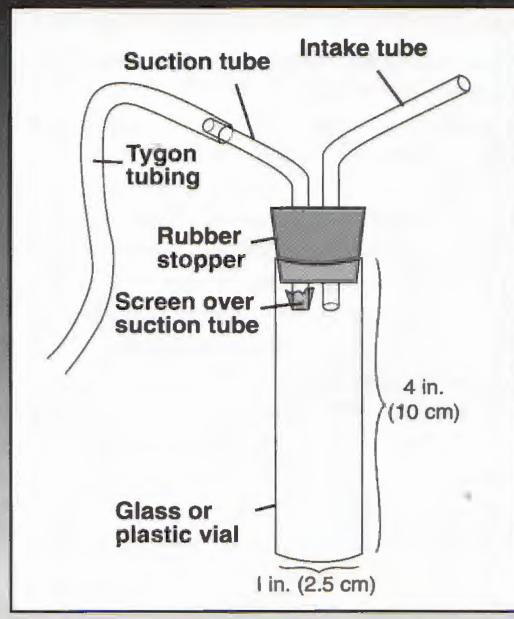
Pheromone traps

Pheromone traps are a quick and convenient way to monitor many moth species, San Jose scale and campylomma. When used in conjunction with phenology models, they enable growers to apply controls at precise times in an insect's life history rather than according to a calendar-based schedule. Pheromones are volatile chemical attractants produced by insects to communicate with their own species. Most pheromones used in traps are synthetic compounds that mimic those released by females to attract males for mating (see section on Mating Disruption and Degree Day Models in Part I). The main limitation of pheromone traps is that only the adult males can be monitored, and activity of males may not always be representative of female activity.

Pheromone traps can be used to help:

- monitor when adult flight begins (biofix), as well as peak flight and its duration;
- track seasonal development;

Insect Aspirator



An insect aspirator is used for for collecting small, fragile or fast-moving insects for identification. It can be purchased from entomological supply catalogs or made from a few simple parts. The vial has a tight-fitting stopper. Two sections of glass or copper tubing, about 4 to 6 in. (10 to 15 cm) long and 1/4 in. (5 to 7 mm) outer diameter, are bent at an angle of 30 to 45 degrees and inserted through holes of the stopper. Glass can be bent by softening in the flame of an alcohol lamp; copper can be bent by hand. To avoid inhaling insects, place a screen of very fine organdy mesh over the suction tube and secure with tape or a ring of tygon tubing. To extend the working distance of the aspirator, place a length of tygon tubing, 12 to 18 in. (30 to 45 cm) long with an inner diameter of 1/4 in. (5 to 7 mm), over the end of the suction tube. To collect insects, place the end of the intake tube near the insects and the tygon tubing in your mouth. Inhale in a quick burst, and the insect will be drawn into the vial by suction. Tissue packed loosely in the vial will help cushion the insect's fall and help preserve fragile specimens.

Figure 3

- determine when populations reach treatment thresholds;
- assess how well control programs are working; and
- synchronize degree-day models with actual pest development.
- monitor the presence of exotic or introduced pests

Traps of various designs and sizes are available commercially. Some are cylinder shaped, while others are referred to as wing or tent types. Most are made of cardboard and have an adhesive on the inside (*Figure 29*). A lure containing the pheromone is placed inside the trap. Pheromone is slowly released and insects are attracted to and caught in the trap's adhesive surface. The number of insects that can be caught in a trap depends on the size of the sticky surface.

Choosing a trap system: The size and shape of the trap can make a difference in how efficiently it catches the target insect. The trap should be easy to assemble, efficient, and the lure should release pheromone at a constant rate. The trap system also should allow easy maintenance, such as removing trapped insects, replacing the adhesive catch surface or installing a new pheromone lure. A permanent trap with a replaceable adhesive liner can be used for several seasons and may be cheaper in the long run than a disposable trap used for one season. Permanent traps should be cleaned periodically to remove contaminants such as spray residues, which could make the traps repellent to the pest.

Placement: Place traps in the orchard before the pest starts to emerge. Hang them within the tree canopy as recommended for the pest being monitored. The number of traps needed depends on why they are being used. A few strategically placed traps are all that is needed to establish biofix for degree-day models. More traps are needed if the objective is to assess a pest's distribution and density. To assess pest density, traps should be placed in a grid pattern. Usually the number of moths caught per trap will increase as the number of traps within an area decreases. This relationship should be taken into account when comparing data from different orchards using different trapping densities. It also can be useful to place traps on the border of the orchard to monitor movement of insects into the orchard. If the number of insects captured in border traps is higher than interior traps, it usually signals problems from an external source. When using the number of insects captured in pheromone traps as a treatment threshold, always use the trap density specified.

Maintenance: Traps should be checked at regular intervals, at least weekly. As the season progresses, the sticky surface inside the trap can become contaminated with moth scales, debris, dust or non-target insects. Any deterioration of the trap's adhesive surface will reduce its efficiency. Contaminated adhesive surfaces should be changed as needed. For example, the efficiency of the wing-type trap declines after an accumulated catch of about 30 moths. When trapping in blocks where pest densities are low, as is often the case with codling moth, the adhesive should be stirred after removing insects to maintain the efficiency of the trap.

Interpreting data: Though the pheromone trap is easy to use, it may not be as easy to interpret the results. Moth capture can be influenced by:

- Density of the male insect population.
- Age of the male insects.
- The effect of wind and slope on male movement.
- Competition from calling females.
- Trap design and size.
- Condition of the pheromone lure.
- Trap maintenance, placement and density.

For these reasons, moth capture in a pheromone trap provides only a rough estimate of pest density. However, if pheromone traps are used properly throughout the season and from one year to the next, they can provide useful comparative data.

Other traps

Other types of traps can be used to monitor insects, including sticky traps (with or without attractants), light traps and bait traps. Two kinds of sticky traps are used to monitor flies. They are a yellow panel baited with ammonium acetate and casein hydrolysate or ammonium carbonate, and a red sphere. The cherry fruit fly, a relative of the apple maggot, is usually monitored with a baited yellow panel. Pails containing an ammonia-, molasses- or terpinyl acetate-based liquid bait can be used to trap several species of moths. Moths are also attracted to light sources placed in the orchard. Little is known about the effectiveness of most bait or light traps so their use in estimating pest density has limited value.

Degree day models

Degree day models, when coupled with monitoring, enable you to determine the most effective time for treatment applications. Insect development is influenced by temperature, and treatments applied on a calendar basis can often be poorly timed due to fluctuations in weather from season to season. Many selective controls, such as insect growth regulators and microbial insecticides, must be applied at a precise time in the pest's life cycle to be effective.

A degree day model predicts insect development by accumulating heat units (degree days) and associating these with critical events in its life cycle. Models are usually initiated at some easily monitored event (biofix), such as first capture of males in pheromone traps. Thereafter, daily temperatures are used to calculate degree days specific to that insect. Degree day tables for some key tree fruit pests are given in Appendix 1. The primary benefit of degree day models is their ability to predict critical events in the insect's life history that would be difficult to observe directly.

Decision making

The presence of an insect in the orchard is not sufficient justification, in most cases, to initiate control measures. If an insect is a potential pest, the severity of the problem depends on the type of damage

IPM Decision making

There are two fundamental components to decision making in an IPM mode: Sampling and economic injury levels. Information about pest infestation levels must first be gathered through sampling or monitoring and then the information in the sample must be compared to an economic injury level (EIL). Ideally, all sampling methods and economic injury levels would be numerical, making decisions very straightforward:

Sample leafhoppers	⇨	0.1 nymphs/leaf	⇨	EIL = 0.5 nymphs/leaf	⇨	Decision: No control needed

However, our sampling method and EIL may not be very well studied, or vary greatly, depending on the circumstances:

Sample aphids	⇨	20% terminals infested	⇨	Age of trees? Time of year? Cultivar? Predators present? Insecticide available?	⇨	Decision: No control needed yet, but sample again in 2 weeks

Even if the sampling method is fairly qualitative, and the EIL subjective, the same basic process should be carried out before initiating a control measure. It usually takes less time and money to sample an orchard that to spray it. Even use of the most environmentally safe control technologies should be preceded by the use of sampling and thresholds.

it causes and how much damage the grower is willing or able to accept. For example, indirect (foliage-feeding) pests such as western tentiform leafminer and white apple leafhopper can be tolerated in higher numbers than direct pests such as codling moth, which attack fruit. In addition, it may pay long-term dividends to accept a small amount of fruit injury from a pest such as pear psylla to allow natural enemy populations to increase,achieving biological control and thus minimizing the effects of pest control activities on the environment.

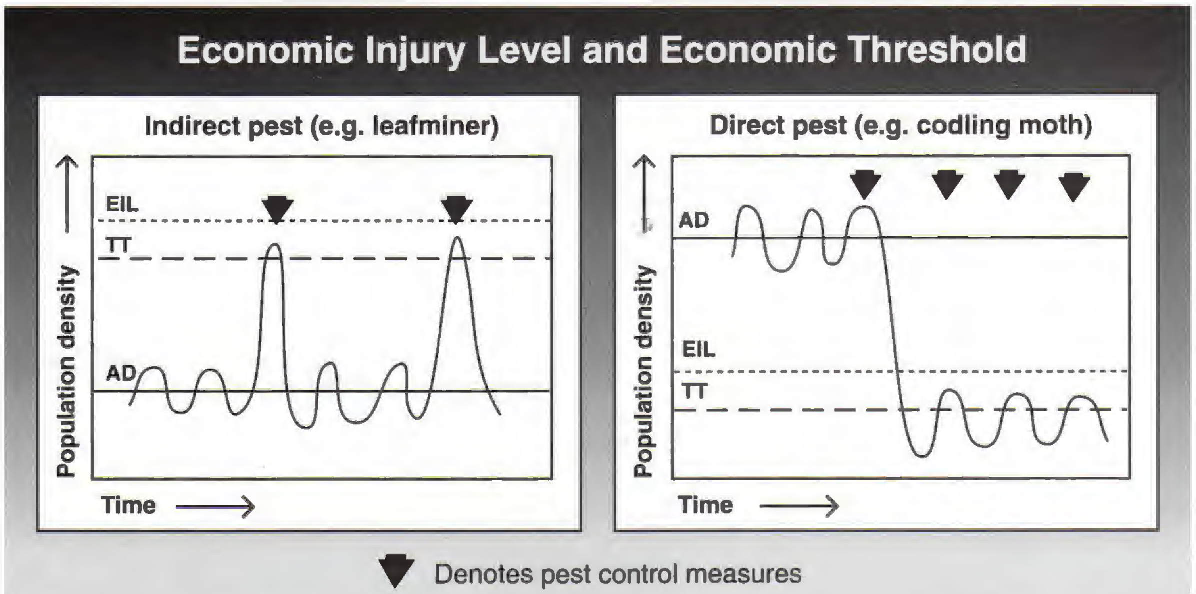
Economic injury level

The economic injury level is defined as the pest density that causes damage equal in value to the cost of control. In other words, it is the lowest pest level at which control becomes economically feasible by weighing the cost of potential losses due to crop damage against the cost of control. The economic injury level will be different for different cultivars and will vary with tree vigor, crop load and the time of year. In addition to biological components, growers must also factor in the costs and profitability of their own orchard operations.

Economic injury levels for direct pests (where a damaged fruit is culled) are usually easier to establish than those for indirect pests. In reality, economic injury levels have been determined for very few fruit pests.

Treatment or action threshold

The treatment threshold is the density at which control measures must be applied to prevent pest densities from exceeding the economic injury level. The treatment threshold is lower than the economic injury level, allowing time for control



AD represents the **average density** of a pest population over a period of time. The density fluctuates, depending on effects of natural enemies, weather, pest control measures and other factors.The **economic injury level** (EIL) is the highest density of the pest that can be tolerated without significant crop loss.The **treatment threshold** (TT), sometimes called the economic threshold, or action threshold, is the density at which control is needed to prevent the pest population exceeding the economic injury level.The economic injury level may be above or below the average density, depending on the type of pest. Direct pests attack the fruit and can dramatically affect crop yields and marketability. Indirect pests attack the foliage, wood, or roots and can reach higher densities before they cause economic damage.

Figure 4

measures to take effect (*Figure 4*). The treatment threshold can vary depending on the abundance of a pest's natural enemies. Higher densities can be tolerated when populations of natural enemies are also high. For example, the treatment threshold for an insect might be 3 per leaf if there are no natural enemies, but 6 per leaf if predators or parasites are abundant.

Management tactics

A variety of management tactics can be used to prevent a pest population from exceeding the economic injury level (*Figure 5*). Integrated pest management stresses reliance on control methods that will be the least disruptive of natural enemies while still providing adequate control of pests.

Synthetic organic insecticides have been the dominant pest control tactic used in orchards since their introduction soon after World War II. There are four main groups: organophosphates, organochlorines, carbamates and pyrethroids. They have been relatively inexpensive, highly effective and fast acting, often providing almost complete control. They affect a wide range of organisms and often kill natural enemies as well as pests. In addition, many pests have developed resistance to them. These powerful pest control tools should be used only as a last line of defense against pests. Natural enemies, selective insecticides and other non-disruptive control tactics should be given every opportunity to work before broad-spectrum insecticide are used.

Insect growth regulators are synthetic chemicals that mimic or inhibit natural hormones that govern an insect's development (see section on Insect Growth Regulators in Part I). When exposed to these chemicals, the insect develops abnormally and dies.

Insect growth regulators have been an important component of IPM programs in Europe since the 1980s, but none have been registered in the United States for use on fruit crops.

Botanical insecticides are derived directly from plant or plant products. The three botanicals most frequently used to control orchard pests are ryania, pyrethrum and rotenone. Ryania is extracted from the roots of *Ryania speciosa*, a shrub grown in tropical America. Its use in orchards has been primarily against lepidopteran larvae, particularly codling moth. Pyrethrum is extracted from flower petals of certain *Chrysanthemum* species and has a fairly wide spectrum of activity against insects. Rotenone is obtained from the roots of certain species of leguminous shrubs grown in Malaysia, the East Indies, and South America. This insecticide can be used to control some chewing and sucking insects. Since botanicals are fairly expensive and generally less effective or have a shorter residual effect than synthetic organic insecticides, they are used primarily in production of organic fruit.

Insecticidal soaps are available to control soft-bodied pests such as pear psylla, aphids, scales, leafhoppers and mites. Applications must be timed precisely to coincide with the pest's most susceptible stage and applied frequently for greatest success. Soaps may have phytotoxic effects on some crops. The major advantage to using soaps is their low toxicity to natural enemies, as well as humans.

Diatomaceous earth is finely milled fossilized shells of fresh water diatoms. The microscopic silica dust is damaging to soft-bodied insects such as aphids and pear psylla. It is thought to kill them by physically damaging their membranes, leading to a loss of body fluids.

Lime-sulfur and wettable sulfur are used to control fungal diseases and mites, scale insects, aphids and pear psylla. Both formulations are incompatible with many other spray materials and if used improperly can be phytotoxic. Sulfur is toxic to predaceous mites and can be disruptive to integrated mite control programs if used in summer.

Horticultural spray oils are produced by distilling and refining crude petroleum oils. They are often used in combination with other chemicals but can be used alone to suppress insects and mites. Applied during the dormant or delayed dormant period, they kill overwintering stages of pests such as scales and eggs of European red mite. They also inhibit egg laying by pear psylla females. To date, there are no documented cases of an insect developing resistance to oils. The mode of action is not clear, but several mechanisms are suspected: smothering the insect or its eggs, or penetrating the insect's cuticle and interfering with nerve transmission. Oils can be phytotoxic to fruit and foliage of deciduous tree fruits. Damage varies with the type of oil (paraffin content, unsulfonated residue, distillation range, viscosity), the tree species, application concentration, and the weather before, during or after the application. Combining oil with certain pesticides or nutrients may exacerbate phytotoxicity.

Microbial insecticides are developed from insect pathogens such as viruses, bacteria or fungi. They have several advantages over traditional pesticides. They are more selective, usually not toxic to predaceous or parasitic insects, and have a much less harmful effect on the environment.

The bacterial insecticide *Bacillus thuringiensis* (Bt) is effective against lepidopteran larvae such as leafrollers, peach twig borer and cutworms. Bt is not a contact insecticide and must be consumed to be effective. When ingested, the Bt produces a biotoxin which makes holes in the insect's stomach lining. Bacterial spores then get into the insect's blood stream and poison it. Once it has consumed a toxic dose, the larva stops feeding, but may remain alive for several days. Bt is most effective against young larvae, as it takes a smaller dose to kill them than it takes for more mature larvae. Bt will kill codling moth larvae in the laboratory, but because they are exposed for such a short time before entering the fruit (probably not long enough to consume a lethal dose) it is not a highly effective field control.

Management Tactics for Insects and Mites

Pest	Chemical	Biological	Autocidal*	Cultural**
Codling moth	E	N	E	U
Leafrollers	E	P	P	U
Campylomma	E	N	P	P
Lygus bugs	E	N	N	U
Stink bugs	E	N	N	N
Thrips	E	N	N	P
Pear psylla	E	U	N	U
European red mite	E	E	N	U
Twospotted spider mite	U	E	N	U
McDaniel spider mite	U	E	N	P
Rust mites	E	U	N	N
White apple leafhopper	E	U	N	N
Green apple aphid	E	U	N	U
Cherry fruit fly	E	N	N	P
Oriental fruit moth	E	P	E	P
Woolly apple aphid	E	U	N	U
San Jose scale	E	U	P	N
Green fruitworms, cutworms	E	P	N	U
Western tentiform leafminer	E	E	P	N

N - Not used **P** - Potential for use **U** - Useful to some extent **E** - Generally effective

* Includes mating disruption

** Includes pruning, thinning, irrigation and fertilizing practices, sanitation,

Figure 5

The codling moth granulosis virus is a highly selective microbial insecticide. To be effective, it must be eaten by larvae just after they hatch, so sprays must be applied frequently. Both Bt and viruses have a short effective life of 3 to 7 days. They break down in sunlight and must be applied more frequently than traditional insecticides to achieve adequate control. Because larvae must consume these products, thorough coverage is essential.

Biological control

Biological control is a pest control tactic where a pest's natural enemies (predators and parasitoids) are used to keep its density below damaging levels. Every pest has natural enemies, but whether they can provide adequate control in an orchard is difficult to predict. To make the most effective use of biological control you must know the life cycle, biology and ecology of both the pest and its natural enemies.

Biological control alone will not be sufficient to control all pests attacking a tree-fruit crop, but it plays an important part in an IPM program. Biological control can either occur naturally or can be encouraged by introducing natural enemies into the orchard. It also can be enhanced by protecting natural enemies that are in the orchard and providing suitable habitat near the orchard or in the cover crop to promote their survival.

Natural enemies have the potential to control many secondary pests such as mites, aphids, leafminer, pear psylla and grape mealybug. Broad-spectrum insecticides kills most natural enemies, allowing outbreaks of pests they would normally control. Biological control is relatively safe, often permanent and economical. However, it can take time to implement a biological control program and it may mean having to tolerate some crop injury until natural enemies build up to sufficient numbers to provide adequate control (see also section on Biological Control in Part I).

Mating disruption

In mating disruption, pheromones are used to prevent male insects from finding females. When used in place of broad-spectrum insecticides for control of key pests, such as codling moth, it allows improved biological control of many indirect pests and slows the development of insecticide resistance. Pheromones are highly specific, affecting only the target pest, and are not toxic to mammals in the amounts used for mating disruption. They leave no residues on the crop and have no adverse impact on the environment (see also section on Mating Disruption in Part I).

Cultural controls

Cultural controls are used to some extent for most apple pests. However, few provide complete control of any pest on a regular basis. They are used most often to reduce the potential for pest development and are combined with other control tactics. Cultural controls include:

- Pruning out water sprouts, sucker growth or foliage preferred by insects such as aphids, pear psylla and leafhoppers.
- Sanitation, including the removal and destruction of infested fruit and pupation sites of key pests, such as codling moth.
- Pruning practices that eliminate optimum sites for mealybug and scales and which enhance penetration of sprays.
- Planting high density orchards with trees that have relatively smooth bark and easily sprayed canopies.
- Managing fertilizer to limit the excessive plant growth preferred by plant-sucking insects.
- Eliminating pests' alternate plant hosts in or around the orchard.
- Maintaining a ground cover that provides habitat for beneficial insects.

Introduced Pests and Quarantines

Pest	Place of origin	When introduced in United States
Codling moth	Asia Minor	More than 200 years ago
Oriental fruit moth	China	About 1913
Eyespotted bud moth	Europe	Before 1840
European leafroller	Europe	19th century
Peach twig borer	Europe	Before the 1880s
Pear psylla	Western Europe	1832
Campylomma	Europe or Asia	Before 1886
Pear sawfly	Europe	Since colonial times
Dock sawfly	Europe	Before 1862
European earwig	Europe	
European red mite	Europe	Before 1911
Pear rust mite	Europe	19th century
Prunus rust mite	Europe?	19th century
Pearleaf blister mite	Europe	Before 1900
Rosy apple aphid		About 1870
Green peach aphid	Europe	
San Jose scale	China	1870s
Oystershell scale	Europe	Before 1850
European fruit lecanium	Europe	
Shothole borers	Europe	Early 1900s
Cherry bark tortrix	Europe	Before the 1990s
Apple ermine moth	Eurasia	Ca. 1985
Pear leafcurling midge	Europe	1931

Listed above are some of the introduced pests of tree fruits. Our cultivated deciduous tree fruits are from the Old World, and a substantial number of their pests were imported along with them, before the idea of a quarantine was conceived. A few more pests we are currently dealing with are native to the eastern United States, and were eventually transported to the Pacific Northwest. Notice that many of our worst pests are listed here, and consider how much different pest management would be if we didn't have to deal with these non-native arthropods. Although much of the damage has already been done, this list underscores the importance of quarantines and how they may impact future pest management strategies. Despite our current quarantine regulations, we are finding new pests in the Pacific Northwest on a regular basis.

Insect Growth and Development

INSECTS AND MITES belong to a large group of animals known as arthropods. Several characteristics differentiate insects from other arthropods. The body is segmented, and the segments are grouped into three sections: head, thorax and abdomen (*Figure 6*). The eyes, antennae and mouthparts are on the head and the legs and wings are on the thorax.

In contrast, mites have no antennae and adult forms usually have four pairs of legs. The head and thorax are smaller and fused in mites. The abdomen is relatively large and bulbous and is not distinctly segmented.

An insect's skeleton is on the outside of its body and is called an exoskeleton. It serves as a support for muscles and internal organs as well as a covering. The body wall of an insect has three layers. The outer layer is cuticle containing chitin, proteins and often pigments. This is secreted by a cellular layer beneath it called the epidermis. The inner layer is called the basement membrane.

Structure of an Insect

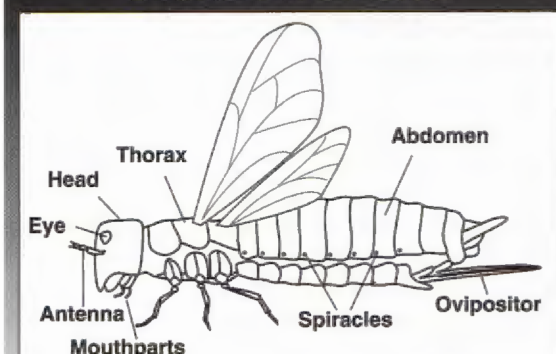


Figure 6

The type of mouthparts an insect has determines how it feeds and what sort of damage it does. There are two general types: chewing and sucking. Insects with sucking mouthparts suck liquid food through an elongated beak. Insects with chewing mouthparts tear off pieces of host tissue and ingest it.

Growth progresses through successive stages. Females lay eggs, which hatch into an immature stage. After passing through a series of immature stages, the insect emerges as an adult. Adults mate and the cycle begins again. (*Figure 7*)

Most insects start as eggs, which vary in size shape and color. They can be deposited singly or in compact masses, but are usually protected in some way. They may be laid in the ground, or in or on plant tissue. Eggs left exposed are often protected from the elements and natural enemies by a coating.

Eggs may be round, oval, barrel shaped, disk shaped or suspended on long stalks. The tough outer surface protects the embryo and prevents water loss.

The first immature stage of the insect hatches from the egg. As the insect's rigid exoskeleton cannot expand much, it must be shed and replaced with a larger one as the insect grows. This process is called molting. The life stage between each molt is called an instar.

Molting is governed by hormones. Cuticle secretion and the molt cycle are controlled by ecdysone, a steroid hormone. The hormone is secreted by a gland in the thorax, which is in turn controlled by a hormone from the brain. Whenever the brain receives the appropriate stimulus, the insect will molt. A new cuticle forms under the old one, then the old exoskeleton splits and the insect wriggles its way out. Many insects eat their own discarded skin. The new cuticle is soft at first. The insect may swallow air to expand its own volume and stretch the new exoskeleton before in hardens, usually within about an hour.

Metamorphosis

Most insects change in form during their development and the successive stages are not all alike. This change in form is called metamorphosis. It is controlled by a juvenile hormone secreted by glands in the insect's head. The juvenile hormone is released during each molt, but the amount decreases each time. As the concentration of juvenile hormone declines, more adult characters will appear until very little or no juvenile remains and the adult stage is produced. If the juvenile hormone is introduced at the wrong time or in the wrong amount during the insect's life cycle, normal growth can be disrupted. Insect growth regulators use this principle for pest control (see section on Insect Growth Regulators in Part I). Some insects change very little in form, and the young and adults are similar except for size (*Figure 8*). This type of development is known as simple metamorphosis. The young, which are called nymphs, usually share the same habitat and feed on the same host as the adults. Nymphs lack wings and reproductive organs. Aphids and leafhoppers are among the insects that go through simple metamorphosis, as do mites.

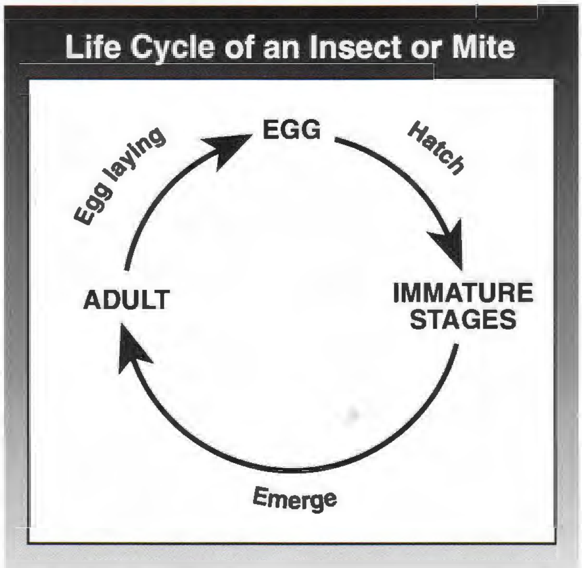


Figure 7

Some insects have young and adults that are quite different in appearance and often live in different habitats.This type of development is known as complete metamorphosis. The young are called larvae. Larvae generally have chewing mouthparts even when the adults have sucking mouthparts. The larva goes through a series of stages, finally transforming into a pupa before becoming an adult. The pupa does not feed and is usually inactive. Many insects pass the winter in the pupal stage before emerging as adults.

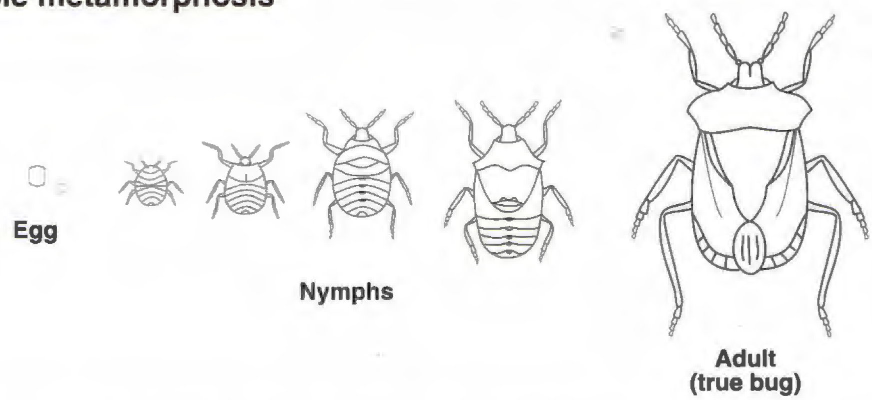
Insects that go through complete metamorphosis include moths (whose larvae are caterpillars), flies (whose larvae are worms or maggots) and beetles (whose larvae are grubs) (*Figure 8*). The metamorphosis of some insects is somewhere between simple and complete. These include thrips and male scale insects.

The length of a generation and how it is influenced by the seasons vary from insect to insect. Many insects have one generation a year. However, some beetles and moths need two or three years to complete one generation. Other insects have more than one generation a year. In some cases, the insect has a constant number of generations. In others, the number of generations may vary depending on the climate. A few insects, such as aphids, have many generations a year and keep reproducing as long as the weather is favorable.

In most cases, the insect passes the winter in a state of dormancy. The overwintering stage can be the egg, nymph, larva, pupa or adult. Dormancy can last from days to years. It can be triggered either by environmental or genetic factors. Most insects go into dormancy when the weather becomes unfavorable and become active again when it turns favorable. Others will go into dormancy at a certain time of year before conditions become unfavorable. This is known as diapause. Diapause is often triggered by the shortening days as winter approaches. Many insects require a prolonged period of chilling before they will break diapause.

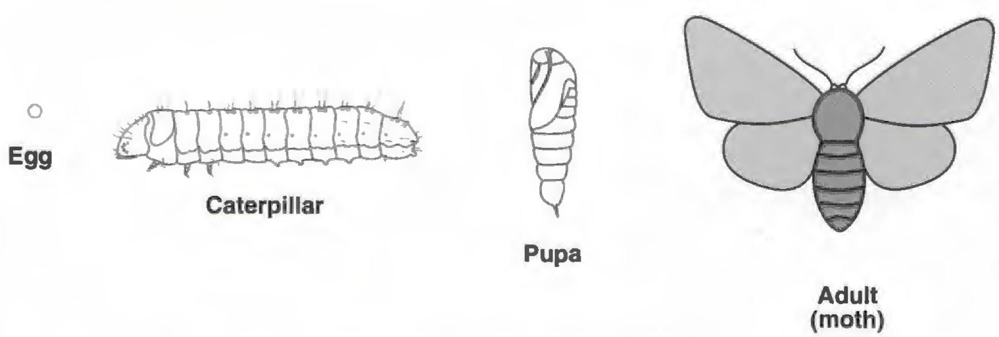
Metamorphosis

Simple metamorphosis



After hatching, the insect passes through a series of molts before becoming an adult. After each molt it is slightly larger. There are only three life forms: egg, nymph and adult. Nymphs resemble adults and usually feed on the same host, but they lack wings and reproductive organs. Bugs, leafhoppers, aphids, scales and mites are among the pests that have a simple metamorphosis.

Complete metamorphosis



In complete metamorphosis, the insect passes through four life forms: egg, larva (e.g. caterpillar, grub, or maggot), pupa and adult. The immature stages do not resemble the adult and their feeding habits and host plants may differ from those of the adult. Many extremely destructive tree fruit pests, including codling moth and cherry fruit fly, go through complete metamorphosis.

Figure 8

Reproduction in Insects and Mites

Reproduction in insects and mites can take a wide variety of forms, often very complex. Some can switch their type of reproduction during their life cycle based on environmental triggers. Others reproduce the same way throughout their life history. The basic theme, and some of the variations are described below.

Sexual reproduction: The standard model for reproduction is where males and females occur throughout the life cycle, and each produces a germ cell (egg and sperm, respectively). The male inseminates the female during mating. The female often stores sperm in special pouches in her abdomen called *spermathecae* (singular, *spermatheca*). The eggs are fertilized within the female's body, producing an embryo. Eggs are deposited on a host. They hatch and develop into either male or female offspring.

Parthenogenesis: This is asexual reproduction, where eggs grow and develop without fertilization. There are several variations of parthenogenesis. *Arrhenotokous* parthenogenesis is where unfertilized eggs produce only males. In *deuterotokous* parthenogenesis, both males and females are produced from unfertilized eggs. In *thelyotokous* reproduction, unfertilized eggs produce only females. Spider mites, for example, undergo arrhenotokous parthenogenesis, where unfertilized eggs produce males and fertilized eggs produce females.

External insemination: Insects may reproduce by sexual means, but insemination occurs without mating. The males deposit spermatophores, which are packets of sperm, and the females extract the sperm from these packets by various means. Rust mites undergo external insemination.

Viviparity: Most insects deposit eggs that hatch into nymphs or larvae, a process called *oviparity*, but some insects bear living young. A common example are aphids, which are viviparous during part of their life cycle. A variation is *ovoviviparity*, where eggs are held within the female's body, where they hatch, and the young are born live.

Polyembryony: This is where two or more embryos develop from a single egg, as in the parasitic Hymenoptera, such as braconid, encyrtid, and dryinid wasps. Typically, between two and several dozen embryos are produced, but some encyrtids can produce up to 1,500 embryos from a single egg.

Animal Classification

Insects and mites are arthropods. The name arthropod is derived from the Greek words for "jointed" and "foot." Insects are one class of arthropods (Insecta), and mites and spiders another (Arachnida). Each group, called a *taxon* (plural, taxa) is subdivided into smaller, more closely related groups. The base unit of classification is a single species.

Figure 9 gives the classifications of two important tree fruit pests, codling moth (an insect) and European red mite (a mite). The name after the species name is the person who first described that species, or the author. If the name is in parentheses, it means the scientific name has been changed since the species was first described. By convention, the genus and species (the scientific name or Latin binomial) are italicized.

Entomologists often refer to a taxon (usually a family) of insects collectively by dropping the ending -idae and adding -id. So, insects in the family Tortricidae are referred to as tortricids, and the Tetranychidae are called the tetranychids.

Similarly, entomologists sometimes refer to a group of related families with a taxon called a superfamily. The name is made by dropping the -idae ending of one of the typical families in the group and adding -oidea. The wasp families Eulophidae, Encyrtidae, Mymaridae, Trichogrammatidae and Chalcididae are in the superfamily Chalcidoidea.

Common and scientific names of pests found in orchards in the Pacific Northwest are listed in Appendix 3. *Figure 10* lists pests and their main characteristics by order.

Common names of insects can be confusing. For instance, sawflies and snakeflies are not flies (Diptera) at all, but belong to the orders Hymenoptera and Neuroptera, respectively.

As a rule of thumb, if the word "fly" or "bug" is kept as a separate word in the name, then the insect belongs to the order indicated (e.g. a syrphid fly is in the order Diptera and a stink bug in the order Hemiptera). However, if the word is used in a compound term (sawfly, mealybug), then it probably belongs to a different order than expected.

Classification Examples

Taxon	Codling moth	European red mite
Kingdom	Animalia	Animalia
Phylum	Arthropoda	Arthropoda
Class	Insecta	Arachnida
Order	Lepidoptera	Acari
Family	Tortricidae	Tetranychidae
Genus	*Cydia*	*Panonychus*
Species	*pomonella* (Linnaeus)	*Panonychus ulmi* (Koch)

Figure 9

Orders of Orchard Pests

Order	Pests	Main characteristics
DERMAPTERA (Earwigs)	European earwig	• Slender body with forceps at rear • Winged or wingless • Chewing mouthparts • Simple metamorphosis
THYSANOPTERA (Thrips)	Western flower thrips	• Small • Feed on plant juices through piercing mouthparts • Intermediate metamorphosis
HEMIPTERA (Bugs)	Boxelder bug, lygus bug, stink bugs, campylomma	• Forewing divided into leathery inner half and transparent outer half • Sucking mouthparts • Simple metamorphosis
HOMOPTERA	Aphids, grape mealybug, pear psylla, scales, leafhoppers	• Small, sometimes winged • Sucking mouthparts • Mostly sedentary plant feeders • Simple metamorphosis
COLEOPTERA (Beetles)	Flatheaded borer, June beetles, rain beetles, shothole borers	• Hard forewings • Hard, round body • Chewing mouthparts • Complete metamorphosis – larvae called grubs
LEPIDOPTERA (Moths and butterflies)	Apple ermine moth, cherry bark tortrix, codling moth, cutworms, fall webworm, green fruitworm, leafrollers, leafminer, lesser appleworm, oriental fruit moth, peachtree borer, peach twig borer, redhumped and yellownecked caterpillars.	• Two pairs of wings with scales • Sucking mouthparts (adults) • Complete metamorphosis – larvae called caterpillars
DIPTERA (Flies)	Apple maggot, cherry fruit fly, walnut hust fly, pear leafcurling midge	• One pair of wings • Sucking mouthparts • Complete metamorphosis – larvae called maggots
HYMENOPTERA (Ants, wasps and sawflies)	California pear sawfly, dock sawfly, pear slug	• Usually 2 pairs of membranous wings • Chewing mouthparts • Complete metamorphosis – larvae are grublike or resemble caterpillars
ACARI (Mites)	Spider mites, rust mites	• Small or minute • Two to four pairs of legs • Mouthparts for piercing or sucking • Simple metamorphosis

Figure 10

Sampling

Why sample?

The reason for sampling is to base pest management decisions on the best information possible. A pest management program cannot work if it is based on false premises.

For example, if you mistakenly believe the mite population in your orchard is below the treatment threshold, you will not spray when you should, and this could lead to economic damage. Or, if you estimate the pest population to be above the economic threshold when it is actually below, you would spray when it was not necessary and waste money. In both cases, the fault was not in the treatment threshold or your pest management plan, but in your estimate of the pest population.

Should I sample?

Sampling should be done if:

• The pest does not feed on the fruit.
With pests such as spider mites and tentiform leafminer, which damage foliage, you can tolerate much more damage than from pests that attack fruit. This allows you more latitude to sample and assess if control is needed.

• The pest has the potential to increase very quickly.
In this case you need a constant check on what is happening in the field. If pest populations do not vary much, there is little use in frequent sampling.

• You need accurate estimates to determine whether natural enemies will suppress the population.
If sampling shows they will not, then you may need to take treatment.

• You need to evaluate your pest controls.
Before-and-after comparisons will show if a pesticide application or introduction of natural enemies is working and if further control is needed.

• An accurate economic injury level for the pest is available.
Although sampling will estimate pest populations, it is most useful when an economic injury level has been established to indicate when control is needed.

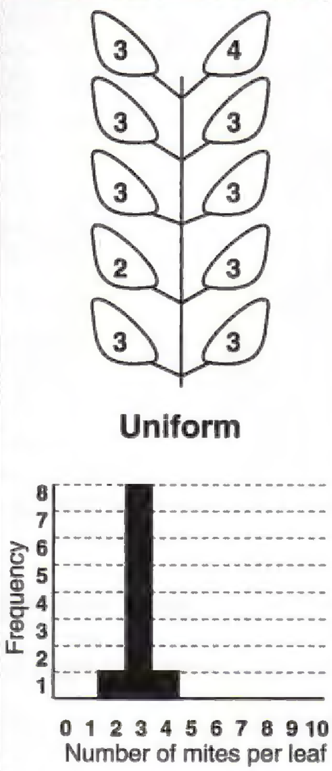
Accurate estimates of pest populations allow you to compare its relative density from generation to generation and decide if it needs to be controlled. Data should also be saved from year to year so you can fine-tune your management programs based on past performance.

How often should I sample?

This depends on the biology of the pest and its natural enemies. For example, the western tentiform leafminer has 3 to 4 generations per year. The potential for population increase from generation to generation is high, but a generation can take a month or more to complete. It doesn't pay to sample the leafminer more than once per generation unless you need to assess the degree of biological control. Weekly sampling of leafminer will show little change.

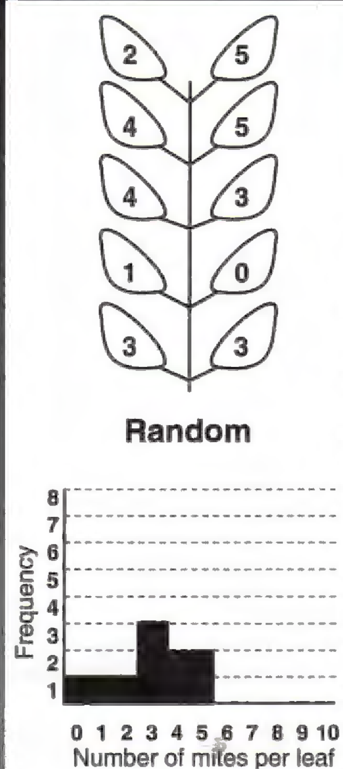
On the other hand, spider mite populations can complete a generation in 7 to 10 days during hot

Types of Sample Distributions



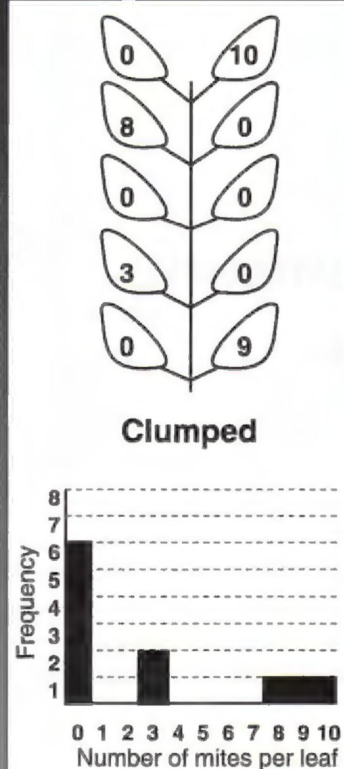
Mean = 3
Variance = 0.2

Each leaf has about the same number of insects on it. Only a few leaves would have to be sampled to accurately estimate the population level. However, insects rarely have this type of distribution.



Mean = 3
Variance = 2.6

Each leaf has an equal chance of having an insect on it. This is harder to sample than a uniform distribution and is rare for insects and mites.



Mean = 3
Variance = 18.2

Numerous leaves have no insects on them and only a few have large numbers. This is the most common type of distribution for insects and mites and is the most difficult to sample. A large sample size is needed to be sure that the few leaves with large numbers of insects are included in the estimate.

Figure 11

weather. Sampling should be done every 7 to 10 days so you are continually aware of what is happening before populations surpass the economic injury level.

What size should the sample be?

If you take a 10 leaf sample and find 30 mites, the average number of mites per leaf is 30 divided by 10, or 3 mites per leaf. This average, or mean, gives you important information about the population, but the mites could be differently distributed among the 10 leaves. By tallying the number of leaves that have no mites, then the number with one, then the number with two, and so on, you can work out a frequency distribution. *Figure 11* shows three typical different frequency distributions, each of which has a mean of 3 mites per leaf. In the uniform distribution, sampling even one or two leaves gives a close estimate of the mean population. Unfortunately, this sort of distribution is rare with insects or mites. The other extreme is the clumped distribution. Here, most leaves have no or few mites on them, while the remaining leaves have many. If you took a sample of three leaves and calculated the average, the estimate could vary from 0 to 9 mites per leaf. This kind of error in estimating mean populations leads to management mistakes. Unfortunately, this sort of distribution is typical of insect populations.

To decide how many samples must be taken to accurately estimate populations, it is important to know the ratio between the mean (or average) population density and the variance. The variance is a measure of the variation in the number of insects from leaf to leaf compared with the average population density. The ratio changes as the mean population changes, but it changes in a predictable way. With a large enough collection of samples, you can

Sampling Terms

Sampling unit: This can be an individual leaf, trap or fruit, on which insects are counted in order to estimate population levels.

Sample: A collection of sampling units used to estimate a population level. The number of sampling units in a sample is referred to as the sample size.

Precision: The repeatability of the sample. It is generally in the form of a ratio of the mean and its variance.

Mean: Average. The number of insects collected in a sample divided by the number of sampling units. It is the value most commonly used in decision-making for pest management.

Variance: The variation in the number of insects from leaf to leaf compared with the average population level. For example, at an average of five mites per leaf, some leaves might have no mites whereas other leaves could have 20 or more.

Frequency distribution: If you take a sample of 10 leaves and tally how many have no mites, how many have one mite, and so on, you create a frequency distribution. The shape of the distribution, as shown in *Figure 11*, gives you a feel for the size of sample needed to accurately assess the mean population level.

Economic injury level: The lowest number of insects or mites that will cause economic damage, expressed as a number of insects per leaf or per plant part.

Treatment threshold: The population level at which control measurers are needed to prevent pest populations reaching the economic injury level. The treatment threshold is lower than the economic injury level, to allow time for control measures to take effect before the population reaches the economic injury level.

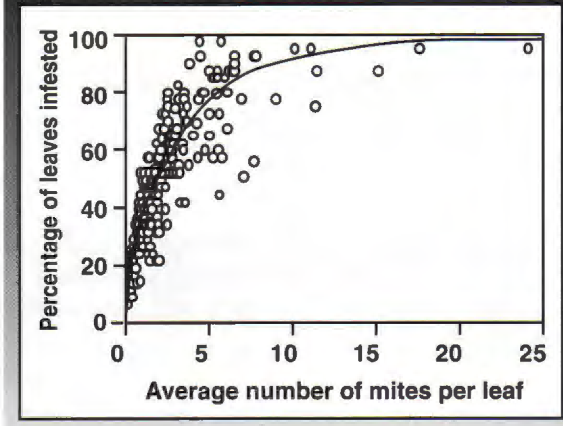
plot the relationship between the mean and the variance. From this, you can predict what the variance is from an estimate of the mean population density.

Knowing the relationship between the mean and variance also allows you to predict the distribution for any given population level. Using this relationship, we can predict how many leaves need to be sampled to give a certain degree of accuracy. Even more important, it allows us to use presence-absence sampling programs. If you know what percentage of the leaves are infested at a range of densities, you can estimate the average population density from just tallying the number of infested leaves without needing to count the insects. To show how well this works, you can plot the percentage of leaves infested and the average population level calculated from counting all the mites (*Figure 12*). The problem with this type of sampling plan is that estimates of the mean population density are unreliable when more than 80% of the leaves are infested.

However, presence-absence sampling can still be used by looking for the presence or absence of some easily recognized number of insects or mites, still without counting every one. For example, using the same relationship between mean and variance, we can predict the relationship between the mean and the percentage of leaves which have, say, 2 or more mites.

Samples using higher tally thresholds (2 or more, 3 or more, etc.) are still binomial samples in that each sampling unit is put into one of two classes. Although the term "presence-absence" is still used, you are no longer truly classifying on the basis of presence or absence. Several of the sampling schemes in later sections of this manual use a tally threshold of 2 or more (e.g. twospotted and McDaniel spider mites, *Typhlodrumus occidentalis*, western tentiform leafminer).Because estimates are unreliable when more than 80% of the leaves are infested, the highest mean that can be accurately predicted with 2 or more mites per leaf is about 10.6. That compares with 6.7 mites per leaf for the normal presence-absence sample where all infested leaves are included. If this is still not high enough,

Predicting Mite Populations



The percentage of leaves infested can be used to predict the average number of mites per leaf. However, it is difficult to predict with accuracy when more than 80% of the leaves are infested.

Figure 12

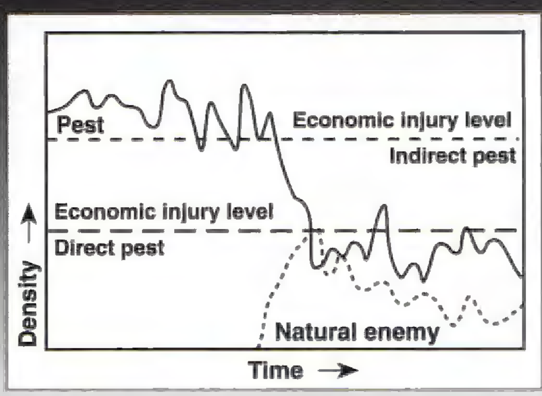
you can count only the leaves with more than 3 mites or more than 4 mites, and so on. However, beyond a certain point you save less time with the presence-absence sampling because you end up counting many of the mites anyway to make sure they exceed your tally threshold.

Sequential sampling

If you know the distribution, you can set up a sequential sample. In a sequential sample the total number of leaves (sampling units) is variable. It depends whether or not results so far show the treatment threshold is surpassed. This can be done either by counting the number of insects or mites, or it can be combined with presence-absence sampling. For monitoring purposes, it is often easier to sample a fixed number of leaves from a fixed number of trees that will give an accurate enough estimate when the average population level is near the economic threshold.

Biological Control: Concepts and Opportunities

BIOLOGICAL CONTROL is a means of keeping pests below damaging levels through the activities of predators and parasitoids. Successful biological control can occur with native natural enemies or may be due to the introduction of predators or parasitoids from foreign countries or different regions of the same country.



The figure shows how pest populations candecline after the introduction of a natural enemy. It also shows how successful biological control – suppression of the pest below the economic injury level – depends on the type of pest. Direct pests, which attack the fruit, cause economic damage at much lower densities than indirect pests, which attack other parts of the tree such as foliage, roots, or woody tissues.

Figure 13

There are three major types of augmented biological control: classical, inoculative and inundative. These are distinguished by the input needed to create a balance between the pest and natural enemy populations.

Classical biological control involves introducing natural enemies from a pest's native range into a new area where native natural enemies do not provide control.

Inoculative biological control means releasing natural enemies periodically or seasonally to re-establish a balance that has not been maintained naturally or has been disrupted by other control methods.

Inundative biological control involves the massive production and release of natural enemies to control the pest quickly.

Figure 13 shows an example of how pest populations might drop after a natural enemy is introduced. Unfortunately, biological control is seldom a predictive science. Biological control introductions are, in effect, grand ecological experiments.

For example, winter moth, a pest of oak, apple and several other deciduous trees, colonized Nova Scotia and British Columbia, Canada, where it became a pest. Dramatically successful control followed the introduction of two of the moth's natural enemies, a parasitic fly *Cyzenis albicans* and a parasitic wasp *Agrypon flaveolatum*. However, in England, part of the moth's native range, two decades of ecological studies indicated those parasites did not control the moth. This discrepancy underscores the difficulty of measuring what factors are important in providing natural biological control.

The great benefit of natural enemies is often demonstrated in experiments by using cages or screens to keep pests in, while excluding their natural enemies. Under these conditions, pest populations grow rapidly, often exceeding the damage thresholds for the plant. (*Figure 14*).

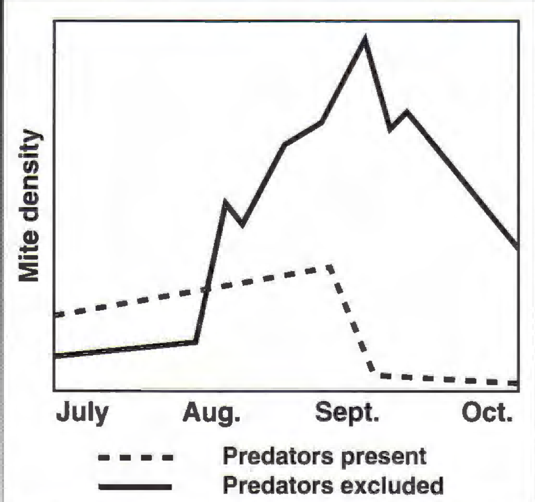
Induced pests

The value of biological control often becomes evident when natural enemies are disrupted by insecticides or other factors, such as road dust or weather extremes.

An example of how insecticides can disrupt biological control is the explosion of mealybug populations in California pear orchards in the early 1960s following treatments with DDT. The DDT destroyed lacewings that normally kept mealybug populations in check. The problem was solved by periodically inoculating orchards with lacewing eggs, as the immature stages of lacewings could tolerate DDT.

Insects that become pests because their natural enemies are killed by insecticides are referred to as insecticide induced pests. Several secondary pests of tree fruits are induced pests. Pest mites are induced by use of pyrethroids, which kill their natural enemies. Western tentiform leafminer and white apple leafhopper are induced to pest status by broad-spectrum insecticides. Crop damage by pests such as San Jose scale and woolly apple aphid may be induced partly by overzealous and mistimed insecticide use. Pear psylla is also an induced pest because broad-spectrum insecticides commonly used to control codling moth kill its natural enemies.

Effect of Natural Enemy



The effect of natural enemies can be demonstrated in experiments by using cages or screens to exclude natural enemies. Invariably, pest populations grow rapidly. In this example, all mite natural enemies were manually removed from an avocado tree for a 3-month period. The density of avocado brown mites on a tree with natural enemies removed is compared with the density in surrounding trees where they were present.

Figure 14

What makes a good natural enemy?

A good biological control agent:

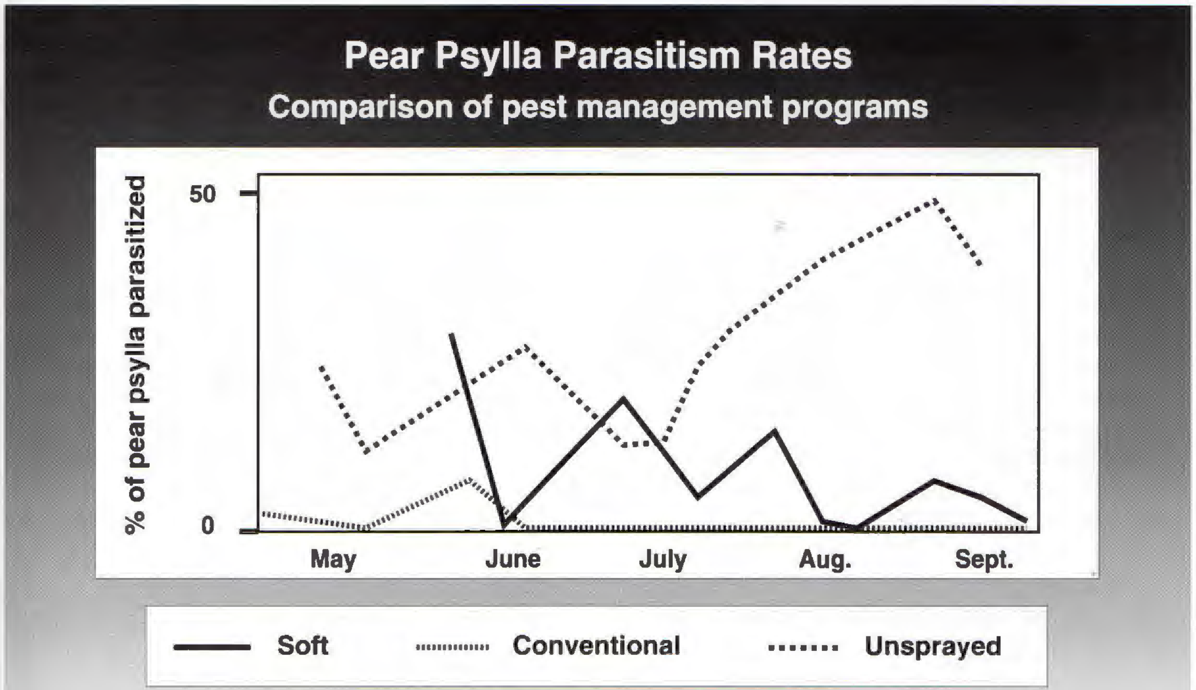
- is adapted to the pest, and preferably specializes on it;
- does not interfere with other natural enemies;
- able to reproduce rapidly;
- is suited to the climate and in synchrony with its host or prey;
- can find its host or prey at relatively low densities.

Specialization

Specialization, the close association of pest and natural enemy, is a key to success in many cases. The woolly apple aphid is controlled in many countries by the parasitoid *Aphelinus mali*, which is its only host. Sometimes there are specialized races of a natural enemy, which differ in their preference for a particular host or prey. For example, strains of *Trioxys pallidus* that were imported for walnut aphid did not control the filbert aphid in Oregon when they were released there. However, a race of *Trioxys pallidus* that attacks filbert aphid was discovered and introduced, which provided excellent biological control.

Interference

As a number of different natural enemies can attack a pest, it is possible that one might interfere with another, resulting in worse control than if just one



Pear psylla parasitism rates by *Trechnites psyllae* are compared in commercial orchards under soft and conventional pest management programs and an unsprayed research orchard.

Figure 15

natural enemy had been present. Such cases are rare, however, and often two or more natural enemy species work in concert to control a pest.

Climatic matching

The natural enemy must be suited to the climate in its new home. Otherwise, cold winters or hot summers may make it ineffective at controlling the pest. Another aspect of climatic matching is synchrony between the population cycles of predator and prey, or parasitoid and host. For example, synchrony is critical in the interaction between pear psylla and one of its natural enemies, the parasitic wasp *Trechnites psyllae*. The wasp lays its egg in the second through fifth nymphal stages of pear psylla. The parasitoid larva develops inside the nymph for about 2 weeks before killing it. Many pear psylla migrate out of the orchard to overwinter and return in early spring to lay eggs. *Trechnites*, however, remains in the orchard. Parasitoid larvae that develop in psylla nymphs in the fall induce their hosts to crawl off the leaves into bark, where mummies are formed. Thus, *Trechnites* overwinters in the orchard in diapause within the host mummy. The timing of pear psylla egg laying, hatch, and population growth in the spring varies considerably from year to year. To control pear psylla, emergence of *Trechnites* must coincide with the presence of young nymphs. Studies in unsprayed pear orchards suggest that *Trechnites* can kill a significant proportion of the spring brood of pear psylla when insecticides are absent (*Figure 15*). However, in some locations, or some years, *Trechnites* is not well synchronized with the development of pear psylla and control is poor. A parasite with better synchrony with pear psylla under Pacific Northwest conditions would be valuable.

Finding the prey

A natural enemy's ability to find and use its prey or host can dramatically affect the success of biological control. How the predator responds to different prey densities is called its functional response. The critical question is: Does the pattern and rate of prey consumption lead to control?

If a predator is to control the prey, a greater proportion of the prey must be killed as prey densities increase. This maintains a stable interaction between predator and prey populations.

There are two types of predator response to increases in prey density (*Figure 16*). With a type A response, the number of prey killed increases at a slower rate at higher prey densities. This means that as prey density increases, the percentage killed decreases. This type of response does not lead to stable predator-prey interactions.

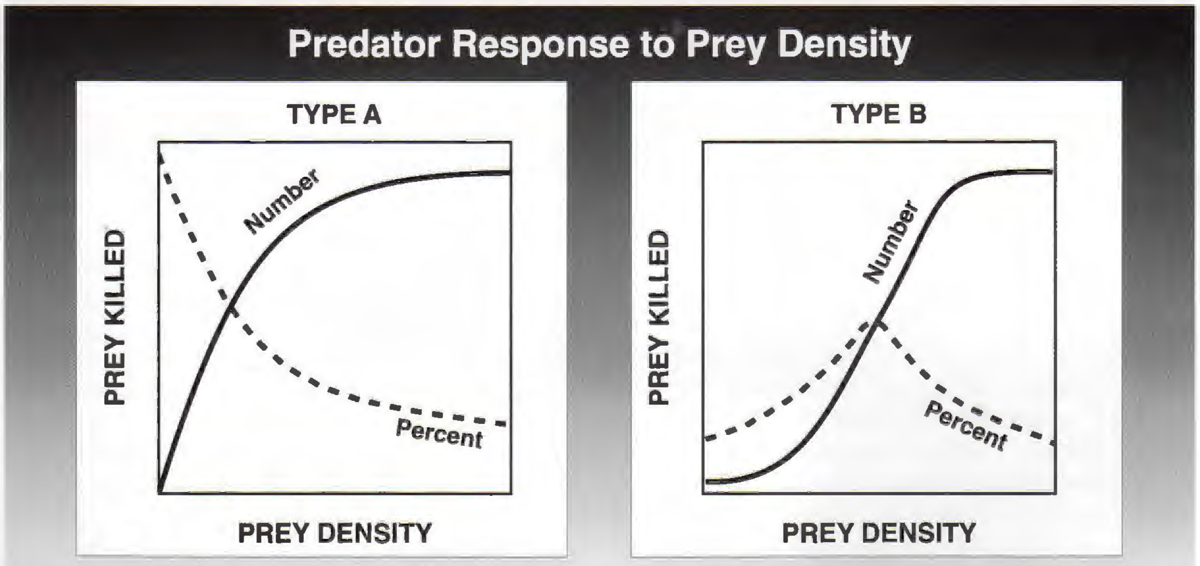
With a type B response, there is an increasing percentage of prey killed as density rises...up to a point. Then, as densities rise further, the increase in the prey consumption slows down and so a lower percentage is killed. This type of response can lead to a stable predator-prey interaction under some circumstances.

Changes in the behavior of the predator can lead to a type B response. Prey switching is one example. A predator may feed on one prey species until another's density increases to the point where it is more profitable for the predator to switch and feed on it instead. Such switches are common among generalist predators.

A searching behavior that increases the likelihood of a predator finding prey at high densities can also result in a type B response. Picture a pest unevenly distributed in patches on leaves of a tree. A predator arrives on a leaf and begins to search. If it fails to find prey after a certain time, it leaves, but if the predator finds a prey, it tends to stay and search the leaf more thoroughly. So, when many prey are on the leaf the predator is more likely to encounter one, which encourages it to look for more. As a result, the number of prey found increases disproportionately as the predator starts actively looking. However, prey densities may eventually reach the point where they are increasing faster than the predator can consume them, and the proportion killed will begin to drop.

Biological control opportunities

Biological control has an expanding role in fruit pest management in the Northwest. Although fruit



Functional response is the change in foraging behavior of a natural enemy in response to changes in the density of its prey. With a *Type A* response, an ever-decreasing proportion of prey is killed as prey density increases. With a *Type B* response, the proportion of prey killed increases at lower prey densities but decreases at higher prey densities.

Figure 16

growers have accepted and used integrated mite management tactics for more than a generation, there is increasing emphasis on the biological control aspect of IPM for other pests.

There are many opportunities to improve biological control of fruit pests. Decisions to spray for a pest must be weighed carefully against the potential effects on predators and parasites. These decisions require better knowledge of the natural enemy complex and relative abundance of natural enemies. These strategies are already available for mites and the tentiform leafminer (see Part III, Indirect Pests).

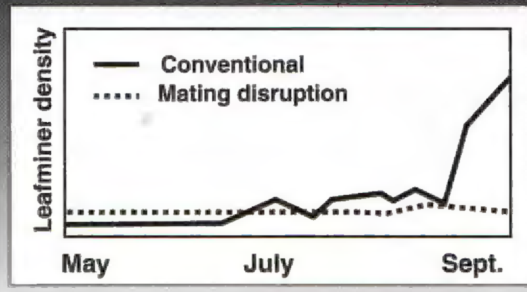
Codling moth is the key to most of the pest management decisions in pear and apple. As a direct pest, one which damages the fruit, it has a low economic injury level (*Figure 13*). Codling moth probably originated in Soviet Central Asia and, with only one of its old-world parasites established in the Pacific Northwest, natural enemies have little impact. For the last 60 years or more, it has been controlled with insecticides, to the detriment of biological control of other pests.

New approaches to codling moth control include mating disruption (see section on Mating Disruption in Part I) and releases of sterile moths. Pests, such as the white apple leafhopper and tentiform leafminer, should diminish in orchards where mating disruption replaces broad-spectrum insecticides (*Figure 17*). In addition, soft insecticide programs, such as those based on insect growth regulators, are being developed and should provide other selective, nondisruptive tools to control pests such as leafrollers and other pests that occur as sporadic outbreaks.

Left uncontrolled, codling moth will damage almost the entire crop. If nothing else, introducing and establishing codling moth's natural enemies in trees outside the orchard, such as in crab apple and back-yard trees, could halve the numbers of codling moth migrating into orchards from those sources.

There has been limited foreign exploration for exotic enemies of pear psylla, which also originated in Eurasia. Studies published in the Soviet Union suggest that parasitoids related to the *Trechnites* species that is found in the Pacific Northwest give good control of pear psylla in eastern Europe and central Asia. It is difficult to find pear psylla there, even in commercial orchards where the climate is

Effect of Pesticides on Western Tentiform Leafminer



An orchard block with a conventional pest management program is compared with a block in the same orchard where codling moth was controlled by mating disruption. Late-season increases in leafminer populations in the conventional block are thought to be due to the destruction of parasitoids and the release of the pest from suppression by insecticides near harvest.

Figure 17

similar to that in the Northwest. It is important to find out if natural enemies are regulating pear psylla in those regions and, if so, what biological control agents should be imported. Similarly, additional natural enemies for San Jose scale, woolly apple aphid and leafrollers should be sought and imported as new biological control agents.

New pests

One of the greatest concern for fruit growers is the invasion of the Pacific Northwest by new pests. Apple maggot and plum curculio, both endemic in the eastern United States, present real threats to the pome fruit industry. Although soft management programs have been developed for apple maggot, they are expensive and labor intensive. No soft insecticide or alternatives are available to control plum curculio. In the eastern United States one or two applications of broad-spectrum insecticides are used for control.

Washington was recently colonized by two exotic pests of apple: apple ermine moth and winter moth. It should be possible to control winter moth by importing and establishing the parasites that now control it in Canada.

An outbreak of apple ermine moth was detected on suburban trees in the Bellingham area in 1985. It has since spread south to the Columbia River west of the Cascade mountain range. Populations near Bellingham have stabilized or declined because of the activities of generalist predators, such as birds and spiders. An important parasite of apple ermine moth from Eurasia has been established in the area to help improve biological control.

Apple ermine moth is not a threat to orchards where broad-spectrum insecticides are used regularly but could be a persistent pest in orchards where codling moth is controlled with mating disruption or sterile males.

Degree Day Models

PHENOLOGY is the study of relationships between the weather and biological processes such as insect development. Phenology models, also known as degree day models, can help predict the best timing of pest management activities such as pesticide applications. These models are based on the fact that an insect's growth is closely linked to the temperature where it is found. Phenology models do not operate on a calendar-day basis, but on a heat unit (degree day) scale. They are usually begun at some easily detected event, such as first flight of codling moth, and are used to predict events that are important, but not easily sampled, such as egg hatch or peak moth flight.

Models are not a replacement for sampling but can be used to predict the best time to sample. For example, the phenology model for the western tentiform leafminer can be used to determine the best time to collect samples to estimate the level of parasitism in each generation.

How degree day models work

Metabolic rates of animals are influenced by temperature. There is generally a temperature at which a chemical reaction goes fastest. At temperatures above the optimum, the enzyme that causes the reaction is disrupted and the reaction slows. If the temperature remains high too long, the enzyme can be permanently disrupted and the animal will die. At temperatures below the optimum, the reaction rate slows down and finally stops.

In warm-blooded animals, body temperatures rarely vary more than a few degrees. So, the rate of chemical reaction is fairly constant and their development can be easily predicted by calendar time. However, insects and mites have no built-in mechanism to regulate their body temperature. So, in general, their body temperature is affected by the surrounding temperature, and development can best be predicted from accumulated heat units rather than calendar time.

Using heat-unit accumulation to predict an insect's development rate works because a specific number of heat units is required for the insect to complete a certain physiological process. The heat unit scale is often called a physiological time scale. Whether

How degree day models are developed

The number of degree days needed for a certain insect to develop can be calculated in a laboratory. Normally, 30 or more insects are reared at a constant temperature and the time needed for each insect to complete each stage — egg, larva, pupa and adult — is recorded. This is repeated at several different temperatures.

The rate of development at the various temperatures is then plotted and from the graph the lower and upper development thresholds and the degree days needed to complete a stage of development can be calculated.

Field information from several different sites and several different years is required to validate the models.

the heat units accumulate quickly or slowly is immaterial (within reasonable limits). A good analogy would be the filling of a gallon container. It doesn't matter how fast or how slowly you do it, it still takes a gallon to fill it.

The temperature limits on physiological reactions are called the upper and lower developmental thresholds. When the temperature rises above the upper threshold, development stops and if temperatures continue to rise, the insect dies. When the temperature drops below the lower threshold, development stops, but insects rarely die unless the water in their cells freezes.

Degree days

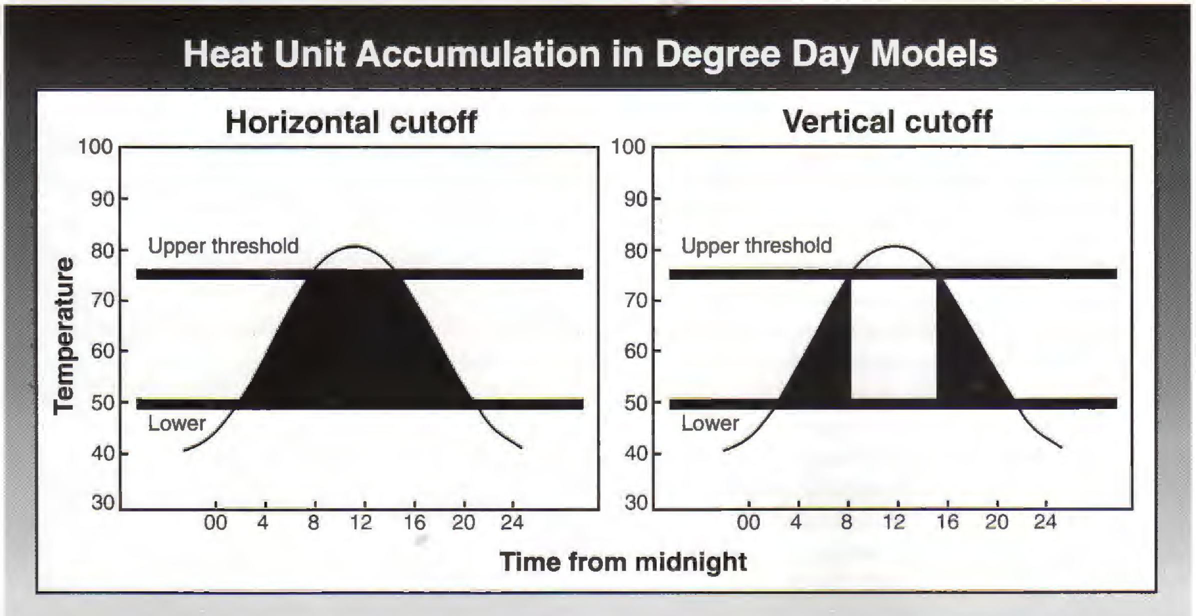
Degree days are used to measure the number of accumulated heat units. A degree day is the heat experienced by the insect when the temperature is one degree above the lower threshold for 24 hours. The starting point for degree day accumulation can be some easily observed event, such as first moth capture in a pheromone trap, often referred to as a biofix or biological fix point. Alternatively, it can be a calendar date, such as March 1, before which there is generally no degree day accumulation. Using a biofix generally gives a better prediction of future life history events, such as egg hatch, because of a better synchronization between the insect's development and degree day accumulations.

Degree day models

Most degree day models use a sine-wave curve, similar to that in *Figure 18*, to approximate the daily temperature cycle from night to day. The upper threshold can have at least two forms:

- A **horizontal** cutoff, where degree day accumulations above the upper threshold do not count ; or
- A **vertical** cutoff, where, once the upper threshold is surpassed, no more degree days are accumulated until the temperature drops below the threshold again.

The degree days accumulated are represented by the area under the curve within the upper and lower thresholds, shown in black in the figure. Although the horizontal cutoff method seems less reasonable from a biological standpoint, it does give better predictions of insect development in some cases. Often, a table is available in which orchardists can look up the maximum and minimum temperatures for each day and find the number of degree days



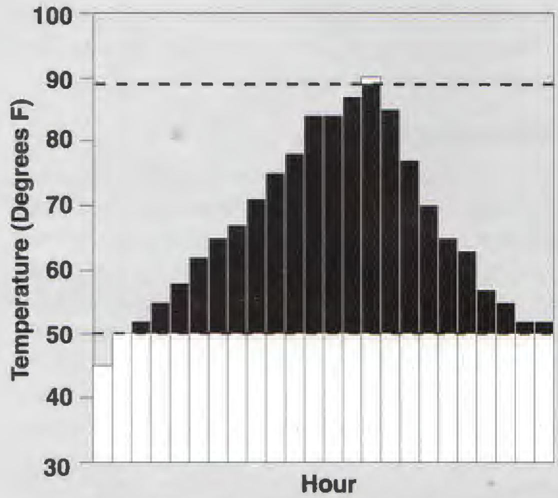
Dark areas represent accumulated degree days.

Figure 18

Calculating Degree Days from Hourly Temperatures

Hour	Temp.(F)	Hourly heat units	Adjusted values
1	45	-5	0
2	50	0	0
3	52	2	2
4	55	5	5
5	58	8	8
6	62	12	12
7	65	15	15
8	67	17	17
9	71	21	21
10	75	25	25
11	78	28	28
12	84	34	34
13	84	34	34
14	87	37	37
15	90	40	38
16	85	35	35
17	77	27	27
18	70	20	20
19	65	15	15
20	63	13	13
21	57	7	7
22	55	5	5
23	52	2	2
24	52	2	2
		Total	402

Divided by 24 hours = 16.75 degree days



Upper threshold 88, lower threshold 50

To calculate degree days from hourly temperatures, subtract the lower threshold (50˚F) from hourly temperature to arrive at hourly heat units. Adjust negative values to 0. For temperatures above the upper threshold (88˚F), subtract the difference between the hourly reading and the upper threshold from the hourly heat units. For example, if the temperature reading is 90˚F, subtract 2. Add the adjusted values for the 24 hours and divide total by 24.

Figure 19

accumulated during that day for a particular insect (see Appendix 1). These daily degree days are accumulated from biofix, or a specified calendar date, and are used to predict the timing of critical life history events.

A direct calculation method where temperatures are recorded at frequent intervals (e.g. hourly) can also be used to determine degree days. Degree days are calculated by adding the number of degrees between the thresholds, then dividing the total by the number of reading times in a 24-hour period (*Figure 19*). Several computerized temperature monitoring devices, known as biophenometers, are available for accumulating degree days in this way. Some allow the grower to program the thresholds and display degree day accumulations at the touch of a button, while others require temperature information to be first downloaded into a computer and then analyzed. Be aware, however, that a direct calculation method will not always give the same degree day values as a sine-wave method. Differences are greatest in the spring and fall. You should know the degree day calculation method used by the model you are following and if you are using a different method of calculating degree days you should know how to adjust values to predict the same life history events. For example, if a sine-wave model is used, the recommended timing of the first cover spray for codling moth control is 250 degree days after biofix, or predicted 3% egg hatch. But if a biophenometer is used, the timing would be approximately 230 degree days after biofix because the instrument tends to accumulate degree days more slowly during the spring.

Successful models

Degree day models for the following tree fruit pests are, or soon will be, available in Washington: codling moth, white apple leafhopper, western cherry fruit fly, San Jose scale, peach twig borer, oriental fruit moth, western tentiform leafminer, apple maggot, pandemis leafroller and obliquebanded leafroller. Probably the most successful degree-day model is the one for codling moth. It is used in most fruit-growing regions of the United States to time sprays. The codling moth model is used to predict egg hatch based on the number of degree days accumulated since biofix, which in this case is the first consistent flight of codling moth. The main objective of cover sprays is to kill the newly hatched codling moth larva before it bores into the fruit. The model allows us to get maximum longevity of the cover sprays. It is critical to apply them as close to the predicted time as possible. If the spray is applied too early the residue will have weathered before the eggs hatch and it must be reapplied that much sooner. When sprays are applied late, more larvae already will have entered the fruit where they are difficult to kill.

Using the calendar method, the first codling moth spray is applied 21 days after first bloom, a timing that is often several days before egg hatch has begun. Some years it could be as much as 18 days early, and the spray residue is effective for only 21 days (*Figure 30*).

Insect Growth Regulators

SEVERAL FEATURES of insect growth regulators (IGRs) make them attractive as alternatives to broad-spectrum insecticides. Because they are more selective, they are less harmful to the environment and more compatible with pest management systems that include biological controls.

Insects have demonstrated a propensity to develop resistance to insecticides. Broad-spectrum insecticides that are used routinely will eventually be lost because of resistance. Intelligent use of IGRs should reduce the likelihood of resistance developing.

IGRs show good potential on pears because their selectivity preserves the natural enemies that can help control pear psylla. Because of its ability to rapidly develop resistance to insecticides, it is important that psylla be controlled by an integrated system, incorporating several control factors, The selectivity of IGRs is due to the different way they act on insects, compared with most conventional insecticides.

Compared with conventional pesticides, insect growth regulators are:

- More selective
- Less harmful to the environment
- More compatible with biological controls
- Less likely to be lost because of resistance

Virtually all chemicals used to control insects fall into one of three categories: neurotoxins, growth regulators and behavior modifiers.

Neurotoxins

Most chemicals used to control insects are neurotoxins, which interfere with normal nerve function. Organophosphate insecticides were derived from nerve gases that were first exploited for military purposes. Other insecticides were discovered by testing chemicals to find those that killed pests quickly. About the only thing that kills quickly is a neurotoxin, so chemicals that acted on neutrotransmissions were sought and developed as insecticides. In the early discovery and development of insecticides, efforts were focused on chemistry rather than biology. As all animals share basically the same neurochemical systems, neurotoxins are toxic to all animals.

Insect growth regulators

The origin of IGRs was entirely different. Their discovery was based on knowledge of how insects grow, develop, function and behave. They have been discovered in two ways. One way was to expose an insect to IGRs and observe abnormalities in how it develops, functions or behaves. Chemicals that produce desired effects were developed. Another was to find out what processes in the insects' development in-volve hormones and to use those hormones as models to synthesize chemical analogs that will interfere with normal insect growth and development. As IGRs act on systems unique to insects, or shared with close relatives, they are less likely to affect other organisms.

Behavior modifiers

Behavior-affecting chemicals, such as pheromones, are discovered in the same way as IGRs, but tend to be even more specific. Pheromones aid the sexes of a single species to find each other so that effort is not wasted chasing mates of a different species.

How insect growth regulators work

Insects wear their skeletons on the outside. The skeletons are called exoskeletons. As the insect grows, a new exoskeleton must be formed inside the old exoskeleton, and the old one shed. The new one then swells to a larger size and hardens. The process is called molting. The changes from larval to adult form, a process called metamorphosis, also take place during molting. Hormones control the phases of molting by acting on the epidermis, which is part of the exoskeleton.

There are three types of IGRs, each of which has a different mode of action:

Chitin synthesis inhibitors

These prevent the formation of chitin, a carbohydrate that is an important structural component of the insect's exoskeleton. When treated with one of these compounds, the insect grows normally until the time to molt. When the insect molts, the exoskeleton is not properly formed and it dies. Death may be quick, but in some insects it may take several days. As well as disrupting molting, chitin synthesis inhibitors can kill eggs by disrupting the normal development of the embryo.

Juvenile hormone analogs and mimics

When applied to an insect, these abnormal sources of juvenilizing agent can have striking consequences. For example, if the normal course of events calls for a molt to the pupal stage, an abnormally high level of juvenilizing agent will produce another larval stage or produce larval-pupal intermediates. Juvenoid IGRs can also act on eggs. They can cause sterilization, disrupt behavior and disrupt diapause, the process that triggers dormancy before the onset of winter. In theory, all insect systems influenced by juvenile hormone are potential targets for a juvenoid IGR.

The early juvenoid IGRs were true analogs of juvenile hormone and were unstable when exposed to ultraviolet light. This seriously limited their use in plant protection. Another group of juvenoid IGRs, called juvenile mimics, was discovered. Entomologist found that extracts of many plant tissues have juvenilizing effects, but they have different chemical structures from juvenile hormones and are much more stable. They have been used as models to synthesize some highly effective and stable juvenile hormone mimics, which have potential to control tree fruit pests.

Anti-juvenile hormone agents

Anti-juvenile hormone agents cancel the effect of juvenile hormone by blocking juvenile hormone production. For example, an early instar treated with an anti-juvenile hormone agent molts prematurely into a nonfunctional adult. A disadvantage of these chemicals is that they are so selective, they may not be economic for a manufacturer to develop.

Managing Pesticide Resistance

THOUGH IT HAS been over 80 years since the first discovery of a major agricultural pest becoming resistant to a pesticide, it was not until the 1950s that most growers became familiar with pesticide resistance as a result of the widespread development of insect resistance to DDT. Since then, growers have come to expect the eventual loss of pesticide effectiveness because of resistance. By the mid-1980s, there were records of about 450 resistant species of insects and mites.

What is resistance to pesticides?

It is essential to distinguish between two common but very different contexts in which the word "resistance" is used. Specifically, it is important to understand how resistance is defined in the scientific context versus how it is manifest in the field.

Resistance as defined in the laboratory

Resistance, from the scientific perspective, is a heritable, statistically defined decrease in sensitivity to a chemical in a pest population, relative to the response of susceptible populations that have never been exposed to pesticides. Resistance can be demonstrated by comparing, in laboratory tests, differences in susceptibility between a population that can withstand to some degree the effects of a pesticide, and a susceptible population.

Evidence of resistance in the laboratory does not necessarily mean that a chemical will fail in the field. Pesticide effectiveness is influenced by several factors and resistant pests may or may not be adequately controlled by the insecticide, given a set of treatment conditions (rate, volume, coverage, etc.). However, the fact remains that resistant pests can be demonstrated to defeat the toxic action of a pesticide to a greater degree than susceptible pests.

Resistance as manifested in the field

Resistance that is manifest in the field results in measurable reductions in the relative efficacy of a pesticide. Estimating the impact of this reduction of control is an important step in managing resistance. To do this, conventional spray trials are replicated, with the same application equipment and conditions used by growers, at field locations with different levels of resistance.

When resistance reduces the relative efficacy of a pesticide, the chemical will provide significantly less control of the pest at locations with higher frequencies of resistance than at locations with lower frequencies, or no resistance. Because field trials usually do not reveal the development of resistance in its early stages, by the time field personnel notice that pesticide performance is declining, resistance often has built up to fairly high frequencies in populations. It is for this reason that information from laboratory tests, rather than field experience, must be used for early detection of resistance.

Loss of relative efficacy of a chemical is not necessarily proof of resistance. For example, some instances of poor pesticide performance initially attributed to pest resistance have proved to be caused by a breakdown of the pesticide by soil microorganisms or high pH of spray water, or by poor pesticide application procedures.

How Resistance Develops

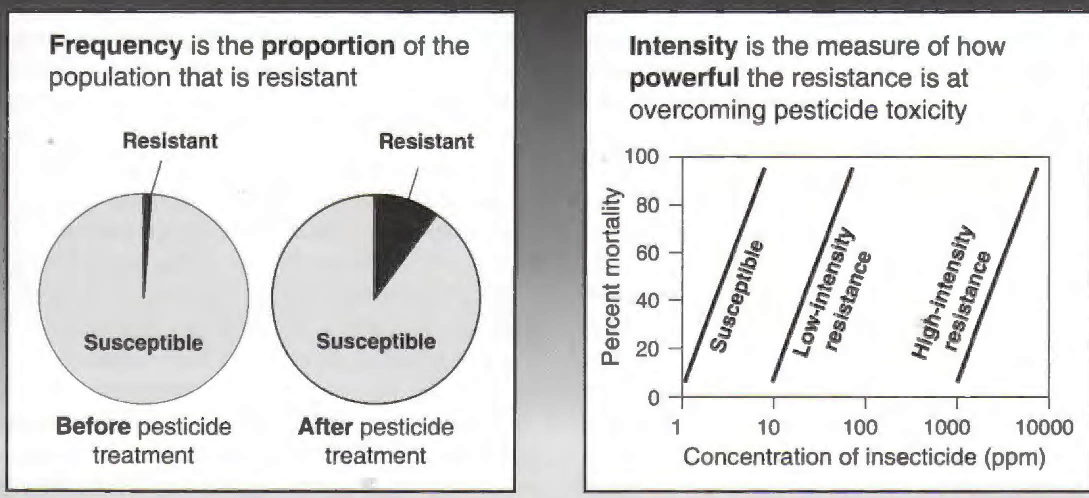
Resistance develops via the process of selection by a chemical on the genetic variation in susceptibility within a pest population.

How selection happens is easy to understand. At first, only a very small proportion of a pest population can survive exposure to the pesticide, but each time the pesticide is applied, a greater proportion of resistant individuals survive than susceptible types. These resistant individuals pass the genes for pesticide resistance to their progeny. Each use of the pesticide increases the proportion of the less-susceptible individuals in the population.

The degree to which resistance reduces the relative efficacy of a pesticide depends on both the *frequency* and *intensity* of the resistance *(Figure 20)*. Frequency refers to the proportion of the pest population that is resistant; intensity is the strength of the resistance in each resistant pest. Obviously, resistance is more likely to become a problem as the frequency of resistant individuals increases in a population. But the intensity of a resistance can also affect the pesticide's efficacy in the field. In some cases, control of the resistant pest is only slightly affected by resistance. In other cases, the pest becomes virtually immune to the pesticide (*Figure 20*).

A pest population may have a resistance of low intensity at a high frequency (proportion of the population) without significantly affecting field performance of the pesticide. On the other hand, a very intense resistance might reduce the efficacy of a chemical, even when present at low frequencies in a pest population.

Frequency and Intensity of Resistance



The frequency and intensity of resistance both determine the degree that resistance will reduce the effectiveness of pesticide applications.

Figure 20

Mechanisms of resistance

There are two common mechanisms by which insects and mites overcome the toxic action of pesticides: increased metabolic detoxication and decreased target site sensitivity. Resistant pests with enhanced metabolic detoxication are able to disarm toxic pesticide molecules more rapidly than susceptible individuals. As a result, less of the active pesticide sprayed on the field reaches the target site in the pest.

With the second common mechanism, decreased target site sensitivity, the physiological target for the pesticide in the resistant insect is less sensitive to poisoning than in susceptible individuals. For example, organophosphate insecticides kill pests by inhibiting acetylcholinesterase, an enzyme that is important in nerve function. Some insects, mites, and ticks resistant to organophosphates have a form of the target enzyme that is less sensitive to poisoning.

Resistance also can be enhanced by reduced cuticular penetration of the pesticide, though this appears to be a less common mechanism than those above. Reduced penetration alone generally results in only low intensities of resistance, but when combined with increased metabolic detoxication or decreased target site sensitivity it can result in very intense resistances. A little-studied but potentially important resistance mechanism involves changes in pests' behavior. It is likely that some behavioral resistances enable pests to reduce contact with pesticides on treated plants.

Cross resistance and multiple resistance

In nearly half the recorded cases of resistant insects and mites, the pests are resistant to between two and five different classes of chemicals. Pests that are resistant to many pesticides pose an especially difficult problem when chemical control is required. Understanding the distinction between multiple resistance and cross resistance is important in order to grasp the practical ramifications of pests having more than one resistance factor.

Cross resistance

Many resistances are conferred by a single major genetic factor that differs between resistant and susceptible pests. When a single factor confers resistance to more than one pesticide, this is cross resistance. For example, a mechanism making insects resistant to parathion also dramatically reduces susceptibility to a number of other organophosphates. Therefore, when parathion becomes ineffective due to resistance, some other organophosphates also lose efficacy because of cross resistance. The key point is that with cross resistance a single mechanism is responsible for resistance to more than one pesticide, and cross resistance can cause resistance to build up to pesticides that you may never have used. cross resistance also means other classes of pesticides, e.g. organophosphates and carbamates, would be less effective where resistance occurs to either.

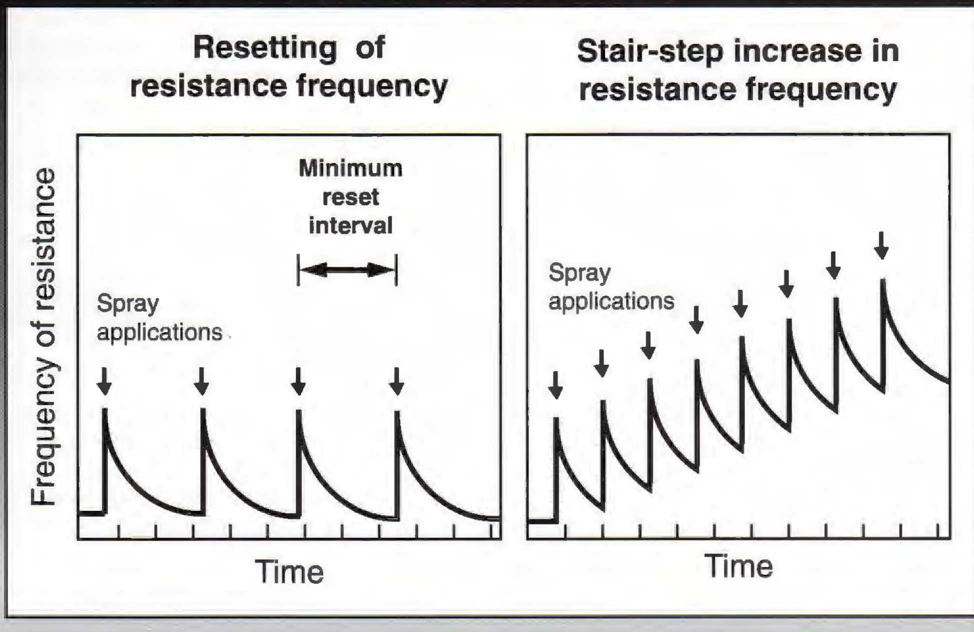
Multiple resistance

With multiple resistances, two resistance mechanisms are acquired independently through exposure to two different pesticides. For example, some spider mites possess resistance to cyhexatin (Plictran) and dicofol (Kelthane). However, these resistances are acquired by two separate genetic modifications, and resistance of the pest to one product does not affect susceptibility to the other. When a pest is resistant to two pesticides the only way to find out if it is due to cross resistance or multiple resistance is by conducting genetic studies in the laboratory.

Resistance stability

Resistances can be either stable or unstable in the field, depending upon many factors involving the pest, the chemical, and the agricultural system used. A stable resistance increases in frequency when a pesticide is used and does not decline appreciably thereafter. An unstable resistance similarly increases in response to pesticide treatments but decreases in frequency during intervals when the pesticide is no longer used.

The phenomenon of unstable resistance can be exploited to manage resistance. Under a given set of circumstances, research can be conducted to estimate the length of time needed for the frequency of resistant pests to be reset, i.e., to decline to levels existing before the last treatment was applied. Then a resistance management program can be developed that employs pesticide rotations that allow for this resetting of resistance. The



When spray applications of a chemical are made to a population with unstable resistance at intervals equal to or greater than the minimum reset interval, it prevents the stair-step increase in resistance that occurs when the chemical is used more frequently.

Figure 21

shortest interval in which the same chemical can be used and still allow resistance frequencies to reset is called the minimum reset interval. If treatments are spaced at less than the reset interval, the resistance increases in a stair-step fashion, but if the interval between treatments is as long or longer than the reset interval, there will be no net increase in resistance (*Figure 21*).

Reset intervals will vary between crops and geographic locations. Once an appropriate reset interval has been established for a system, appropriately selected pesticides can be used in rotation to maintain their efficacy and resistance can be monitored to evaluate the success of the program.

Factors influencing resistance

Researchers have shown that resistance development in pest populations is influenced by many biological, ecological, genetic, and operational factors.

Biological and **ecological** factors include:

- Characteristics of the pest, such as the rate of reproduction, the number of generations per year, and mobility of the species.
- Characteristics of the orchard, such as proximity to untreated areas, suitability of alternate hosts for pest development, immigration of susceptible pests and effectiveness of biological control.

Genetic factors include:

- The number of genes conferring resistance.
- The frequency and intensity of resistance genes in the population.
- The ability of resistant individuals to grow and reproduce relative to susceptible pests.

Operational factors include:

- Characteristics of the chemical.
- Treatment thresholds.
- Application methodology and equipment.
- Chemical use strategies such as chemical rotations or mixtures.

In practice, many of these factors are not readily manipulated by growers. From the practical standpoint, growers wishing to manage resistance should give attention to the following factors:

- How effectively you employ methods of integrated pest management.
- How often you use pesticides.
- How you select and apply the pesticides you use.

Growers who use pesticides the least have the most effective resistance management programs. Resistance cannot be managed in situations where a pesticide is used many times each season.

Chemical use strategies for resistance management

Since selection and use of pesticides are variables that growers can normally manipulate, identifying optimal chemical use recommendations is a critical step in building a resistance management program. Chemical use recommendations are based on one of three different strategies:

- Management by moderation.
- Management by multiple attack.
- Management by saturation.

Management by moderation is probably the most universal principle for successfully managing resistance. It involves reducing overall chemical use or persistence by:

- using lower dosages of pesticides (when appropriate);
- using higher treatment thresholds;
- using chemicals with shorter residual activity;
- treating only limited areas in orchard;
- maintaining unsprayed areas as refuges for susceptible individuals; and
- spraying only specific pest stages.

Many of these approaches are already common components of IPM programs. Practices that protect and promote natural enemies contribute to resistance management since they reduce pesticide use. In addition, natural enemies consume resistant and susceptible individuals indiscriminately, thus helping counteract pesticide selection.

Management by multiple attack involves using either mixtures or rotations of pesticides to thwart resistance. Use of mixtures, for example tank mixes of two or more pesticides, is based on the concept that insects resistant to one pesticide will be killed by the other component(s) of the mixture, and that few pests will be resistant to the entire mixture.

Though mixtures of fungicides have been used for years to combat resistance, both field experience and models have shown that mixtures should be avoided whenever possible with insects and spider mites. Commonly, use of mixtures of insecticides or acaricides has resulted in pest populations developing high frequencies of resistance to all pesticides in the mixture, an outcome with disastrous consequences for IPM programs. By far the safest approach is to rotate insecticides or acaricides so that each product is used as seldom as possible in any given season.

Management by saturation involves methods that overcome resistance mechanisms present in pests. The most common method is to combat resistance by using high rates of pesticides, ones that kill even resistant individuals. Deceptively reasonable on first inspection, this approach rarely works in practice. The reason is that pesticide residues are usually deposited very unevenly in most field situations, even when very high rates are used. Uneven deposition of pesticides allows resistant pests to survive in greater proportions than susceptible, thereby increasing resistance. In addition, use of high rates can have many detrimental impacts on natural enemies, the environment, and human health.

A completely different application of the management by saturation concept involves using chemical synergists, products that enhance the action of pesticides. Some synergists have been used successfully to neutralize metabolic pathways conferring resistance.

Proactive versus reactive resistance management

In the past, resistance studies typically have been undertaken or supported by chemical manufacturers only after a pesticide has been used for many years and failures of the product in the field have become commonplace. This is reactive resistance management. Resistance is known or strongly suspected because of repeated reports of product failure, and the initial research objectives are to develop ways to monitor resistance, assess its intensity and frequency in field populations, and characterize the biochemical mechanism of resistance. Thereafter, field studies focus on understanding how quickly resistance builds up following chemical treatment and how fast, if at all, it declines in the absence of the pesticide.

In recent years, progressive chemical manufacturers have not waited until their products have failed before initiating resistance management efforts. Some producers are now addressing management of resistance from the very early stages of product development. They are collecting base-line susceptibility information from populations collected from around the world, looking for potential resistance problems, and proposing provisional resistance management strategies for their products early in the process of development. These proactive resistance management efforts reflect an overall increase in the sophistication of chemical industry's resistance management efforts and are likely to prove very beneficial.

Resistance management as a component of IPM

Pesticide resistance management will extend the useful life of valuable IPM-compatible pesticides. Yet, resistance management is likely to be successful only where orchardists:

- routinely monitor pests;
- use reasonable treatment thresholds; and
- make full use of non-pesticidal methods, such as biological and cultural control, sanitation and host plant resistance.

For well developed IPM systems, like those of Pacific Northwest tree fruit, researchers have made considerable progress toward putting in place the essential components of resistance management programs. For example, the efficacy of acaricides for mite control in the Pacific Northwest has been sustained for long periods of time, where they were used as part of IPM programs.

The lack of registration of new pesticides, coupled with a loss of registered pesticides to the regulatory process or to resistance, will leave growers with few or no registered products that adequately control key pests. It is unrealistic to believe that we can successfully manage resistance if pesticides are not used sparingly. Experience from the Pacific Northwest and elsewhere demonstrates that with good IPM practices, the efficacy of key pesticides can be prolonged considerably and, in some cases, maintained indefinitely.

Mating Disruption

MATING DISRUPTION involves the use of sex pheromones to prevent male insects finding females and mating. Pheromones are chemicals produced by an insect to communicate in some way with others of the same species.

There are several types of pheromones. For example, ants lay a trail pheromone to direct other ants to a food source. Aphids release an alarm pheromone that warns other aphids of potential danger, usually the presence of a predator or parasite. Sex pheromones are chemicals released by female insects to attract males from long distances to mate. A female releasing a pheromone is said to be "calling" the male. The male flies upwind, crisscrossing the pheromone plume, following the increasing concentration until it finds the source (*Figure 22A*). After mating, the female stops calling.

Pheromones of many different insects have been identified and synthesized. When a small amount of a species' pheromone is put into a rubber or plastic dispensers and placed in a trap, males of that species are attracted to the trap as they would be to a calling female. These ***pheromone traps*** are used to monitor the activity or even estimate the density of some Lepidoptera that are pests of fruit crops.

The pheromone of most moths has from 2 to 6 components. Different components or different ratios of the same components make them specific attractants for a species. For example, several leafroller species have pheromones with the same components. Specificity results from components being present in different ratios in different species. Other insects, such as campylomma, scales and mealybug, also produce pheromones, and may be candidates for mating disruption.

How mating disruption works

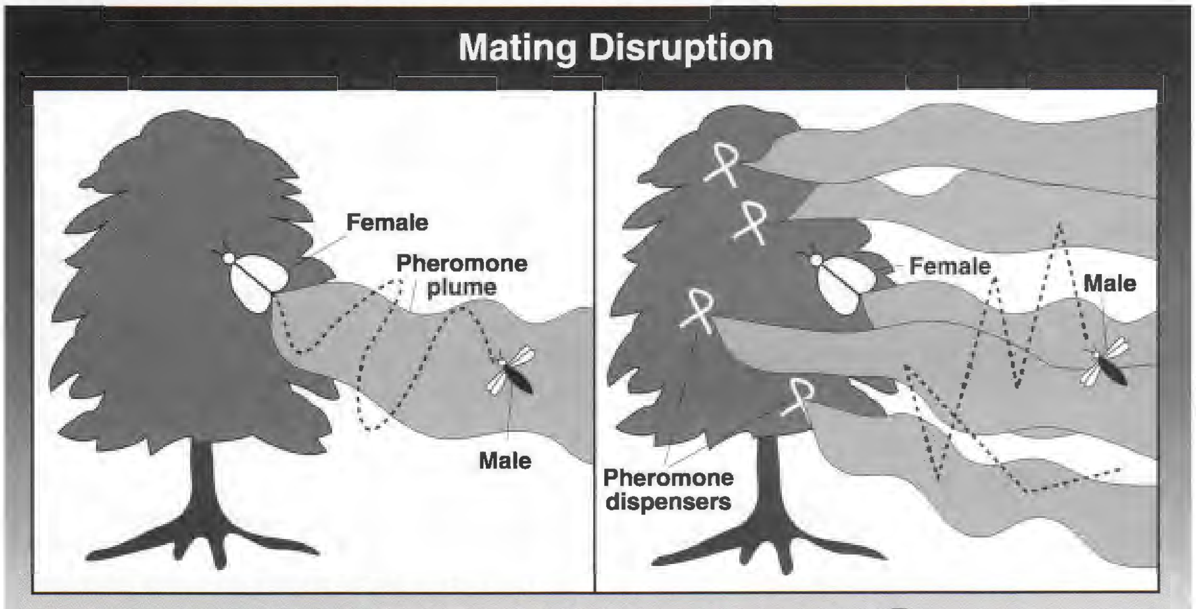
There are several ways mating disruption may work. Dispensers in the orchard might mimic a calling female, attracting the male to many false sources. Or, dispensers might release so much pheromone that the background concentration masks normal communication.

It is important to understand how mating disruption works because different mechanisms can influence how pheromones should be used in the orchard. Four different mechanisms have been proposed to explain how mating disruption works. It is possible that for a pest species more than one of these mechanisms could be operating at the same time to achieve control. The mechanisms are:

- **Adaptation or habituation:** Long-term exposure to a stimulus can affect the sensory organs or nervous system of an insect, so it does not function properly. Moths detect pheromones through olfactory receptors on their antennae.

Adaptation occurs when sensory organs are exposed constantly to high and uniform levels of pheromone in the orchard, inhibiting their ability to detect the pheromone. Adapted sensory organs recover rapidly, in 2 to 3 seconds, when they are no longer exposed to the pheromone.

Habituation occurs when high concentrations of a pheromone inhibit the insect's ability to respond for several minutes or even a few hours. The effect is apparently on the nerve that fires in response to high concentrations, but does not recover normally. Then, when exposed to a normal amount of pheromone, the nerve does not send the proper



Normal mate location, where the female releases pheromone and the male flies towards the source.

In mating disruption, pheromone is released from dispensers that act as false sources, or pheromone is released at such a high rate that the male is disoriented or unable to detect the plume of the calling female.

Figure 22

signal. Habituation could play an important role in mating disruption by making males less responsive for long periods after exposure to high concentrations of pheromone.

• **False trails:** Unlike habituation or adaptation, this mechanism assumes the male moth can still sense and respond to the pheromone. If numerous sources of pheromone are placed in the orchard, male moths would spend time and energy following pheromone trails to false sources. If there were enough false sources, the chances of a male finding a calling female would be very low. Ideally, the false pheromone sources would be distributed evenly and would all emit about the same amount of pheromone as a calling female. (*Figure 22B*)

Most dispensers used in mating disruption release much more pheromone than a calling female. While male moths are no longer attracted to a pheromone source when the concentration gets too high, false-trail following might still be the mechanism at work. The male moths may follow false pheromone trails until they reach concentrations that are too high and no longer attractive.

• **Masking:** This mechanism also assumes the moth's sensory system is working normally. In this case, the background level of the pheromone is high and uniform enough to mask the odor trail from a calling female. The male's normal navigation system for finding a mate is useless in the pheromone fog.

• **Imbalanced sensory input:** The pheromone of most moths has more than one component. Even where the pheromones of different species have the same components, different ratios make them distinctive. If a single component of the pheromone, or an altered ratio of components, is released, males might not be able to detect or find the blend of pheromone released by females. If they continually receive signals that are out of balance with the one their sensory system is designed to pick up, their mate-seeking behavior might be inhibited. Antipheromones are chemicals that resemble the true pheromone or may have completely different chemical structures. It is possible that some antipheromones compete with the true pheromone for the same receptor sites on the moths' sensory organs. However, some antipheromones that do not chemically resemble the true pheromones may also block mate location.

Pheromone dispensers

The dispensers used to release a pheromone in mating disruption are just as important as using the right chemicals. If the right pheromone is used, but is released too slowly, then the concentration in the atmosphere might be too low to block mate finding. If, on the other hand, the dispenser releases pheromone too fast, control might not last as long as needed.

Several types of dispensers have been used in mating disruption tests. Pheromones have been impregnated in rubber tubing, incorporated in plastic wafers, placed inside hollow fibers and even formulated into sprays.

The most common dispenser systems used in mating disruption on fruit crops incorporate pheromones in plastic tubes, ampules or packets designed to release the product slowly over several weeks. The dispensers are usually placed in the orchard by hand, at a rate of 150 to 400 per acre. Different dispenser systems containing the same pheromone may not provide the same level of pest control. It will take careful research on each type of dispenser system to find out how well they disrupt mating.

Benefits of mating disruption

• Improved biological control

The use of mating disruption to control a key pest, such as codling moth, would reduce the use of broad-spectrum insecticides in Pacific Northwest orchards and improve biological control of many other pests.

In 1989, more than a third of all insecticides applied in Washington orchards were aimed at codling moth. Secondary pests, such as aphids, leafhoppers and leafminers, have developed resistance to insecticides used against codling moth, so orchardists have also had to apply other insecticides to control those insects. Eliminating the broad-spectrum organophosphates used to control codling moth would allow better survival of natural enemies of aphids, leafhoppers and leafminers. In many orchards, these secondary pests could eventually be controlled by their natural enemies.

Use of mating disruption over several years could suppress pest populations to very low levels, or even lead to local eradication. Under these conditions, controls may be suspended until pest populations increase again. The recovery of the pest population could be monitored with pheromone traps or by inspecting fruit at harvest.

• Slower development of pesticide resistance

Pesticide resistance is all too common in agriculture. Mating disruption is an alternative control tactic that could help slow the development of resistance to insecticides. It is important to conserve the usefulness of insecticides at a time when many are being lost in the re-registration process.

• Less exposure to pesticides

Exposure of farm workers to insecticide residues during fruit thinning and harvest is another important issue. Pheromones are not toxic to mammals at the levels released in mating disruption programs. As the chemicals are enclosed in the dispenser packet, workers are not directly exposed to them.

• No residues

As pheromones are not applied directly to the fruit, there are no residues on the crop. The use of mating disruption to control key pests could help reduce the already low levels of insecticide residues on fruit. Consumers who have difficulty understanding the complex issues of food safety would welcome technology that reduces chemical residues on their food.

Factors influencing mating disruption

• Size and location of orchard

Mating disruption may not work for every insect that communicates by pheromones, nor will it work equally well in every location. The success of mating disruption can be influenced by orchard size and isolation. In small orchards (less than 10 acres) or in larger ones near a source of the pest, mating disruption may not provide reliable control. The pheromone does not kill the pest, thus, mated females can fly into the treated area and lay eggs, producing larvae that will cause damage. For an insect like codling moth, isolation of between 50 and 100 meters (55 to 110 yards) should be adequate. Border sprays may be needed as part of a mating disruption program if a source of the pest is nearby.

• Pest levels
Mating disruption alone will normally not be adequate to reduce high pest populations to non-damaging levels. It is primarily intended as a tactic to keep pest populations low. The first year mating disruption is used, insecticidal control may be required to reduce pest populations to levels that can then be maintained by pheromones alone.

• Non-target pests
The highly selective nature of mating disruption has a negative side. Pests that were kept at non-damaging levels by insecticides aimed at the target pest of mating disruption will be released from control. Predators and parasites will keep some of these pests below damaging levels, but others may have to be controlled with insecticides. Thus, the switch to mating disruption as a control for codling moth does not mean that insecticides will not be needed to control other pests.

• Monitoring
More intensive monitoring will be needed in a mating disruption program. Because the target of mating disruption is not killed by the treatment, its activity and density in the orchard must be followed to insure control is adequate. Although monitoring has been encouraged in the past, the reliance on insecticides for control meant little was actually done. To take full advantage of mating disruption and the increased potential for biological control of other pests, it will be necessary to monitor populations of pests and their natural enemies.

• Cost
The cost of mating disruption will be higher than conventional chemical control, at least in the short term. In 1991, the cost of a mating disruption program for codling moth in apple averaged about 50% more than an average chemical control program. Cost differences between mating disruption and conventional programs could lessen if sprays for secondary pests, such as aphids and leafminers, are eliminated because of better controls. However, if pests that had been controlled by codling moth sprays increase, additional sprays might be needed.

• Other factors
Other factors might influence the success of mating disruption, and these need further research. The uniformity of the orchard canopy can affect distribution of the pheromone, leaving areas where control could fail. In orchards on windy sites or steep slopes, the pheromone might not be evenly distributed throughout the orchard or might not be in high enough concentrations to provide control. Weather patterns could also influence the success of mating disruption. Mating disruption in regions with high summer temperatures might require dispensers with different release rates than those in cooler regions.

Mating disruption in the Pacific Northwest

Several characteristics of fruit production in the Northwest make mating disruption appealing and may contribute to its success.

• Pest complex
The insect pest complex attacking fruit crops in the Pacific Northwest is smaller than in the eastern United States. The absence of pests such as the apple maggot and plum curculio should make mating disruption for codling moth and leafrollers more feasible, since if these pests were present, 3 to 5 additional insecticide treatments would be needed. Also, populations of most pests, especially codling moth, are already low in most commercial orchards because of broad-spectrum insecticide use. This means mating disruption could be implemented immediately without having to reduce pest levels first.

• Contiguous plantings
Most orchards in the Pacific Northwest are not isolated units, but contiguous plantings, often of several hundred acres. That, plus the tradition of controlling pests on a regional basis, could work to increase the chances of success of mating disruption.

• Lack of alternate hosts
The habitat surrounding most Northwest orchards does not contain alternate host plants for the targets of mating disruption. The chance of pests immigrating from native habitats is thus much lower than in regions where orchards are surrounded by hosts for target pests.

• Natural enemies
Without the disruption caused by broad-spectrum insecticides, natural enemies can provide biological control of some pests. This is especially true for the western tentiform leafminer and possibly the apple aphid, white apple leafhopper and grape mealybug. Although more research is needed, there is evidence that orchardists would be able to rely more on biological control where mating disruption is used for codling moth control.

Regulation and registration

The U.S. Environmental Protection Agency (EPA) regulates only certain uses of pheromones. The use of pheromones in traps to monitor insects is not regulated. However, if the intent is to prevent, destroy, repel or otherwise mitigate a pest population, the EPA considers pheromone a pesticide and regulates its use through registration.

The EPA has recognized that pheromones are inherently different from conventional pesticides and supports the concept of mating disruption as an environmentally safe pest control tactic. Pheromones have a unique, non-toxic mode of action, are highly specific, occur naturally, and are used in very low volumes.

The EPA has developed a tiered testing scheme to ensure that the minimum amount of data is needed to register them. Pheromones do not need to undergo further testing if they pass all the first tier data requirements. The EPA has waived the requirement for a tolerance on food crops, as the chances of residues are nil. The EPA has registered phero-mone products to control oriental fruit moth, peachtree borer and codling moth, as well as pests on some non-food crops. It has taken much less time to register these products than to register conventional pesticides.

Mating disruption successes

One of the most successful examples of mating disruption has been on oriental fruit moth. Control of oriental fruit moth with a pheromone has been reported to be as good or better than with conventional insecticidal control in several orchards in California. The pheromone was registered in 1986 and in 1990 was used on 10,000 acres of peach orchards in Washington and California.

A pheromone product to control codling moth was registered in 1991. Research has produced mixed results, although under the right conditions the product has given good control.

TORTRICID MOTHS

This is one of the largest families of moths, with about 950 North American species. It includes a number of important tree fruit pests, such as codling moth, oriental fruit moth and leafrollers. The moths are small, usually gray or brown, and their wings have bands or mottled areas. The front wings are usually square tipped. While at rest, the moths hold their wings rooflike over the body.

Codling moth

Cydia pomonella (Linnaeus)

(Lepidoptera: Tortricidae)

Codling moth originated in Asia Minor, but has been a principal pest of apple and pear in North America for more than 200 years. With the exception of Japan and part of mainland Asia, it is found wherever apples are grown throughout the temperate regions of the world.

Its larvae bore deep into the fruit, making it unmarketable. If uncontrolled, codling moth can destroy most of the crop. By the first half of the 20th century, it was a major pest in all apple growing districts of North America. It was not until synthetic organic insecticides became available in the late 1940s that it could be maintained at very low levels in commercial orchards. It can produce from 1 to 5 generations a year, depending on the climate.

Hosts

Codling moth prefers apple but also attacks pear, large-fruited hawthorne and quince. In California, races of codling moth attack prune and walnut. Pears are resistant to attack when small because of their hardness but may become heavily infested in late summer as they mature. Infestations in stone fruits such as apricot and cherry are extremely rare, and usually occur only where heavy infestations of apple or pear are nearby.

Life stages

Egg: The codling moth egg is oval, flat and, when first laid, almost transparent. It is about 1⁄12 inch (2 mm) long. Eggs are laid individually on leaves or fruit and are almost impossible to find, especially in a commercial orchard.

Larva: The newly hatched larva is only about 1⁄10 inch (2 to 3 mm) long. Its head is black and the

Figure 23: The mature codling moth larva has a pink body and a brown or black head capsule and thoracic shield.

Figure 24: The wings of the adult codling moth have fine alternating gray and white bands and are tipped with a patch of bronze scales.

Figure 25: A codling moth larva overwinters inside a cocoon.

Direct Pests

body is creamy white. The full grown larva is ½ to ¾ inch (12 to 20 mm) long, has a brown or black head capsule and thoracic shield. The body is usually creamy white but turns slightly pink when mature (*Figure 23*). Unlike other caterpillar larvae that feed inside the fruit, such as oriental fruit moth and lesser apple worm, the codling moth larva feeds in the center on flesh and seeds. The others feed on flesh away from the center.

Pupa: The codling moth pupa is brown and about ½ inch (12 mm) long. It lies inside a cocoon spun by the mature larva beneath bark scales on the tree or in a sheltered place at the base of the tree.

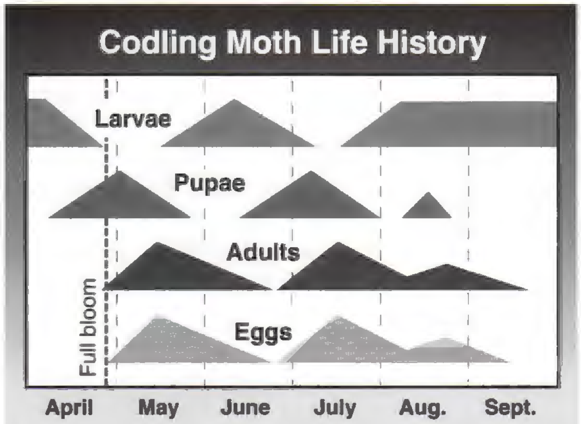
Adult: The adult codling moth is about ½ inch (12 mm) long. At first glance, it seems a nondescript dull gray, but closer inspection shows the wings are crossed with fine alternating gray and white bands. The wings are tipped by a patch of bronze-colored scales that reflect in sunlight (*Figure 24*). The moth holds its wings tent-like over its body when at rest.

Life history

The codling moth spends the winter as a mature larva in a cocoon (*Figure 25*). Larvae are found under loose bark scales on the tree, in litter at the base of the tree, in wood piles, on picking bins in the orchard or on farm buildings near packing sheds where culled apples might have been dumped. Overwintering larvae begin changing into pupae when the first apple blossoms show pink color.

The first adult moths begin to emerge about full bloom of Red Delicious (*Figure 26*). Peak emergence is usually 17 to 21 days later, though this depends on temperature. Adults continue to emerge for 6 or 7 weeks and are most active on warm evenings when temperatures are above 60°F. Moths mate and begin laying eggs within a day of emerging. First generation eggs are laid primarily on leaves, although some are found on fruit. They take 8 to 14 days to incubate.

Newly hatched larvae find fruit and enter either at the calyx end or through the side. They bore through the skin and feed on the fruit flesh for a few days, then move towards the core where they feed on seeds and flesh. As they feed, they push excrement out of the apple through the entry hole, which is gradually enlarged and often serves as an exit hole (*Figure 27*).



Codling moth usually develops through two generations a year in the Northwest. In warm years, a partial third generation may be produced. Timings are based on observations on Red Delicious apples in Washington.

Figure 26

When the larvae are fully grown in three to four weeks they leave the fruit in search of sheltered places to spin cocoons. The larvae may pupate and emerge as second-generation adults or remain as larvae until the following spring. Each year, some first generation larvae enter diapause, a state of delayed development and inactivity. The rest stay in the cocoon for 2 to 3 weeks, then emerge as adults.

Second generation adults begin emerging in early July. Adult activity peaks in mid-July to early August and continues into early September. Second generation larvae are in the fruit from mid-July until late September. Mature larvae of the second generation leave apples as early as mid-August in search of overwintering sites.

In exceptionally warm years a partial third generation may be produced. Moths representing a third flight emerge in late August or early September and deposit eggs. While larvae will enter fruit, causing severe damage in some cases, they usually do not complete development before winter conditions arrive or the fruit is harvested.

Damage

Damage is caused by feeding of the larvae in fruit. There are two types of damage: deep entries and stings. Deep entries occur when larvae bore to the center of the fruit and feed on seeds. Brown frass, or excrement, extrudes from the entry hole or a new hole destined to be an exit (*Figure 27*). In pear, this type of injury is first noticed in the calyx. On more mature fruit, a new entry is often surrounded by a red ring (*Figure 28*).

Stings are shallow entries where the larvae died or gave up and tried another place. Both types of damage make the fruit unmarketable, but deep entries are a problem in stored fruit because bacteria and fungi in them lead to fruit rot.

Monitoring

Pheromone traps can be used to monitor adult activity. Place traps in the orchard by the pink stage of apple flower-bud development. Examine traps each day until first moths are captured, usually about full bloom. Trap placement and maintenance are critical for reliable information. Place traps at mid-canopy height and within the canopy of the tree, making sure the entrance is not blocked.

The wing-type trap, such as Pherocon® 1CP (*Figure 29*), is recommended as a monitoring standard. This trap must be well maintained to work properly. Make sure the trap maintains its proper shape, change pheromone caps every 4 weeks (or as recommended by the manufacturer) and change trap bottoms after catching 30 moths, or every time a cap is changed. Stirring the adhesive surface of the trap will increase its effectiveness in areas where dust is prevalent. Moth capture in pheromone traps is used to initiate the codling moth degree day model, but can also be used to determine the need to apply sprays.

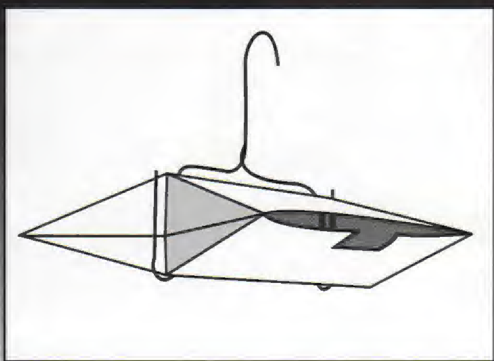
To assess fruit damage, examine fruit at the end of the first generation, in early July, and again just before harvest. Examine 25 fruit per tree from at least 40 trees per block of 5 acres. In large trees, most damage occurs in the upper half, so sample in this area. It is critical to assess fruit damage when sprays are not applied because of low trap catch or if soft insecticides or mating disruption are used for control.

Some organic growers have banded trees with cardboard strips as a monitoring or control technique. Mature larvae migrating down the tree in search of shelters to spin cocoons will enter these bands. Bands can be removed and examined after

Figure 27: Deep entries are caused when larvae bore to the center of the fruit. Brown frass, or excrement, extrudes from the entry hole in the fruit or from a new hole destined to be an exit.

Figure 28: A recent entry in mature fruit with a small amount of frass and surrounded by a red ring.

Codling Moth Trap



A wing-type pheromone trap is recommended for monitoring codling moth.

Figure 29

the first generation or after harvest. If the intent is to estimate the population, 40 bands per block are recommended. This technique is much more efficient on young trees with smooth bark. In older trees the bark should be scraped and the bands attached in the scraped area.

Biological control

Several parasitoids attack codling moth. However, it is impractical to rely upon them alone to suppress codling moth populations to levels that would result in acceptable crop loss. Most conventional insecticides are toxic to these natural enemies. Where mating disruption or soft insecticides are implemented, parasitoids can be an important component of the control program.

Trichogramma minutum is a parasitoid of the codling moth egg. It can parasitize a high percentage of eggs in favorable conditions. Another parasitoid, *Ascogaster quadridentata*, was introduced to the United States from France as a possible control for codling moth. It attacks the codling moth egg but does not kill the host until the larva is nearly full grown. This parasitoid is easily reared in the laboratory. (See section in Part IV, Natural Enemies and Pollinators, for more information.)

Management

Degree day model

Insecticides have been the primary control tactic used against codling moth for over 50 years. Since the early 1980s a degree day model has been used to help time insecticide applications to make better use of chemical controls. The lower and upper thresholds for codling moth are 50 and 88°F. A horizontal cutoff is used when calculating degree days using maximum and minimum temperatures. A degree day look-up table for codling moth is given in Appendix 1.

Pheromone traps are used to establish the biofix (biological fix point) for the model. Place traps in the orchard at about 160 degree days from March 1 or at the pink stage of Red Delicious flower bud development. First codling moth usually fly at full bloom. The codling moth model is started with the first consistent catch of moths in traps. Traps within a region should be placed in locations where codling moth populations are known to be fairly high. The first consistent moth catch is when several moths are caught in a single trap in one night or when a majority of traps within a similar growing region catch one or more moths on the same night.

In some years, a few moths may be captured on one night and it appears to be a good biofix. Then, a cold period follows when no more moths are captured. If this period is prolonged, 7 to 10 days, ignore the first moth catch and start the model based on the next consistent moth capture. In many apple and pear orchards, codling moth populations are very low and moths may not be caught until several days after biofix for the region. If you do not trap moths, use the date of full bloom to begin the degree day accumulation for the codling moth model.

Set the degree day total to zero at biofix. Apply the first control spray after 250 degree days are accumulated, which coincides with first observed entry where codling moth pressure is high. Timing of the second spray will depend on the product used. Some insecticides provide 21 days of residual control, while others may only provide 10 to 14 days. The target of most conventional insecticides is the young larva hatching from the egg. The goal is to kill the larva before it can bore into the fruit. The egg hatch period lasts 30 to 45 days, so usually only two control sprays are required against each generation.

Timing of sprays against the second generation is also based on degree day totals. Apply the first spray against the second generation at 1250 degree days after biofix. Timings of subsequent sprays should be based on the residual life of the products used.

Figure 30 shows how accurate the degree day model for codling moth has been in predicting the first fruit entry compared with a calendar approach. In 10 years, the degree day model predicted larval entry the same day it was observed and was at worst only 2 days early or late. By comparison, the calendar approach, which recommends the first spray 21 days after full bloom, was almost always early, in some cases by as much as 18 days.

Mating disruption

Mating disruption is a promising control tactic for codling moth. Dispensers are placed in the orchard before first moth flight. The number of dispensers, placement and treatment intervals may vary depending on the type of product used. See the section on Mating Disruption in Part I for information on the special requirements of this type of management approach. While monitoring for pests is recommended in any pest management program, it is essential in a pheromone-based program.

Soft pesticide programs

Codling moth has not been controlled satisfactorily with soft pesticides in the hot, dry regions of the west. *Bacillus thuringiensis* (Bt) products used alone have not provided satisfactory control, even when applied weekly. Neither have viruses proven effective. Organic growers have used combinations

Comparison of Spray Timing Methods for Codling Moth

Year	Full bloom	Biofix (1st moth)	Calendar method	Model method	Observed 1st entry	Model accuracy	Calendar accuracy	Days between biofix and 1st entry
79	Apr 28	Apr 29	May 19	May 22	May 22	0	3	23
80	Apr 26	Apr 27	May 17	May 21	May 21	0	4	24
81	Apr 23	Apr 22	May 14	May 29	May 27	-2	13	35
82	May 5	May 3	May 26	May 28	May 28	0	2	25
83	Apr 24	Apr 28	May 15	May 24	May 23	-1	8	25
84	Apr 30	May 6	May 27	June 8	June 8	0	18	33
85	Apr 30	Apr 29	May 21	May 23	May 22	-1	1	23
86	Apr 25	May 1	May 16	May 29	May 29	0	13	28
87	Apr 23	Apr 20	May 14	May 10	May 12	2	-2	22
93	May 6	May 5	May 26	May 20	May 20	0	6	15

Biofix: The first capture of male moths in pheromone traps.
Calendar method: Spray 21 days after full bloom.
Model method: Spray 250 degree days after biofix.
Accuracy: Difference, in days, between observed first larval entry in the field and predicted timing. Negative numbers indicate predicted timing was too late; positive numbers indicate predicted timing was too early.

Figure 30

of Bt, virus and botanical insecticides plus sanitation with reasonable success. The botanical insecticides have probably provided most of the control in these programs. Use of summer oil sprays has shown promise for controlling codling moth on pear and may have a place in soft pesticide programs on apple.

Treatment thresholds

Another use for pheromone traps is to estimate population levels to help make control decisions. The number of traps used, location and maintenance of traps, and the quality of the pheromone trap are all critical to the successful use of a threshold-based decision making program.

Use one trap (Pherocon® 1CP wing type trap or similar) for every 2.5 acres. Place in the orchard before the first moth is active. Trap placement within the orchard and tree will influence moth captures. Traps should not be placed at the very edge of a block. Placing a trap in the center of the 2.5 acres to be monitored by the trap is the standard approach, but placement toward a border with known high pressure is an acceptable alternative. Attach the trap to a limb within the tree canopy at a height of 6 to 7 feet. A pheromone cap loaded with 1 milligram of codlemone, the major component of the codling moth pheromone, should be used as a lure. Replace pheromone caps every four weeks.

Check traps once a week after the first moths are caught. After 30 moths have been captured, or if the trap becomes dirty in the meantime, change the trap bottom. The trap adhesive should be evenly distributed over the bottom of the trap. Count moths in traps weekly and remove. Record the catch separately for each trap in the orchard.

The idea behind using trap catch as a treatment threshold is that sprays are not applied if catch is below a certain number. Two threshold methods can be used with moth capture data:

• With the first method, the trap catch threshold is 2 moths on two consecutive weeks. Thus, if a trap catches 2 moths one week and 3 the next, a spray should be applied to that area (2.5 acres). However, if a trap catches 2 moths, then 1 moth, then 2 moths, a spray is not recommended. This method has worked well for some growers in British Columbia and Washington.

• With the second method, the degree day model is incorporated with moth capture in pheromone traps. The same density of traps is used as in the other method, one trap every 2.5 acres. Moth capture in a trap is accumulated from biofix to 250 degree days, the recommended time for the first control spray. The treatment threshold is 5 moths, so if 6 or more moths have been captured, then the area associated with the trap is treated and moth catch accumulation begins at zero again. It may be possible, where codling moth populations are low, to delay the first spray if moth catch remains below the threshold at 250 degree days. If fewer than 6 moths have been captured, extend the moth accumulation period to 350 degree days. If by 350 degree days the threshold is not exceeded, do not apply a control. If it is exceeded, apply a control at once.

The number of sprays required to control larvae hatching from eggs deposited between biofix and 250 degree days depends on the residual life of the product used. Conventional insecticides have a residual life of 10 to 21 days; some organic products are effective for only 2 or 3 days. At this point, whether the threshold is reached and a spray applied or not, begin accumulating catch from zero again. Accumulate moth catch for the next 21 days and if the threshold is again exceeded apply additional controls. If it is not, no further sprays against the first generation are needed.

For the second generation, the threshold is 4 moths. Start accumulating moth catch at 1000 degree days after biofix. If 5 or more moths are captured in the next 250 degree days, apply a control spray. If not, do not apply a control and start accumulating moth catch from zero again. In either event, accumulate moth catch over the next 21 days and treat if the threshold is exceeded.

Caution: The thresholds recommended here are for a trap density of one per 2.5 acres and are for each individual trap, not an average over the entire orchard. Control treatments should be applied to the part of the orchard represented by the trap where moth catch exceeded the threshold. However, an area larger than that represented by the trap may have to be treated, depending how the orchard is designed. The use of trap catch thresholds for codling moth usually reduces use of insecticides.

Oriental fruit moth

Grapholitha molesta (Busck)
(Lepidoptera: Tortricidae)

The oriental fruit moth originated in China. It was introduced in the United States from Japan on flowering cherry about 1913 and is now found in all fruit growing regions of the United States, southern Canada and northern Mexico. It is also common throughout Europe, Asia, Australia and South America. The larvae bore in shoots or feed in fruit.

Hosts

Although the primary hosts of the oriental fruit moth are peach and nectarine, it will also attack quince, apricot, apple, plum, cherry, pear, rose and flowering cherry. However, infestations of apple are rare in the Northwest.

Life stages

Egg: The egg is a small, flat, oval disc, which is white at first but changes to amber.

Larva: The larva has 4 or 5 instars. The newly hatched larva is white or cream with a black head. When full grown it measures $\frac{3}{8}$ to $\frac{1}{2}$ inch (8 to 13 mm). It has a brown head capsule and thoracic shield, and a pinkish or creamy white body (*Figure 31*). It can be distinguished from a codling moth larva by the presence of an anal comb, which is lacking in the codling moth larva (*Figure 32*).

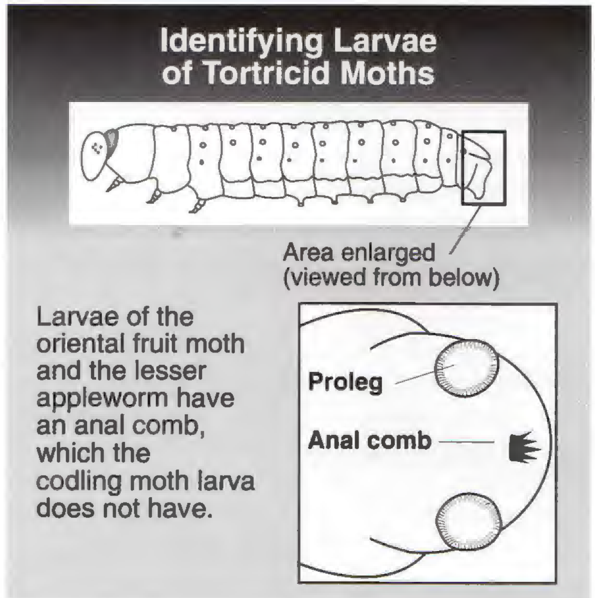


Figure 32

Pupa: The pupa is contained within a cocoon found in a sheltered place, such as under a bark scale or litter at the base of a tree. It changes from yellowish brown to reddish brown as adult emergence nears.

Adult: The adult oriental fruit moth is gray and measures about $\frac{1}{4}$ inch (5 mm). The wings have indistinct light and dark lines, giving the moth a salt-and-pepper appearance (*Figure 33*).

Figure 31: The oriental fruit moth larva has a pink or creamy white body and a brown head capsule and thoracic shield.

Figure 33: The wings of the oriental fruit moth have indistinct light and dark lines, giving a salt-and-pepper appearance.

Life history

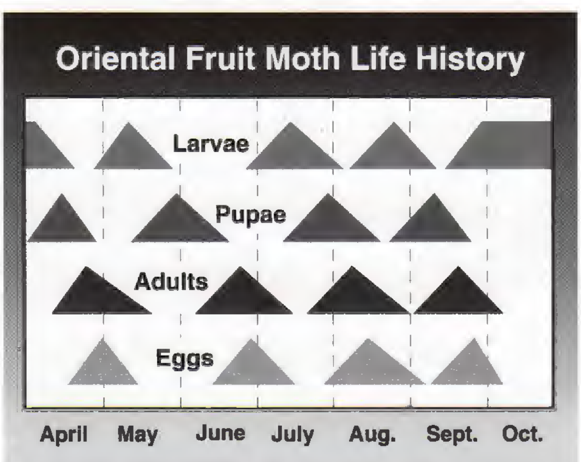
The oriental fruit moth overwinters as a fully grown larva in a hibernacula of silk webbing, either in tree crevices or in the ground cover. It pupates in the spring. Moths of the overwintering generation first appear when peach is in bloom (*Figure 34*). Eggs are laid on the foliage, usually on the upper sides of leaves of terminal growth. A female can produce up to 200 eggs. Incubation can take anywhere from 5 to 21 days depending on the temperature.

First generation larvae feed by boring into the growing shoots. They reach maturity by mid- to late May. First-generation moth flight is from early June through mid-July. There are 3 to 4 flights per year in Washington. Some second and most third and fourth generation larvae attack fruit before seeking overwintering sites where they spin cocoons.

Damage

First and second generation larvae tend to damage mainly shoots, while most of the injured fruit is due to third and fourth generation larvae. The oriental fruit moth attacks succulent terminals of rapidly growing twigs during spring and early summer.

A newly hatched larva enters the tender, growing shoot at its tip, near the base of a young leaf. An immature larva that has abandoned an old, injured twig enters a new one at the axil of a fully developed leaf. The larva bores inside the twig, working its way down the shoot for 2 to 6 inches (5 to 15 cm). When the larva matures or no longer finds the twig desirable, it makes an exit hole and leaves. If it needs more food to develop fully, it may enter another twig or a fruit.



Timings are based on observations in Washington.

Figure 34

Figure 35: Twigs infested by the oriental fruit moth usually have wilted leaves.

Infested twigs usually have wilted leaves (*Figure 35*). If an upright twig has one small, wilted leaf, it means the larva has entered within the last day or two. As the larva moves down into the twig, more leaves wilt. The number depends how far the larva penetrates. If a twig is dark colored or has dry leaves and gummy ooze, the larva has left.

When twigs of young trees are attacked, lateral shoots form below the damage. Young trees under severe and continued attack become bushy. In nurseries, shoots of recently budded peach are sometimes attacked, resulting in crooked stems.

Fruit of peach and nectarine can be damaged early in the season by partly grown larvae after they leave shoots. They usually feed on the side of the fruit, causing gumming with brown sawdust-like frass. As fruit grow, they become deformed, and the more severely damaged fruit may drop. Fruit are more often attacked when nearing maturity. Newly hatched larvae usually, though not always, enter through the stem end. They bore through the flesh

Figure 36: Larvae bore through the flesh to the pit of peaches and nectarines.

to the pit of peaches and nectarines, where most of the feeding is done (*Figure 36*). When mature, larvae move to the fruit surface, making a round exit hole. Larvae feed only on one fruit and do not move from fruit to twigs.

Apples infested with oriental fruit moth larvae look similar to those infested by codling moth. However, the codling moth larva tunnels directly to the core and feeds on the seeds, whereas the burrows of oriental fruit moth are smaller and follow a more meandering course, not necessarily to the core. Oriental fruit moth larvae do not push frass to the surface of infested fruits as do codling moth larvae.

Monitoring

Damage to shoot tips looks like that caused by the peach twig borer. Examine growing shoot tips while the first generation larvae are active. Infested shoots will be wilted. Pheromone traps can be used to monitor adult moths. Traps should be placed in the orchard prior to peach bloom and monitored daily until the first moth is observed. Good trap maintenance and care are important for good information.

Biological control

The braconid wasp *Macrocentrus ancylivorus*, which is native to North America, is a leafroller parasite that has adapted to the oriental fruit moth. Females lay eggs in young oriental fruit moth larvae. The larva of the parasitoid larva develops and matures when the host cocoons. For more information on *M. ancylivorus* see Part IV, Natural Enemies and Pollinators.

Management

Chemical control of the oriental fruit moth can be improved by using a degree day model to establish optimum timing, as with codling moth. The target of control sprays are the young larvae before they have bored into shoots or fruit. Development thresholds for oriental fruit moth are 45°F and 90°F, whereas those of the codling moth are 50°F and 88°F. Also, the method of calculating degree days is slightly different in that a vertical cutoff is used instead of a horizontal one. (See section on Degree Day Models in Part I for more information). Refer to the degree day look-up table in Appendix 1 to calculate degree days.

Moth capture in a pheromone trap is used to establish biofix, the start of degree day accumulation. When the first moth is captured, the degree-day total is set at zero. According to research in California, the best time to apply control sprays is between 500 and 600 degree days after biofix. Good control of the first generation larvae in late April or early May may mean no further controls are necessary for the rest of the year. The generation of oriental fruit moth lasts about 1000 degree days. Thus, if sprays are required for the second generation they should be applied at 1500 to 1600 degree days after biofix. These degree day timings have not been thoroughly tested in Washington but have worked very well in California.

Mating disruption

Mating disruption has proven to be a successful control for oriental fruit moth. Dispensers should be placed in the orchard before the April moth flight. In warm years, or in orchards with high moth populations or outside pressure, a second application of dispensers may be needed. Dispenser types that last only 2 months may also require multiple applications.

Lesser appleworm

Grapholitha prunivora (Walsh)
(Lepidoptera: Tortricidae)

The lesser appleworm is an internal fruit feeder, similar to codling moth and oriental fruit moth. It is a relatively obscure pest of several deciduous trees in the United States and Canada and is not commonly found in commercial orchards. It became a concern in the Pacific Northwest in the early 1990s as a quarantine issue on apples for export, particularly to Japan, but has not been a production problem for the grower.

The insect is native to northeastern North America and was first reported as a pest in the Pacific Northwest in the late 1940s when it infested prunes, plums and cherries in the Milton-Freewater area of Oregon. It was not then a problem on apricot, peach, pear or apple. Within a short time, the insect was no longer considered a pest, perhaps due to the introduction of more effective pesticides in commercial orchards. Surveys by the Washington State Department of Agriculture and the U.S. Department of Agriculture in the early 1990s indicated the insect may be distributed throughout the fruit-producing areas of Washington and Oregon. However, it is not an economic pest in orchards.

Hosts

The lesser appleworm prefers fruits of plants in the rose family. Hawthorn is its principal host. Before apple and other deciduous fruits were introduced to North America, it probably infested the fruits of hawthorn, native plums and crab apples, shadbush, wild cherry and wild rose. Since then its host range has widened to include apple, European plum and prune, and cherry. There are also reports that it has been reared from fruits of Christmas berry (toyon), from woody tissue of galls of black knot disease of plum, and from insect galls on elm and oak leaves.

Life stages

Egg: The egg closely resembles a small codling moth egg. It is a flat, oval disk about 1/40 inch (0.75 mm) long. When first laid, it is shiny white and slightly opaque. As it matures, it turns yellowish white and develops a red ring inside. Just before it hatches, the dark head capsule of the developing larva is visible.

Figure 37: Wings of the lesser appleworm have a colorful pattern of gray, white, golden brown and bluish bands.

Larva: The newly hatched larva is creamy white with a black or dark brown head capsule and is about 1/20 inch (1 mm) long. The mature larva is pinkish white and measures up to 3/8 inch (9 mm) long. It is difficult to distinguish from other larvae that might be found in the same host fruits, particularly oriental fruit moth. The larva of the lesser appleworm can be distinguished from the codling moth larva by an anal comb, which the codling moth larva does not have (*Figure 32*).

Pupa: The pupa is golden brown and about 1/5 inch (5 mm) long.

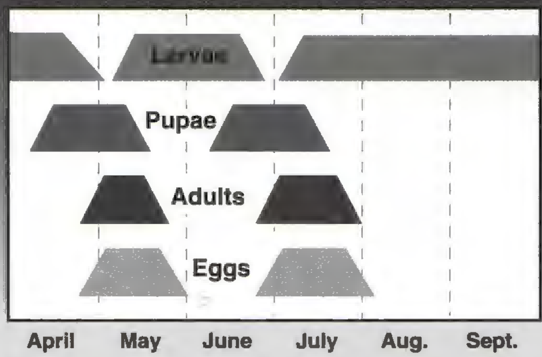
Adult: The adult lesser appleworm is a small moth, about 1/4 inch (5 to 6 mm) long. The body color is dark brown to almost black. Its main distinguishing characteristic is a pattern of white, grayish orange, and golden brown with iridescent light blue bands on the forewings (*Figure 37*).

Life history

The lesser appleworm overwinters as a mature larva in debris on the ground under the host plant or under bark scales on the tree. In the Pacific Northwest, the pupa develops over a 2- to 3-week period in early spring. Adult emergence begins in early April, depending on weather conditions, and adults that develop from overwintering larvae may be active until early June (*Figure 38*).

Soon after emerging, adults mate and females lay eggs on leaf surfaces or fruit. Eggs hatch in 7 to 10 days. Larvae feed on the fruit immediately after hatching and continue to feed for 18 to 24 days.

Lesser Appleworm Life History



The lesser appleworm has two generations a year, although early studies in Oregon showed a partial third in some years. Timings are based on observations in northeastern Oregon.

Figure 38

When mature, they spin tightly woven cocoons in debris or fruit on the ground or under bark scales on the tree.

Second generation adults are active from mid-June through early August. Moths from this generation tend to deposit more of their eggs on fruit than on leaves. After maturing, the larvae spin cocoons and most overwinter. In some years, a third flight of adults may occur.

Damage
The larvae feed inside the fruit, most often entering through the calyx end.

Monitoring
If monitoring for lesser appleworm is required, several commercially available pheromone traps are effective, but routine monitoring for control purposes is unnecessary.

Biological control
Little is known about predators or parasitoids of the lesser appleworm.

Management
As this insect is not an economic pest, control is not necessary.

Eyespotted budmoth
Spilonota ocellana (Denis and Schiffermüller)
(Lepidoptera: Tortricidae)

This insect, introduced from Europe before 1840, is now common throughout the northern United States and southern Canada. It is most common in abandoned orchards or native vegetation, and is rare in commercial orchards.

Hosts
The eyespotted budmoth feeds on apple, pear and all stone fruits, as well as on deciduous trees such as hawthorn, oak, beech, larch, and alder. It prefers rosaceous plants.

Life stages
Egg: The egg is oval, flattened, and is a translucent, creamy white.
Larva: The body is a dull chocolate-brown, while the head and thoracic shield are shiny dark brown to black (*Figure 39*). When full grown the larva is ¾ to 1 inch (18 to 25 mm) long.
Pupa: The pupa is golden brown and resembles a leafroller pupa.
Adult: The adult moth is marked by large gray and white areas on the wings. When at rest, it has a broad white band across the middle of the wing, while the front and rear are gray (*Figure 40*).

Life history
The eyespotted budmoth has only one generation per year (*Figure 41*). It overwinters as a partially grown larva within a hibernaculum in crotches of small diameter wood. Larvae become active in spring as buds begin to show green tissue. The young larva first burrows into a bud, feeding on the leaf and flower parts. Later in the spring, the larva

Figure 39: Larva of the eyespotted budmoth feeding on apple

Figure 40: The adult eyespotted budmoth has gray and white markings on the wings.

forms a tubular feeding nest by webbing together several leaves and flower parts of a spur or growing tip. The nest may contain one or more dying or dead leaves produced by the larva partially severing the petioles of leaves in the cluster. The first larvae are full grown by late May or early June. When mature, they pupate within the feeding nest. The pupal stage lasts 10 to 15 days. Adults begin to emerge in mid- to late June, with the flight continuing into July. Eggs are laid singly, usually on the lower surfaces of leaves, and incubation takes 7 to 14 days. Larvae begin feeding on lower leaf surfaces, constructing feeding sites near the midribs. The sites are covered by silken webs strewn with frass. Leaves touching one another or a leaf touching an apple are also desirable feeding sites. Development continues until larvae are half grown, usually by late July or early August, when they leave feeding sites and construct hibernacula. The larvae incorporate bits of frass and plant parts into the hibernacula so that after some weathering they appear similar to the bark and are inconspicuous.

Damage

Feeding by larvae on buds and blossoms in early spring is not a problem unless populations are very high. Boring of larvae into growing shoots can be serious in young trees or nursery stock where it results in restricted growth or abnormal tree form. Larval feeding on fruit is most important. Feeding on fruit by mature larvae just after bloom results in damage similar to that caused by early season leafroller feeding. Feeding on fruit by young larvae in mid- to late summer results in a cluster of tiny, circular excavations in the fruit. These excavations are not deep and are usually separated from each other. They can look very similar to damage caused by young leafroller larvae in mid-summer.

Monitoring

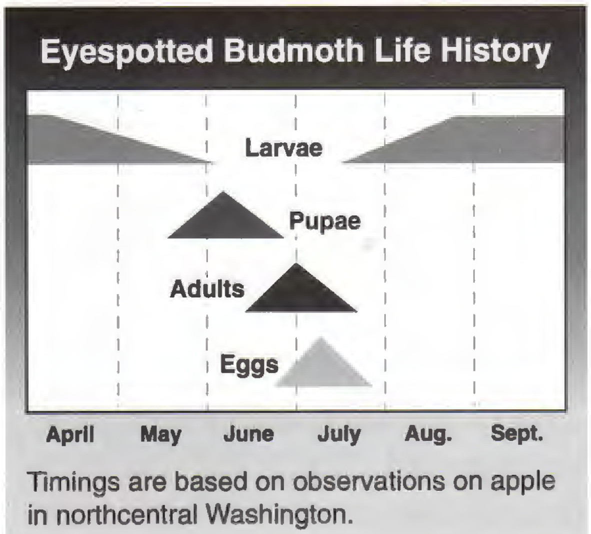
Overwintered larvae can easily be found by examining foliage pre-bloom. The tubular feeding nests resemble those made by leafrollers. While monitoring orchards in July and August, watch for leaves attached to the side of apples. The color of the eyespotted budmoth larva helps distinguish it from leafrollers that might be there at the same time. Adult activity can be monitored with a pheromone trap.

Biological control

Several species of parasitic wasps have been reported to attack larvae of the eyespotted budmoth in unsprayed habitats. It is unclear how effective natural enemies would be in a commercial orchard.

Management

The best time to suppress eyespotted budmoth is before bloom. Treatments targeted at overwintering leafroller larvae will also control larvae of the eyespotted budmoth. This insect is relatively easy to control with conventional neurotoxic insecticides used in orchards to control other pests, which explains why it is seldom reported as a significant pest.



Timings are based on observations on apple in northcentral Washington.

Figure 41

LEAFROLLERS

(Lepidoptera: Tortricidae)

Several important tree fruit pests belong to the family of tortricid moths called leafrollers. Most are native North American insects that use several species of native plants as hosts, in addition to feeding on commercial tree fruits. The name leafroller comes from the larvae's habit of rolling or tying leaves together when building feeding sites or shelters (*Figure 42*)

The leafrollers most often found in mature apple orchards in Washington are pandemis leafroller and obliquebanded leafroller. Both have two generations a year. Although they feed primarily on foliage, fruit can be damaged when the foliage is close to or touching fruit, or when fruit is in clusters. The fruittree leafroller has only one generation a year and is rare in commercial orchards in Washington, although it is a serious problem in some British Columbia orchards. The European leafroller is found in British Columbia, Washington and Oregon. It also has only one generation a year.

Pandemis leafroller

Pandemis pyrusana Kearfott

Obliquebanded leafroller

Choristoneura rosaceana (Harris)

Fruittree leafroller

Archips argyrospilus (Walker)

European leafroller

Archips rosanus (Linnaeus)

Hosts

Pandemis leafroller: The pandemis leafroller was reported as a fruit pest in Washington as early as 1921. In the late 1940s and early 1950s growers reported pandemis leafroller feeding on cherry, apricot and apple in Yakima, and cherry in the Wenatchee area. Since the mid-1970s, pandemis leafroller has become a common pest in cherry and apple orchards in Eastern Washington. In 1989, growers reported it as a pest of peach in the Yakima area.

Figure 42: Leafrollers are so named because of the larvae's habit of rolling leaves.

Where pandemis leafroller is a problem in bearing apple, it is often due to infestations in nearby cherry, prune or non-bearing apple orchards. Reduced sprays after cherry harvest allow populations of both pandemis and obliquebanded leafroller to build up and spread to apple orchards. Pandemis leafroller larvae have been found on wild plants such as cottonwood, rose, willow, dogwood, hawthorn, antelope brush, big-leaf maple, chokecherry, lupine and alder. Generally, numbers are low and though wild hosts are potential sources of infestation for commercial orchards they do not pose as great a threat as nearby infested fruit orchards.

Obliquebanded leafroller: The obliquebanded leafroller survives on an even wider range of plants than do the pandemis or fruittree leafrollers. Historically, it has not often been found in apple orchards that are sprayed regularly for codling moth. It has most often been a pest in young apple orchards but is an increasing problem in bearing orchards in Washington. Cherry orchards in The Dalles, Oregon, have reported severe damage from obliquebanded leafroller and it is the dominant leafroller pest in the Milton-Freewater fruit growing area of Oregon.

Fruittree leafroller: The fruittree leafroller is most often a problem on apples, but also attacks apricot, cherry, pear, plum, prune, quince, raspberry, currant, loganberry, blackberry, gooseberry, English walnut, ash, box elder, elm, locust, oak, poplar, willow and rose.

European leafroller: Apple, pear, hawthorn, cherry, currant and privet are the primary hosts of

Figure 43: Egg masses of the pandemis and obliquebanded leafrollers are green at first, but turn light brown.

Figure 44: Egg masses of the fruittree and European leafrollers are brown at first but turn light gray. Picture shows new and old hatched egg masses.

the European leafroller. In Oregon, it is a pest of filberts and is known as the filbert leafroller. It originated in Europe and was introduced to North America in the 19th century. It colonized two separate areas of North America — the Northeast and the Northwest. It is a pest of tree fruits in British Columbia, Washington and Oregon.

Life stages

Egg: Eggs of the pandemis and obliquebanded leafrollers are laid in masses of 50 to 300 on the upper surface of leaves. At first, the egg mass is light green (*Figure 43*), but as eggs mature they turn light brown. Just before hatching, the dark head of the larva can be seen in each egg. After hatching, egg masses often remain on leaves and are much more visible, appearing white against the dark green leaf.

The egg is the overwintering stage of the fruittree and European leafrollers. Eggs are laid on the bark of the tree trunk or limbs in irregular flat masses. They are covered with a whitish or grayish gelatinous substance. When first laid they are light brown, later turning to dark brown. By spring, egg masses have bleached to a light gray (*Figure 44*).

Larva: It is difficult to identify the species of young

Distinguishing Features of Mature Leafroller Larvae

Species	Head capsule	Thoracic shield	Body
Pandemis	Green to light tan	Green to light tan	Green
Obliquebanded	Brown to black	Dark brown to dull green with dark brown or black sides	Green
Fruittree	Dark brown to black	Dark brown to black, often with white or cream leading edge	Green
European	Light to dark brown	Greenish brown to dark brown	Green

Figure 45

Mature Leafroller Larvae


Pandemis leafroller


Obliquebanded leafroller

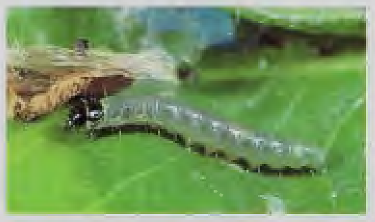

Fruittree leafroller

Figure 46

leafroller larvae, especially in the spring. All have green bodies but the head capsule and thoracic shield (the segment just behind the head capsule) may range from light brown to black.

When mature, the larvae of the different leafroller species can more easily be distinguished (*Figures 45* and *46*). The **pandemis** leafroller larva has a light green to light tan head and a light green thoracic shield. The mature **obliquebanded** larva has a brown to black head capsule and a thoracic shield that varies from brown to dull green. The sides of the thoracic shield are dark brown to black and the leading edge is often white or cream. The mature **fruittree** leafroller larva has a black head and thoracic shield. The front margin of the thoracic shield may be white or cream colored. It is usually smaller than the obliquebanded leafroller larva. The mature **European leafroller** has a green body, light to dark brown head and a greenish brown to dark brown thoracic shield. Larvae should be reared to the adult stage to confirm species identity.

A leafroller larva is usually found inside a leaf that has had one side folded and attached to the other, between two leaves attached together, or beneath a leaf attached to an apple with silk webbing. When disturbed, the leafroller larvae will wiggle rapidly backwards, often dropping from its shelter on a slender thread. This behavior distinguishes leafroller larvae from other caterpillars found in the orchard.

Pupa: The leafroller pupa is a typical moth chrysalis (*Figure 47*). It is light green or greenish brown at first, but soon turns tan and then a darker brown. The pupa develops in a protected place, usually in a folded and webbed leaf. It may be surrounded with light silken webbing, though it does not have a dense silken cocoon. Pupae of all leafrollers look the same. To identify them, keep them in a container until the moth appears.

Adult: The adult **pandemis** leafroller is a buff or tan colored moth, ½ to ¾ inches (13 mm to 18 mm) long. Its main distinguishing feature is a banding pattern on the wing. When the moth is at rest, a darker tan or brown band obliquely crossing the middle of each wing appears to join at the center. On the leading and trailing edges of the darker band is a narrow, light-tan to yellow line separating the darker area from the lighter-colored portion of the rest of the wing (*Figure 48*). Color intensity varies considerably from moth to moth, sometimes making identification difficult.

The **obliquebanded** leafroller moth is larger and darker than the pandemis leafroller. It is ¾ to 1 inch


Figure 47: The pupa of all leafrollers is a typical moth chrysalis.

Leafroller Adults

Pandemis leafroller | Obliquebanded leafroller | Fruittree leafroller

Figure 48

(18 mm to 25 mm) long. The banding pattern on the wing is similar, but the leading and trailing edges of the oblique wing bands are darker than the rest of the wing, not lighter as on the pandemis leafroller (*Figure 48*).

The **fruittree** leafroller appears fawn or rusty brown with a prominent light triangular spot on the outside edge of the wing. It is ½ to ¾ inch (13 to 20 mm) long. The wings do not have a distinct banded pattern, but have mottled light and dark brown patches interspersed with lighter ones (*Figure 48*)

The **European** leafroller about the same size as the fruittree leafroller. It is a chocolate brown color and is darker than the other leafrollers. A distinct dark band runs diagonally across the wing with a dark patch near the base and outer tip in the male. The female has a less distinctive banding pattern.

Figure 49: In the spring, larvae feed on expanding leaves and flower clusters.

Life history

Both pandemis and obliquebanded leafrollers have two generations a year, whereas the fruittree leafroller and European leafroller only have one generation. Pandemis and obliquebanded leafrollers overwinter as second or third instar larvae within a silken case known as a hibernaculum. Hibernacula are found in protected parts of the scaffold limbs, such as pruning scars or small crevices in the bark.

Young larvae of the overwintering generation become active in the spring as fruit buds open. Most larvae have left their hibernacula by the half-inch green stage of apple bud development. They bore into opening buds and later feed on expanding leaves and flower clusters (*Figure 49*). Larvae are fully grown by mid- to late May. Pupae are present from mid-May through early June. First adults of the overwintering generation appear from late May to early June, depending on spring temperatures. Adult activity peaks about mid-June (*Figure 50*).

Timing of summer generation egg hatch varies from year to year but is generally from mid- to late June. Larvae mature by late July or early August and summer generation adult activity peaks in mid-to late August. Eggs of the overwintering generation appear in mid-August. Hatching begins in late August and continues through September and into early October some years. Newly hatched larvae feed for a short time on foliage and fruit before moving to scaffold limbs and building hibernacula in October.

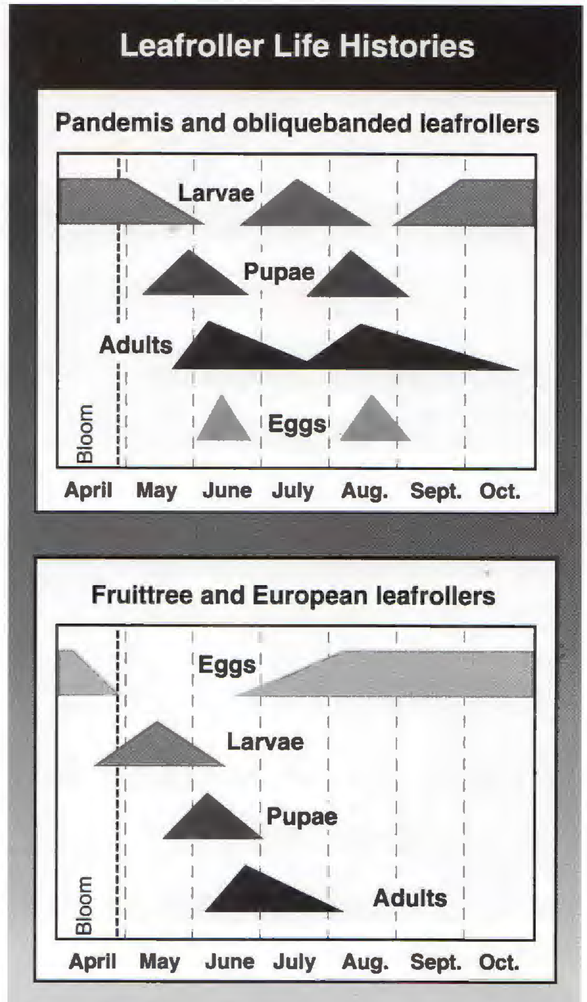
The fruittree and European leafrollers overwinter in the egg stage (*Figure 50*). Egg hatch begins at about the half-inch green stage of flower bud development and continues until bloom. Larvae feed on leaves, flower parts and young fruit. Larvae mature by mid- to late May. Pupae are present from late May through early June. Adult activity peaks in late June and the flight may continue into early July.

Females deposit eggs in masses on smooth bark of 1- to 3-year-old wood. The eggs remain there until the following spring.

Damage

Apple: Larvae of all four species feed primarily on foliage. In spring, larvae web together leaves and flower parts of expanding buds, feeding on plant parts within these shelters *(Figure 49)*. As larvae mature, they tend to migrate to growing shoots, where they may web together several newly formed leaves at the shoot tip or make a shelter out of a single leaf. Although larvae do not require fruit to complete their development, they may attach leaves to an apple or use fruit clusters as sheltered feeding sites. Larvae of the obliquebanded and pandemis leafrollers can damage fruit at three periods during the growing season:

- First, larvae of the overwintering generation may eat portions of young fruit in May. If damaged fruit do not abort, they are deeply scarred and severely deformed *(Figure 51 top)*. This is the only period in which larvae of the fruittree and European leafroller will damage fruit.
- Next, young, summer generation pandemis larvae attach leaves to apples in late June and early July and feed. There can be several separate feeding sites within a small area and the feeding is usually no deeper than 1⁄16 of an inch (1.5 mm) *(Figure 51 center)*. As larvae grow, they tend to feed on the foliage of growing shoots. Larger larvae of the obliquebanded leafroller sometimes continue to feed on fruit, causing even more extensive damage *(Figure 51 bottom)*. Both types of feeding damage scab over by harvest and are often surrounded by lighter colored areas on the fruit where leaves were attached.
- The third period when fruit may be damaged is just before and during harvest. Larvae of the overwintering generation may attach leaves to fruit after hatching from egg masses in late August or early September and feed on the fruit. The young larva chews a small hole through the skin of the apple



Both pandemis and obliquebanded leafrollers overwinter as larvae and develop through two generations a year. The fruittree and European leafrollers overwinter in the egg stage and have only one generation a year. Timings are based on observations on apples in Washington.

Figure 50

Typical Apple Damage

Fruit damaged early in the season is deeply scarred and severely deformed.

Feeding damage by summer pandemis larvae is shallow and discontinuous.

Feeding damage by summer obliquebanded larvae can be deeper and more continuous than that of pandemis.

Figure 51

and feeds on the apple flesh. While the pin-hole sized feeding sites usually occur singly, several may be found close together. The damage is difficult to detect at harvest but becomes obvious as the apple flesh around the feeding sites decays or dries during storage *(Figure 52)*. Feeding damage from this period is often mistaken as codling moth damage.

The distribution of leafroller larvae and feeding damage depend on tree size and type. In large trees, there can be 2 to 10 times more larvae in the upper half than the lower half. Spur varieties tend to have more fruit damage than non-spur varieties. That is because fruit and leaves are closer together in spur varieties, which increases the likelihood of leaves touching fruit and providing feeding shelters for the larvae.

Cherry: Overwintering larvae can damage young cherries in the spring, but most damaged fruit abort, so are not on the tree at harvest. Young, summer generation larvae of the pandemis or obliquebanded leafroller feed on cherries just before harvest *(Figure 53)* and have been mistaken as larvae of the cherry fruit fly by fruit inspectors

Other tree fruits: Damage to other fruit crops is usually caused by surface feeding. Damage to pear, prune and apricot can be severe if leafroller populations are not managed.

Monitoring

Pheromone traps can be used to monitor male leafroller activity *(Figure 54)*. The pheromone of the threelined leafroller, *Pandemis limitata,* is used to monitor the pandemis leafroller. If leafroller populations are moderate to high, traps may be filled with moths in one night. This makes it difficult to pinpoint peak activity unless the traps are checked daily. A new trap bottom should be installed after 50 or more moths are captured.

Moth capture in pheromone traps has not been a good indicator of leafroller population density or potential damage. Capture of 15 or fewer moths per week usually, though not always, indicates little potential for damage, but higher numbers do not always mean there will be damage. Male leafrollers of some species can travel long distances and high numbers may be captured in orchards where chances of larval infestations are low. Female pandemis leafrollers do not move very far, often only a few yards from where they emerge, before laying

Figure 52: Damage near harvest may be difficult to detect at first but becomes obvious after the fruit is stored.

Figure 53: Cherries damaged by feeding of the European leafroller. Larvae in cherries may be mistaken for cherry fruit fly larvae.

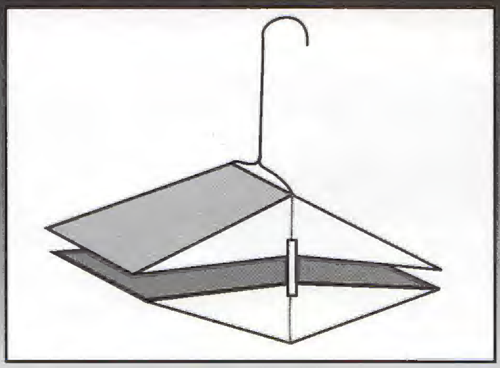
their first egg mass. Sampling leafroller larvae in the spring is difficult. Larvae of pandemis and obliquebanded leafrollers begin attacking fruit buds as soon as they open (at green tip). Most pandemis leafroller larvae have left their hibernacula and are feeding in buds by the half-inch green stage of apple bud development. Emergence of obliquebanded leafroller larvae from hibernacula may extend over a longer period.

Between green tip and tight cluster leafroller larvae are difficult to detect by visual examination in the field. To accurately estimate leafroller density at this time, collect buds in the field and return to the laboratory or office and examine under a magnification. Collect at least 150 fruit buds (6 buds from 25 trees) from a block (5 acres). Due to the time required to collect and examine this sample it has limited value as a management tool, but can be used to determine if a delayed-dormant control is necessary.

By the tight cluster or pink stage of apple bud development larvae can be detected without magnification, as webbing and feeding damage is more obvious. Examination of at least 20 fruit buds from 20 trees will provide a good estimate of larval density during this period. As shoots begin to elongate, leafroller larvae move and start to feed at growing points. In trees over 10 feet (3 meters) tall, more pandemis leafroller larvae are in the upper half of the canopy. Sample from that part of the tree to avoid underestimating the density.

In summer, young pandemis larvae are difficult to detect. They remain in the fruiting canopy where they spin small, webbed shelters near the mid-vein on the undersides of leaves or attach leaves to fruit and feed on both. When pandemis larvae are about half grown, they feed on leaves at the tip of growing shoots. Larvae of the obliquebanded leafroller

Leafroller Pheromone Trap



A pheromone trap is used to monitor male leafroller activity.

Figure 54

tend to move to shoot tips sooner than pandemis. The easiest way to determine leafroller presence is to examine 20 shoots per tree on 20 trees per block in late July or early August. While this sample is relatively easy to make, it occurs after most fruit damage has been done. However, it is a good indication of larval density and if fruit should be protected prior to harvest.

Biological control

Leafrollers have many natural enemies. Several species of parasitic wasps and a parasitic fly attack leafroller larvae. Most of these parasitoids have larvae that develop inside the leafroller larvae, existing only to pupate. However, the larva of one species, *Colpoclypeus florus*, feeds externally. Parasitoid larvae or pupae, or their empty pupal cases, can often be found with dead leafroller larvae still inside the rolled leaf. The potential for biological control of leafrollers is low in orchards using insecticides to control codling moth and other insects. However, in orchards using mating disruption and soft chemicals for pest control, the impact of parasitoids on leafroller populations can increase dramatically. For more information on the biology and identification of common parasitoids of leafrollers, refer to Part IV, Natural Enemies and Pollinators.

Management

The fruittree and European leafrollers are usually controlled by insecticides applied during the prebloom period for other insects, and these species have not been reported as serious problems in Pacific Northwest orchards. Following are management guidelines for the pandemis leafroller, most of which also apply to the obliquebanded leafroller.

The best strategy to manage leafrollers is to control larvae of the overwintering generation in spring. Conventional insecticide applications in the delayed-dormant period (at half-inch green tip stage of apple flower bud development) have given the best control of pandemis leafroller. Bacterial insecticides — strains of *Bacillus thuringiensis* (Bt) — have given good control of leafroller larvae when 2 or 3 applications have been made in the period from tight cluster through petal fall.

In summer, insecticides can be used to control either adults or larvae. Sprays targeting adults should be timed at peak moth flight. In most years, the second cover spray directed at codling moth coincides fairly well with the peak flight of pandemis leafroller adults and is a reasonably good timing for adult control. Peak pandemis moth flight can be predicted using degree days. The first moths emerge about 950 degree days after January 1. First moth capture in pheromone traps is used as a biofix, similar to the codling moth model, to predict future events in the life history of pandemis leafroller. At biofix, the degree day value is set at zero. Moth flight peaks between 200 and 220 degree days after first catch.

Summer sprays should target young larvae before they can damage fruit. Pandemis leafroller egg hatch begins about 420 degree days after first moth catch. Chemical controls should be applied between 420 and 450 degree days so that residues remain during the hatch period. If insecticides with short residual activity are used, such as Bt products, a second or even third treatment may be required at intervals of 7 days. Egg hatch is complete by 1000 degree days.

Controlling pandemis or obliquebanded leafrollers as larvae or adults in late summer (late July though August) is very difficult and normally should not be considered. If, however, more than 5% of the

Pandemis Leafroller Life History Events and Degree Day Values

Event	Degree day value
First moth in pheromone trap	950 = 0 biofix
Peak moth flight	220-250
First hatch	420
End of hatch period	1000
Beginning of second flight	1600
Peak of second flight	2300
Beginning of second hatch	2750

Figure 55

shoots are infested in late July, some type of control may be needed to protect fruit from injury before and during harvest. Bt sprays have been effective against larvae feeding in shoot tips during late July and early August.

Timing of sprays to control adults in the second flight is difficult. The second flight begins about 1600 degree days after first moth catch in the spring and peak flight is between 2300 and 2350 degree days, usually in mid-August. The second egg hatch period begins at 2750 degree days, usually in late August or early September.

Pandemis leafroller has different developmental thresholds than the codling moth. The lower threshold is 41°F and the upper 85°F. A degree day look-up table is given in Appendix 1. Key life history events associated with degree days are given in *Figure 55*.

Peach twig borer

Anarsia lineatella Zeller

(Lepidoptera: Gelechiidae)

The peach twig borer is one of the most important peach pests. It originated in Europe and was first reported as a pest in California in the 1880s. The twig borer has become a common pest of peaches and other tree fruits in eastern Washington. It can kill twigs, and disfigure or infest fruit. The damage is similar to that caused by the oriental fruit moth.

Hosts

Peach twig borer attacks apricots, nectarines, plums and prunes as well as peaches.

Life stages

Egg: The egg is yellowish white to orange and oval.
Larva: The larva has a dark brown head and prothorax with distinctive alternating dark and light brown bands around the abdomen (*Figure 56*). The larva has 4 or 5 instars. A mature larva may grow to ½ inch (12 mm) long.
Pupa: The pupa is smooth, brown and does not reside in a cocoon. Pupae are usually found beneath bark scales or cracks in the bark.
Adult: The adult moth is between ⅓ and ½ inch (8 to 12 mm) long. It is steel gray with white and dark scales (*Figure 57*).

Life history

The peach twig borer has three complete generations in Washington most years. It overwinters as first or second instar larvae in cells, known as hibernacula, under the thin bark in limb crotches or in bark cracks. To detect the hibernacula, look for small chimneys of frass and wood chips built up by larvae feeding under the bark.

During bloom and petal fall, overwintered larvae emerge from their cells, migrate up the small limbs and twigs and begin to feed on buds and young leaves. As terminal growth develops, a larva will enter a single shoot, boring down the center, causing the terminal to wilt or flag. When mature, the larva leaves the mined shoot in search of a protected place to pupate. Adults from overwintering larvae usually begin to emerge in mid- to late May. Females each lay between 80 and 90 eggs on fruit, shoots or the undersides of leaves next to veins. The eggs, which are laid singly, hatch in 5 to 18 days, depending on temperature (*Figure 58*).

Figure 56: The larva has distinctive alternating dark and light brown bands around the abdomen.

Figure 57: The adult moth is steel gray with white and dark scales and is between ⅓ and ½ inch long.

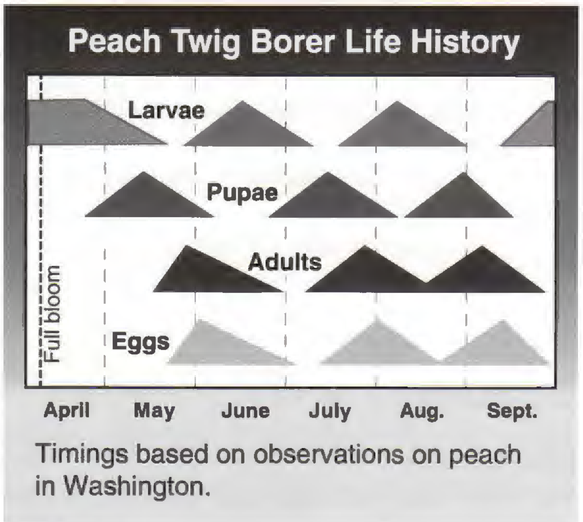


Figure 58

The larvae can develop equally well in shoots or immature fruit. The first summer generation larvae develop during late May and June. The next adult flight is in early July. During this flight and the following one in late August, moths prefer to lay eggs on maturing fruit. Some larvae that develop from the eggs laid in August go into cells to overwinter. Others continue to develop on fruit and shoots and produce a partial third summer flight of moths in October. These moths lay eggs that produce larvae that overwinter and emerge as moths the following spring.

Damage

The first sign that the peach twig borer is in the orchard may be wilting, or flagging, of new growth in the spring (*Figure 59*). As buds open and new leaves begin to grow, the overwintering larvae burrow down the tender shoots, which then wilt and die. Twig or shoot damage may be more severe on young trees. One overwintered larva may attack more than one shoot. In high numbers they can cause extensive damage to young trees or nursery stock.

Larvae of the succeeding generations feed on shoots or fruit. They attack fruit at the stem end, where two fruit touch or where leaves touch the fruit (*Figure 60*). They also may feed along the sides of the fruit, disfiguring it.

Monitoring

Shoots should be examined in late April or early May to determine if the pest is in the orchard. Wilted shoots are easy to spot and several trees throughout the orchard should be examined. Damage to shoots by oriental fruit moth larvae looks the same as that caused by the peach twig borer. Wilted shoots should be opened to determine if peach twig borer larvae are inside. Examine shoots again in mid-June to look for larvae of the first summer generation.

Adult twig borers can be monitored with pheromone traps, which should be placed in orchards by early May to detect emerging moths. Moths in the traps should be counted and removed once a week. Trap bottoms should be replaced after 50 moths have been captured.

Biological control

A tiny wasp, *Pentalitomastix pyralis*, is a parasitoid of the peach twig borer egg. After hatching, the twig borer larva develops normally until maturity. Then, the parasitoid egg in the body of the twig borer is activated and divides several times, producing 25 to 50 larvae. Adult wasps are active in the orchards at shuck fall.

Management

Early sprays aimed at young larvae give the best control of twig borer. The best times to spray are

Figure 59: Larvae of the overwintering and first summer generations burrow down shoots.

the pre-bloom and petal fall stages. However, these sprays may disrupt natural enemies of the green peach aphid, which are active at this time.

Delaying sprays until first summer generation larvae are present can help conserve natural enemies of green peach aphid and improve control of that pest. Larvae of the overwintering generation of peach twig borer do not feed on fruit and, unless numbers are extremely high, cause little economic injury to trees.

A degree day model can be helpful in timing insecticide treatments against the summer generation of peach twig borer. The developmental thresholds of the peach twig borer are 50°F and 88°F, the same as the codling moth. The same method of calculating degree days is used so that the degree-day look-up table for codling moth in Appendix 1 can be used for both species.

Start accumulating degree days at first moth capture in a pheromone trap. The first moth is captured at 400 to 410 degree days after March 1. The best timing of insecticide treatments is between 400 and 500 degree days after first moth capture. The duration of a generation is about 1060 degree days. If additional sprays are required, they should be applied at 1400 to 1500 degree days after capture of the first moth of the overwintering generation. Table 7 in Appendix 1 gives the relationship between degree days after first moth capture and moth flight and egg hatch.

Figure 60: Peach twig borer larvae of the second and third generations feed on shoots or fruit.

GREEN FRUITWORMS AND CLIMBING CUTWORMS

(Lepidoptera: Noctuidae)

Green fruitworms and climbing cutworms are closely related moths of the family Noctuidae. Tree fruits are the primary hosts of green fruitworms but only secondary hosts of climbing cutworms. Very few of the more than 150 species of noctuid moths in the Pacific Northwest are tree fruit pests.

Green fruitworms

Three species of green fruitworms are native to the Northwest: the speckled green fruitworm (*Orthosia hibisci*), the pyramidal fruitworm (*Amphipyra pyramidoides*) and the green fruitworm (*Lithophane antennata*). They are found throughout temperate fruit-producing areas of the United States and Canada. Usually, green fruitworms do not cause extensive damage in commercial orchards that are sprayed for codling moth. They are more often pests in organic orchards or back yard trees. However, they may prove troublesome in orchards where codling moth are controlled by non-chemical methods such as mating disruption.

As green fruitworm infestations tend to recur in the same orchards, historical information is useful for monitoring and developing control strategies.

General description

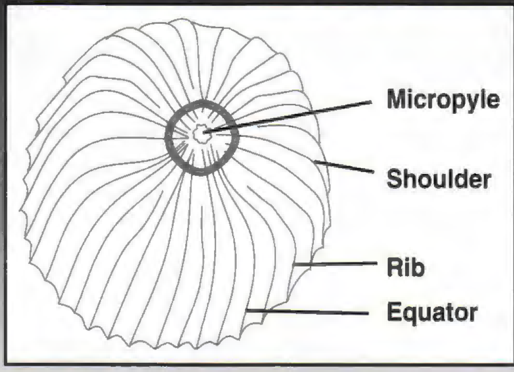
Eggs: Green fruitworms lay eggs on leaves of the host tree, unlike cutworms, which lay eggs in the cover crop. The egg of a green fruitworm, like that of a cutworm, is almost spherical with a slightly flattened top, a tiny opening in the center called a micropyle, and vertical ribs (*Figure 61*). The base is flat where the egg is cemented to the plant. It is about $\frac{1}{30}$ inch (0.8 mm) in diameter.

Larvae: Green fruitworm larvae are caterpillars with distinctive colors and markings. See discussion of green fruitworm species that follow for more detailed descriptions.

Pupae: All green fruitworm pupae are brown and about ½ to ¾ inch (13 to 19 mm long). They are found in the soil or litter in the cover crop.

Adults: The Adult moths are nondescript and are difficult to identify.

Typical Cutworm Egg



The egg of a cutworm or green fruitworm is almost spherical with a slightly flattened top and a tiny opening in the center called a micropyle. It has between 29 and 50 ribs, depending on species.

Figure 61

Hosts

The speckled green fruitworm, pyramidal fruitworm and green fruitworm are general feeders. All tree fruits grown in the Northwest are hosts. Apple is the primary host, followed by pear. Green fruitworms also attack many other plants including crab apple, beech, chokecherry, mahaleb cherry, bird cherry, hawthorn, rose, quince, almond, blackthorn, strawberry, box elder, sugar maple, red alder, hickory, poplar, oak, current, willow, birch, aspen and, in Canada, conifers.

Figure 62: Pear damaged by green fruitworm feeding

Damage

Green fruitworms damage buds, flowers, leaves and fruit (*Figure 62*). Bud damage usually goes unnoticed until it is too late for treatment.

Monitoring

The following monitoring methods have been developed for green fruitworms in California:

- Take one fruit cluster from at least 100 trees per 20-acre block (or 5 trees per acre) at intervals starting at tight cluster stage and continuing until about 2 to 3 weeks after petal fall.
- Take 50 samples per 20 acres with a beating tray.
- Spend 30 minutes searching for damaged fruit clusters.

Populations are often spotty, so blocks should be covered thoroughly when sampling. If any worms are found, the potential for crop loss is high because this pest can cause severe damage in a short time.

The only way to sample for bud damage is to look in the trees. Ten trees per acre should be enough. If you find bud damage, you need to know if the damage was caused by green fruitworm or climbing cutworms. Cutworm damage could have been done during the winter before the cover crop grew and there may be no further damage. If it is due to green fruitworms, they are probably still active. If you find fruitworm larvae, then you don't need to look for cutworms. Adults can be collected with blacklight traps, in bait pans and by sugaring. For sugaring, soak a sack or cloth in a solution of molasses or brown sugar and beer, fold it into a pad or bandage and place in the tree or around the trunk. Check for moths at night, as they are nocturnal. However, there are no guidelines relating trap catches of adults to damage by larvae.

Biological control

Although a number of parasitic wasps and flies attack green fruitworms, the percentage of larvae parasitized is too small to provide control. Parasitoids attacking green fruitworms include *Apanteles, Microplitis, Comedo, Paniseus, Meteorus* and *Eulophus* wasps; *Wagneria, Tachinomyia, Winthemia, Campsilura* and *Ernestia* flies; and *Mermis* (hairworm) nematodes.

Management

Insecticides used to control codling moth appear to control green fruitworms. *Bacillus thuringiensis* (Bt) may also give some degree of control.

Speckled green fruitworm

Orthosia hibisci (Guenée)

Life stages

Egg: The egg is pale gray when first laid. It is spherical with a flat base where it is cemented to the plant. It has 40 to 48 ribs and is 1/30 inch (0.8 mm) in diameter. After a day or two, purple blotches appear around the micropyle and the shoulder.

Larva: The larva develops through six instars and measures between 1 and 1⅔ inches (25 to 41 mm) long when mature. It is green with five white stripes the length of the body (*Figure 63*). The head is brown at first but gradually turns green.

Adult: The adult is a nondescript, reddish-brown moth about ¾ inch (19 mm) long.

Life history

There is one generation per year (*Figure 64*). The speckled green fruitworm overwinters as a pupa in the soil. Adults emerge from March to May and lay eggs on tree leaves. Larvae begin to hatch in April and climb to the tips of limbs and spurs where they feed and grow. They prefer fruiting spurs and often conceal themselves by webbing the leaves together with silk. They feed at first on buds, then later on flowers, leaves and fruit. In summer, mature larvae drop to the ground and burrow into the soil to pupate.

Figure 63: Speckled green fruitworm larva.

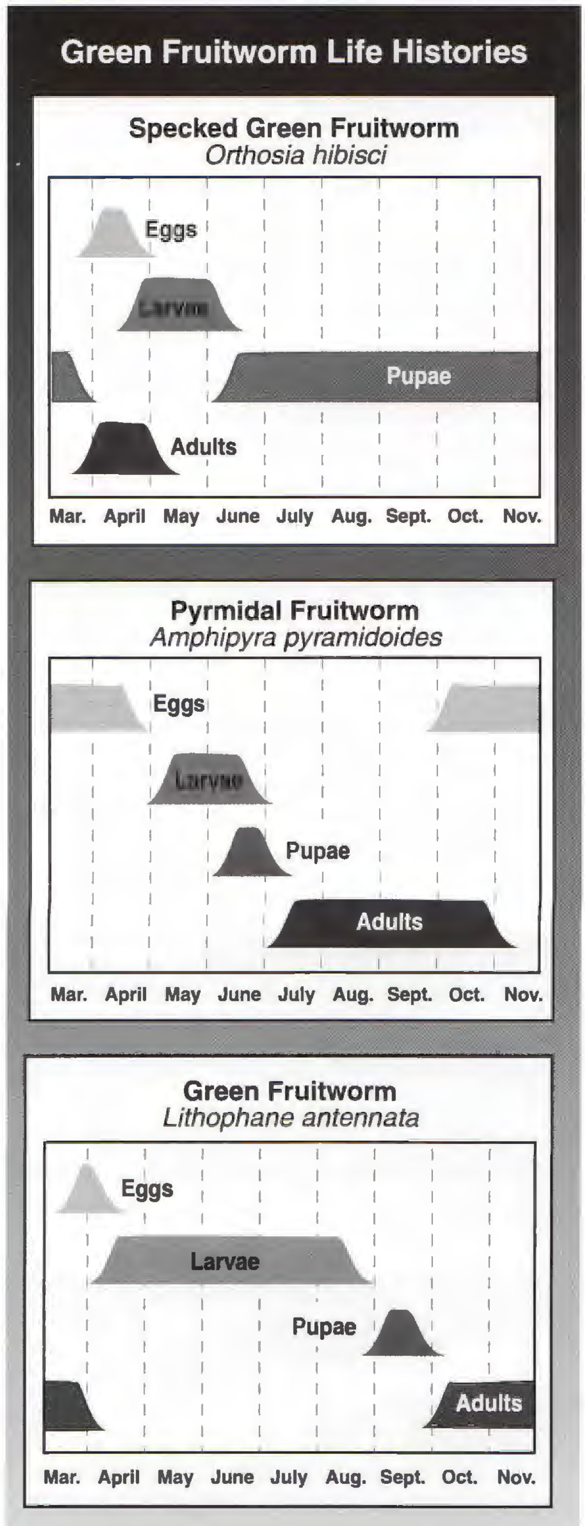


Figure 64

Pyramidal fruitworm

Amphipyra pyramidoides (Guenée)

Life stages

Egg: The egg is similar to that of the speckled green fruit worm, except it is a reddish-violet color and has a depressed micropyle.

Larva: The larva is cream colored at first, but turns green in the second instar. It has five white stripes (*Figure 65*). It can be distinguished from other green fruitworms by a dorsal hump at the posterior end, which develops in the fourth instar. When mature, the larva is about 1½ inches (38 mm) long.

Adult: The adult is a nondescript brown moth, about 1 inch (25 mm) long.

Life history

The pyramidal fruitworm has one generation per year (*Figure 64*). It overwinters on the tree as eggs, which hatch in April and May. Because larvae do not appear until after bloom, they do not damage buds. Larvae feed primarily on leaves, but also eat away patches on the surface of fruit. In June, mature larvae drop to the ground and make cocoons of silk and debris in which they pupate. Adults appear in July and are active until October. Eggs are laid in the fall either singly or in groups of up to 230.

Green fruitworm

Lithophane antennata (Walker)

Life stages

Egg: The egg is reddish brown, about 1/30 inch (0.8 mm) in diameter, and has 30 to 36 ribs and a nipple-like micropyle.

Larva: The larva turns from a light cream color to yellow and then to green. In the third instar it develops five white stripes (*Figure 66*), which are less distinct than those on the speckled green fruitworm. During the last two instars it has a prominent white subspiracular stripe, which distinguishes it from the speckled green fruitworm. The larva is a little smaller than the other species and is about 1 inch (23 to 28 mm) long when mature. It pupates in a cocoon of silk and debris.

Adult: The adult is gray with hints of blue (*Figure 67*). The orbicular spot has a partially separated lower loop called the suborbicular spot (*Figure 69*).

Life history

The green fruitworm has one generation per year (*Figure 64*). It overwinters as an adult on the ground. Eggs are laid singly or in masses of up to 360 on leaves in spring. Larvae, which are found from April through August, feed on buds, flowers, leaves and fruit. When mature, larvae burrow into the soil to pupate. Adults emerge in the fall.

Figure 65: Pyramidal fruitworm larva

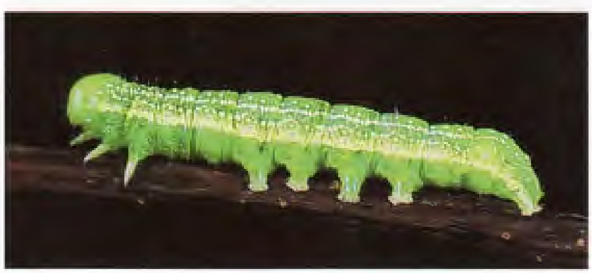


Figure 66: Green fruitworm larva

Figure 67: Green fruitworm adult

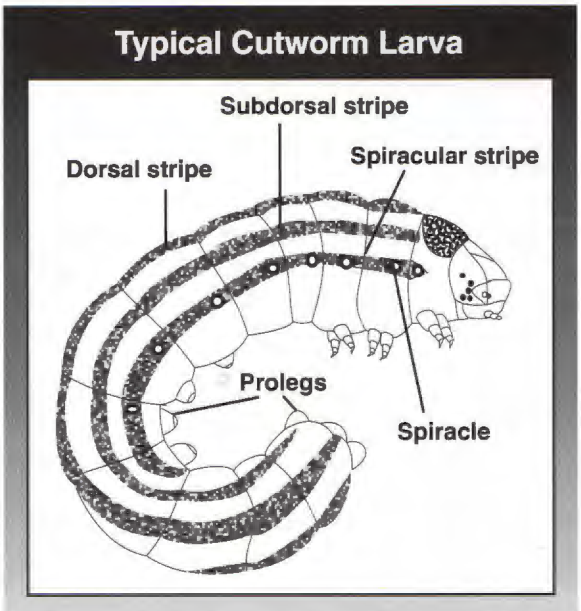


Figure 68

Cutworms

The same species can be either a climbing cutworm or armyworm, depending on its behavior, and its behavior often depends on the source of food. Cutworms feed on the roots and shoots of herbaceous plants, and the plant is often cut off at ground level. Armyworms are so named because the larvae often migrate in large numbers to a new feeding area.

Cutworms are found in the majority of orchards in the Northwest, but most species are harmless. *Scotogramma trifolii* (the clover cutworm), *Diarsia pseudorosaria* and *Leucania* sp. are among the harmless species.

The two climbing cutworms that have been the most destructive to tree fruits in the Northwest since the 1970s are the spotted cutworm (*Xestia [Amathes] c-nigrum)* and the Bertha armyworm (*Mamestra configurata*). The variegated cutworm (*Peridroma saucia*), black cutworm (*Agrotis ipsilon)* and the western yellowstriped armyworm (*Spodoptera praefica)* seldom cause sufficient damage to warrant treatment.

The spotted, black, and variegated cutworms are found worldwide. The Bertha and western yellowstriped armyworms are found only in the western United States and Canada. Many of the cutworm larvae look alike, so it is easy to mistake a harmless species for a destructive ones.

As weeds are the primary hosts of cutworms, proper weed control in the orchard can help prevent fruit trees becoming infested. Unlike green fruitworm that lay eggs on trees, cutworm moths lay eggs on weeds near the ground. They like dense cover. Larvae spend the days on the soil surface and at night move into trees by climbing tree trunks, drooping limbs, tall weeds, props or stakes. If the trunk is the only pathway, damage is likely to be confined to the lower center of the tree.

General description

Eggs: Eggs of cutworms are similar to those of green fruitworms, although they can be as small as $\frac{1}{50}$ inch (0.5 mm) in diameter.

Larvae: Larvae of the spotted cutworm, Bertha armyworm and variegated cutworm can be distinguished by their different colors and markings (*Figure 70*).

Pupae: Pupae of all cutworm and armyworm species are brown and about $\frac{3}{4}$ inch (19 mm) long.

Adults: Adults are dull in color but some, like the spotted cutworm and Bertha armyworm, can be identified easily by their wing markings.

Hosts

All cutworms that attack tree fruits prefer herbaceous plants. Their preferred host is lamb's-quarters,

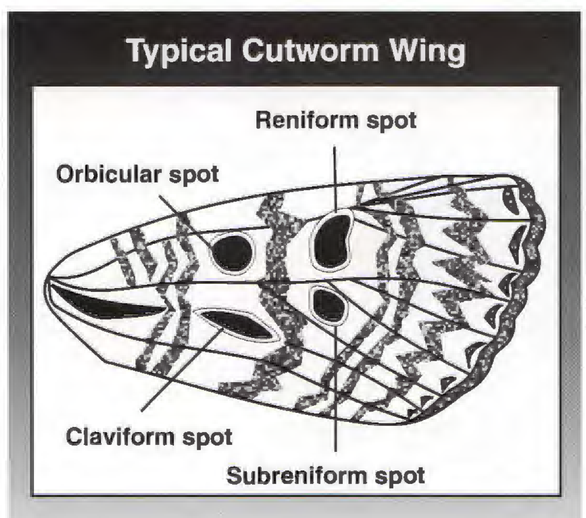


Figure 69

a weed that is common in Northwest orchards. Other primary hosts include mustards, plantain, mallow, pigweed, morning glory, Canada thistle and cultivated crops such as potatoes, sugar beets, hops, alfalfa and mint. Tree fruits are secondary hosts.

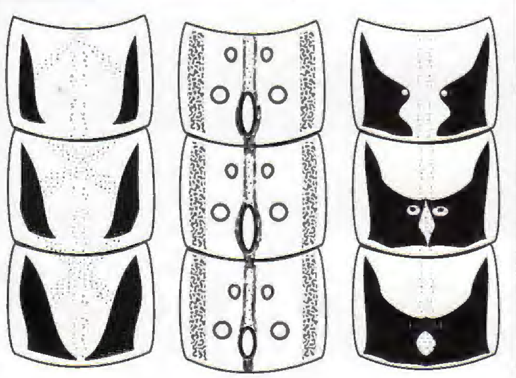
Damage

Before bloom, look for damaged buds, usually in the low center of the tree. In summer, examine the cover crop, trees and fruit for feeding damage. Buds may be partly or completely eaten. Larvae feed from the edges of the leaves, often eating most of the leaf. Larvae often follow trails they make from the ground to their feeding sites on the tree, so damage is often confined to a few stems or limbs, while nearby stems or limbs are undamaged.

Monitoring

Monitoring is similar for all cutworms. It is not practical to sample for eggs, as they are too hard to find among the weeds. Instead, monitor for damage, larvae or adults.The larvae are nocturnal and hide in the soil or under stones and debris during the day. To find them, carefully sort through an area of soil and debris at the base of the tree. One or two areas of ½ square yard (0.5 square meter) are probably enough. Larvae are generally at the depth where the soil becomes moist. If there is debris on the ground, keeping the soil surface moist, the larvae remain at the surface. Traps also can be used to catch larvae. The most effective and simple is a board, 8 by 12 inches (20 by 30 cm), or heavy shingle placed on the ground near the trunk of the tree. A rock should be placed on top to hold it snug to the ground or debris and prevent it being blown around by the wind. Leave the trap for a few days, then lift it up and count the larvae that are sheltered beneath it. Adults can be monitored with blacklight or pheromone traps, although reliable treatment thresholds have not been established. If enough food is available in the cover crop, a large number of larvae could be tolerated, otherwise even a small number could be damaging.

Cutworm Larva Markings



Characteristic markings of older cutworm and armyworm caterpillars.

Figure 70

Biological control

Cutworms have many natural enemies. Insects, spiders, birds and rodents all prey on cutworm eggs, larvae and adults. Rodents are good predators but can also damage trees. Predators and parasites, together with good weed control, will usually keep cutworm populations in check.

Cutworm populations are often greatly reduced by a viral disease. Spotted cutworms and Bertha armyworms that are infected by a virus climb to the top of a plant or branch to die. They attach themselves by their legs and hang from the plant. The skin turns black and everything inside liquifies. When the skin breaks, the liquid drips out. The liquid full of virus runs down the plant. Insects feed on the liquid and spread the virus.

Management

Good cover crop management is the most effective way to control cutworms. Eliminating weeds removes egg-laying sites and their preferred food. Mowing discourages egg laying and encourages predation. It also exposes eggs so they dry out and do not hatch. Insecticides can be used to control cutworms. However, the different species of cutworms differ in their susceptibility to these products so it is important to know which species is being treated. Spotted cutworm and Bertha armyworm cohabit, which can complicate control. Spray only the tree trunk and the area under the trees. Keeping chemicals off the tree canopy will allow predators and parasites to survive.

Spotted cutworm

Xestia (Amathes) c-nigrum (Linnaeus)

Life stages

Egg: The egg is a pinkish flattened sphere, about 1/40 inch (0.6 mm) in diameter with 29 to 35 ribs. Eggs are often laid singly on fescue or in clusters on broadleaf weeds.

Larva: The larva develops through seven instars. The first instar is whitish with a dark head. The second, third and sometimes the fourth instars are green with three indistinct white stripes. The larva then turns brown, and black triangles appear on the seventh to ninth abdominal segments (*Figure 70*). The mature larva is brown with gray flecks and is 1¼ to 1½ inches (30 to 36 mm) long. There may be triangles on all abdominal segments, but they tend to be paler on the forward segments. Usually it has a light subspiracular stripe tinged with yellow or orange.

Adult: The adult moth is a dark gray-black and has a distinct pyramid-shaped orbicular spot in white bordered with black and a brown reniform spot with a white border. These markings make it easy to identify (*Figures 69 and 71*).

Life history

There are two generations in the Pacific Northwest (*Figure 75*). It overwinters as a larva in the soil. Adults of the first generation are active from May into July. Second generation adults are active from August into October. Eggs can be found all summer long on the ground or cover crop. Second generation larvae overwinter in a cold torpor, rather than diapause, and can become active and feed on warm days during the winter when the temperature reaches 40 to 50°F.

Damage

Larvae often feed before cover crops have begun to grow in the spring, making fruit buds particularly vulnerable. Bud damage ranges from small round holes on the side of the bud to fully eaten buds. Normally buds are half eaten (*Figure 72*). Spring is when they cause the most damage. Before applying controls, make sure the damage is fresh. It is possible that feeding on buds will have stopped and there will be no further damage. Later in the year, larvae feed mainly on leaves and can defoliate young trees. However, they may also damage fruit and often excavate holes large enough to conceal their entire bodies.

Figure 71: The spotted cutworm adult has a distinct white orbicular spot.

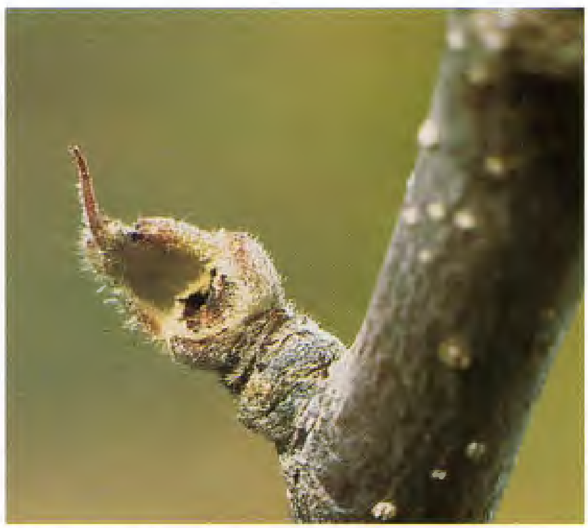


Figure 72: Apple buds damaged by the spotted cutworm

Figure 73: The Bertha armyworm larva has black patches down the center, which help distinguish it from other species.

Figure 74: Bertha armyworm larvae can excavate holes in fruit.

Bertha armyworm

Mamestra configurata Walker

Life stages

Egg: The egg is white when first laid, but within 24 hours develop brown markings around the micropyle and the equator *(Figure 61)*. It has about 38 ribs. Eggs are laid on the cover crop in batches of 100 to 150 in neat diagonal rows.

Larva: The larva develops through six instars. The first four can be shades of gray, brown or green with five broken white stripes *(Figure 73)*. The later instars generally turn brown with conspicuous yellow stripes often flushed with orange. No matter what the basic color, the larva always has black patches down the center back which help distinguish this species *(Figure 70)*. When mature the larva is about 1¼ inches (30 mm) long.

Adult: The adult moth is gray with a black-green background color. The green fades after it dies. The orbicular wing spot is gray or gray-brown with a black border and the reniform spot is white, making this moth easy to identify *(Figure 69)*.

Life history

The Bertha armyworm has two generations overlapping those of the spotted cutworm *(Figure 75)*. It overwinters as a pupa in the soil. Adults begin to emerge in May. Eggs are laid on the cover crop from late May until October. The first generation overlaps the second. Larvae are most numerous in late June and in late August and September. Bertha armyworm inflicts most of its damage in the fall, as there are no larvae in the spring.

Damage

Where weed control is neglected, the Bertha armyworm can defoliate young trees. Newly hatched larvae damage only the surface of fruit but older larvae excavate large holes *(Figure 74)*. Young larvae skeletonize leaves and older larvae consume the entire leaf except for the midvein.

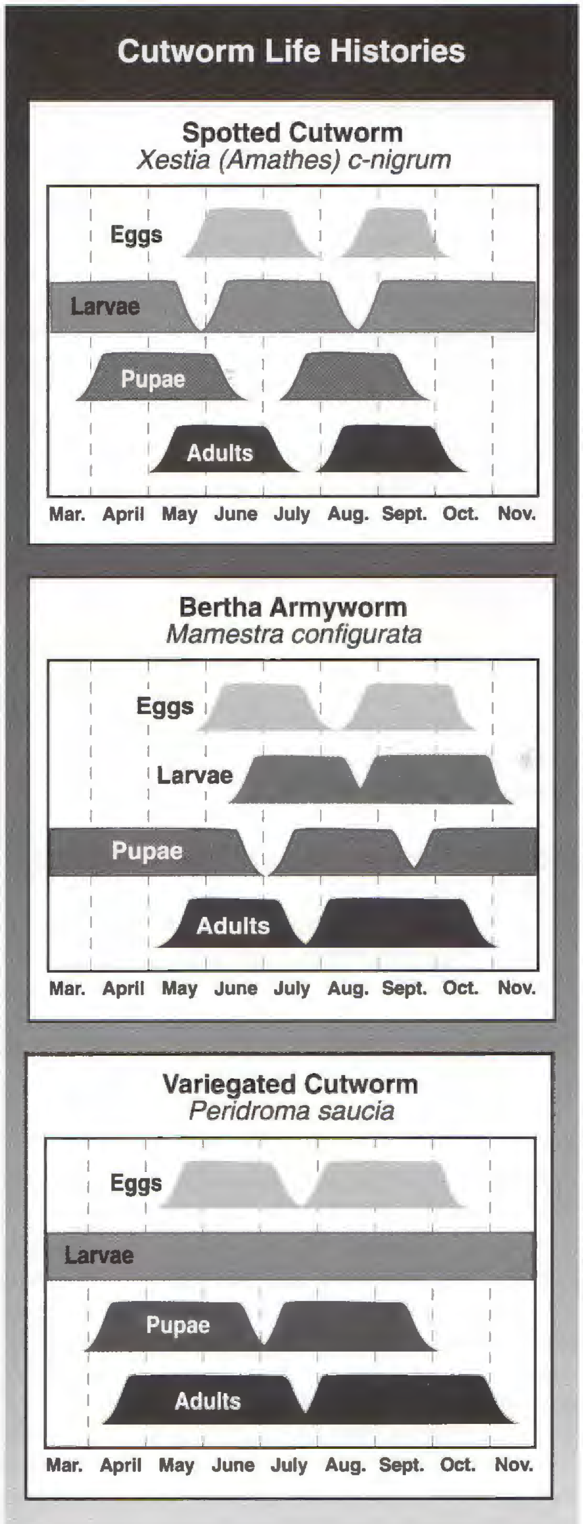


Figure 75

Variegated cutworm

Peridroma saucia (Hübner)

Life stages

Egg: The egg is white with a reddish coloring around the equator and micropyle. It is about 1/50 inch (0.5 mm) in diameter and has 35 to 50 ribs.

Larva: The larva goes through six instars that vary from gray to dark brown. A mature larva of this species can be distinguished easily by 4 to 7 distinct pale yellow spots, one per segment, down the middle of the back (*Figure 70*). Usually, it has a narrow orange-brown spiracular stripe and irregular orange and yellow markings.

Adult: The adult moth is a nondescript rusty-brown color. The orbicular spot is often distinct (*Figure 69*). The reniform spot is darker but not obvious. This moth is less easy to identify than the spotted cutworm and the Bertha armyworm.

Life history

The variegated cutworm overwinters as a larva in the soil. It does not go into diapause to overwinter and many larvae do not survive. This may be one reason variegated cutworm populations rarely reach damaging levels. Surviving larvae may damage buds early in the year. Larvae pupate in the soil and adults begin to emerge in in the spring. Adults fly and lay eggs from April through November (*Figure 75*).

Damage

Larvae are in the orchard throughout the year but usually do not become numerous until fall. Populations are seldom high enough to cause economic damage.

Pear psylla

Cacopsylla pyricola (Foerster)
(Homoptera: Psyllidae)

Pear psylla probably arrived in the United States along with shipments of pear nursery stock from western Europe. It was first found in Connecticut in 1832 and spread to Washington state by 1939. Within a few years it became a serious pest throughout all pear-growing areas in the Pacific Northwest. As well as causing fruit russet, serious infestations can stunt, defoliate and even kill trees.

Figure 76: Freshly laid pear psylla eggs are creamy white, but turn yellow to orange as they develop.

Figure 77: Nymphs pass through five instars. The first is creamy yellow. Each successive stage is larger, flatter and darker colored than the last.

Figure 78: Fifth instar nymphs are called hardshells. All stages have conspicuous red eyes.

Hosts

In the Pacific Northwest, pear psylla is a pest only of pear. Pear cultivars vary in their suitability as hosts and, to a greater degree, in their susceptibility to damage from the honeydew. In general, russeted cultivars, such as Bosc, sustain less fruit damage than smooth skinned pears. Red pears are less suitable hosts because they are generally less vigorous and Asian pears are less prone to infestation than those of European origin.

Several other plants serve as transitory hosts and overwintering sites for winterform pear psylla adults. The psylla may feed on other deciduous fruit trees, especially apples, as they disperse from pear orchards in the fall and return in the spring. However, pear psylla does not reproduce on these transitory hosts.

Life stages

Egg: The egg, shaped like a grains of rice, is attached to the host by a small protrusion extending from the rounded end. A curled filament extends from the pointed end. The egg is creamy white when laid but turns yellow to orange as it develop towards hatching (*Figure 76*).

Nymph: The nymph (*Figure 77*) passes through five instars, each of which ends in a molt. The first instar is creamy yellow. It is long, cylindrical and about the size of the egg. Each successive stage is larger, flatter and more oval than the last. The fourth-instar nymph is yellow-green to light tan, while the fifth instar is dark green to dark brown. Third, fourth and fifth instars have progressively larger wing pads (*Figure 78*). All stages have two conspicuous red eyes.

Adults: There are two adult forms: winterform and summerform. The winterform adult measures about $\frac{1}{10}$ inch (2.5 mm) long, whereas the summerform is only $\frac{1}{12}$ inch (2 mm) long. Wings of both forms are held rooflike over the abdomen. Winterform wings have a dark, smoky area about halfway back along the inner margin (Figure 79), while the wings of the summerform are almost clear except for the veins (*Figure 80*). The dark wing patch on the winterform helps distinguish pear psylla from other psylla species occasionally found in pear orchards. Both nymphs and adults feed by sucking juice from their host. While feeding, the nymph produces honeydew, which forms into a droplet near or over it. Fifth instars, which are called hard-shells, leave the honeydew droplets before molting into adults. Adults coat the honeydew droplets with wax, which prevents the honeydew from sticking to their wings.

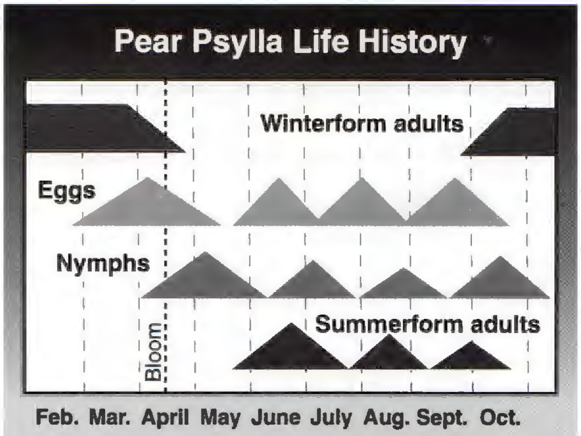
Figure 79: Wings of the winterform adult have a smoky patch half way along the inner edge.

Figure 80: Wings of the summerform adult are almost clear, except for the veins.

Life history

Pear psylla pass the winter as winterform adults in a state of reproductive diapause (*Figure 81*). They begin laying eggs when pear buds begin to swell. They deposit them around the base of buds and in other rough places on small twigs. After buds open, they lay eggs along midveins and petioles of developing leaves, and on stems and sepals of blossoms. Adults continue to lay eggs through petal fall. This long egg laying period produces a wide age distribution of first generation nymphs, and some complete their development before the last have hatched. Summerform adults lay eggs on terminals and the nymphs feed on leaves and stems of tender new growth. Some first-generation nymphs feed on sepals and calyx ends of fruit.

There are 2 or 3 generations of summerforms before the winterform generation develops in the fall.



Pear psylla has two adult forms: winterform and summerform. It overwinters as a winterform adult in a state of reproductive diapause. Timings are based on observations in Washington.

Figure 81

Damage

Fruit russet: Nymphs and adults are phloem feeders. Honeydew, produced by nymphs, drips or runs onto fruit, causing dark russet blotches or streaks (*Figure 82*). This results in downgrading of fresh and sometimes processing fruit.

Psylla shock: In large numbers, pear psylla can stunt and defoliate trees and cause fruit drop. A carry-over effect may reduce fruit set the following year. These symptoms, called psylla shock, are caused by toxic saliva injected into the tree by feeding nymphs. When psylla are controlled to prevent fruit russet, psylla shock does not occur.

Pear decline: Pear psylla also transmits a mycoplasma disease organism through its saliva. The disease damages sieve tubes in the phloem, which prevents synthesized nutrients moving down the tree and results in root starvation. Diseased trees may either decline slowly or collapse suddenly and then die. Trees suffering slow decline can recover if psylla density is low. The severity of the disease depends on the origin of the rootstock. Cultivars

Figure 82: Honeydew, produced by nymphs, drips or runs onto fruit, causing dark russeting in blotches or streaks.

Figure 83: Monitor adults by jarring them from limbs onto a white cloth tray and counting them.

grafted onto *Pyrus pyrifolia* or *Pyrus ussuriensis* are more susceptible than those with *Pyrus communis* roots. Resistant rootstocks have helped remedy the problem.

Biological control

Several predators and at least two parasitoid species attack pear psylla in Washington. Common predators include anthocorid bugs, predaceous plant bugs, lacewing adults and their larvae, and ladybird beetle adults and larvae. These predators feed on eggs and nymphs. Many species of spiders prey on adults. Most predators of psylla are general feeders and will prey on other pests in pear orchards, such as aphids and grape mealybugs. The two parasitoids, *Trechnites psyllae* and *Prionomitus mitratus* are small wasps. The adult wasps lay eggs inside the bodies of the psylla nymphs, where the wasp larvae consume their hosts as they develop. See Part IV, Natural Enemies and Pollinators.

Monitoring

It is important to monitor psylla carefully throughout the growing season in order to detect increases in populations before they reach damaging levels.

Adults: Adults are monitored by jarring them from limbs onto a white cloth tray and counting them (*Figure 83*). Instructions for making a beating tray are given in *Figure 2* in Part I. Hold a tray, 18 inches square, under an almost horizontal section of limb that is ¾ to 1½ inches in diameter and has an average complement of branches and spurs. Tap the limb firmly three times with a 1-foot length of stiff rubber hose. Old spray hose works well. Adult psylla jarred from the tree cling to the cloth and can be counted. Remove insects and debris from the tray by turning the tray upright and tapping it lightly with the hose. A standard sample consists of 25 beating tray counts taken at random throughout the area surveyed. Emphasize sampling in parts of the orchard with a history of high populations.

Nymphs and eggs: To determine the density of first generation eggs and nymphs, carefully examine new growth on spurs. Collect at least 10 fruiting spurs at random from the area being sampled. Horizontal or upward pointing spurs are best. Count eggs and nymphs on each leaf, fruit and stem with a dissecting microscope or a 10-power hand lens.

Subsequent generations of eggs and nymphs should be sampled on new shoot growth. Pick at least 50 leaves from randomly selected shoots throughout the area being sampled. Take equal numbers of leaves from near the tips and the bases of shoots. Examine them as above. As with adults, concentrate sampling on parts of the orchard most damaged by psylla in the past.

Management

As populations of psylla increase rapidly on highly vigorous trees, avoid practices that overstimulate tree growth. Apply only enough nitrogen fertilizer to achieve adequate fruit set and good fruit size. Prune trees moderately each year, rather than lightly for a few years and then heavily to correct tree size and shape. Irrigation through overtree sprinklers will reduce fruit russet by removing honeydew from leaves and fruit but should be used cautiously as it may encourage development of diseases.

Pulling off water sprouts or suckers growing from scaffold limbs through the center of the trees not only removes tender foliage that psylla feed on, but also allows sprays to penetrate better. Pull water sprouts by hand, rather than cut them with loppers, to minimize regrowth. This should be done before sprouts develop woody attachment to limbs, normally before the end of June.

The best approach to chemical control is to destroy winterform adults before they lay eggs. It may take 2 or 3 pre-bloom sprays to accomplish this. Apply the initial dormant spray as soon as adults begin to lay eggs. Female winterform adults can be dissected to monitor egg development in the ovaries. Eggs turn yellow when they are almost mature and about to be laid. Monitor surviving and immigrating adults after spraying. Spray again at delayed-dormant or clusterbud stages, or both, when density exceeds 5 per 25 trays.

The risk of reinfestation can be reduced by coordinating spray timing with neighbors. Oil, in place of or combined with the first pesticide application, delays egg laying by winterform adults until green tissue appears on developing buds. This delay helps to synchronize egg hatch, which makes subsequent sprays more effective.

Sprays after petal fall are usually needed to keep populations below damaging levels through the growing season. Monitor nymphs as above and treat when density exceeds 0.3 per leaf. Sprays are more effective if applied when most of the nymphs are in the first three instars rather than later instars.

Pesticides applied to pears greatly reduce the effectiveness of natural enemies. Soft pesticide programs that spare natural enemies would reduce the need for chemical control of pear psylla and other pear pests. Soft programs have been researched but not implemented due to the lack of registration of suitable selective pesticides.

Grape mealybug

Pseudococcus maritimus (Ehrhorn)

(Homoptera: Coccidae)

The grape mealybug was originally described as a pest of grapes, but can attack most deciduous fruit crops. Since the 1970s, it has become an increasingly severe pest of pear and apple. It is slow to spread from orchard to orchard, but once an orchard is infested, the infestation is difficult to clean up. It is usually only a problem on large, mature trees, which are difficult to spray thoroughly and provide shelter for the mealybugs.

Hosts

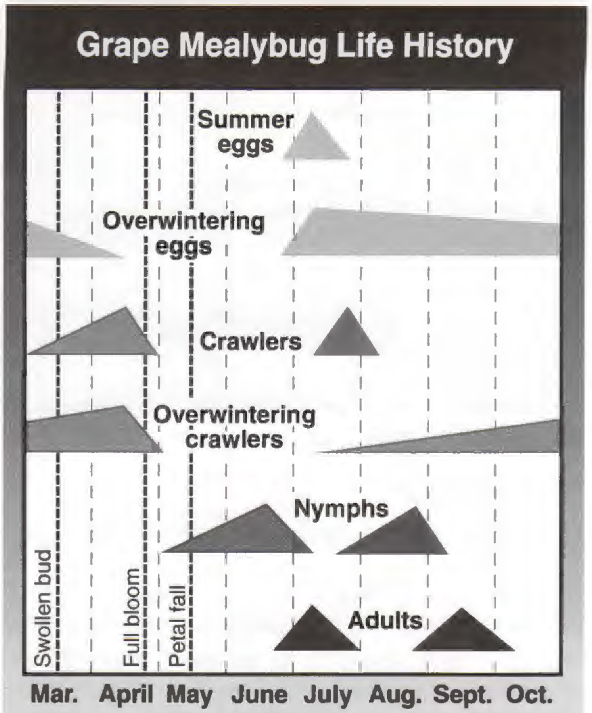
Grape mealybug attacks many plant species including all tree fruits grown in the Northwest as well as other rosaceous plants, grapes, ornamental trees and shrubs. This insect is able to develop new host strains, which allows it to adapt to more hosts. Adaptations may include different development rates and numbers of generations per year.

Life stages

Egg: The egg is a salmon colored, elongated oval. Eggs are laid in masses of waxy filaments that have a cottony appearance.

Nymph: The first instar nymph, or crawler, is pink to salmon colored and has well developed legs. The crawler is covered with a light coating of waxy granules, giving it the appearance of being coated

Figure 84: The feeding nymph is light purple, similar to a woolly apple aphid, but is covered with long, waxy filaments that give it a whitish cast.



There is one full and a partial second generation each year. Some eggs laid by first generation adults hatch during the summer; others overwinter. Some second generation crawlers also overwinter. Timings based on observations on pears in central Washington. Dates may vary on different hosts.

Figure 85

with flour (*Figure 84*). After settling to feed, the crawler molts into a sedentary nymph, and the coating of wax becomes heavier. The sedentary nymph has poorly developed legs. It is pink to purple, but the waxy filaments give it a whitish cast.

Adult: The adult female is wingless and looks similar to a nymph. It can be up to 3⁄16 inch (5 mm) long. It has a well developed ring of waxy filaments around the sides of its body. Filaments are longest at the posterior end of the body and become progressively shorter towards the front of the body. The adult male is much smaller than the female and has wings held flat over the back. It is a fragile insect and resembles a male scale.

Life history

Grape mealybugs overwinter as eggs or crawlers within the loose cottony egg sac under bark scales on scaffold limbs, in other sheltered places on trees, or in duff at the bases of trees.

Crawlers start emerging from egg sacs at the beginning of bud swell and begin feeding on the bases of buds (*Figure 85*). When buds open they go directly to new shoots and leaves. Because some overwintering sites are exposed to sun while others are shaded, crawler movement occurs over a long time, ending at about petal fall. First generation nymphs mature during late June and July in the Northwest. Adult males appear first, mate with last instar nymphs or adult females and die. Receptive females release a pheromone to attract males. Mated females migrate to sheltered areas, lay eggs and die in the egg sac. A partial second generation matures in late August and September. Nymphs of this generation sometimes settle in or around the fruit calyx.

Damage

The most obvious damage by grape mealybug results from the honeydew it secretes. Honeydew is cast off in small drops and falls down through the canopy. When it lands on fruit it causes a coarse, black russet, which is similar to pear psylla russeting. However, mealybug russeting is scattered over the fruit surface (*Figure 86*), while honeydew from psylla is in patches or streaks. Mealybug russeting is most common in low centers of trees, whereas psylla damage occurs more evenly over the trees or in the tops.

When mealybug populations are dense, they can may enter the calyx ends of fruit, causing contamination problems on processed fruit. Their feeding softens tissue in the calyx and around the seed cavity. Symptoms resemble those of a disorder called pink end.

Monitoring

There are no established treatment or damage thresholds for grape mealybug. When infestations are detected they usually need to be controlled. Check during the dormant season for eggs and crawlers in egg sacs under bark scales on scaffold limbs and in other protected areas on trees. The white cottony mass makes egg sacs easy to see. During delayed-dormant and clusterbud stages, crawlers can be monitored by examining developing buds on short limbs and spurs arising from scaffold limbs in low centers of trees. It is easy to detect infestations in late June or July when mature females are crawling back to larger limbs to deposit eggs, or during harvest when damaged fruit is evident in bins. However, little can be done to control mealybugs at these times. If the infestation is spotty, as it often is when this pest first invades orchards, mark infested trees so they can be given special attention.

Biological control

The predator-parasitoid complex that attacks grape mealybug in orchards has not been thoroughly studied. Many generalist predators, such as lacewings, ladybird beetles and predaceous bugs, will feed on this pest. An encyrtid egg parasitoid, *Acerophagus notativentris*, is common in infested orchards. Grape mealybug populations are generally reduced to non-damaging levels by natural control in orchards where soft pesticide programs are used for a few years.

Management

Chemical control: Chemical control of grape mealybug works best when sprays are aimed at the crawler stage. Once crawlers settle and cover themselves with wax they are less susceptible to chemicals, as are crawlers still in the egg sac. Crawlers emerge from egg sacs over a long period. First generation emergence continues from delayed-dormant stage of tree development to petal fall. Effective chemical residues must be maintained throughout that period. A series of sprays, including delayed-dormant, clusterbud and petal fall applications, is required to control first generation crawlers. The two most effective times to spray are clusterbud and petal fall. Both sprays are needed and good spray coverage is essential. If possible, apply succeeding sprays at right angles to the preceding one to improve coverage of hard-to-hit areas of trees. Scaly areas on trunks and limbs and sucker crowns in the tops of trees should be sprayed with a handgun.

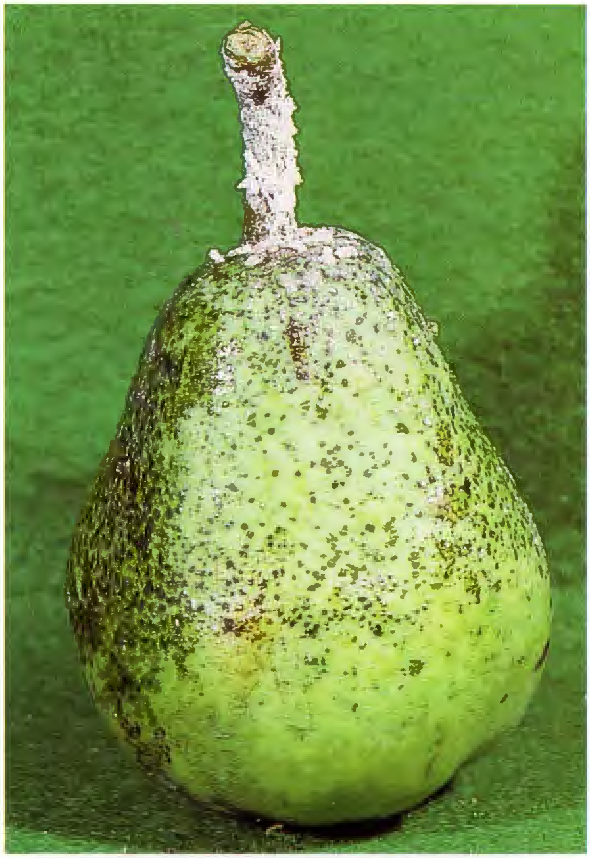


Figure 86: Honeydew secreted by the grape mealybug causes a coarse, black russet on fruit.

Cultural practices: Certain cultural practices can reduce severity of grape mealybug attack. This pest is more difficult to control on large, old trees with high scaffold limbs and large sucker crowns. Pruning out sucker crowns, removing high scaffold limbs during winter pruning and removing water sprouts (suckers) from scaffold limbs through the center of trees during early summer not only removes tender growth susceptible to attack by mealybugs but also improves spray penetration. Pull water sprouts by hand, rather than cut them with loppers, to minimize regrowth. This should be done before sprouts develop woody attachment to limbs, normally before the end of June.

FRUIT FLIES

Apple maggot

Rhagoletis pomonella (Walsh)

(Diptera: Tephritidae)

Apple maggot is a native North American pest whose original host was hawthorn. It was first reported as a pest of apple in the 1860s and has become a key pest of commercial apples throughout eastern Canada and the northeastern United States.

The first confirmed apple maggot infestations in the Northwest were in Oregon in 1979. Since then, trapping programs have located maggots in western Washington and western Oregon, as well as on both sides of the Columbia River Gorge and in Spokane, in eastern Washington. It has also been found in Idaho, Utah, Colorado and California. The pest apparently can survive in a wide range of conditions, from the cool, coastal climate of western Oregon and Washington, to the hot, dry climate of The Dalles, Oregon, or the mountain conditions of Utah.

It is likely the maggot was introduced to the western United States by people transporting infested fruit from the eastern states. It probably had been in the West for many years before being detected. Since 1980, detection of apple maggot at new sites is attributed more to intense monitoring than a spread of apple maggot infestations.

In the early 1980s, states in the Pacific Northwest launched programs to control and contain apple maggot. The emphasis was on preventing the pest becoming established in the major apple growing regions of eastern Washington. Host trees, usually apple or hawthorn, were sprayed or removed to reduce the number of apple maggot flies and potential breeding sites.

The control/containment program ended in 1985 when financial resources became limited and the apple maggot was found in native hawthorn along streams, preventing control by insecticides. While the distribution of apple maggot has spread to a few more counties in western Washington since 1985, infestations in eastern Washington are still restricted to the Spokane area and along the Columbia River Gorge.

If apple maggot were to become established in major fruit-growing regions of the Pacific Northwest, it could have a serious economic impact on the industry. Direct costs to the fruit grower for additional insecticide applications would account for only a small portion of the potential losses. Export markets would be lost and additional fruit would be channeled to the domestic market. Sprays to control apple maggot would have to be applied late in the growing season when most apple growers apply few insecticides. Such additional sprays may disrupt the IPM systems already in place in commercial orchards.

Figure 87: The apple maggot larva can be distinguished from other larvae found in apples by its lack of a distinct head capsule.

Figure 88: The apple maggot fly is about the size of a house fly. The wing pattern distinguishes it from most other fruit flies. See also *Figure 89.*

Hosts

Apple maggot is very adaptable and can infest many different plants including apple, hawthorn, plum, apricot, pear, sweet cherry, sour cherry, wild rose, *Cotoneaster* sp. and *Pyracantha* sp. However, in

Washington it has been found only on apple, crab apple and hawthorn. It most often attacks early maturing, sweet varieties of apples.

Life stages

Egg: The egg is whitish, small, smooth, elongated and slightly curved. As eggs are laid beneath skin of the host fruit they are rarely seen.

Larva: The apple maggot larva is a typical fly larva (*Figure 87*). It is cylindrical, tapering from a blunt posterior to a pointed head, and has no legs. The mature larva is creamy white except for two dark mouth hooks and is ¼ to ⅜ inch (6 to 9 mm) long The larva tunnels through apple flesh and can be distinguished from other insect larvae found in apples by its lack of a distinct head capsule.

Pupa: The pupa looks like a large, dark brown grain of wheat. It is usually found in the top 2 inches (5 cm) of soil under infested trees.

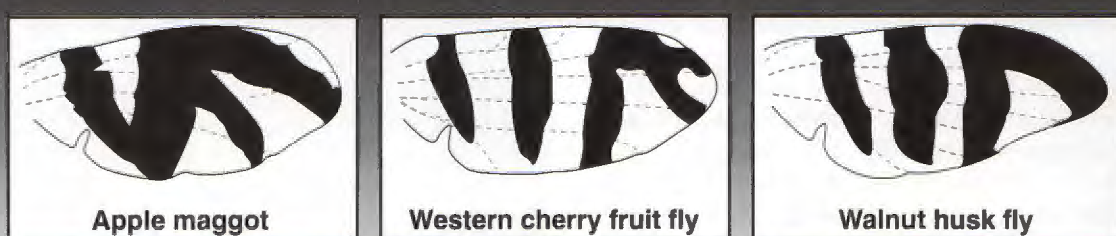
Adult: The apple maggot fly is about the size of a common housefly (*Figure 88*). Its body is black, its eyes are dark red, and the thorax and abdomen have distinctive white or cream bands. The male has a blunt abdomen with three white lines, while the female's more pointed abdomen has four white stripes. A distinct banding pattern on its wings distinguishes it from most other *Rhagoletis* species (*Figure 89*) except the snowberry maggot, which is found throughout the western United States.

Life history

Apple maggot spends the winter in the soil as a pupa. As the soil warms in the spring, it begins to develop. In late June or early July, adults begin to emerge (*Figure 90*). Flies continue to emerge from the soil throughout the summer and are active until October. Peak activity on various hosts depends on fruit maturity. Apple maggot activity peaks earliest on apple varieties maturing in midsummer, followed by native hawthorn and apple varieties maturing in early fall and finally by imported hawthorn and apple varieties maturing in late fall. In Washington, the apple maggot appears to move from one host to another as fruit matures. After emerging, the adult apple maggot feeds for 7 to 10 days until it becomes sexually mature. It eats mainly insect honeydew. Soon after mating, females lay eggs just under the skin of the host fruit. A female can lay between 300 and 500 eggs, which can hatch in as little as 3 to 7 days.

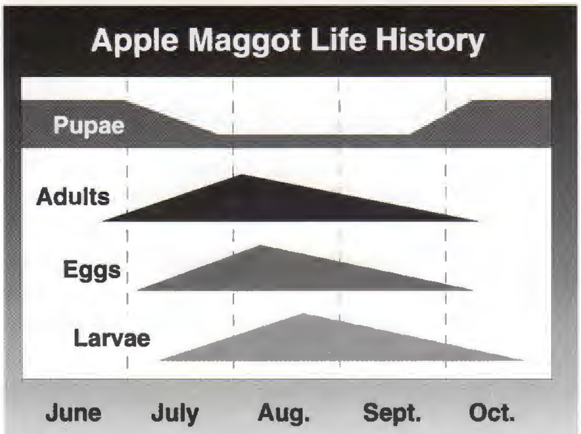
The larvae feed while tunneling through the fruit. It can take from 13 to more than 50 days for the larvae to develop. Temperatures and fruit hardness influence the rate of development. Full grown

Fruit Fly Wing Patterns



Fruit flies of the Tephritidae family are small to medium sized and usually have spotted or banded wings. The wing patterns are often complex and attractive. The larvae, or maggots, of most fruit flies feed on plants and some are serious orchard pests. The larva of the apple maggot, *Rhagoletis pomonella*, tunnels into apples and other tree fruits. The larva of the cherry fruit fly, *Rhagoletis indifferens*, develops inside cherries from eggs laid under the skin. The walnut husk fly, *Rhagoletis completa*, is a serious pest of walnuts in the Pacific Northwest and occasionally attacks peaches.

Figure 89



Most apple maggot pupae stay in the soil for one winter, though some remain there for two years or more. A few flies may complete development the same year and produce a partial second generation. Timings are based on observations in Washington.

Figure 90

larvae leave the fruit, usually after it has fallen to the ground, and enter the soil to pupate.

Most apple maggot pupae stay in the soil for one winter, though some remain there for two years or more. A few flies may complete development the same year and produce a partial second generation. In Washington, this is suicidal, as there would not be enough time to complete larval development before the onset of winter.

Damage

Apple maggot feeds on fruit and if left unchecked can damage almost all the fruit on infested trees. Even small numbers of apple maggot can heavily damage apple crops. When eggs are deposited under the fruit skin the cells surrounding the puncture are damaged (*Figure 91*).

As the apple grows it becomes dimpled and lumpy. This is more evident in apples attacked early in the season. Feeding by the larvae leaves brown trails in the apple flesh (*Figure 92*). When many larvae feed on a fruit, the flesh often turns mushy and the apple drops early. In hard, later-maturing apples, internal breakdown may not be apparent until after the apple drops.

Monitoring

Adults can be monitored with sticky traps. Use either a red sphere or a bright yellow panel with protein and ammonia extracts as a lure (*Figure 93*). Unlike pheromone traps, which attract moths from several yards, an apple maggot trap is effective only over short distances, generally the tree in which it is located. Because traps, particularly the yellow panel type, attract many kinds of insects, they need to be inspected and cleaned regularly.

Place traps within the fruiting canopy of the tree in the outer third, with panel traps positioned so that the broad surface is exposed to the foliage. Remove foliage from around the trap for 12 to 18 inches (30 to 45 cm) to make it more visible to the apple maggot flies. Place traps at intervals of 150 feet (45 meters) along the orchard border. Where the orchard borders a dusty road, place the traps one or two rows into the orchard. The commercially available pre-baited apple maggot trap should be changed every 7 days. Yellow panel traps using ammonium carbonate as a lure can be changed every 14 to 21 days, depending on how long the lure lasts and how contaminated the trap's surface becomes. Red sphere traps should be replaced or have the adhesive renewed every 4 weeks, or more often if they lose their tackiness. Examine traps 2 or

Figure 91: When eggs are deposited under the fruit skin, the cells surrounding the puncture are damaged and the fruit becomes dimpled.

Figure 92: Larvae leave brown trails in the apple flesh as they feed.

3 times a week. Apple maggot trapping in the Northwest is complicated by the presence of the snowberry maggot, a fly that does not attack apple or other fruits but looks like the apple maggot. These two species cannot be distinguished in the field and must be examined under magnification by an expert. Remove any flies that look like the apple maggot, place in a vial with a solvent (Citra-Safe®) and take to an expert for identification. In Washington, this is usually done by the Washington State Department of Agriculture. In areas where there are high populations of snowberry maggot near orchards, the red sphere may be the trap of choice, since it is less attractive to this insect.

Biological control

The three most common parasitoids of apple maggot in the western United States are *Biosteres melleus, Opius downesi*, and a species of *Pteromalus*. They are all parasitic wasps that attack apple maggot larvae. The first two develop inside the host, while *Pteromalus* sp. is an ectoparasitoid and feeds on the outside of the larva. However, during three years' research in Washington no parasitism of apple maggot in apple was found, probably because the larvae burrow too deep in the fruit for the parasitoids to reach with their small ovipositors. Parasitism levels in hawthorn ranged from 0 to 60%. Biological control of apple maggot in commercial apple orchards holds little promise as a management tactic. However, parasitism in native habitats plays a role in suppressing of apple maggot populations.

Figure 93: Common types of traps used to monitor presence and activity of apple maggot adults.

Management

The management guidelines outlined here relate only to orchards in areas of Washington where apple maggot occurs. It has been detected in the Columbia River Gorge, Spokane and western Washington. The quarantine area is all of western Washington (except Whatcom, Skagit and Snohomish counties) and Skamamia, Klickitat and Spokane counties in eastern Washington.

Control recommendations depend on how close the orchard is to an apple maggot detection. If the closest apple maggot detection is more than ¼ mile from the orchard, no control is needed. If an apple maggot has been detected within ¼ mile of the orchard, the orchard is considered threatened and the orchardist has two management options: no trapping or trapping.

No trapping: No monitoring is done and it is assumed that the apple maggot is in the orchard. As soon as the orchard is recognized as threatened, apply controls every 14 to 21 days until harvest. Have fruit inspected by the Washington State Department of Agriculture to certify it is free from apple maggot infestation, or place the fruit in cold storage for at least 40 days before shipping out of the quarantine area.

Trapping: The need for control is based on results of monitoring. Apply control treatments within 7 days of trapping an apple maggot fly in the orchard. If flies continue to be caught, repeat treatments in 14 to 21 days. If no more flies are caught within 14 to 21 days of the first capture, do not treat again until another fly is detected. Have fruit inspected by the Washington State Department of Agriculture to certify it is free of apple maggot infestation or place fruit in cold storage for at least 40 days before shipping out of the quarantine area.

Other recommendations: Remove apple maggot hosts within ¼ to ½ mile of the orchard to reduce potential sources of infestation. Look particularly for wild or unsprayed apple trees, ornamental hawthorns and crab apples. Insecticides applied against the second generation of codling moth in mid-July or early August will give protection from apple maggot for 14 to 21 days.

Western cherry fruit fly

Rhagoletis indifferens Curran

(Diptera: Tephritidae)

The western cherry fruit fly is a key pest in all cherry-growing regions of the western United States. It is native to North America and was reported attacking commercial cherry in the Pacific Northwest in the early 1900s. It was found in the Yakima Valley in 1942 and the Wenatchee area in 1950.

The fly's larva develops in ripening cherries. If uncontrolled, the pest can ruin almost all the fruit on a tree. Even poor control can have serious consequences since major markets for Northwest cherries, such as California and many foreign countries, do not tolerate any infestation of packed cherries.

Adults are weak migrators and will travel no further than necessary to find a host tree. For this reason, infestations in a region tend to be spotty. However, infestations within an orchard, where the trees are close together, can spread rapidly.

Hosts

Cherry fruit fly attacks all varieties of cultivated and wild cherries.

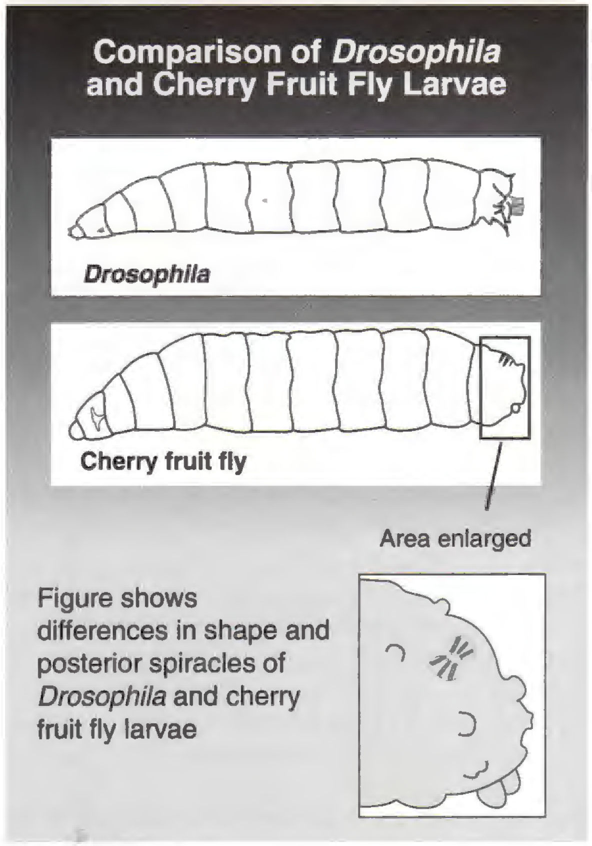


Figure 94

Life stages

Egg: The egg is yellowish and elongated with a stalk at one end. It is about $\frac{1}{30}$ inch long (0.8 mm) and is deposited under the cherry skin.

Larva: The larva is a creamy white, legless maggot, which is tapered at the head and blunt at the rear. It passes through three instars and grows to about $\frac{5}{16}$ inch (8 mm) long. Maggots found in cherries may be those of the cherry fruit fly or could also be larvae of the family Drosophilidae. The *Drosophila* fruit flies do not attack fruit unless the skin has been physically damaged, allowing an opening for deposition of eggs. This usually happens when cherries are cracked because of wind or rain damage or bird feeding, or are decayed. Larvae of the cherry fruit fly, and other *Rhagoletis* species, can be distinguished from the *Drosophila* species by examining the posterior end of the larvae. The posterior end of the cherry fruit fly larva is rounded and the anal spiracles, which are not raised, each have three darker lines extending laterally from the mid-line. The posterior of *Drosophila* larva has two protuberances on which the anal spiracles are found (*Figure 94*).

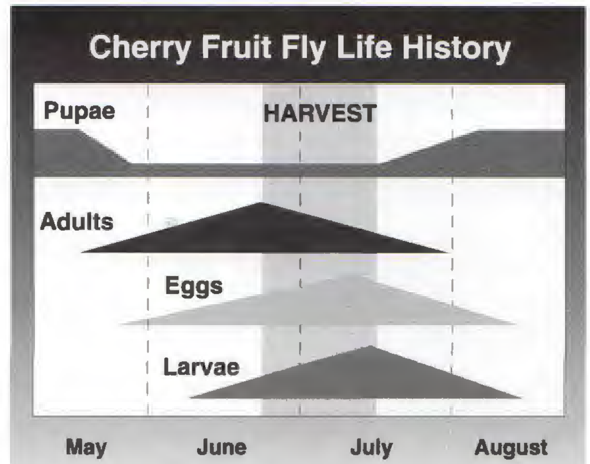
Pupa: The pupa is yellowish brown to dark brown and looks like a large grain of wheat. It is about 3/16 inch (4 mm) long.

Adult: The adult has a black body with white bands on the abdomen. The wings are transparent with a distinctive dark banding pattern (*Figure 95*). It can easily be distinguished from other fruit flies by the wing pattern (see *Figure 89*). The fly is about 1/5 inch (5 mm) long. The female is slightly larger than the male.

Life history

Cherry fruit fly completes only one generation a year (*Figure 96*). It overwinters as a pupa in the soil. The pupae are affected by soil temperature and do not all develop at the same rate. Adults begin to emerge in May, about 5 weeks before harvest, and are active until 3 or 4 weeks after harvest. Peak emergence often coincides with harvest. The emergence pattern is shown in *Figure 97*.

Adults live 16 to 35 days, depending on temperatures. They feed on deposits on the leaves, such as honeydew and pollen. Adult females undergo a 7- to 10-day preoviposition period before they are sexually mature. After mating, they lay eggs under the skin of the fruit. Females frequently feed on juices exuding from the puncture made during egg laying.



Cherry fruit fly overwinters as a pupa. Most pupae develop into adults the following season, but some remain in diapause for two years. Timings are based on observations in northcentral Washington.

Figure 96

Figure 95: Adult western cherry fruit fly captured in adhesive on a yellow trap.

Each female can lay from 50 to 200 eggs in a 3-week period. The optimum temperature for egg laying is between 75 and 85°F. The eggs hatch in 5 to 8 days and the larvae burrow towards the pit of the fruit, where they are unreachable by most pesticides. When fully developed, 10 to 21 days after hatching, they bore their way out of the cherries and drop to the ground. Within a few hours they burrow into the soil to pupate. The majority develop into adults the following season, though a few remain dormant for two years.

Damage

Adults do no damage to fruit. Maggots, which develop inside the cherries, make the fruit unmarketable (*Figure 98*). In unsprayed trees a high percentage of fruit is likely to be attacked. The adult cherry fruit fly does not fly long distances, so some unsprayed trees may remain uninfested for many years.

Monitoring

The western cherry fruit fly is difficult to monitor, as it is not strongly attracted to traps. The most

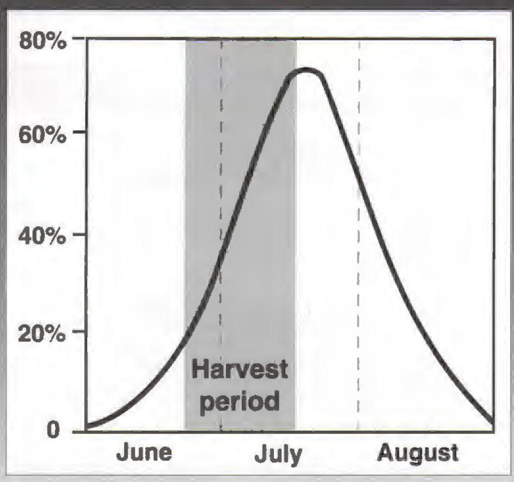


Chart shows the percentage of total uncontrolled population laying eggs. It is based on data from northcentral Washington in 1991.

Figure 97

effective trap is an adhesive covered yellow panel with an ammonium-carbonate lure. These traps should be placed in the fruiting canopy of the tree, with fruit and foliage removed from around it for 12 to 18 inches. Do not assume that because no cherry fruit flies are caught in traps the orchard is safe. Because of the profound consequences of a single infested fruit being detected, control is recommended, regardless of whether flies are trapped or not. Traps are most useful in determining when the first flies emerge in a region. For this purpose, traps are placed in trees with a history of heavy infestation. Orchardists are notified of the first catch so they can begin their control programs. The date when first flies emerge and control should begin varies from year to year by up to 4 weeks. A degree day model is available to predict first emergence and seasonal activity.

Biological control

Parasitic wasps are reported to attack larvae of the western cherry fruit fly, but control is not significant in commercial orchards.

Management

Timing of the first chemical control spray is based on the interval between emergence of the females and the first egg laying, usually 7 to 10 days. Because trapping flies in a commercial orchard is not a reliable way to determine the presence or emergence of the first fly, a degree model is helpful. This model uses a lower developmental threshold of 41°F, but no upper threshold. A degree day look-up table for the western cherry fruit fly, based on daily maximum and minimum temperatures, is given in Appendix 1. The table gives the relationship between the percentage of fly emergence and degree days. First fly is expected at 950 degree days after March 1. Chemical control sprays should be applied on or before 1060 degree days to target mature, egg-laying flies.

Sprays should be repeated every 10 to 21 days, depending on the residual activity of the product, to maintain residues high enough to kill adults before they lay eggs. Rain may reduce residues, requiring shorter intervals between sprays. Applications of products with a very short residual life are best repeated every 7 days. Emergence and egg laying continue after harvest, making it important to maintain a control program through harvest. Most larvae found in fruit at packing houses in recent years have been very small, indicating that control programs have broken down just before harvest or during an extended harvest.

Since there are always a few cherries left on the

Figure 98: Maggots, which develop inside the cherries, make the fruit unmarketable.

trees after harvest, a post-harvest control should be applied to prevent late-emerging flies from completing their life cycles. If trees are not harvested, perhaps due to poor fruit quality, a poor market for the variety, or rain damage, they should be sprayed to prevent late season infestations and problems the following year.

Walnut husk fly

Rhagoletis completa Cresson

(Diptera: Tephritidae)

The walnut husk fly originated east of the Rocky Mountains. It was first reported in California in 1926 and by the 1950s had spread to the Pacific Northwest. It has become a serious mid- to late-season pest of walnuts in the West. In Washington's Yakima Valley, it occasionally attacks peaches grown close to walnuts.

Hosts

The walnut husk fly's primary host is walnuts, but it may also attack late-maturing varieties of peaches near infested walnuts. Like the cherry fruit fly, the walnut husk fly remains on a single walnut tree or group of trees as long as there are plenty of nuts. It is a peach pest primarily in urban areas, where peaches and walnuts are grown side by side, rather than in commercial orchards.

Life stages

Egg: The egg is elongate, slightly curved and about 1/25 inch (1 mm) long. A freshly laid egg is pearly white. Shortly before hatching, the mouth hooks of the young larva can be seen.

Larva: The newly hatched larva is maggot-like and white except for its dark mouth parts. The larva turns yellow as it matures. It is about ½ inch long (13 mm) when mature. If a maggot is found in peach, it is probably walnut husk fly or *Drosophila.*

Pupa: The pupa is straw colored with conspicuous dark brown anterior spiracles. It is the size and shape of a large grain of wheat.

Adult: The adult is about ¼ inch (6 mm) long, slightly smaller than a housefly. It has large, iridescent, greenish eyes, a tawny brown body color and

Figure 99: The walnut husk fly has a yellow spot on its back and conspicuous wing markings. See also *Figure 89.*

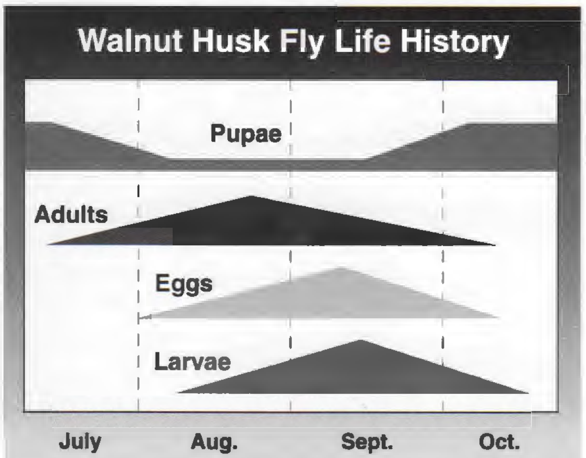
banded wings. It has a yellow spot on its back. Its conspicuous wing markings make it easy to identify (*Figure 99*). The female is larger than the male and its abdomen is more pointed.

Life history

The biology, behavior and life history of the husk fly are similar to those of other tephritid fruit flies, such as apple maggot and cherry fruit fly (*Figure 100*). The husk fly produces one generation a year and overwinters as a pupa in the soil beneath the trees. Adults usually emerge from July until early September, but sometimes as late as October. They mate about 8 days after emerging.

Egg laying begins anywhere from 2 to 6 weeks after the first emergence and continues until fall. The period before egg laying is much more variable than that of cherry fruit fly or apple maggot. Eggs are laid in groups of about 15 in a small cache beneath the fruit skin. Peaches are attacked when they are almost mature. Eggs hatch within 5 days. The white maggots feed inside the fruit for 3 to 5 weeks, depending on the temperature.

Mature larvae leave the fruit through a small exit hole or the hole through which the eggs were deposited, usually at the opposite end of the fruit from the stem. They drop to the ground and burrow into the soil to pupate. They remain in their pupal case for at least a year. Some remain in diapause for 2 years, and a few even 3 or 4 years.



Walnut husk fly overwinters as a pupa. Most pupae emerge as adults the following year, though some remain in the ground for 2 years, and a few even 3 or 4 years. Egg laying can begin anywhere from 2 to 6 weeks after adults emerge.

Figure 100

Damage

Husk fly larvae destroy peaches by feeding internally on the fruit flesh.

Monitoring

A yellow sticky trap developed to monitor apple maggot works well for walnut husk flies (*Figure 93*). A trap can be made from a piece of yellow cardboard, about 5½ by 9 inches (14 by 23 cm), coated with Tanglefoot adhesive, and with a small bottle of ammonium carbonate attached to the bottom. Yellow rectangle traps are not specific to husk fly and will catch many other flies. A more specific trap is a green sticky spherical trap the same size used to monitor apple maggot. However, the green sphere trap is less efficient than the yellow rectangle.

At the beginning of July, hang traps at least 6 feet above the ground in a shady part of the tree. If husk flies were a problem the previous year, hang traps in trees that were infested.

Biological control

The husk fly has few natural enemies. A predatory mite, *Pyemotes ventricosus* and an anthocorid bug *Triphleps insidiosus* have been seen feeding on eggs. Ants and spiders reportedly prey on larvae and adults. However, these predators have little impact on husk fly populations.

Management

Remove fallen infested fruit and remove the source of the infestation, probably a nearby walnut tree. Apply an insecticide recommended for walnut husk fly that is also registered on peaches within 10 days after trap catches show a sharp increase over a 3-day period. This will usually be from late July to mid-August. Apply again in 10 days if the husk fly was a problem the previous year. A third application may be needed 3 to 4 weeks later if flies continue to be caught in traps. A protein bait can be used to attract the flies to the insecticide to make it more effective.

As some pupae remain in the ground for more than one year, flies may continue to appear after the source is removed and control may be needed over several years.

Campylomma (Mullein plant bug)

Campylomma verbasci (Meyer)

(Hemiptera: Miridae)

Campylomma is European or Asian in origin, but was recorded from the eastern United States as early as 1886. Its area of distribution includes southeastern Canada and the northeastern United States, as far south as Pennsylvania, and as far west as Iowa. In the West, it is recorded from British Columbia, Washington, Oregon, Idaho, and Colorado. In Washington, reports of damage have come from throughout the main fruit growing region east of the Cascades (with the exception of Spokane/Greenbluff area), although problems have been more intense from Wenatchee to the Canadian border.

Campylomma was not reported as a pest in western North America until the early 1970s in British Columbia. Damage in Washington has occurred for several decades, but was sporadic and primarily confined to the northern part of Okanogan county, bordering British Columbia. Damage increased dramatically in the mid- to late 1980s, and became widespread in 1990. In Europe and Asia it is reported only as a predator, usually of mites.

Hosts

Campylomma has two distinct types of hosts: a woody host, which is necessary for the overwintering eggs; and an herbaceous host, which may be used for one or more generations during the summer. Although campylomma seems to need a woody host to complete its development, a herbaceous host may not be vital. Woody hosts include apple and pear, serviceberry, grape, oak, and wild rose. Herbaceous hosts include common mullein *Verbascum thapsus* (hence the common name of this insect), potato, sugar beet, corn, small grains, and various weeds. In orchard areas, by far the greatest numbers have been found on mullein.

There appear to be distinct differences in susceptibility among tree fruit species and varieties, although it is not clear why. Damage to pears is quite rare even at high populations, although some damage to Bartlett has been reported from British Columbia. Of the two major apple varieties in the Pacific Northwest, Golden Delicious appears to be much more susceptible to damage (given an equivalent campylomma population) than Red Delicious, although both cultivars are damaged. McIntosh and Winesap do not appear to sustain any damage. Information on newer varieties is lacking, although Gala appears to be readily attacked.

Figure 101: Nymphs are translucent when first hatched but gradually turn pale green.

Life stages

Egg: The overwintering egg is about 1/28 inch (0.87 mm) long and sac-shaped. It is inserted into the bark of host plants with only the operculum (lid or cover) exposed, making it almost impossible to see.

Nymph: The nymph is ovate and translucent when first hatched, but gradually takes on a pale green color (*Figure 101*). Older nymphs have black spines on the legs. In its early instars, a campylomma nymph may be confused with a young white apple leafhopper nymph. However, the leafhopper nymph can be distinguished by its thread-like antennae which project laterally from the head, and by its distinctly segmented and wedge shaped abdomen (*Figure 102*). The campylomma nymph has thicker, four-segmented antennae, with a dark colored joint between the first and second segments. First instar campylomma nymphs have also been confused with predatory mites (*Typhlodromus*) and early instar aphids. An aphid may be distinguished by its globular shape, darker green color, and cornicles on the abdomen. Aphids are also much more sluggish than either campylomma or leafhoppers.

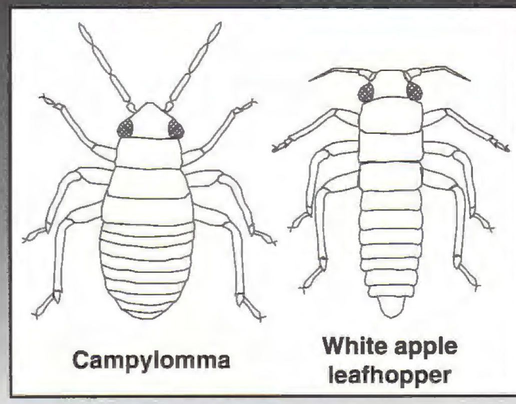
Adult: The adult is gray-brown, an elongated oval shape, and about 1/10 inch (2.5 mm) in length (*Figure 103*). Like the nymph, it has a dark spot on the first antennal segment, and black spines on the legs.

Life history

Campylomma overwinters as an egg, which is inserted deeply into the tissue of a woody host plant. Eggs hatch in the spring, beginning as early as tight cluster to pink stage of tree development and continuing through petal fall. Egg hatch peaks during or shortly after bloom. Nymphs pass through five instars. The total period of nymphal development depends on temperature and takes about 21 days at 72°F.

Nymphs from the overwintering eggs may be present from mid-April to mid-June in central Washington. Adults first appear in mid-to late May (*Figure 104*). Studies of campylomma colonies on a herbaceous host showed females lived an average of 17 days and laid an average of 38 eggs. Eggs hatch in 7 to 13 days at constant temperatures between 68 and 81°F. On apple and pear, the highest densities are usually detected in the spring, with minor peaks throughout the rest of the year. The majority of the campylomma population spends the summer on herbaceous hosts, especially mullein, so samples taken in tree fruits represent only a part of the population. In summer, campylomma they feed on insects (primarily thrips) and on the host plant. In late August, adults begin migrating back to woody hosts, such as apple and pear, where they mate and lay overwintering eggs through October. Observations indicate 2 to 4 generations occur annually in the Pacific Northwest.

Distinguishing Campylomma and Leafhopper Nymphs



Leafhopper nymphs may be distinguished by their thread-like antennae, which project laterally from the head, and by their distinctly segmented and wedge shaped abdomen.

Figure 102

Figure 103: The adult is gray-brown and, like the nymph, has a dark spot on each antenna.

Damage

Campylomma is one of the few tree fruit pests in the Pacific Northwest that is also a predator. Throughout most of its distribution in Europe and Asia, no fruit damage has been noted and it has been reported as an important predator of mites and occasionally aphids. In the Pacific Northwest, it preys on aphids and pear psylla, and can greatly enhance biological control of these species. However, for a relatively short period around bloom, it feeds on flower parts and developing fruitlets. Although fruit feeding may occur later than this period, it does not seem to cause damage. Early feeding causes a reaction in the fruit, producing a dark, raised, corky wart, often surrounded by a shallow depression (*Figure 105*). Feeding punctures can occur individually, or an entire quadrant of the fruit may be damaged. Multiple stings on a fruit usually causes some degree of fruit deformity. Stings tend to be more visible on the skin of Golden Delicious than on darker colored cultivars, and the scars may be a lighter tan color.

Figure 105: Feeding by campylomma can deform fruit.

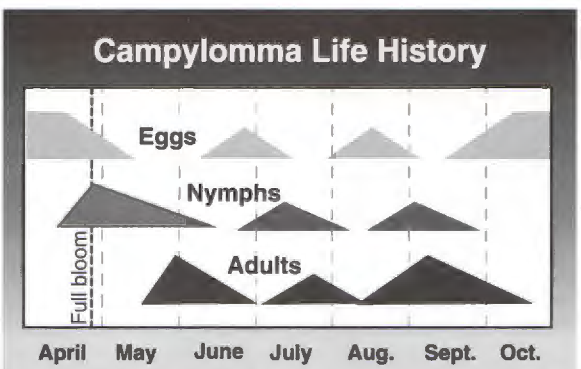
Monitoring

Campylomma may be sampled using several methods, depending on the stage and time of year. One of the most critical periods for sampling is before and during the bloom period, when a control decision should be made. Either a beating tray or direct visual examination can be used at this time. The beating tray takes less time to cover an area, but direct examination may reveal nymphs that are not jarred from the foliage using a beating tray. It is estimated that about 70% of the nymphs are recovered using the beating tray method.

A standard beating tray is an 18-inch square piece of cloth stretched tautly on a wood or aluminum frame (see *Figure 2* in Part I). A circular tray with a surface area of 324 square inches (a diameter of about 20.3 in) can also be used. The tray is placed beneath a limb with abundant foliage and flower clusters, and the limb is struck sharply three times with a length of thick rubber hose or cushioned wood. This is referred to as a tap sample. During the early season, a black cloth surface on the beating tray can make the translucent nymphs more visible. The accumulated pollen and debris that falls on the tray should be brushed or shaken off after each sample, and the surface should be washed when stains start to interfere with the ability to detect campylomma.

Action thresholds for campylomma are currently tied to the tap sample method. Action thresholds developed for British Columbia are an average of 1 nymph per tap for Golden Delicious and 4 nymphs per tap for Delicious. A sequential sampling plan was also developed under British Columbia conditions (*Figure 106*). Because the distribution of campylomma is aggregated, or clustered, a fairly high number of taps is needed to estimate the population with accuracy. Although neither the sampling plan nor the action thresholds have been validated under Washington conditions, they provide a good starting point. Note that this sampling plan was developed for 0.5 hectare (1.2 acre) blocks only. Realistically, any block of trees that are of the same age and managed similarly must suffice. If the block contains mixed cultivars, the most sensitive cultivar should be sampled. A fixed sample of 20 taps per block has been recommended in the past in absence of good statistical information. Although not precise, it will provide a rough estimate of the campylomma population.

In summer, when campylomma are most likely to be in or around aphid colonies, direct examination of the aphid infested terminals is probably the most



There are 3 to 4 generations of campylomma a year. After the first generation, some campylomma migrate to herbaceous hosts. Adults return to orchards in late summer to mate and lay overwintering eggs. Timings are based on observations in Washington.

Figure 104

Sequential Sampling Plan for Campylomma

Red Delicious (threshold 4 per tap)

Total taps	Cumulative no. of nymphs Upper	Cumulative no. of nymphs Lower
10	53	27
11	58	30
12	62	34
13	67	37
14	71	41
15	76	44
16	80	48
17	85	51
18	89	55
19	94	58
20	98	62
21	103	65
22	107	69
23	112	72
24	116	76
25	121	79
26	125	83
27	129	87
28	134	90
29	138	94
30	143	97
31	147	101
32	151	105
33	156	108
34	160	112
35	164	116
36	169	119
37	173	123
38	177	127
39	182	130
40	186	134
41	190	138
42	195	141
43	199	145
44	203	149
45	208	152
46	212	156
47	216	160
48	221	163
49	225	167
50	229	171

Golden Delicious (threshold 1 per tap)

Total taps	Cumulative no. of nymphs Upper	Cumulative no. of nymphs Lower
10	15	5
11	17	5
12	18	6
13	19	7
14	20	8
15	21	9
16	23	9
17	24	10
18	25	11
19	26	12
20	27	13
21	29	13
22	30	14
23	31	15
24	32	16
25	33	17
26	34	18
27	36	18
28	37	19
29	38	20
30	39	21
31	40	22
32	41	23
33	43	23
34	44	24
35	45	25
36	46	26
37	47	27
38	48	28
39	49	29
40	51	29
41	52	30
42	53	31
43	54	32
44	55	33
45	56	34
46	57	35
47	58	36
48	60	36
49	61	37
50	62	38

To use the chart, take a minimum of 10 taps. If the total number of nymphs is above the upper limit, control is warranted. If the number is below the lower limit, no control is needed and sampling may be discontinued. If the number lies between the two limits, continue sampling. If 50 taps are taken and no decision is reached, sample again in 5 to 7 days.

Plan developed for 90% confidence interval, 1st generation nymphs, in a 1.2 acre block of a conventionally managed commercial orchard (H.M.A. Thistlewood. 1989. Environmental Entomology 18(3):398).

Figure 106

efficient means of sampling. Both adults and nymphs can be monitored with either the beating tray or visual examination. Since no damage is known to occur during this time, there are no action thresholds.

In the fall, adults migrating back to orchards can be sampled with pheromone traps. A wing-type trap with spacers between the trap top and bottom is the most effective (*Figure 54*). Pheromone traps may be useful in separating orchards into risk categories, so that sampling the following spring can be prioritized in high-risk orchards.

Biological control

Biological control of campylomma may be difficult, since it is itself a predator. There are currently no reported natural enemies of campylomma that would be useful in a commercial situation.

Management

The first step in management must be to determine if a damaging population is present in the orchard. Damage the previous season has not always been a reliable indicator of damage to the current season's crop, although it is advisable to sample those orchards where high levels of fruit damage occurred in the past.

Some insecticides applied at delayed-dormant stage may kill early hatching campylomma nymphs. Thus, it is possible that several negative samples be taken before and during early bloom, but when residues of the delayed dormant application wear off, nymphs may be suddenly found in what was thought to be a clean orchard. If temperatures are warm during the pre-bloom period and tree development is rapid, or if there are few overwintering eggs, the delayed-dormant application may provide sufficient control. However, when cool weather extends the period from delayed-dormant to petal fall, or the number of overwintering eggs is high, an application targeted specifically for campylomma may be necessary. It is advisable to take repeated samples throughout the pink to petal fall period if no decision is reached.

Spray timing is the key factor in preventing damage by campylomma. Petal fall sprays may fail to prevent much of the potential damage, even though they may kill the campylomma present. Pre-bloom and bloom sprays have been more successful in preventing fruit damage.

Choice of materials at bloom is restricted to those that are less toxic to bees (see section on Honeybee in Part IV). Most of the materials effective on campylomma are Class 1 bee toxicants and cannot be used during bloom. There may be some potential for cultural or behavioral controls for campylomma. Removing the summer hosts, such as mullein, may reduce potential campylomma problems. High campylomma populations in spring have been associated with high aphid populations the previous late summer and fall, when campylomma adults are laying overwintering eggs.

Lygus bug (Tarnished plant bug)

Lygus lineolaris (Palisot de Beauvois)

(Hemiptera: Miridae)

Lygus bugs attacks many field and vegetable crops, and often attacks tree fruits, particularly where they are near uncultivated land or alfalfa fields. Lygus bugs are found in Europe, Asia, and throughout the United States and southern Canada. *Lygus lineolaris*, also known as the tarnished plant bug, is the most prevalent species attacking tree fruits in the Northwest, but the brown lygus (*Lygus hesperus*) and the green lygus (*Lygus elisus*) are also common.

Hosts

The many hosts of lygus bugs include alfalfa, sweet clover, mullein, Russian thistle, smotherweed, horseweed, wild mustards, western ragweed, rabbitbrush and sagebrush. Green lygus prefers Mexican fireweed over most other plants. Lygus adults will also attack apples, pears, peaches, apricots, but do not reproduce on those hosts.

Life stages

Egg: The egg is creamy white and $\frac{1}{25}$ inch (1 mm) long. It is flask shaped and truncate at the wider end, which has a flat cap. It is inserted into plant tissue with only the cap exposed.

Nymph: The nymph is pale yellow or green. It resembles the adult but is smaller and has no wings. It develops through five instars. The third to fifth

instars have distinct spots on the thorax and abdomen.
Adult: The adult *L. lineolaris* varies from pale green to dark brown, with yellow, black and sometimes reddish markings *(Figure 107)*. It has a yellow triangular region, called the scutellum (a feature shared by all true bugs in the family Hemiptera), on the upper center of the back. It is about ¼ inch (6 mm) long. The male is generally darker than the female. The brown lygus is pale yellow to brown with darker brown, black and red markings. The green lygus is pale and bright green.

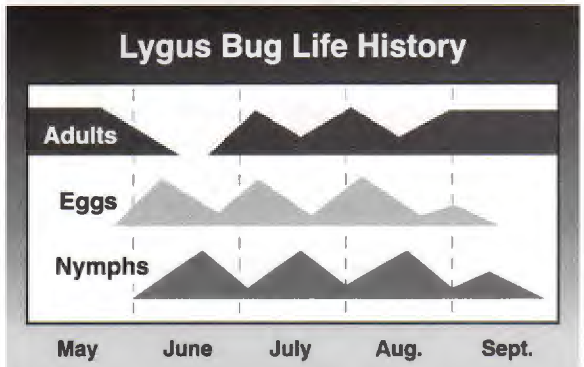
Life history

There are three generations a year and sometimes a partial fourth in the Northwest *(Figure108)*. Lygus bugs overwinter as adults beneath weeds or duff on the orchard floor, or in nearby uncultivated areas. A favorite overwintering site is between the dead leaves of mullein. Adults become active in the spring and fly to fruit trees, where they feed on developing flower buds. Apples are most susceptible to damage between early pink stage of bud development through 2 weeks after petal fall. On peaches, adults appear when the buds are in the pink stage and are most abundant at petal fall. Most adults leave trees soon after petal fall to feed on weed hosts or other crops.

Lygus bugs prefer to lay eggs on plants about to flower, and thus move from host to host according to the timing of bloom. Females lay eggs about 10 days after emerging. They insert eggs into the leaves or stems of primary host plants, such as broadleaf weeds. The eggs hatch in 1 to 4 weeks, depending on the temperatures. Nymphs feed on these plants by piercing the tissue and extracting the juices. Nymphs do not move into fruit trees.

Lygus bug adults may move into orchards at any time when host plants in surrounding rangeland begin to dry or crops like alfalfa are cut.

Figure 107: The adult lygus bug varies from pale green to dark brown, and has yellow and black markings.



Lygus bugs overwinter as adults on the orchard floor or in nearby uncultivated areas. They migrate to fruit trees from bud break through petal fall. Immigration also occurs in the summer when when adjacent rangeland dries.

Figure 108

Damage

Pome fruit: Most feeding damage is done just before or after bloom. Adults puncture buds and remove juices from the flower parts. Severely damaged buds shrivel and dry before they open. Buds that have been fed on sometimes exude a clear drop of liquid. If the terminal bud is killed, shoot growth in young trees can be distorted, altering the desired training form. The most important damage occurs when adults feed on flower parts or young fruit. This feeding kills some cells in the fruit, which fail to grow, leaving the fruit deformed with deep pits *(Figure 109)*. Females deposit eggs in young fruit, causing shallow pitting and deformity.
Stone fruit: Feeding by lygus bugs causes cat-facing and dimpling, which tends to be more severe on stone fruit than pome fruit. Cat-facing is a term used

for rough, corky areas on the fruit. Damaged fruit has sunken spots where the flesh has dried out. Fruit is deformed because surrounding areas grow more quickly than the damaged parts.

Monitoring

Lygus bugs can be monitored by using a sweep net to sample the ground cover, limb jarring or visual examination. As most damage is done around bloom, monitoring should begin in April near the borders of the orchard to detect the bugs as early as possible.

Biological control

Several parasitoids attack eggs, nymphs and adults. The braconid wasp *Peristensus pallipes* attacks nymphs and the mymarid wasp *Anaphes ovijentatus* attacks eggs. Big-eyed bugs, damsel bugs, assassin bugs and crab spiders are important natural enemies and can help control lygus bug nymphs on host plants outside the orchard or on the cover crop.

Management

Lygus bugs do not reproduce on tree crops, so problems can be alleviated by removing alternate hosts. Cover crops containing mostly grasses and few alternate hosts for lygus bugs will help minimize populations in the orchard. Where possible, destruction of weed hosts, such as mullein, outside the orchard can help reduce numbers of adults migrating into the orchard in spring and summer.

If lygus bugs are in the orchard before bloom, or if the orchard has a history of lygus bug damage, chemical controls should be applied during the delayed-dormant or pre-pink stage of tree development. Opening lower nozzles on the sprayer can help improve control. Lygus bugs tend to stay in the cover crop while temperatures are cool and move into the tree during the heat of the day.

If lygus bugs are moving in from drying rangeland or a nearby crop, such as alfalfa, border treatments can reduce numbers and damage. When alfalfa fields are cut, large number of lygus adults can suddenly move into orchards. Border treatments of six rows can help stop movement throughout the entire orchard.

Figure 109: Deformed fruit caused by lygus bug feeding when the fruit was small.

STINK BUGS

(Hemiptera: Pentatomidae)

Consperse stink bug

Euschistus conspersus Uhler

Green stink bug (Green soldier bug)

Acrosternum hilare (Say)

Stink bugs are sporadic pests of most deciduous tree fruits and can occasionally cause severe damage. The name stink bug comes from the insects' habit of exuding a fluid, which has a strong and usually disagreeable odor, from glands between the legs.

There are more than 200 species of stink bugs in North America. Adults are usually some shade of green, tan, or gray-brown. Many feed on plants, but a few are predaceous (see *Brochymena* sp. in Part IV, Natural Enemies and Pollinators). The two most common stink bugs in apple and pear orchards are the consperse stink bug and the green stink bug. The redshouldered stink bug (*Thyanta accerra*), Say stink bug (*Chlorochroa sayi*) and the onespotted

Figure 110: Stink bug eggs and nymphs.

Figure 111: The consperse stink bug is pale brown with small red specks.

Figure 112: The green soldier bug is bright green with inconspicuous yellow-orange and black markings.

stink bug (*Euschistus variolarius*) will also attack tree fruits.

Hosts

The green stink bug is a pest of several crops other than tree fruits, such as alfalfa, beans, and cotton. It also survives and reproduces on many uncultivated plants, such as mullein, mustard and dock. Consperse stink bug attacks many weeds (mustards, dock, mallow, plantain), shrubs (blackberry) and vegetables. Damage on almonds has also been noted.

It is uncertain whether or not nymphs of stink bugs can survive on tree fruits. Observations indicate that although eggs are laid and will hatch, the nymphs do not survive for any length of time. The primary concern is for adults migrating in from herbaceous hosts and feeding during either late spring, or close to fruit harvest. Damage has been observed on apple, pear, cherry, peach, apricot and plum.

Life Stages

Consperse stink bug:

Egg: The egg is barrel shaped (*Figure 110*). It is pearly white at first, but turns pink. On top of each egg is a circle of white projections. Eggs are laid in clusters.

Nymph: The nymph develops through five instars. The color of young nymphs can vary from black to white with reddish markings (*Figure 110*). Older nymphs have yellow and brown bodies with black markings.

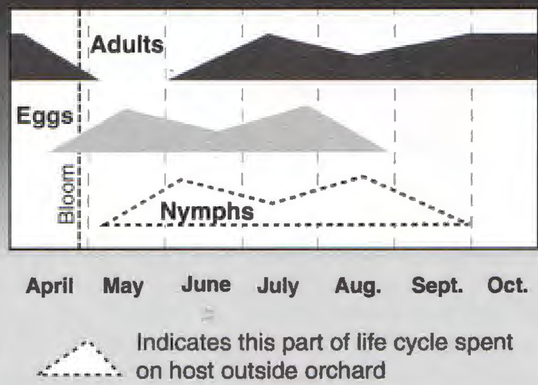
Adult: The adult is shield-shaped and about ½ inch (12 mm) long. It is pale brown with small black specks on the back, yellow beneath, and red antennae. The black specks help distinguish it from the predaceous *Brochymena* stink bug species, which are gray with white specks.

Green stink bug:

Egg: The egg is barrel shaped. Eggs are laid in clusters of about 30 to 40 on the undersides of leaves.

Nymph: The color of the nymph varies from instar to instar and from individual to individual. Young nymphs are generally dark with red or orange markings. Older nymphs are mostly green, with orange markings at the edge of the thorax and abdomen

Stink Bug Life History



Overwintering adults move into orchards around bloom time. In summer, adults move into orchards when hosts in uncultivated areas dry up. First and second generations overlap. Timings are approximate.

Figure 113

and several large black disks down the center of the upper surface of the abdomen. The first instar is $\frac{1}{25}$ to $\frac{1}{17}$ inch (1 to 1.5 mm) long, and the fifth instar is $\frac{3}{8}$ to $\frac{1}{2}$ inch (10 to 13 mm) long.

Adult: The adult is $\frac{1}{2}$ to $\frac{3}{4}$ inch (14 to 18 mm) long and is a bright green (*Figure 112*). It has inconspicuous yellow-orange and black markings along the lateral edge of the abdomen. The lateral margins of the head and thorax are yellowish.

Life history

Adults overwinter beneath weeds or honeysuckle on the orchard floor, or in protected places outside the orchard such as brush piles or bin stacks. They become active in April and feed on broadleaf weeds either in or outside the orchard, usually when the trees are in the pink to early bloom period. Females lay eggs on the leaves of host plants. Some stink bugs move into orchards as soon as they emerge in the spring and deposit eggs on fruit trees. When this happens, fruit can be damaged by feeding nymphs.

Adults often migrate to orchards in late summer from surrounding areas in search of moisture when uncultivated vegetation starts to dry. Trees in outside rows are likely to be the most severely damaged. Eggs for the second generation are usually laid on broadleaf plants in the cover crop. There are 2 or 3 overlapping generations each season (*Figure 113*). Adults seek overwintering sites in October or before fall frosts.

Damage

Pome fruits: Adults puncture fruit with their beaks and feed in the fruit flesh. The puncture may not be visible, but the surrounding area is sunken and often dark green. Beneath the skin is a group of loose spongy cells, often with brown discoloration (*Figure 114*). Damage looks similar to the disorder bitter pit, but bitter pit tends to be around the bottom of the fruit, while stink bug damage is typically around the top. Also, bitter pit produces a mass of corky brown cells beneath the skin, whereas the spongy cells caused by stink bug injury are only slightly discolored. Pome fruits tend to be damaged in late summer as they approach maturity.

Peaches: Feeding of adults causes cat-facing or dimpling on fruit. If fruit is almost mature when injured, the flesh does not turn corky, but begins to decay. Damage on peaches is more noticeable than on apples or pears.

Cherries: Early season feeding causes cat-facing, dimpling and deformity (*Figure 115*). Feeding later in the year discolors the flesh around the pit. As the damage is not visible from the outside, cherries with this type of injury are generally not sorted out during packing.

Monitoring

Stink bugs are easy to see on trees because of their large size. However, they will quickly move to the opposite side of the fruit when disturbed. Look also for spots of excrement, which they deposit while feeding. They can be found in beating-tray samples, but this method is not practical when fruit nears maturity, as more fruit than bugs will drop onto the tray. If the orchard has a history of stink bug damage, herbaceous hosts at the orchard borders can be swept with a canvas sweep net.

Biological control

Telenomus podisi and *T. utahensis*, two scelionid wasp egg parasitoids, will help suppress stink bug populations.

Figure 114: Adult stink bugs puncture apples. The puncture may not be visible but beneath the skin are loose spongy cells, often with some brown discoloration.

Figure 115: Early-season feeding on cherries causes cat-facing, dimpling and deformity. Feeding later in the year discolors the flesh around the pit. The damage is not visible externally.

Management

It is difficult to detect and control stink bugs because of the sporadic nature of damage and problems involved with sampling. Adults usually migrate into orchards from nearby uncultivated plants when they dry out. Damage will usually be concentrated at borders near wild hosts, and spot treatments or border treatments can be effective. If the orchard has a history of damage, be on the alert during critical times of the season (fruit set on cherries and late summer on apple and pear). Although a number of materials will kill stink bugs on contact, providing residual control of new migrants is difficult. Treatments may have to be repeated as adults continue to be found.

Western boxelder bug

Leptocoris rubrolineatus Barber

(Hemiptera: Rhopalidae)

The western boxelder bug is a sporadic, and usually minor, orchard pest found throughout western North America. It reproduces on maple and boxelder trees but may migrate in large numbers to orchards during late summer. It is occasionally a household pest. When populations are high they will move to buildings from nearby host trees.

Hosts

The western boxelder bug's primary host is boxelder. There are two types of boxelder trees: those that bear seeds and those that do not. The boxelder bug lives mostly on the seed bearing type. It also feeds on the foliage of maple, ash, alfalfa and potatoes, and will attack fruit on apples, pears, cherries, peaches and plums.

Life stages

Eggs: Eggs are small, rusty red and are laid in groups of two or three.

Nymph: The young nymph is bright red and becomes marked with black when about half grown.

Adult: The adult is flat, elongated and ⅜ to ⅝ inch (10 to 14 mm) long (*Figure 116*). It is gray-brown to black with conspicuous red lines on the thorax and wing coverings. The body beneath the wings is dark orange, which makes it easy to spot in flight. The head and antennae are black.

Life history

Adults hibernate during the winter in crevices of trees and buildings. They may appear in swarms on sunny winter days. In spring, females lay eggs in cracks in tree bark. Eggs hatch in 10 to 14 days. Nymphs feed on flowers, fruits, foliage and tender twigs. Adults may migrate to orchards in late summer, shortly before fruit matures. There is one generation a year in the Northwest *(Figure 117)*.

Damage

Adults suck juices from fruit as they feed, causing dimples and deformations. The flesh of fruit where the bug has fed is corky and white. The damage looks similar to late season stink bug damage.

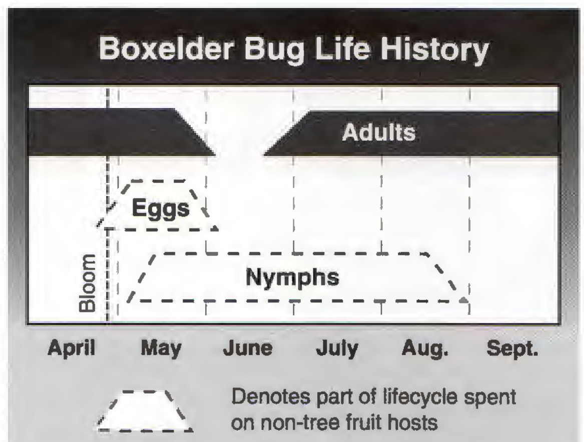
Monitoring

Potential damage in orchards cannot be determined by monitoring populations on host plants. Large numbers of western boxelder bugs may be found but they do not always move into orchards and feed on fruit. A beating tray can be used to monitor adults in the orchard. However, this is not a practical method in late summer because too many fruit are dislodged. Visual observations are probably the best method. Adults are very easy to detect if they are in the orchard in large numbers.

Management

Problems with western boxelder bug are sporadic, but can be persistent and annual in some locations. Most orchards are not threatened by this pest. When populations are high on native hosts that dry out in late summer, adults will migrate in large numbers to orchards in search of food. Many insecticides will kill adults but repeated applications may be required to protect fruit if they continue to immigrate from outside sources. Removal of hosts plants near the orchard may help reduce problems in orchards that suffer annual damage.

Figure 116: Adult western boxelder bugs feeding on pear.



In summer, nymphs feed primarily on boxelder and maple trees, which are primary hosts. Adults migrate to orchards in late summer. Timings are approximate.

Figure 117

SAWFLIES

Sawflies are related to bees and wasps. They are medium to large insects with two pairs of wings. The name sawfly comes from the saw-like ovipositor that the female uses to cut slits in the leaf and deposit its eggs. The larvae of some species, such as the California pear sawfly, resemble caterpillars, while others, such as the pear sawfly, look like slugs (*Figure 118*).

Pear sawfly (Pear slug)

Caliroa cerasi (Linnaeus)

(Hymenoptera: Tenthredinidae)

Pear sawfly originated in Europe and has probably been in the United States since colonial times. It is now widely distributed in the United States wherever susceptible crops are grown. It is known as pear slug because of the larva's slimy, slug-shaped body. Although damage from the insect can be severe, especially on pear and sweet cherry, it is not considered a major pest. A standard spray program for other orchard pests usually keeps pear sawfly populations below damaging levels. However, frequent, limited outbreaks have been reported in sweet cherry orchards in the Mid-Columbia region of Oregon and Washington.

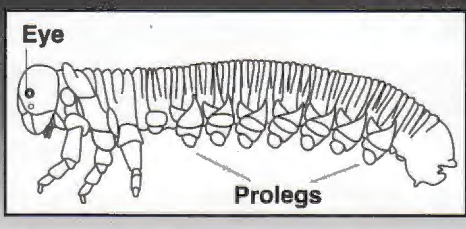
Hosts

Pear sawfly prefers pears and cherries, but will also damage leaves of plum, quince, and occasionally apple. Eggs are often laid on peach leaves in trees near infested pear and cherry orchards, but larvae do not thrive on peach.

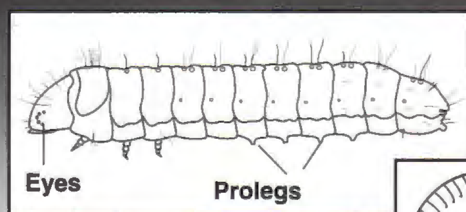
Life stages

Egg: The egg is small, white and oval, and looks like a small blister on the leaf. Eggs are laid just under the upper epidermis, the leaf's topmost layer of cells.

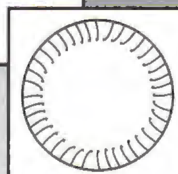
How to distinguish a sawfly larva from a moth larva



Sawfly larva



Caterpillar



Detail of proleg (viewed from below) showing crochets

Sawflies are Hymenoptera (gauze-winged insects like bees and wasps) but their larvae are often mistaken for caterpillars, which are the larvae of Lepidoptera (moths and butterflies). The sawfly larva's caterpillar-like body is called eruciform. Several characteristics distinguish sawfly larvae from caterpillars:

- Sawflies have five or more pairs of abdominal prolegs (the short, fleshy paired legs on the abdomen), caterpillars have four or fewer prolegs.
- The prolegs do not have crochets, or rows of hooks, on the bottom as do the prolegs of caterpillars.
- Sawflies have only one pair of ocelli (primitive eyes), whereas caterpillars can have more than one.

Figure 118

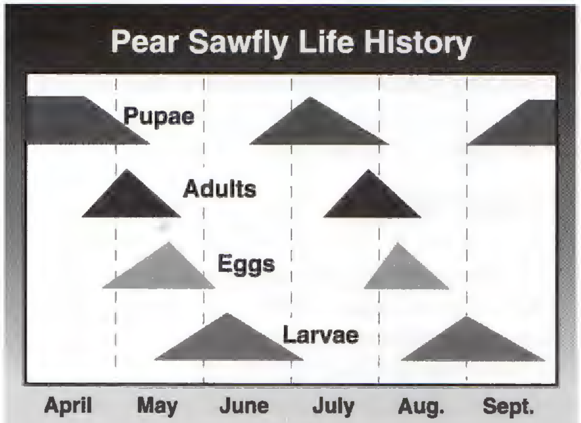
Larva: The larva passes through five instars. The young larva resembles a small slug due to the olive green slime that covers its body (*Figure 119*). The front end of the insect is wider than the rest of the body. The back end is slightly tapered and raised a little from the leaf surface on which it feeds. Newly molted larvae are yellow until the slime is secreted. During the last instar, the larva loses its slimy covering and is a light orange-yellow color. At this stage, it is about ⅜ inch (10 mm) long and has 10 pairs of legs.

Adult: The adult is a glossy black wasp, about ⅕ inch (5 mm) long (*Figure 120*).

Life history

Pear sawfly overwinters as a pupa in a cocoon 2 to 3 inches deep in the soil. In the Northwest, first-generation adults emerge over an extended period in late spring (*Figure 121*).

The adult female inserts eggs into the leaf tissue with her saw-like ovipositor. Incubation lasts 10 to 15 days. Larvae are present in late spring or early summer and immediately begin to feed on the upper surface of the leaf. It takes 3 to 4 weeks for the larvae to pass through the five stages of development. Fifth instar larvae do not feed, but crawl or drop to the ground and pupate.



Pear sawfly has two generations a year. It overwinters as a pupa in the ground. Timings are based on observations in Oregon.

Figure 121

Figure 119: The young pear sawfly larva is covered in green slime and resembles a small slug.

Figure 120: The adult pear sawfly is a glassy black wasp.

Second generation adults begin to emerge in July. They emerge over a shorter period of time than the first generation. Adults lay eggs soon after mating and larvae appear in August and September. It is this generation of larvae that is the most destructive. Mature larvae drop to the ground and for the overwintering pupal stage.

Damage

Pear sawfly feeds on the upper surface of leaves, skeletonizing them. On heavily infested trees, leaves turn brown, wither and drop. Defoliation on either pear or cherry can weaken the tree. Infestations can also stunt fruit and prevent maturation.

Monitoring

It is important to monitor continually for the slug-like larvae in August and September when large populations can build up rapidly and cause significant damage. Pay special attention to cherries, which are often neglected after harvest. A few acres within a block can easily become infested unless the trees are monitored regularly.

Biological control

Little is known about biological control of the pear sawfly. Since the insect is usually not a problem in unsprayed backyard trees, natural enemies may be controlling it.

Management

As pear sawfly larvae are susceptible to most insecticides they are easily controlled in commercial orchards. Generally, normal spray programs for other pests will keep this insect in check. If a problem develops, it is usually after harvest on cherries when insecticides are no longer being used. In these cases, trees can be defoliated in August or September. This seems to have little effect on the following year's crop on mature trees, but the consequences may be more serious on young bearing trees. If control is necessary, an organophosphate insecticide would be effective.

California pear sawfly

Pristophora abbreviata (Hartig)

(Hymenoptera:Tenthredinidae)

California pear sawfly has historically been only a minor pest on pear. It has been found primarily in abandoned orchards. Although the common names are similar, it should not be confused with pear sawfly, *Caliroa cerasi*. *C. cerasi* has a slug-like larva, whereas the larva of *P. abbreviata* resembles a caterpillar.

Hosts

It is primarily a pest of pear.

Life stages

Egg: The egg is small, oval and a translucent white.
Larva: The mature larva is bright green, about ½ inch (13 mm) long and has seven pairs of prolegs. Unlike the pear sawfly, the larva of the California pear sawfly resembles a caterpillar (*Figure 122*).
Adult: The adult is black with yellow marks on the prothorax and is about ¼ inch (7 mm) long.

Life history

Adult California pear sawflies emerge in early spring (*Figure 123*). After mating, females deposit their eggs in leaf tissue, usually around the edges of the leaves. Larvae emerge at petal fall or soon after and feed on the leaves in a characteristic circular pattern, leaving holes along the edges and within the leaves. They remain on the tree, eating only leaves, until April and May. Mature larvae fall to the ground and enter the soil where they pupate and overwinter. There is only one generation per year.

Damage

Heavy populations of larvae can consume entire leaves, leaving only the midribs. In large enough numbers, California pear sawflies can defoliate an orchard in a matter of weeks. They do not attack fruit.

Monitoring

Soon after petal fall inspect the leaves for small holes. Sample 100 leaves, one leaf per tree, throughout each 20-acre block. Take no action if fewer than 6 leaves are infested. If between 6 and 25 leaves are infested, continue monitoring weekly for increases in population or damage. If more than 25 leaves are infested, consider control.

Management

Most years, insecticides applied for codling moth and other orchard pests control California pear sawfly. However, it could become a problem where

Figure 122: The larva of the California pear sawfly resembles a caterpillar. See also *Figure 118*.

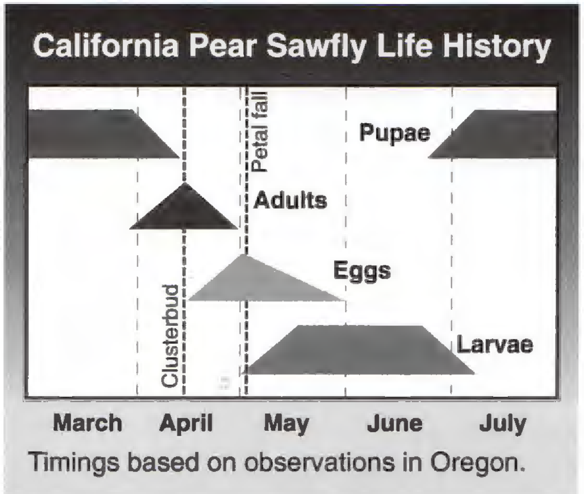


Figure 123

orchardists delay or eliminate codling moth controls. Use of mating disruption in place of insecticides to control codling moth may allow California pear sawfly populations to increase. If insecticide applications for codling moth are delayed until 2 to 4 weeks after petal fall, pear sawfly numbers could be high enough to damage leaves, and within a few weeks they can defoliate an orchard.

If mating disruption is used to control codling moth, and California pear sawfly needs to be controlled, an organophosphate material can be used. Use low rates to avoid disrupting natural enemies in the orchard.

Dock sawfly

Ametastegia glabrata (Fallén)

(Hymenoptera: Tenthredinidae)

Dock sawfly, or dock falseworm, lives on weeds found in orchards. It damages fruit when it tunnels into the flesh in search of a hibernation site. Damage to tree fruits in Pacific Northwest orchards is minor and sporadic, although in the past it has caused substantial injury. The insect originated in Europe, and was first described in the United States in 1862. Damage in Washington was first noted in 1903. Its distribution is in the northern United States from coast to coast, and in the southern Canadian provinces.

Hosts

Larvae feed on herbaceous plants in the buckwheat family, such as dock, sorrel, knotweed, bindweed and wild buckwheat. The final instar may seek a pupation or hibernation site in a place other than its food plant.

Life stages

Egg: The egg is kidney shaped, somewhat flattened, pearly white, and about $\frac{1}{32}$ inch (0.8 mm) long.

Larva: The larva is eruciform (*Figure 118*), ranging from about $\frac{1}{10}$ inch (2.5 mm) for the first instar to $\frac{2}{3}$ inch (14 to 17 mm) in the final two instars. Color of early instars is variable, but ranges from grayish to yellowish green. The final instar ranges from apple green to olive or blue-green, with the ventral side lighter in color than the dorsal side. It has a brownish head, conspicuous white tubercles on its body, and seven pairs of abdominal prolegs.

Pupa: The pupa is greenish at first, gradually darkening to dark brown or black. The female can be distinguished by the saw-like serrations on the ovipositor.

Adult: The adult is a blue-black wasp, about $\frac{1}{3}$ inch (7 mm) long, with reddish legs. It is a typical sawfly (*Figure 120*).

Life history

Dock sawfly overwinters as a mature larva, usually in the dry pithy stem of a weed host but occasionally in fruits. Larvae pupate in early spring, and adults emerge over a fairly long period (about 7 weeks), with peak emergence in late April (*Figure 124*).

Adults have a lifespan of about 13 days. They mate, and females lay eggs singly in leaf tissue of the weed host. Females can lay over 100 eggs, which require about 10 days to hatch. The total life cycle, from egg deposition to adult emergence, takes about 52 days for the spring generation. The second and third generations require less time — about 31 and 27 days, respectively.

First instar larvae skeletonize the leaf, but later instars eat large holes in the leaf. The larvae pass through six instars, but the final instar does not feed. Instead, it seeks a pupation site in the stem of the host. Fourth generation larvae are the overwintering larvae.

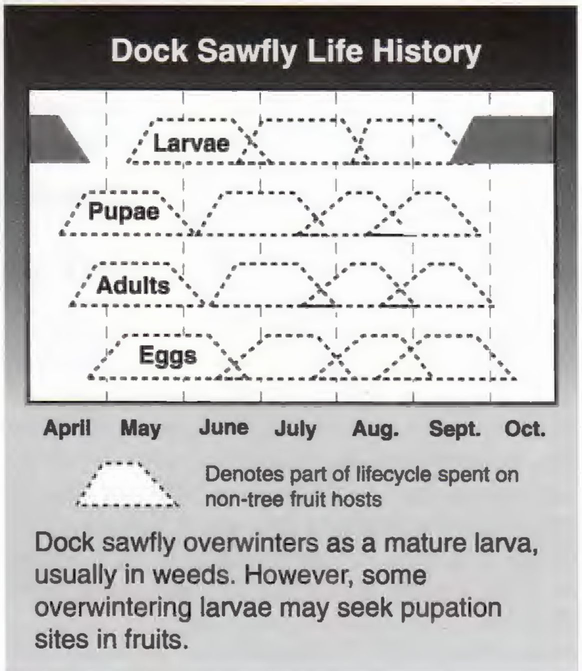


Figure 124

Figure 125: The larva excavates a neat chamber, about the same size as its body, in the flesh of the fruit.

Damage

Fruit damage caused by the larva looks similar to that of the codling moth larva from the outside, except the characteristic frass is missing. The entry hole is about 1/12 inch (2 mm) in diameter, often surrounded by a reddish ring. The larva excavates a neat chamber in the flesh of the fruit about the same dimensions as its body (*Figure 125*). Entries are often found on the cheek of the fruit. A single larva may bore several holes in one or more fruits before constructing its final chamber. Injured fruits may be invaded by decay fungi.

Monitoring

No sampling schemes exist for dock sawfly, nor is monitoring necessary unless the orchard has a history of damage. Typically, infested fruit are those that were hanging down into weeds on the orchard floor. Weed hosts may be examined for larvae near fruit harvest. Examining fruit in the bins for the circular entrance holes will help diagnose the problem, but the damage will have been done.

Management

Dock sawfly is rarely a problem in orchards where weeds are controlled conscientiously. Insecticides applied to control a range of orchard pests usually keep this insect under control. Opening the lower nozzles of the airblast sprayer will help suppress populations. Mowing, herbicides, and limb propping will also reduce fruit infestation by reducing contact of fruit and weeds.

Western flower thrips

Frankliniella occidentalis (Pergande)

(Thysanoptera: Thripidae)

Thrips are small, slender insects, with four long, narrow wings fringed with hairs (*Figure 126*). The western flower thrips is widely distributed throughout the United States. It feeds on a number of plants and occasionally damages tree fruit. Thrips rasp the surface of the fruit as they feed, and their feeding weakens flowers and fruit stems. Females puncture the fruit with their serrated ovipositors to lay eggs in the tissue.

Damage does not occur every year and is difficult to predict. Thrips visit many other flowering plants as well as tree fruits, and if those plants are in bloom at the same time, the thrips population will be diluted and there will be less chance of fruit damage.

Hosts

Western flower thrips feeds on apple, apricot, peach, plum, nectarine, orange, lemon, alfalfa, potato and numerous weed species.

Life stages

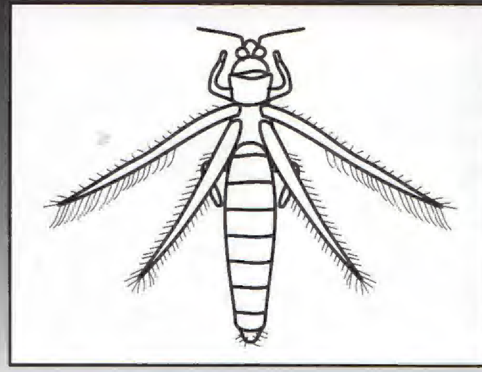
Egg: The egg is cylindrical and slightly kidney-shaped. The female makes an incision into the leaf, stem or fruit of plants with her serrated ovipositor and deposits a single egg. The egg is embedded and protected within the plant tissue.

Larva: The young thrips resembles the adult, but is smaller. The first two instars are wingless and are called larvae (*Figure 127*). They feed on nectar, pollen and plant tissue, as do adults. The third instar, called the prepupa, is inactive, does not feed and has wing buds.

Pupa: The pupa, the fourth instar, is also a resting, non-feeding stage.

Adult: The adult is about 1/25 inch (1mm) long. It is slender, with four narrow wings fringed with hairs folded flat over the back (*Figure 128*). It is yellow with dusky markings on the side of the abdomen. The two sexes look similar but the male is smaller and always light colored. The abdomen of females ranges from pale yellow to dark brown.

Thrips



Thrips belong to the order Thysanoptera. The name of the order is derived from the Latin words *thysanus*, meaning tassel, and *pteron*, meaning wing. The term *thrips* denotes both the singular and plural. Thrips have long, narrow, membranous wings fringed with long hairs. When at rest, they fold their wings flat over the back. The cone-shaped, piercing and sucking mouthparts are on the underside, near the front legs. The female has a saw-like ovipositor with which she lays eggs in plant tissue.

Figure 126

Figure 127: Early instar thrips are wingless and are called larvae.

Figure 128: The adult thrips is yellow and about $\frac{1}{25}$ inch long.

Life history

Thrips overwinter as adults in protected places on the ground. When they emerge in the spring they seek out flowering plants. On fruit trees, they enter blossoms at the full-pink stage and feed on flower parts. Females lay eggs in the pistils, stamens and receptacles of the blossoms. Larvae that hatch from the eggs feed within the calyx end of the young fruit. They feed by rasping the fruit surface with their mouth parts and sucking the liquid. When mature, 7 to 14 days after petal fall, they drop to the ground and pass an inactive stage under dead leaves near host plants before molting into adults. New adults may lay eggs in the young fruit before flying to other flowering plants. They have several overlapping generations each year (*Figure 129*). Thrips may migrate into the orchard during the summer as nearby wild host plants dry up.

Damage

Pre-bloom feeding deforms blossoms and leaves, reducing fruit set or weakening the fruit so it is more susceptible to frost and temperature stresses. Thrips also spoil fruit finish by rasping the surface while feeding and by puncturing the fruit while laying eggs.

Feeding damage is usually more severe on stone fruits than on apples. On stone fruits, feeding causes scars similar to frost injury. On apples, feeding damage is usually only one cell deep on the fruit. When the fruit is damaged early in the season, it is russeted at harvest.

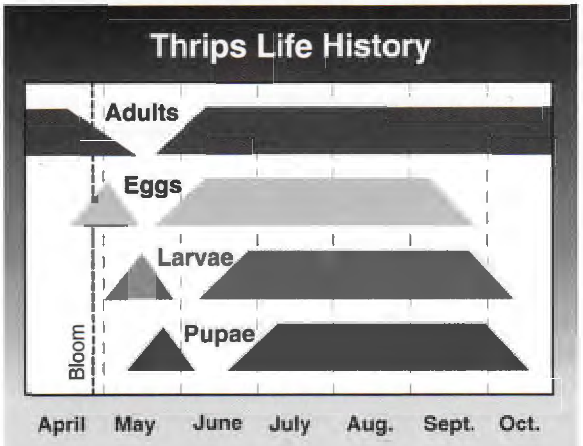
The major damage on apples is due to egg-laying punctures that cause a condition called pansy spot, a whitish discolored area shaped like the petals of a pansy surrounding a small scar where the egg was laid (*Figure 130*). On dark red apples, the pansy spot is usually covered with color at harvest but yellow, pink and green varieties will still be discolored at harvest.

Monitoring

Thrips can easily be monitored by shaking a pink bud or flower cluster into a white plastic cup. Flick the cluster vigorously to ensure that most thrips are dislodged. Adults are easy to detect without magnification, but larvae are light colored and difficult to see. Larvae may be confused with small adult males, but they do not fly when disturbed.

Sample 5 or 6 clusters per tree and 5 or 6 trees per 10-acre block. Monitor border trees also, as thrips may move into the orchard from wild host plants. Sample in the morning, preferably at the same time of day, as thrips densities can change dramatically throughout the day if the weather is warm and calm, which is when they tend to fly.

The correlation between thrips densities and egg-laying damage is poor. However, if there are more than 1 to 2 adult females per cluster in apple, there is a risk of fruit damage due to egg laying. Feeding



Overwintering adults lay eggs in blossoms. First generation adults may lay eggs in young fruit before flying to other flowering plants, where they produce several generations a year.

Figure 129

damage may occur at different densities. It tends to be more severe on soft fruits than on apples.

Biological control

Important predators include adults and nymphs of the minute pirate bug, *Orius tristicolor*, and larvae of green lacewings and predaceous thrips. These will attack thrips late in the growing season and prevent populations from increasing.

Management

Thrips prefer to lay eggs on leaves rather than fruit buds. During pink stage, however, leaves are small and thrips may lay eggs on flower buds. Thrips may also cause egg-laying damage to fruit after petal fall if densities are high and there are few other flowering hosts to attract them. The timing of bloom of wild hosts and the weather influence the movement of thrips into and out of the orchard and therefore potential damage. They move about more in warm temperatures. On both apples and soft fruits, insecticides should be applied at petal fall to kill immature thrips before they mature and lay eggs in the fruit. If the orchard has a history of thrips injury, sprays may be needed at both the pink stage and petal fall. Avoid exposing bees to sprays (see Section IV, Natural Enemies and Pollinators).

Figure 130: The major damage caused by thrips on apples is pansy spot. A whitish area shaped like a pansy surrounds a decayed spot where an egg was laid.

European earwig

Forficula auricularia Linnaeus

(Dermaptera: Forficulidae)

The European earwig is chiefly a garden pest but occasionally attacks tree fruits. Adults and nymphs can damage pome and stone fruits. The name earwig comes from an old, unfounded superstition that the pest invades the ears of humans.

Hosts

Earwigs attack a wide range of plants including vegetables, flowers, tree fruits, berries, ornamental trees and shrubs. At times, they can be scavengers or predators, feeding on decaying vegetation or insects such as aphids.

Life stages

Egg: The egg is small, oval and pearly white.

Nymph: The young earwig passes through four instars. The immature earwig starts out creamy white but the cuticle soon hardens and darkens in color. It looks like the adult, except it is wingless (*Figure 131*).

Adult: The full-grown earwig is brownish black, about ¾ inch (2 cm) long and has a pair of forceps at the rear (*Figure 131*). The male has curved forceps and the female's are straight. It has short, leathery forewings under which are tucked a rear pair of wings that look like tiny fans when open. However, it rarely flies. Some species of earwigs have scent glands on their abdomen that release a foul-smelling odor, which is probably for defense.

Life history

Adults go into the soil in the fall to form earthen cells in which they live in pairs. The females lay eggs in clusters of 20 to 50 during the fall and spring. The cells containing the eggs are in the top 2 to 3 inches of soil. In the spring, the females open the cells and the nymphs emerge (*Figure 132*). Earwigs are semisocial and will look after their young in the early stages.

After leaving the ground they hide in deep crevices or under loose bark on trees. The nymphs mature in midsummer, and a partial second generation may develop some years. As earwigs rarely fly, infestations in orchards spread slowly.

Figure 131: The nymph (top) looks like the adult, except it is wingless.

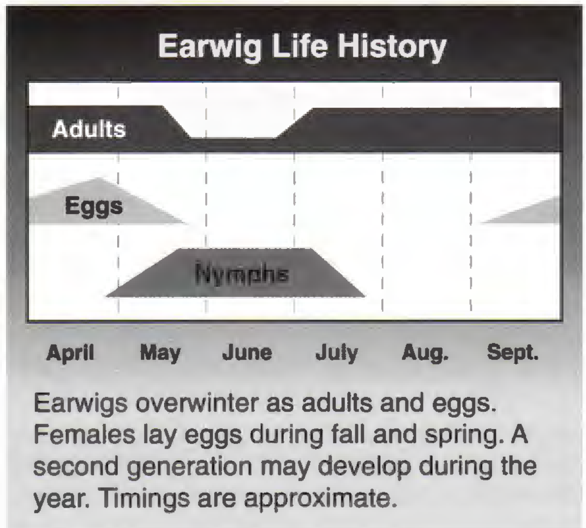


Figure 132

Damage

Earwigs damage both leaves and fruit. Leaf damage is unsightly but of little concern on mature trees. On young seedlings, however, the earwig's feeding on shoot tips can stunt tree growth. Damage on tree-fruit crops is usually confined to shallow, irregularly shaped feeding areas on the surface (*Figure 133*), but occasionally an earwig will bore through and feed on the flesh near the pit of stone fruits. Earwigs will get into any area damaged by other pests, such as birds and caterpillars.

Monitoring

Earwigs are nocturnal and feed at night. During the day they will hide under leaves, inside leaves rolled by leafrollers, in refuse on the ground, under loose bark or in crevices on the tree trunks. When disturbed they move about quickly looking for new hiding places. A flat board laid on bare ground can be used to monitor the presence of earwigs.

Management

If damage is unacceptable, apply a pesticide around bases of trees and on trunks during the summer, observing the appropriate pre-harvest interval. Do not apply to blooming cover crops because of the hazard to bees. If you provide a hiding place such as corrugated cardboard or deep-pile carpet (with the pile toward the inside) on the tree trunks, the earwigs may gather there, allowing you to treat just a limited area. This can also be used for monitoring. Large numbers may be trapped in boxes that are filled with straw or newspapers and inverted on the ground.

Figure 133: Earwig feeding damage to stem end of apple (note adult earwig in cavity and fecal pellets).

Mites

Mites are not insects, although in agricultural contexts they are often discussed with insects for convenience. They are more closely related to spiders than insects. Both mites and insects are in the phylum Arthropoda (see section on Animal Classification in Part I), which is why the term "beneficial arthropods" is used to refer to parasitic or predatory insects, mites, and spiders. The order to which mites belong (the Acari) is the root for the term "acaricide."

Most insects have three pairs of legs, and three major body parts, whereas mites have two body regions (cephalothorax and abdomen) and can have two, three or four pairs of legs. Many adult insects have wings, but mites never do. Mites are extremely numerous and are found in many kinds of habitats. Their small size makes them difficult to detect, identify, and monitor.The mites that attack fruit trees in the United States fall mainly into two groups: spider mites (Tetranychidae) and rust mites (Eriophyidae).

Tetranychids: Overall, the spider mites are one of the largest, most important, and most destructive groups of pests in agriculture. Spider mites are less than 0.5 mm (1/50 inch) long and adults can just be seen with the naked eye. The word "spider" in their name refers to their ability to spin webs. McDaniel spider mite is a prolific web spinner, twospotted mite is intermediate, and European red mite produces only a modest amount of webbing.

Eriophyids: Rust mites are more elongated and about half the length of spider mites.They can be seen only under magnification.They are somewhat wedge-shaped, and have only two pairs of legs at the front end of the body. These mites are usually host specific in that they attack only one species (monophagous) or a related group of species (oligophagous). Their host plants are primarily perennials. Many of the eriophyids are gall formers, and spend their life inside a gall which is produced in response to their salivary toxins. Eriophyids are also the only important group of mites that transmit plant viruses. Mites from all of these groups attack tree fruits. Spider mites pierce foliage and suck plant juices. When numbers are high, their feeding can turn foliage silver, bronze, or black, depending on the mite species and the tree species attacked. Rust mites also suck plant juices, but their feeding causes a silvering or brownish cast on leaves and russeting of fruit.

Predatory mites: Not all mites that occur on tree fruits are pests. Several mite species prey on pest mites. The most important predatory mites in the Pacific Northwest fall into two families: the Phytoseiidae, which includes *Typhlodromus occidentalis* (also known as *Metaseiulus occidentalis* and *Galandromus occidentalis*), and *Typhlodromus pyri*; and the Stigmaeidae, which includes *Zetzellia mali*. The phytoseiids are a family of very important predatory mites, and contain species which provide biological control of mites all over the world. The stigmaeids are much less important, in terms of distribution and total impact. Both species of *Typhlodromus* mites will attack spider mites and rust mites, and *Z. mali* will attack European red mite and rust mites.

Relationships between the mite species are complex, and control of one may affect populations of another. Orchard mites have several natural enemies but some broad-spectrum pesticides used for insect control can reduce or eliminate them. For that matter, many acaricides (miticides) have been as or more toxic to predatory mites than to pest mites. Orchardists can effectively adopt practices (both in terms of chemical choices and cultural practices) that will allow predator populations to thrive. While this might not immediately solve mite problems, it can lead to more stable, long-term mite control and eliminate or slow the development of resistance to miticides.

Twospotted spider mite

Tetranychus urticae Koch

(Acari: Tetranychidae)

The twospotted spider mite is probably one of the most polyphagous arthropods that feeds on tree fruits. It is distributed worldwide, and is an economic pest of many crops. It is in the same family as the European red mite and McDaniel spider mite, but is more closely related in feeding habits and life cycle to the latter.

Hosts

Its innumerable hosts include many weeds, field crops, ornamental and house plants, vegetables, forage crops, small fruit and tree fruits. Among the tree fruits, apple, pear, peach, nectarine, apricot, cherry (sweet and sour), plum, and prune are suitable hosts. High mite populations encountered on pear are likely to be either twospotted or McDaniel spider mite. Twospotted mites are much less common on apple and are rarely the predominant species in a flareup.

Comparison of Tree Fruit Mites

Mite	Crop	Overwintering stage	Description of adult
European red mite	Apple, pear, stone fruit	Egg	Red with large bristles on back
McDaniel spider mite	Apple, pear	Female	Greenish or yellowish with large spot on each side and smaller spots at rear
Twospotted spider mite	Pear, apple, stone fruit	Female	Light green to straw color with large back spot on each side
Yellow spider mite	Apple, pear	Female	Pale yellow to white with dark markings on each side of abdomen
Apple rust mite	Apple	Female (deutogyne)	Very small, yellowish brown, tapered body
Pear rust mite	Pear	Female (deutogyne)	Very small, yellowish brown, tapered body
Prunus rust mite	Plum, cherry, peach, nectarine	Female	Pale yellow at first, turning brownish yellow or tan
Pearleaf blister mite	Pear	Female	Very small, white to light red and wedge shaped, usually found inside blisters

Life stages

Egg: The egg is spherical and about 1⁄150 inch (0.14 mm) in diameter (*Figure 134*). When first deposited, the egg is translucent, taking on the greenish tinge of the leaf where it is laid. It becomes more opaque as it matures, finally turning a pale yellow. The red eyespots of the embryo are visible just prior to hatch.

Immatures: The larva is round, about the same size as the egg, and has three pairs of legs. Initially it also is translucent (except the red eyespots), but once it begins feeding, it turns pale green to straw color, and the characteristic black spots begin to form on the dorsum (back). The protonymph is larger and more oval, and has four pairs of legs, as do all succeeding stages. The two dorsal spots are more pronounced, and the green color is slightly deeper. The deutonymph is slightly larger than the preceding stage, and males can be distinguished from females at this stage by the smaller size and more pointed abdomen. Each immature stage goes through three phases: active feeding, a quiescent period, and a molt. The integument (the outer covering of the body) may take on a silvery appearance in the quiescent stage as it separates from the skin below in preparation for the molt.

Adult: The adult male is smaller than the female, and is characterized by its distinctly pointed abdomen. It sometimes has an orange or brown tinge and is more active than the female. The female is about 1⁄60 inch (0.42 mm) and more robust than the male, and is more oval in shape (*Figure 135*). Color of the female can also vary. Typically, it is a pale leaf-green, but it can be tinged with yellow, brown, and orange. As the name implies, there are generally two distinct spots on the front half of the dorsum behind the eyes. These spots are caused by pigments in the digestive tract, which is why the size, distinctness, and pattern of spots can vary considerably among individuals or at different times during the life span of a single individual. Overwintering females are usually a distinct solid orange, and the spots disappear. During this stage, they can only be distinguished from McDaniel mite by slide mounting, and examining the integument of the dorsum for a diamond-shaped section of striations (*Figure 136*).

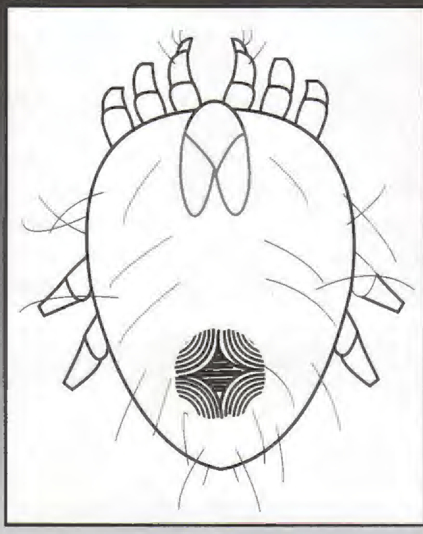
Figure 134: Eggs are spherical and about 1⁄150 inch in diameter.

Figure 135: The female is longer, more robust and more oval shaped than the male.

Life History

The twospotted spider mite overwinters as orange-colored adult females in the duff at the base of trees and in sheltered sites beneath bark scales (*Figure 137*). Only females are known to overwinter. They emerge from their overwintering sites about the half-inch green stage of apple development. As these mites begin feeding, they gradually lose their orange color, and gain their normal greenish hue and dorsal spots. After about 2 to 5 days, egg laying begins, primarily on the underside of newly

Identifying the Twospotted Spider Mite



Twospotted spider mite can be distinguished from McDaniel spider mite by the diamond shaped striation pattern on the dorsum of the adult female.

Fisher, G., J. DeAngelis, D.M. Burgett, H. Homan, C. Baird, R. Stoltz, A. Antonelli, D. Mayer, and E. Beers. 1993 Pacific Northwest Insect Control Handbook. Oregon Extension Service Bulletin. p. 335.

Figure 136

expanded leaves and, later, on the fruitlets. Overwintering females lay an average 39 eggs over a life span of 23 days, considerably fewer than the summer forms. These eggs may take up to 3 weeks to hatch, depending on temperature. From this point onwards, generations begin to overlap. Summer-form females can lay about 100 eggs over a period of 30 days. Egg hatch takes only one or two days during the warm part of the summer, and the entire generation time (oviposition to adult) may take only 10 days. When leaf quality begins to decline (e.g., from excessive mite feeding), or when cooler temperatures and shorter day lengths occur during the fall, the orange overwintering forms are again produced (*Figure 137*).

For damage, biological control, and management, see sections under European red mite that follow. Figure 138 *gives a binomial sampling scheme for twospotted spider mite and McDaniel spider mite.*

McDaniel spider mite

Tetranychus mcdanieli McGregor

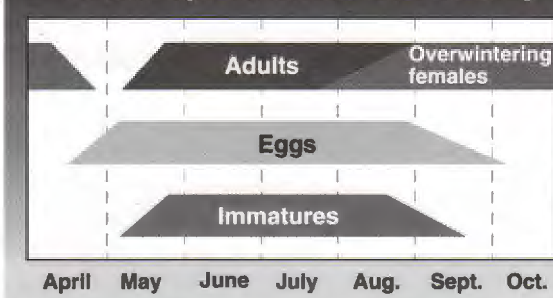
(Acari: Tetranychidae)

The McDaniel spider mite was first described on raspberry in Michigan in 1930, but has gained pest status only on tree fruits in the Pacific Northwest, Utah and certain areas of California, usually in the drier areas. It has been most studied as a pest of apples in central Washington, where it has been a pest since the 1930s. Widespread outbreaks occurred during the late 1950s and early 1960s as a result of severe disturbance of biological control.

Hosts

Although McDaniel spider mite is considerably less polyphagous than twospotted spider mite, its host range is still fairly broad. It attacks most deciduous tree fruits (apple, pear, sweet and sour

Twospotted, McDaniel and Yellow Spider Mites Life History



The twospotted spider mite, McDaniel spider mite and yellow spider mite overwinter as female adults. During the summer, there are multiple overlapping generations.

Figure 137

A Sampling Plan for Twospotted and McDaniel Spider Mites

Sampling Table

No. of leaves with 2 or more mites	% of leaves with 2 or more mites	Average No. mites per leaf
1	4	0.21
2	8	0.35
3	12	0.51
4	16	0.69
5	20	0.87
6	24	1.08
7	28	1.30
8	32	1.55
9	36	1.82
10	40	2.12
11	44	2.44
12	48	2.81
13	52	3.21
14	56	3.67
15	60	4.18
16	64	4.77
17	68	5.45
18	72	6.26
19	76	7.24
20	80	8.51
21	84	10.12

The average number of mites per leaf cannot be estimated accurately when 85 percent or more of the leaves are infested with two or more mites.

To estimate the average number of mites per leaf, collect 25 leaves from each of 10 trees and count the number that have 2 or more mites (see Sampling section in Part I).

Example: On the first tree 15 of the 25 leaves have 2 or more mites. The second through tenth have 10, 7, 18, 6, 5, 17, 10, 11 and 12 leaves respectively with 2 or more mites. Use the table (left) to estimate the average number of mites per leaf for each tree, then average across the 10 trees, as shown below.

Tree	No. of leaves with 2 or more mites	% of leaves with 2 or more mites	Average no. mites per leaf
1	15	60	4.18
2	10	40	2.12
3	7	28	1.30
4	18	72	6.26
5	6	24	1.08
6	5	20	0.87
7	17	68	5.45
8	10	40	2.12
9	11	44	2.44
10	12	48	2.81
		Average:	2.86

Table courtesy of Dr. Vince Jones, Department of Entomology, University of Hawaii, Manoa.

Figure 138

cherry, prune, peach and apricot), some field and vegetable crops (squash, asparagus, alfalfa, clover), and a number of weeds (mallow, milkweed, knotweed, ragweed, mustard, dock, wild buckwheat, wild lettuce). In a study of numbers and survival of eggs, Red Delicious apple, sweet cherry and apricot were better hosts for McDaniel spider mites than pear, peach, and sour cherry.

Life stages

Egg: The egg is spherical and about 1/150 inch (0.13 mm) in diameter. It is translucent when first laid, but becomes darker. Just before hatch it assumes a dull ivory color, and the red eyespots of the embryo are visible. McDaniel spider mite eggs cannot be distinguished from twospotted spider mite eggs (*Figure 134*).

Immatures: The larva has three pairs of legs and is about the same size as the egg. It has little or no color until it begins feeding, when it takes on a greenish tinge from leaf chlorophyll. The quiescent stage is about 1/12 inch (0.20 mm) long. The protonymph is oval and dark green and has four pairs of legs. The female is 1/100 inch (0.25 mm) long, and the males are slightly smaller. The deutonymph also has four pairs of legs, and is generally the same color and shape as the preceding stage, only larger. The

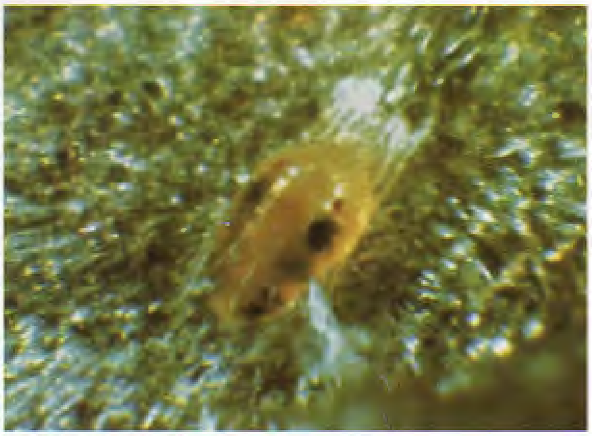


Figure 139: The McDaniel spider mite has multiple pairs of spots.

female, which is about 1/70 inch (0.35mm) long, can readily be distinguished from the male at this stage. The male has characteristic slender, tapered abdomen and is distinctly smaller than the female.

Adults: The adult female is about 1/60 inch (0.44 mm) long whereas the male is only about 1/80 inch (0.29) long. The adult female, like the deutonymphs can also be distinguished from the male by its shape. The female has a broad oval shape, whereas the male has a slender, more pointed abdomen. The dark spots on the abdomen that characterize this species occur on all stages, but are most distinctive in the older stages. The earlier stages may be difficult to distinguish from twospotted spider mite, because of the variability in both species. McDaniel spider mite has multiple pairs of spots, some of which always occur in the posterior portion of the abdomen (*Figure 139*). Twospotted spider mite, on the other hand, usually has two fairly distinct spots, and the area of pigmentation is confined to the front half of the abdomen. Both species lose their spots during a molt, and don't regain them until they begin feeding again. Because of the variability, identification may be difficult. However, slide mounting and examination under high magnification makes it possible to distinguish the two species (*Figure 136*).

Life history

The McDaniel spider mite overwinters as an orange-colored diapausing female under bark scales or in litter at the base of the tree (*Figure 140*). Overwintering mites, which are often in large masses, produce extensive webbing. The mites emerge from their overwintering sites in March or April, depending on the area, but at about the time fruit buds begin to open (*Figure 137*). They move to the green tissue, and begin to feed. Mites may move directly into the tree fruit host or, if available, to nearby weed hosts. As they feed, they lose their orange color and take on the normal greenish tinge and characteristic dorsal spots. After a few days of feeding, egg laying begins.

Eggs are initially laid on the undersides of leaves, but when populations are high, both sides of the leaves are colonized. In apple, the mites tend to stay close to the main trunk and scaffold limbs initially, so their distribution in the early part of the season covers a cone shaped area in the center of the tree. Although there is some lateral distribution, McDaniel spider mites do not tend to infest terminal growth as they prefer older foliage.

Eggs are laid either in or beneath the webbing, possibly providing protection from some chemical sprays and predators other than *T. occidentalis*. Summerform females can lay up to 150 eggs over a 5- to 6-week period. The time required to complete development at very high temperatures can be as little as 6 days, but at typical mid-summer field temperatures development requires about 8 to 11 days. There are up to 10 overlapping generations per year in central Washington, depending on the temperatures. In the absence of predators, populations peak in late July to mid-August, then decline. Overwintering forms may be produced as early as May if foliage quality deteriorates, but they are usually

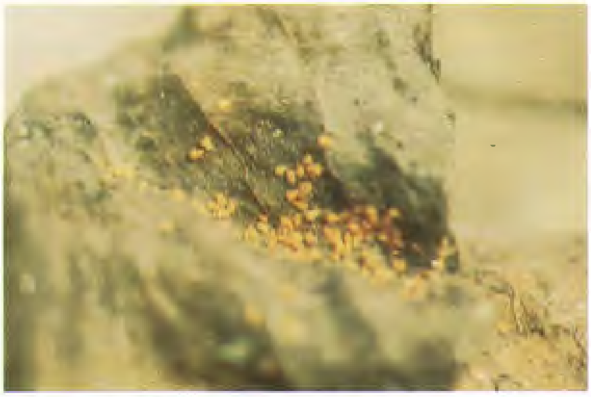


Figure 140: McDaniel spider mite overwinters as an orange colored diapausing female.

produced from mid-July through September. The males die with the onset of cold weather, and the orange-colored females seek sheltered sites to spend the winter.

Damage

Spider mites all cause the same type of feeding damage (see Damage section under European red mite). In addition, the McDaniel spider mite forms very dense webs on leaves and fruit. Webs on the leaves may prevent good spray penetration, making chemical control more difficult. Mites and webbing in the calyx end of fruit have also been noted as a problem, since this species is regulated by quarantine in certain countries.

Monitoring

See monitoring section under European red mite. *Figure 138* gives a binomial sampling scheme for twospotted and McDaniel spider mites.

Yellow spider mite

Eotetranychus carpini borealis (Ewing)

(Acari: Tetranychidae)

The yellow spider mite is an occasional pest in the Rogue River Valley of Oregon. It has never gained pest status outside this area, although it occurs throughout the northwestern United States and southwestern Canada.

Hosts

Tree fruit hosts include apple and pear, which are primarily the crops on which yellow spider mite is considered a pest. It is also found on cherry, raspberry, blueberry, spirea, alder and willow.

Life stages

Egg: The egg is clear, spherical and has a small stipe, or stalk. It is about the same size as the egg of the twospotted and McDaniel spider mites.

Immatures: Immature forms of yellow spider mite are similar to the two *Tetranychus* species in size and shape but can be distinguished by their color, which is tinged with yellow, rather than green.

Adult: The adult female is pale yellow to white with 2 or 3 rectangular, dark markings on each side of the abdomen (*Figure 141*). The male looks similar, but is smaller and has a more tapered body.

Life history

Like the twospotted and McDaniel spider mites, this species overwinters as a diapausing female, which is bright yellow. Females emerge from these sites when fruit buds begin to open in the spring, and move to the newly expanded tissue to feed and lay eggs. The egg laying capacity of the yellow spider mite is only about one sixth of that of the twospotted spider mite under similar conditions. The lifespan of a female is up to 27 days, during which she lays an average of 36 eggs. During the season, there are multiple overlapping generations. In early fall, the bright yellow overwintering forms are again produced. The females seek protected sites behind bark flakes on the trunk and major secondary limbs.

Damage

As far as is known, the damage by yellow spider mite is similar to that of the other tetranychid mites (see Damage section under European red mite).

Figure 141: The adult female is pale yellow or white with 2 to 3 rectangular dark markings on each side of the abdomen.

Figure 142: Overwintering eggs are laid on twigs or limbs, especially in the crevices.

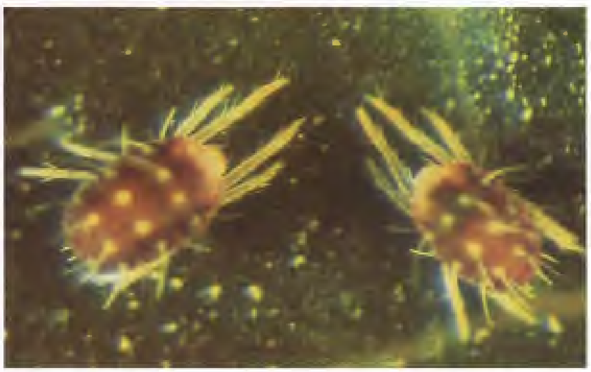


Figure 143: The female European red mite is red with white bristles.

Figure 144: The male is more slender than the female and has a tapered abdomen.

European red mite

Panonychus ulmi (Koch)

(Acari: Tetranychidae)

The European red mite, as the name implies, was originally brought to the United States from Europe, where it is widely distributed and has been a prominent pest for many decades. In the United States, it was first recorded in Oregon in 1911, and has since become common throughout the United States and Canada. European red mite has a long history of developing resistance to miticides. As a result, there has been much work on biological control, with many instances of success. Outbreaks of European red mite do not usually occur in unsprayed habitats. Only release from biological control agents (through the use of pesticides) allows this pest to build to the levels seen in commercial orchards.

Hosts

European red mite is a pest of many crops and ornamentals. Of the tree fruits, it is most commonly a problem on apple, pear, plum, prune and cherry, although mite problems on pear are more likely to be twospotted or McDaniel spider mite. Other hosts include peach, almond, grape, raspberry, currants, gooseberry, rose, black locust, elm, hawthorn, privet, lilac, chestnut, and alder buckthorn (*Frangula*). Although it will attack all apple varieties, it tends to build up higher populations on Red Delicious and Rome. Golden Delicious trees rarely support as high a population as do Red Delicious trees in the same orchard. Other cultivars reported as less susceptible to attack are McIntosh and Winesap. Pear cultivars also vary in their susceptibility to mite feeding.

Life stages

Eggs: Overwintering eggs are found on twigs and small limbs, especially in the crevices (*Figure 142*), beginning in the late summer or fall, throughout the winter, and up until they hatch in spring. They are about $\frac{1}{160}$ inch (0.15 mm) in diameter, are brick red and have a stipe, or stalk (*Figure 145*). Summer eggs are laid on the foliage and, if populations are high, on the fruit, especially the calyx end. These are slightly smaller and about the same color as the

Success story

Few success stories in the history of tree fruit IPM are more striking than that of integrated control of mites in apple. From the uncontrollable outbreak conditions of the early 1960s, currently only about 10 percent of Washington apple orchards are treated annually with specific miticides.

Three important components have led to this widespread biological control:

- Use of a delayed dormant oil against overwintering European red mite eggs.
- Maintenance of a moderate rust mite population in the orchard as a food supply for mite predators.
- Use of selective pesticides to protect predators.

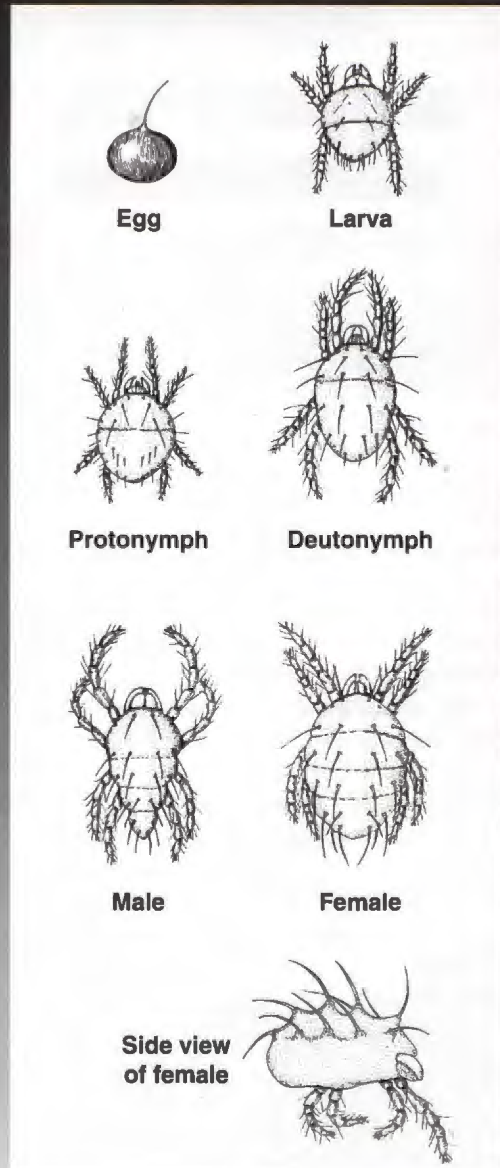
In addition, where dust on the foliage has been a problem, reducing it has been very helpful to integrated control. Because our pest complex and our pesticide options change over time, maintaining these practices will present an ongoing challenge.

overwintering eggs. After the egg hatches, the empty shell is transparent.

Immatures: There are three immature forms (the larva, protonymph, and deutonymph). The larva is only slightly larger than the egg and is an orange-red. It can be distinguished from other immature stages by having only three pairs of legs. The protonymph and deutonymph are successively larger, and have four pairs of legs, as do adults. Immature stages of European red mite are reddish in color, but sometimes have a greenish cast. Between each stage is a quiescent stage, which precedes a molt. The integument can appear silvery during this stage as it separates from the layer beneath.

Adult: The adult female is about 1/72 inch (0.35 mm) in length, typically a solid brick red, and is characterized by her oval shape and strong white bristles on the back of the abdomen. The bristles, which have white bases, look like white spots on the back (*Figure 143*). The male is a yellowish red tinged with red. The male is only about 1/80 inch (0.30 mm) long and is more slender than the female. It has a tapered abdomen (*Figure 144*).

European Red Mite Life stages



Newcomer, E.J. and M.A. Yothers. Biology of the European red mite in the Pacific Northwest. USDA Tech. Bull. 89. p.8.

Figure 145

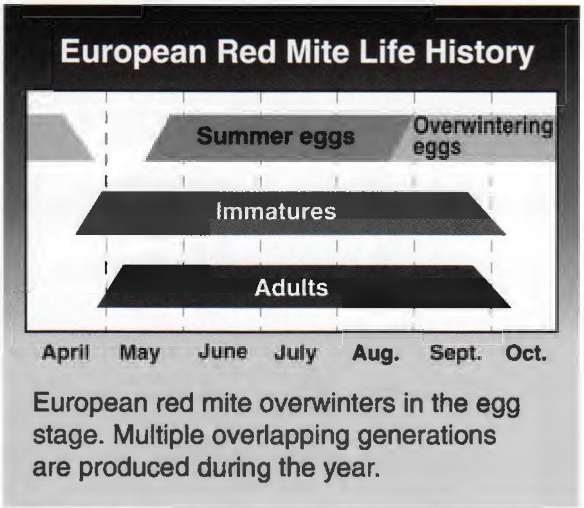


Figure 146

Life history

The European red mite passes the winter in the egg stage (*Figure 146*). Eggs are usually laid on the lower sides of small branches and twigs. They are often found around the forks of two branches, in crevices and other rough areas. Egg hatch begins at about the tight cluster to pink stage of Red Delicious development, and is largely complete within in 7 to 10 days.

The larvae move to young leaves to feed. Immature mites often rest and feed more extensively on the bottom side of the leaves, but adult mites inhabit both surfaces. Although mites feed on newly expanded leaves early in the season, they are more likely to be found on hardened-off foliage when it is available.

The sex of the mite can be determined at the deutonymphal stage when females are already larger and more oval than the males, but the difference does not become obvious until the adult stage. The first adults appear around petal fall on apple. Males emerge first. The male waits near a quiescent female until she emerges, and mates with her immediately. After about two days, females begin to lay eggs. A female mite lives 15 to 20 days and lays 30 to 35 eggs on average. Eggs from unfertilized females produce only males, by arrhenotokous parthenogenesis, but eggs from fertilized females produce both males and females. Eggs are deposited on both sides of the leaf, but are concentrated near veins and midribs. In hot weather, they can complete their life cycle in as little as 10 days, though it can take up to 25 days in cooler weather. There are 6 to 8 generations per year, which overlap more as the season progresses. Populations usually peak in late July or August, although the peak is probably modified by pesticide use patterns.

When mite populations reach high levels, they can disperse by a process known as "ballooning." Mites, sometimes in great masses, crawl to a high point or a tip of a branch and raise the anterior part of the body. The mite spins a silken thread, which is caught by air currents, taking the mite along with it. This is one of the primary means of mite dispersal to nearby trees where canopies do not overlap.

Females start laying overwintering eggs in mid-August to September. An over-exploited food resource (i.e., badly bronzed foliage) can lead to earlier deposition of overwintering eggs. Females usually lay eggs on the bark, but when populations are they sometimes deposit them in the calyx end of the fruit. Although European red mite does spin webbing, it does not do so to the same extent as do twospotted or McDaniel spider mite.

Damage

Note: *The following sections on damage and management cover all four spider mite species. As far as it is known, all of these species feed in the same manner, and no attempt has been made to differentiate the effects of one species vs. another. In the Pacific Northwest, economic injury research on apple was done primarily with McDaniel spider mite, and research on pear was done with twospotted spider mite. Where populations are mixed, there is no reason to assume that feeding by one species differs in its effect on the tree than feeding by the others. Rust mite damage is different, however, and is treated in the appropriate section.*

Mites feed by inserting their mouth parts into leaf cells to suck out the contents, including the green pigment chlorophyll. The individual spots initially look white, giving the leaves a stippled appearance. As damage progresses, the infested leaves take on a brown hue, commonly called bronzing (*Figure 147*). Tree species, and cultivars within species, differ substantially in their reaction to mite feeding. Although Red Delicious trees tend to build higher populations of mites, Golden Delicious is more susceptible to damage by mites. Apples, in general, are more tolerant than pears. Whereas damage to apple foliage will cause bronzing, and eventually some premature leaf abscission in August, damage to pear leaves can lead to "transpiration burn," where leaves develop large necrotic areas and are shed (*Figure 148*). This can occur in mid-season, or whenever substantial mite damage is combined with some additional types of stress on the trees.

Of the common Pacific Northwest pear varieties, the ranking from most to least susceptible to damage is D'Anjou, Bosc, Bartlett, and Comice. The red strains of pear cultivars are not prone to transpiration burn or defoliation, and are considered tolerant of mite damage. As well as damaging foliage, spider mites feed on the epidermis of pear fruit, causing russeting. High populations late in the season are most likely to cause fruit russet.

Prune and other stone fruits have an intermediate reaction. Although the leaves bronze, as opposed to developing transpiration burn, defoliation is more common than on apple.

The effects of mite damage to foliage have been much studied, but are still poorly understood. On apple, studies have examined photosynthesis, transpiration, shoot growth, trunk and limb growth, root growth, fruit size and rate of growth, fruit color (internal and external), soluble solids, firmness and other quality parameters, return bloom and return fruit set. At best, it can be stated that under some circumstances, mite damage affects one or more of these parameters. Similar studies on pears indicate a marked reduction in fruit size and return crop.

As the effects of feeding damage are cumulative over time, mite damage is often expressed as a combination of the population level (intensity) plus an indication of length of time of feeding (duration). The unit is called a mite day, or the damage caused by one mite feeding for one day. Thus, 100 mite days could be the product of 100 mites feeding for 1 day, or 10 mites for 10 days. *Figure 149* shows how cumulative mite days are calculated.

Since mite population curves usually have a single peak, the peak population level is related to the total number of mite days. Some studies have used peak populations as a measure of the economic injury level. The variability in damage makes it difficult to set an economic injury level or a treatment threshold that will be valid for all cultivars, times of season, weather, crop load, etc. For apple, a somewhat conservative level of 800 mite days was set for Washington conditions. This corresponds with a peak population of 30 mites per leaf. On pears, the greater susceptibility is reflected in a lower threshold. The economic injury level is set at 5 mites per leaf, and the treatment threshold used to prevent that from occurring ranges from 0.5 to 2 mites per leaf.

Figure 147: Infested apple leaves may take on a brown hue, a condition called bronzing.

Figure 148: On pear, mite feeding can lead to transpiration burn.

How to Calculate Cumulative Mite Days

As the effects of feeding damage accumulate over time, mite damage is often expressed as a combination of the population level plus an indication of the length of time of feeding. The unit is called a mite day. To calculate cumulative mite days, take the average number of mites per leaf of two successive mite counts, multiply by the number of days between the counts, and add to the running total. Since mite populations usually have a single peak, the peak population level is related to the total number of mite days.

Example

Sample date	Weekly count mites/leaf	Average (this count and last count)	Days between counts	No. days x average	Running total*
June 1	0.10				
June 6	0.15	0.13	5	0.63	0.63
June 14	0.50	0.33	8	2.60	3.23
June 23	1.30	0.90	9	8.10	11.32
June 28	4.70	3.00	5	15.00	26.32
July 2	12.60	8.65	4	34.60	60.92
July 14	10.20	11.40	12	136.80	197.72

* Cumulative mite days

Figure 149

Monitoring

Mites are difficult to detect initially due to their small size, but the effects of substantial feeding will be evident without getting out of the car. Mites are visible on foliage but most people will need a hand lens to distinguish the species. Reddish stains on the fingers after handling infested leaves are usually diagnostic for European red mite.

There are several approaches to monitoring mite populations. One is an in situ examination. Take a hand lens and examine 10 leaves from each of 10 trees per block (total of 100 leaves), and count the number of mites. This is laborious and subject to counting error if populations are high. However, if other equipment is lacking, it can give a reasonable assessment of mite populations.

A standard approach is to collect leaves in the field and bring them back to where a leaf brushing machine and a microscope can be used. The leaf brushing machine is a device with opposable rollers covered with soft bristles which brush mites from the leaf surface down to a revolving glass plate coated with a slightly sticky substance (e.g., liquid detergent). The mites are immobilized on the surface of the plate, and the microscope aids in counting individual species and stages. Usually a paper grid with 20 wedges marked on it is placed beneath the glass plate to help keep track during the count. A grid that can be photocopied for use is provided in Appendix 4. The total mites on the plate divided by the number of leaves brushed onto that plate yields the estimate of the mites per leaf. When populations are high, only a fraction of the plate is counted (one half or one quarter). This method is also laborious and subject to error, but is probably the most accurate of the methods presented. It has been the standard method on which much of the economic injury evaluations have been made.

A technique called binomial sampling has become

Binomial (Presence-Absence) Sampling Scheme for European Red Mite

% of mite-infested leaves	Estimated density (mites/leaf)	95% confidence interval lower	upper
40	0.7	0.25	1.20
45	0.9	0.35	1.45
50	1.1	0.45	1.75
55	1.3	0.60	2.13
60	1.6	0.80	2.65
65	2.0	1.05	3.25
70	2.6	1.35	4.10
75	3.4	1.85	5.35
80	4.7	2.55	7.25
85	6.8	3.85	10.55
90	11.4	6.50	17.55
95	26.4	15.30	40.30

Choose 5 to 10 leaves from 5 to 10 trees scattered throughout a block. Scan the leaves with a hand lens to determine whether or not mites are present. Keep track of the total number of leaves scanned, and the total number of leaves infested by one or more mites. Divide the number infested by the total number scanned and multiply by 100 to calculate the percentage of infested leaves. Use the nearest value from the first column of the table above and read across to obtain the estimated number of mites per leaf for the orchard block.

EXAMPLE

Tree	Infested leaves	Uninfested leaves
1	II	III
2	I	IIII
3	III	II
4	II	III
5	IIII	I
6	III	II
7	I	IIII
8	~~IIII~~	0
9	~~IIII~~	0
10	I	IIII
Total	27 +	23 = 50

Keep a tally sheet of infested and non-infested leaves, similar to the one above, as you go through the orchard. For example, you find 27 infested leaves and 23 uninfested leaves, for a total of 50 leaves. Divide 27 (the number of infested leaves) by 50, which is 0.54. Then multiply by 100 to obtain the percentage of infested leaves, which is 54 percent. According to the table, 54 percent infested leaves is equivalent to 1.3 mites per leaf.

From the *Tree Fruit Production Guide 1992-1993*, Penn State College of Agricultural Sciences

Figure 150

more popular recently, because it simplifies the estimating procedure with the use of statistics (see the section on Sampling in Part I). The binomial sample can be done in the field, and each leaf examined is rated as to the presence or absence of mites. The percentage of leaves infested (i.e., with 1 or more mites) is statistically related to the number of mites per leaf, and can be looked up on a table or chart made expressly for that species *(Figure 150)*. The primary drawback to binomial sampling in the arid regions of the west is that the number of mites per leaf cannot accurately be estimated when 85% or more of the leaves are infested. This means that the highest level that can be estimated with accuracy is 10 mites per leaf for the twospotted and McDaniel spider mite, which is well below the treatment threshold of 30 mites per leaf. The highest level that can be accurately predicted with the European red mite is 26 mites per leaf. An additional drawback is that rust mites and *T. occidentalis*, which are important components in decision-making, cannot be evaluated in the binomial sample. However, this method may be used as an indication if further sampling is necessary. A binomial sample indicating 95% or more of the leaves are infested with either European red mite or the *Tetranychus* species shows the need for a standard brushing-machine sample.

Because mites are on the tree from the pre-bloom period through fall, it is important to make repeated assessments for mites. You cannot take a single sample at a critical point in its life cycle and be finished for the season. Mites can build up at different times in different blocks or years. The only time that might be termed a single critical point is for the overwintering eggs. However, delayed-dormant oil applications are made routinely in the Pacific Northwest, so this is rarely considered a decision making point. Where biological control occurs many people do not monitor populations. It is advisable to sample at least once in mid- to late June to insure that rust mites and predators are present in adequate numbers.

Re-establishing Typhs

In cases where nonselective pesticide use has destroyed *T. occidentalis* populations, it may be possible to re-establish them more quickly by seeding the orchard to hasten recolonization. Predators may be reintroduced by taking shoots from an orchard with rust mites and *T. occidentalis*, and placing them in the affected orchard. Because the movement of *T. occidentalis* between trees is limited, at least one Typh-infested shoot per tree should be used. If a source orchard is not available, *T. occidentalis* can be purchased from commercial suppliers of beneficial insects. Strains have been selected in the field and laboratory for tolerance to commonly used orchard pesticides, so make sure that the strain is appropriate for the area of introduction.

Biological control

The predatory phytoseiid mites are the most important biological control agents in the Pacific Northwest. *Typhlodromus occidentalis* is by far the most important predator in most areas, although in some of the more humid areas of Oregon, *Typhlodromus pyri* can also play a role. A stigmaeid mite, *Zetzellia mali*, is often found in low numbers in orchard blocks, but usually provides only supplemental control. *Stethorus picipes*, a small black coccinellid (ladybird) beetle, can consume large numbers of mites, but is not attracted to the orchard until the infestation level is quite high.Campylomma (a mirid true bug) is also reported to be an effective mite predator in Europe, but its predatory role in the Pacific Northwest has not been explored. Furthermore, its habit of feeding on fruit early in the season outweighs its benefit as a predator. Early stages of Deraeocoris bugs and lacewings also feed on mites. (For more information on individual beneficial species, see Part IV.)

Management

Rust mites play an important role in integrated mite management as an alternate food source for predatory mites. This is a critical component in the system, since it allows predators to maintain themselves during periods of low spider mite densities. If predators are in low to moderate numbers, spider mite populations may not build up much past the level of detection, and consequently stay well below the treatment threshold. Rust mite populations tend to crash during periods of prolonged hot weather; they are usually most abundant during spring and early summer, and then again in fall. In the hottest areas of the Pacific Northwest (e.g., lower Yakima valley), rust mites may not be numerous, and these areas tend to be more vulnerable to spider mite problems. Drip irrigation, unlike overtree or undertree, does nothing to modify hot, dry conditions.

Cultural factors play a role in spider mite population buildup. High populations have been associated with dusty foliage, such as occurs next to dirt roads. Overtree irrigation tends to reduce twospotted and McDaniel spider mite populations in comparison to undertree irrigation, either through microclimate modification or through washing mites from the leaves. European red mite, on the other hand, is little affected by overtree irrigation.

Temperature and humidity also play a role. In areas or years where many heat units accumulate, mite populations can produce more generations. High mite populations are often associated with hot, dry weather (even though in laboratory tests these conditions appear to cause higher mortality). For example, field studies with twospotted spider mite in Oregon show that its potential for population growth is lower in years with below-normal temperatures. If the weather is rainy as well as cooler, this reduces survival of mites, and will further suppress populations.

The value of the delayed-dormant oil application (at about half-inch green tissue) aimed at overwintering eggs of European red mite has been proven consistently under Washington conditions. Eggs are most vulnerable just prior to hatching, thus true dormant sprays will not be as effective. Usually European red mite populations are prevented from building up through May and June because of the delayed-dormant oil spray, although by itself it does not provide season-long control. It does, however, suppress European red mite populations long enough for predators to become established in the trees. In the past, the addition of an organophosphate insecticide has enhanced the efficacy of the oil but, currently, most of the effect comes from the oil alone. Mites are less likely to develop resistance to oil than to other insecticides. No report of resistance to oil has yet been documented.

There is evidence on pear that delayed-dormant or pre-pink sprays suppress the overwintering females of twospotted mites, but this suppression does not prevent buildup later in the season. Overwintering females are physiologically and morphologically different than the summer form, and chemical control of this form is more difficult. Specific miticides should be applied after the females lose their orange coloration and before these forms are produced again in the fall.

Effective specific miticides that are registered for use on tree fruits have grown fewer in recent years. In the past, most major groups of insecticides (e.g., the organophosphates) were initially miticidal, but resistance developed within a few years of commercial use. Similarly, most of the specific miticides were ineffective within a few years. The organotins had a relatively long field life, but resistance to these materials is now widespread. Ovicidal miticides have been notorious for their short field life in the past, and experience from other parts of the world indicates this is an ever-present danger with the newer ovicides.

An important consideration in choosing a miticide, besides efficacy, is how selective it is toward beneficial arthropods, especially predatory mites. Use of a selective miticide greatly enhances the chance of establishing biological control, which should be the ultimate aim of any mite control action. Even a fairly selective miticide, if sprayed too often, or on a prophylactic basis, will deplete the predator population and increase the chance of resistance in the spider mite population. A second consideration is the toxicity of the material to rust mites. Materials with low or moderate toxicity to rust mites will also enhance the chance of establishing or maintaining biological control.

Caution must be exercised not only in the choice of a miticide, but also in the choice of insecticides and fungicides. A number of these materials are highly toxic to predatory mites. Two classes notorious for this are the pyrethroids and the carbamates, although not all materials within a given class are equally toxic. Repeated applications of a material only moderately toxic to predators (e.g., organophosphates) may eventually reduce the predator population below an effective level. In the dry areas of the Pacific Northwest, fungicide use is minimal, and this level of use does not appear to present a problem. However, in areas where apple scab is a chronic and serious problem, the selectivity of the fungicide used should be taken into consideration.

Apple: Before specific miticides are applied, the decision must be made as to whether control is warranted. Factors that need to be considered are:

- the level of direct pests and the pesticides used against them;
- damage incurred by other species of foliage feeders;
- tree age and vigor;
- type of irrigation system;
- crop load; and
- the weather.

Although an all-inclusive threshold is impossible to quantify, mature, vigorous trees with a light or moderate crop load can withstand a considerable amount of foliar damage without any measurable economic loss. Heavier crop loads require an efficient leaf canopy to mature the fruit properly, whereas if the leaf-to-fruit ratio is high, foliar damage may not be as critical. If the trees are water stressed by extremely hot, dry, or windy weather, a sandy or rocky soil that has poor water retention qualities, or inadequate irrigation, then the effects of mite damage will be exacerbated. If no predators are detected during successive samples and mite populations continue to rise, then miticides may be the only recourse. However, if predator populations are building, but more slowly than the pest mites, a miticide (the most selective one available) may be considered. If the use of a nonselective pesticide is required for another pest, then the chances for biological control are diminished and a miticide is more likely to be needed. In the long run, it may be better to incur some damage from mites initially than to run the risk of reverting to a miticide-based program.

Pear: The heavy use of pyrethroids in pears for psylla control has dictated an essentially miticide based program for mite control. Even before the introduction of pyrethroids, the intensive spray program for psylla was very detrimental to predators. This, coupled with pear foliage's inherently low tolerance to mite damage, has prevented biological control from playing a major role. The alternate prey component of the system, rust mites, are present on pear, but can cause fruit russeting. Thus, the tolerance for rust mite damage is less on pear than on apple (with the exception of Bosc, a naturally russeted pear cultivar) and predatory mites are less able to maintain themselves. The replacement of a harsh, nonselective chemical program for pear psylla with softer materials would allow a greater chance for biological control, although it may never approach the success of integrated mite control on apples. An additional consideration on pear is the effect of orchard floor management on mite populations, especially twospotted spider mite. This species can build to high levels on weed hosts, especially bindweed, beneath the trees. When this food resource is depleted or killed with herbicides, mites may be driven up into the trees in large numbers. A survey of the weed composition and its mite population will indicate whether this is a potential problem.

One strategy is to add a miticide labeled for this use to the herbicide. Preferably, the miticide should of a different chemical class than the one used for the tree canopy, to minimize selection for resistance. A second strategy is to open the lower nozzles on the airblast sprayer when applying a miticide to the canopy in order to cover the orchard floor. The drawback to this strategy is that development of resistance to the orchard miticide may be hastened.

RUST MITES

Apple rust mite

Aculus schlechtendali (Nalepa)

(Acari: Eriophyidae)

The apple rust mite has been studied both as a pest and a beneficial arthropod. Although it can damage fruit and foliage of apple, its major role in Pacific Northwest orchards is as an alternate food source for predatory mites. It is found throughout the apple growing regions of the United States, Canada, Europe and Australia.

Hosts

The apple rust mite attacks cultivated apple, and several other species in the genus *Malus*. It can also survive and reproduce on pear, and has been found in mixed populations with the pear rust mite.

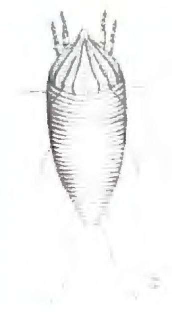
Life stages

Egg: The egg is about 50 microns in diameter and 30 microns high. It is initially clear, but becomes translucent as the embryo matures.

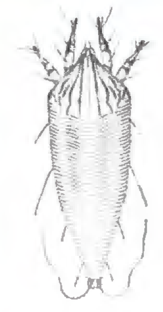
Immatures: The first nymphal stage is white, about 68 microns long, increasing to 104 microns before molting. The quiescent stage is immobile, and the cuticle is shiny, later turning to tan. The second instar nymph is a pale tan, and 104 to 124 microns long. This stage also forms goes into a quiescent stage before molting.

Adult: The adult is medium tan in color, becoming darker with age. Protogyne females are 166 to 181 microns long, slightly larger than the males (*Figure 151*).

Rust Mites

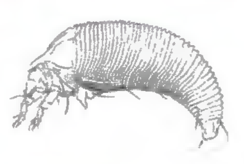


Apple rust mite
(Aculus schlechtendali)

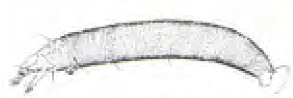


Pear rust mite
(Epitremerus pyri)

Prunus rust mite protogyne
(A. fockeui = A. cornutus)



Prunus rust mite deutogyne
(A. fockeui = A. cornutus)



Pear leaf blister mite
(Eriophyes = Phytoptus pyri)

Parrott, P.J., H.E. Hodgkiss and W.J. Schoene. 1906. The apple and pear mites. N.Y. Agr. Exp. Sta. Bull. 89. plate II.
Keifer, H.H., E. W. Baker, T. Kono, M. Delfinado and W.E. Styer. 1982. An illustrated guide to plant abnormalities caused by eriophyid mites in North America. USDA Handbook 573. pp. 125, 139.

Figure 151

Biology of Tree Fruit Rust Mites

Life stages

Eggs: Rust mite eggs are extremely small, roughly hemispherical, and require 100-power or greater magnification to be seen.
Immatures: Rust mites have two nymphal instars. All stages of immatures and adults have two pairs of legs at the front end of the body, and an elongate abdomen (hystersoma) with many striations appearing as rings. This appearance is referred to as *annulate*.
Adults: Adult females occur in two forms: deutogynes and protogynes. *Deutogynes* are a special form of female that overwinters. The differences between these two forms make species identification difficult. *Protogynes* are the normal females, which occur throughout much of the growing season and reproduced immediately upon becoming adults. These are the forms on which species identifications are usually based. Males also occur in the species that attack tree fruits, but do not overwinter. They are slightly smaller but are similar in appearance to the protogynes.

Life history

Rust mites overwinter as inseminated deutogynes. These females do not reproduce in the year in which they are produced. Some chilling is required before they will lay eggs in the spring. As with protogynes, these eggs produce both males and females. The rust mite has two nymphal instars, which resemble the adult but are smaller. Each molt is preceded by a quiescent phase. Male rust mites are produced by unfertilized eggs and females are produced by fertilized eggs (*arrhenotokous parthenogenesis*). They do not actually mate. The males deposit stalked spermatophores (structures containing a packet of sperm) on the leaves. Females walk over a spermatophore and empty it of the sperm, storing it in a special pouch called a spermatheca. Both sexes will be produced from eggs when females have access to spermatophores. Multiple overlapping generations are produced during the year, the number depending on the climate, location and condition of the host. The hibernating forms (deutogynes) are produced in response to either poor host condition or climatic conditions (cool weather, shorter photoperiod) that occur in the fall.

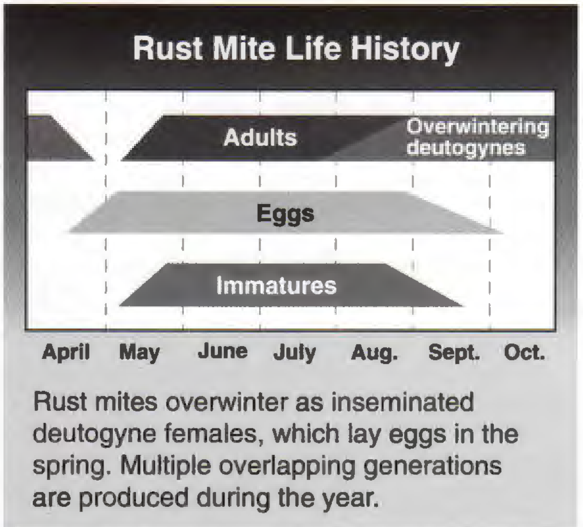


Figure 152

Life history

The species overwinters as deutogynes (females) in crevices on twigs and under bud scales. Often large clusters can be found under a single scale. They emerge to feed principally on the undersurfaces of leaves as the buds begin to open in the spring. They lay eggs that hatch into immature mites, which rapidly grow through two instars. There are several generations per growing season (*Figure 152*). Development is more rapid in warm temperatures. In one study, a generation took 39 days to develop at 50˚F, but only 10 days at 72˚F. The lower developmental threshold is between 39 and 45˚F. Overwintering forms can be produced as early as mid-July if foliage condition is poor, but by fall only overwintering forms remain. They seek sheltered sites to spend the winter.

In cooler climates, apple rust mite populations peak once in mid-summer. In hot, dry climates, populations peak in early summer and again in fall, with the midsummer decline corresponding to temperatures above 95˚F (35˚C) and relative humidities below 20%.

Damage

Apple rust mite inserts its mouthparts into plant cells and sucks up their liquid contents. This feeding produces a silvery cast to the leaf in the early stages, which tends to get browner as the season progresses. Bronzing caused by apple rust mite is more finely textured than spider mite bronzing, and lacks the stippling produced by spider mites. Rust mite damage sometimes causes leaves to roll lengthwise.

Like other pests that affect the foliage, damage disrupts photosynthesis and the trees' water balance. Excessive amounts of damage, with peak populations greater than 300 mites per leaf or 4,800 mite days, can reduce fruit growth. Populations in excess of 2,000 per leaf have been noted.

As well as affecting fruit size, rust mite feeding can cause premature terminal bud set. Depending on the overall vigor of the orchard and other cultural factors, this may not be a problem.

Rust mites can also feed directly on the skin of fruit, causing a tan russeting. Usually this feeding is concentrated around the calyx end. This is only a problem on light colored cultivars such as Golden Delicious (*Figure 153*).

Monitoring

The presence of large numbers of rust mites can be detected by the color of the leaves. Such detection can be confirmed with a hand lens of 10-power magnification or greater. If an estimate of the population is needed, the brushed leaf samples taken to monitor spider mites (see Monitoring under European red mite) can also be used for this. Because of their size, an even smaller fraction of the glass plate is counted, usually 1/10th to 1/20th. It is often helpful

Figure 153: Rust mite feeding on the skin of the fruit causes a russeting, usually around the calyx end.

to make counts of plates in two stages: first, for all stages of spider mites and predatory mites; and then, using a higher magnification, for the rust mites. This allows the eye to readjust to their smaller size.

Biological control

The predatory mites *Typhlodromus occidentalis* and *Zetzellia mali* attack apple rust mites but generally do not control them. Predators can increase their numbers early in the season by feeding on apple rust mites, thus providing better control of spider mite populations that develop later.

Management

Control measures for rust mites as foliage feeders are rarely called for. Populations of up to 50 mites per leaf in May or 250 in late June do not warrant control. Even if populations exceed 300 per leaf, the benefit of having them as an alternate food source for predatory mites must be weighed against the possibility of yield loss. An added benefit of rust mites is that their feeding preconditions foliage so that it is less suitable for buildup of the more damaging spider mites.

The time of year and weather should also be factored into rust mite control decisions. Because of the tendency of rust mite populations to drop sharply during hot weather in July and August, control measures applied just prior to this period could be wasted. Consider control only where rust mite populations remain high into July and there are no predatory mites. Make sure trees are adequately irrigated during this period so trees are not subject to water stress, which would exacerbate the effects caused the mites' feeding. An exception to the above strategy is in the case of high levels of rust mites pre-bloom on Golden Delicious. If populations are high, then control to prevent fruit damage is warranted. Chemical controls will be most effective at about the pink stage of blossom development.

Pear rust mite

Epitrimerus pyri (Nalepa)

(Acari: Eriophyidae)

Pear rust mite was probably brought to the United States from Europe in the 19th century with trees or scion cuttings. It is a common pest throughout the Pacific Northwest and can cause serious fruit damage if untreated. While several predators feed on the pear rust mite, none controls it well enough to prevent commercial damage.

Hosts

Pear rust mite is found only on cultivated pear, several *Pyrus* species, *Cydonia* sp. (quince) and *Pyronia* (*Cydonia* X *Pyrus*).

Life stages

Egg: See description of apple rust mite.
Immatures: See description of apple rust mite.

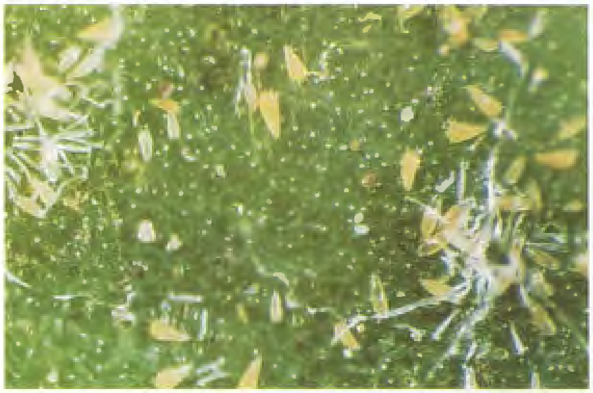


Figure 154: Pear rust mite adults are broad at the front and tapered at the rear.

Figure 155 Overwintering rust mite deutogyne females emerge at bud expansion.

Adults: Adults are about 150 microns long and are difficult to see without magnification *(Figure 151)*. A 10- to 20-power lens is recommended. They are broad at the front, tapered at the rear, and are yellowish brown. They have only two pairs of legs, which are at the front end of the body *(Figure 154)*.

Life history

Pear rust mite overwinters in bark crevices or behind loose bud scales, usually on 2- to 3-year-old wood. Overwintering deutogyne females emerge at bud expansion *(Figure 155)*. They rapidly invade opening fruit clusters, where they feed and lay eggs. The eggs develop into protogynes and males. Between the egg and adult stages, the pear rust mite passes through two nymphal stages. Pear rust mites develop twice as fast as apple rust mites and can develop in slightly cooler temperatures. Numerous generations of the summer form develop each season and the pest can persist through the growing season if it has enough succulent new foliage on which to feed. A lack of suitable foliage is thought to induce formation of the resting deutogyne female. Dispersal is probably by wind.

Figure156: Feeding causes russeting of fruit. It can cover the entire surface but often is confined to the calyx end.

Damage

As pear rust mite starts feeding within the developing fruit clusters, it can damage fruit very early in the season. The feeding causes light russeting that can cover the entire surface of the fruit. Often, however, only the calyx end of the fruit is russeted *(Figure 156)*. The russet most obvious on clear-skinned pears such as Bartlett, d'Anjou and Comice. Naturally russeted cultivars, such as Bosc, and red skinned varieties seem more tolerant of rust mite damage. The pear rust mite also feeds on young leaves, which, if heavily attacked, turn bronze in color *(Figure 157)*. Heavy feeding can cause defoliation and reduced shoot growth. Although pear rust mite may persist on both fruit and foliage throughout the season, it causes the most severe damage in the early spring. For that reason, direct controls are usually applied pre-bloom.

Monitoring

Because of its small size, spotty distribution and low injury threshold, it is very difficult to monitor pear rust mite for the purpose of relating population density to potential damage. In most cases, if pear rust mite is detected at all, especially prebloom, it needs to be controlled.

Because pear rust mite can damage fruit early in the season, sampling should begin at the clusterbud stage of tree development. Large numbers of buds

Figure 157: Rust mite feeding can cause bronzing of foliage, which is more finely textured than spider mite bronzing.

may have to be sampled to detect low, but still injurious, levels of infestation. At least 100 clusters per 10-acre block should be examined. These can be selected at the clusterbud through pink-bud stages and should be taken from 3- to 4-year-old wood. The entire fruit cluster should be examined, including fruit buds or fruit, leaves and the younger green, woody tissue at the base of the bud. Those same samples also can be used to gather information on other pests, including spider mites, pear psylla and predaceous mites.

Later in the season, pear rust mite can be monitored using leaf samples taken to monitor pear psylla and spider mite. In addition, packing house records showing the sources of injured fruit and extent of injury are helpful for detecting sites that are at risk.

Biological control

Pear rust mite is attacked by several indigenous predators including predaceous mites, green and brown lacewings, coccinellids and larvae of the cecidomyiid fly *Arthrocnodax*. However, in the Pacific Northwest, pear rust mite causes severe fruit damage each year where it is left uncontrolled. This suggests there are insufficient natural controls to make biological control a viable alternative to chemical suppression.

Management

A study on the relationship between rust mite density and russet damage on Bartlett pears showed it would pay the orchardist to control the mite if more than 1% of the fruit were damaged. It also showed that populations averaging more than 5 mites per fruit would result in more than 1% of the fruit being damaged, i.e., having more than 5% of the surface russeted.

Sulfur compounds are effective when applied prebloom or post-harvest and are relatively nondisruptive to the natural control agents important in the suppression of other pear pests.

PRUNUS RUST MITES

(Acari: Eriophyidae)

Plum nursery mite
Plum rust mite
Cherry rust mite

Aculus (Phyllocoptes) fockeui (Nalepa and Trouessart)

Peach silver mite

Aculus cornutus (Banks)

For about a century since the original descriptions of the plum nursery mite and the peach silver mite, they have been considered separate species, despite repeated assertions that they were indistinguishable. It was thought that the plum rust mite attacked European plum and cherry, and the peach silver mite attacked peach. Recent evidence indicates that they are the same species, but with a broader host range than previously reported. Thus, *A. cornutus* may be considered a synonym of *A. fockeui*, and their biology, life cycle and damage will be discussed together.

Prunus rust mites are widely distributed in the U.S. and Canada, probably wherever their hosts are grown.

Hosts

Hosts include European plum and myrobalan plum (also known as cherry plum), although injury on the latter is slight. Damson plums are particularly prone to damage. Japanese and American varieties of plums (e.g., *P. hortulana, P. maritima, P. subcordata, P. virginiana melanocarpa*) are incapable of supporting mite reproduction. *P. avium* (sweet cherry), *P. cerasus* (sour cherry), *P. mahaleb*, and *P. persica* (peach and nectarine) are known hosts. See *Figure 158* for cultivar susceptibility. Apple and pear are not hosts.

Life stages

Egg: The egg is flattened, slightly elliptical, and measures about 50 microns in diameter. It is translucent when first laid, turning an opaque white just prior to hatching.

Peach Silver Mite Hosts

Poor host	Moderate host	Good host
Loring	Cardinal	Elberta
Dixie Gem	Halehaven	Maygold
Red Haven	Suwanee	Southland*
Ranger	Red Cap	Rio Oso Gem**
Cornet	Triogem	
Keystone		
Sunhigh		
Sullivan Elberta		

* Wilson & Cochran 1952. (seedlings)
** Oldfield et al. 1970. (seedlings)

From Barké et al. 1972.

Figure 158

Immatures: The immature stages (larva and nymph) are similar in structure to the adult except smaller. The larva is white to translucent, and about 67 microns long. The nymph has a somewhat more yellow cast, and is 105 to 130 microns long.

Adults: The adult mite is a typical eriophyid with two pairs of legs at the front and a cylindrical, annulate abdomen (*Figure 151*). The female is about 157 microns in length, slightly larger than the male. Newly emerged adults are a pale yellow color, but turn brownish yellow or tan with age.

Life history

Prunus rust mites overwinter as diapausing females in buds (just beneath the outer scales) or in crevices of twigs and bark. Females leave their overwintering sites shortly after the buds begin to expand in the spring (*Figure 152*). After feeding a few days, they begin to lay eggs. Females can lay 50 to 60 eggs, while males may deposit several hundred spermatophores. Eggs laid in spring may take up to 15 days to hatch, but in midsummer only 3 to 4 days. The immature stages require from 2 to 18 days to complete, with an average of 2.1 days for the larvae and 1.7 days for the nymphs. The lifespan of the adult is from 20 to 30 days. A complete generation requires 6 to 22 days, with the majority in the 7- to 12-day range. Generations are produced continuously throughout the summer.

When environmental conditions provide the appropriate trigger, usually poor condition of foliage, overwintering females (deutogynes) are produced. This may be as early as mid-summer. Males die in the fall.

Females that are not inseminated produce only male progeny (arrhenotokous parthenogenesis), while those that are inseminated produce both male and female progeny.

Overwintering mortality of females may limit the population the following spring. Dry weather also appears to reduce mite populations, perhaps through the effect of hardening the leaves.

Damage

Mites feed on the surface of the leaf by piercing the epidermis with their mouthparts, and sucking the fluids from the cells. Mature plum foliage attacked by Prunus rust mites may be curled or dwarfed. The lower leaf surface may be have a bronze or silvery appearance. On peach, the silver color is the predominant symptom (*Figure 159*). Feeding of mites on young foliage causes a toxemia, which is called yellow spot on peach, and chlorotic fleck on plum. As the names imply, the symptoms are small yellow spots on the leaves, followed by shotholing in some cultivars.

The impact of Prunus rust mites on yield or quality of their hosts has not been determined. It is probable that photosynthesis and transpiration are affected.

Figure 159: Peach foliage attacked by Prunus rust mites may turn silvery.

Monitoring

Prunus rust mites can be sampled by either examining the leaves with a hand lens, or by brushing them off the leaves on to glass plates, and counting them with the aid of a microscope (see the section on monitoring for European red mite).

Biological control

Predators include phytoseiid mites, including *Typhlodromus occidentalis* in Washington; young nymphs of the anthocorid bug *Orius insidiosus*; and larvae of cecidomyiids. In the Pacific Northwest, it is likely that phytoseiid mites play the dominant role in biological control, and that Prunus rust mites play a similar role as an alternate host to the tetranychid mites as do apple rust mites on apple.

Management

Prunus rust mites are not difficult to control by chemical means, and are still susceptible to sulfur and specific miticides. Populations will be drastically reduced during hot, dry periods, so a midsummer application is not advisable. However, rising populations in spring or fall may warrant treatment. Because of its role in integrated control, damage from Prunus rust mites should tolerated as long as possible. If other tetranychids are a problem and predator populations are building, leaving the rust mite population undisturbed may promote biological control of all mites. If a specific miticide is applied for the tetranychids, it will also reduce the peach silver mite population, so no additional treatment is required. Peach silver mite may be controlled pre-bloom, during the summer, or post-harvest, but the post-harvest clean-up spray is favored because it reduces the overwintering deutogyne population and minimizes the effects on beneficial species. Treatments should be considered only when damage by this species is compounded by other types of foliar injury or environmental stress. Care should be taken that treatments are applied against an active and growing population of mites, as determined by successive samples, and not merely in response to bronzed or silvered leaves where populations have already dropped dramatically.

Pearleaf blister mite

Phytoptus pyri Pagenstecher

Appleleaf blister mite

Phytoptus mali (Burts)

(Acari: Erophyidae)

The pearleaf blister mite was introduced from Europe, probably before 1900. It is currently a pest in most pear growing regions of the world. The appleleaf blister mite was first described in 1970 in Washington, although it may have been present in the Pacific Northwest as long as the pearleaf blister mite. Feeding by these mites causes blisters on leaves and fruit. Although at one time considered serious pests, they are now rare in commercial orchards of the Pacific Northwest.

Hosts

Pearleaf blister mite and appleleaf blister mite are pests of pear and apple respectively, and possibly attack related plants such as mountain ash, cotoneaster, quince, serviceberry, snowberry and hawthorn.

Life stages

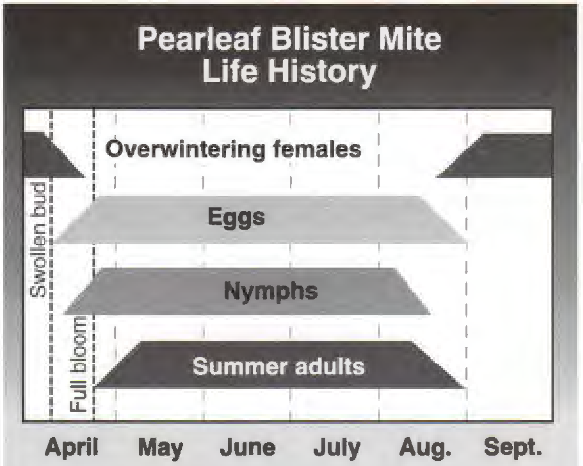
Egg: The egg is oval, pearly white and about 40 microns long.

Immatures: The first instar nymph is wedge shaped, tapering toward the rear, and is about 70 microns long. It has two pairs of short legs near the front of the body. There are two nymphal stages before maturation with an inactive period before each molt. The inactive period at the end of the second nymphal stage is relatively long.

Adult: The female is 200 to 230 microns long and is light to amber yellow. It is cylindrical, tapered sharply at the posterior end, and resembles a short worm (*Figure 151*). It has two pairs of short legs near the front of the body. The male is about 150 microns long.

Life history

Blister mites overwinter as mature females at the base of buds or under outer bud scales. In spring, when buds begin to swell, overwintered females penetrate deeper into buds and lay eggs on live tissue. Development from egg to adult requires 20 to



There are several generations of pearleaf blister mite during the summer. Timings are based on observations in central Washington.

Figure 160

Figure 161: Blisters on foliage are green or red at first, but turn brown or black as the tissue dies.

Figure 162: Mites do not live in the blisters on fruit, but the fruit will be scarred.

30 days during the spring. Feeding of females and their offspring causes blisters on developing leaves. As the blisters form, leaf cells near the center of the blisters die and pull apart as surrounding cells enlarge, creating a hole. Mites of the first spring generation enter blisters through these holes and feed on soft leaf tissue inside.

Several generations develop within blisters during a growing season (*Figure 160*). Summer generations require only 10 to 12 days to develop. When blisters become crowded or leaves become heavily damaged, mites may migrate to growing terminals where their feeding produces new blisters. Fruit damage is caused by injury to buds before bloom.

It is not known exactly how blister mite infestations spread from tree to tree or orchard to orchard. However, there is indication they can be carried by wind or by birds and insects.

Damage

Blister mites attack both foliage and fruit, producing small galls or blisters. Blisters are green or red at first but turn light brown to black as affected tissue dies. Blisters vary in size, with the largest about ⅛ inch (3 mm) in diameter (*Figure 161*). Mites do not live in the blisters on fruit, but the fruit will be scarred (*Figure 162*). Severe infestations can deform apples. Damage to pears is less serious but scarring can make the fruit unmarketable. Severe damage to foliage can cause leaf drop and reduce shoot growth.

Monitoring

A way to detect infestations before they reach damaging densities is to examine shoots in the tops of the trees after harvest using a 20- to 30-power lens to look for mites near or within dormant buds. However, this is time consuming and blister mites are easier to detect on foliage during the growing season.

Check trees before bloom when infested young leaves will have noticeable light green to light red rough areas where mites have been feeding. These will be visible before leaves are completely unrolled. Infestations are even easier to detect later when blisters are clearly visible on fully developed leaves.

Biological control

Blister mites are not normally controlled by natural enemies. The predatory mite, *Typhlodromus occidentalis*, which can control spider mites on apples and pears, will also feed on blister mites when they are exposed. However, it cannot get into blisters.

Management

Orchards under good integrated pest management usually are not infested with blister mites. Blister mites often attacks trees in abandoned or neglected orchards.

Blister mites have not developed resistance to pesticides, as spider mites have, and many effective chemicals are available. When treatment is necessary, choose a pesticide that is compatible with your pest management program. The best timing for chemical controls is after harvest when the mites migrate from leaf blisters to terminal and fruit buds. They are exposed in those sites until buds swell in the spring. Pre-bloom treatments can prevent fruit damage that occurs just before and during bloom.

Summer pesticide applications that have a fuming action or are systemic can give some control but are too late to prevent fruit damage. To evaluate the efficacy of sprays, check blisters for mite survival.

Eriophyes inaequalis Wilson & Oldfield

(Acari: Eriophyidae)

This mite is believed to be the sole vector of the cherry mottle leaf pathogen. It has been found in British Columbia, Washington, Oregon, Montana, Nevada and California.

Hosts

Its only known natural host is the wild bitter cherry *Prunus emarginata*. Cherry mottle leaf often occurs in sweet cherry orchards in canyon areas where bitter cherry grows wild. The mite has never been found on sweet cherry but, in experiments, mites collected from bitter cherry have transmitted the cherry mottle leaf pathogen directly to sweet cherry and peach. It is possible that it moves from bitter cherry to nearby sweet cherry trees, perhaps carried by the wind, and feeds on the cultivated trees long enough to transmit the cherry mottle leaf pathogen. It is not known how long it can survive on sweet cherries. It does not infest choke cherry.

Life stages

Egg: The egg is white and spherical.
Immatures: The two nymphal stages look similar to the adult, but are smaller.
Adult: The adult mite has an elongated body with two pairs of legs at the front.

Life history

The mites live in the buds of bitter cherry and move to new buds as they develop during the growing season. Populations in a single bud may surpass 1,000. Such populations cause buds to swell tremendously and turn red. Infested buds never grow. The mites breed continuously as temperatures permit and overwinter as adults inside the buds.

Monitoring

As *Eriophyes inaequalis* is extremely small, the best way to check for infestations is to look for swollen buds.

Biological control

The mite has no known natural enemies. It is protected inside the buds from most potential biological control agents.

Management

Remove bitter cherry trees near the orchard and take out orchard trees that are infected with cherry mottle leaf.

Figure 163: Overwintering eggs are inserted just beneath the bark, producing crescent-shaped swellings.

Figure 164: In fifth instar nymphs wings can be distinguished in the wing pads.

Figure 165: The white apple leafhopper adult is about ⅛ inch long.

LEAFHOPPERS

White apple leafhopper

Typhlocyba pomaria McAtee

(Homoptera: Cicadellidae)

The white apple leafhopper is the most common leafhopper found on apple in the Pacific Northwest. Until it became a pest of significance in Washington in the mid-1970s, specific control measures were rarely needed. Resistance to organophosphates is the most likely cause of increased populations. White apple leafhopper is native to north America, and occurs throughout the fruit growing areas of the United States and Canada, but its pest status varies from region to region.

Hosts

The white apple leafhopper attacks apple, cherry and prune, but has also been found on peach and hawthorn. It does not usually damage pear, although the rose leafhopper has been noted in sizeable numbers on this crop.

Life stages

Egg: The egg is oblong and about 1/25 inch (1 mm) in length. The opaque embryo can be seen inside the developing egg. Overwintering eggs are inserted just beneath the bark of the host tree on 1- to 5-year-old wood, producing a crescent-shaped swelling in the bark (*Figure 163*). Eggs of the summer generation are inserted into leaf tissues, and cannot be seen.

Nymph: The nymph is usually a translucent white color, although it occasionally can be bright yellow. It has thread-like antennae and, in the early instars, red eyes. The nymph grows from about 1/30 inch (0.8 mm) in the first instar to 1/10 inch (2.7 mm) in the fifth instar. The first two instars have no visible wingpad development, but wingpads become apparent in the last three instars. In the fifth instar, both pairs of wings can be distinguished in the wingpads (*Figure 164*).

Adult: The adults is ⅛ inch (3.4 mm) long, elongate, and pale yellowish-white (*Figure 165*). The wings are held rooflike over the body.

Life history

The overwintering eggs begin hatching at about the tight cluster stage of apple development (late March to mid-April), with peak hatch during or after bloom. There are five nymphal instars. It takes about about 27 days for nymphs of the first generation to develop and 23 days for second-generation nymphs (*Figure 166*). Adults begin to fly in late May, and can be observed almost continuously from then until frost, although there are distinct peaks for the two generations (*Figure 167*). The first peak, in June, is typically much smaller than the second. After a 14-day preoviposition period, the adults mate, and the females deposit their eggs in the leaf tissue of the host tree, usually in the petiole, midrib or one of the larger veins. Adults live for several months. A females lays about 60 eggs over a long period. Second generation nymphs appear in mid- to late July. This generation is quite drawn out, with all stages of nymphs and adults overlapping. Small nymphs, from late-hatching eggs, can be found through harvest. Second-generation adult activity increases sharply in late August, and peaks from mid- to late September. Overwintering eggs are deposited during this period. Adults remain active until killed by a hard frost.

Damage

White apple leafhoppers have piercing-sucking mouthparts, and cause damage to leaves by piercing mesophyll cells and removing their contents. The resulting damage appears as a white or yellowish-white stippling of the leaves (*Figure 168*). Leafhopper damage may superficially resemble mite feeding, but the individual spots are usually larger and there is no bronzing. Damage can be so extensive that injured leaves appear nearly white. Spur leaves in particular can be heavily damaged. Initially, feeding tends to be concentrated near the midrib, then eventually covers most of the interveinal spaces of the leaf blade. Leafhoppers generally prefer more mature leaves and will not infest shoots tips until the leaves have hardened off. Both nymphs and adults feed on leaves, but most damage is probably done by the nymphs.

Like other types of foliar damage, that caused by leafhoppers may reduce leaf photosynthesis, which in turn can affect the tree's ability to set, size or

White Apple Leafhopper Development

Development time, in days, at constant temperature in a growth chamber:

°F	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total
55	11.5	8.2	8.7	9.5	17.4	55.3
66	5.3	4.2	4.3	4.4	7.5	25.7
73	4.2	3.0	3.1	3.1	4.2	17.6
81	3.1	2.5	2.9	2.8	3.5	14.8
86	3.6	2.7	2.8	3.1	4.7	16.9

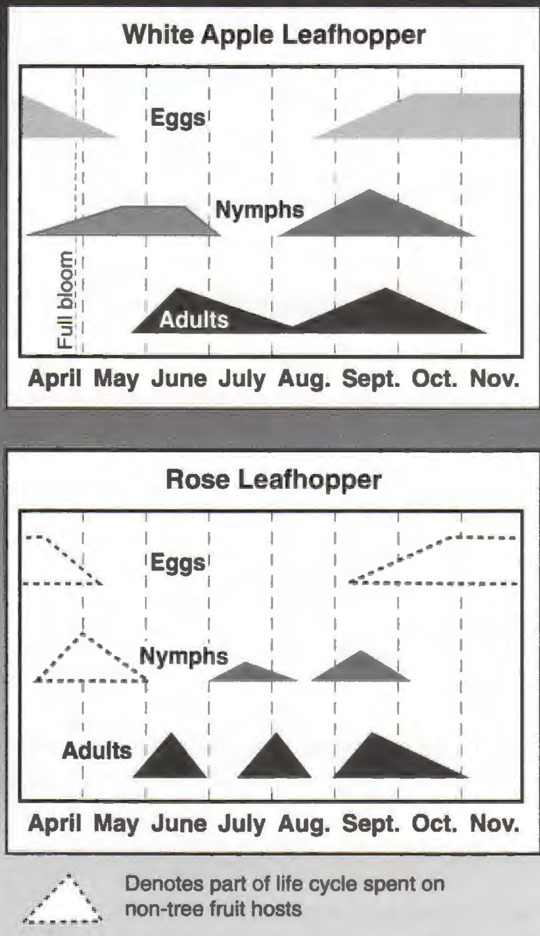
Development time, in days, at fluctuating ambient temperature:

	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total
May	4.0	8.5	5.2	3.8	5.2	26.7
August	4.0	3.0	4.8	4.2	6.6	22.6

Based on observations in Wenatchee, Washington.

Figure 166

Leafhopper Life Histories



White apple leafhopper nymphs begin to hatch at about the tight cluster stage of apple development. Adults fly almost continuously from May until frost, although there are distinct peaks for the two generations.

The rose leafhopper has three generations a year. It overwinters in the egg stage on roses. First generation nymphs are confined to the overwintering host. Second and third generations are produced either on rose or on tree fruit hosts. Timings are based on observations in northcentral Washington.

Figure 167

mature a crop of fruit. However, no effect on fruit size or fruit quality has been found under Washington conditions, even when extremely high leafhopper populations were present. In addition, no reduction in return bloom or set was noted following a single season of heavy damage with a peak of 3 nymphs per leaf, although only one cultivar, Oregon Spur Red Delicious, has been studied. It is assumed that multiple seasons' damage could eventually deplete the tree's reserves, making effects of feeding damage more apparent, but this has not been studied. As with other indirect pest damage, factors such as tree vigor, tree age, drought stress, and damage by multiple pests could exacerbate the effect of leafhopper damage.

A second type of damage is the droplets of excrement, known as tar spots, which the leafhoppers deposit on leaves and fruit. Spotting of the leaves has never been considered important, but spotting of fruit is occasionally a concern. Informal tests indicate that tar spots are removed during the normal washing and brushing that precedes commercial packing of fruit, with the exception perhaps of the stem cavity, where brushes do not reach. However, spotting in the stem cavity is not very conspicuous (especially on darker skinned cultivars) and has not been reported to cause downgrading of fruit.

A third concern with leafhoppers has to do with the annoyance of fruit harvesters by high populations of adults. The harvest season for several of the major fruit varieties falls within the peak adult flight of the second generation. Adult leafhoppers jump and fly when disturbed, and often get in the eyes, ears, nose, and mouth of people working close to the trees. When populations are high, the clicking of thousands of leafhoppers taking off is clearly audible.

Monitoring

All stages except the eggs of leafhoppers are easily monitored. Nymphs may be monitored by examining the leaves. Counting the nymphs on 20 leaves of 10 randomly selected trees per block should give an adequate assessment of leafhopper populations. Nymphs are normally concentrated on undersides of leaves, but both sides of the leaf should be examined. When the leaf is turned over to make the count, nymphs will tend to move to the other side,

Figure 168: Leaves damaged by white apple leafhopper have white or yellowish white stippling.

out of the sun, so counts should be done as rapidly as possible.

Nymphs may be counted at any time from tight cluster to frost, but typically sampling is done when a control decision must be made, which is at about petal fall for first-generation nymphs, and again in mid-August for second-generation nymphs. Sampling when most of the leafhoppers are in the adult stage will tend to underestimate the population.

Adults may be monitored with a sticky trap, such as a yellow panel of the type used for cherry fruit fly. The unbaited version of this trap is preferable, since it is less attractive to flies of all types. Adults can also be caught on traps of various other colors, but yellow is one of the most attractive colors. Although useful in following population trends, adult monitoring will probably not play an important role in management decisions.

Overwintering eggs are more difficult to sample than active stages, but this can be done at any time from late October until eggs begin to hatch the following spring. A standard method is to take 4 inches (10 cm) of the current season's growth from the bud scar toward the tip. Although eggs are laid in older wood, they become progressively more difficult to see as the wood gets rougher. Also, the scars of eggs from previous seasons can be mistaken for viable eggs on older wood, a problem which does not occur on the new growth. Sampling eggs may be useful in determining levels of parasitism, but is unnecessarily laborious for management decisions. Nymphs may be sampled much more easily with enough lead time to apply control measures.

Biological control

The primary biological control agent of leafhoppers in the Pacific Northwest is an egg parasitoid, *Anagrus* sp. (probably *A. epos*), a mymarid wasp (see section on *Anagrus* in Part IV). It attacks both overwintering and summer eggs of white apple leafhopper. In overwintering eggs, parasitism levels of up to 25% have been found in the Wenatchee area. The level of parasitism appears to be generally related to the intensity of pesticide use (primarily that for codling moth) the previous season, but no single application timing or material has been identified. Research in Michigan indicates that more than 90% of the overwintering generation of eggs can be parasitized in unsprayed orchards, so broad-spectrum pesticides undoubtedly suppress parasitoid populations. Levels of parasitism found in conventionally managed orchards are generally too low to prevent substantial populations from developing. *Anagrus* could potentially play a role in biological control of leafhoppers if broad-spectrum chemicals are reduced or removed from the spray program.

A second parasitoid is a wasp in the family Dryinidae (probably *Aphelopus* sp.), which is a parasitoid of both nymphs and adults. It develops internally in leafhopper nymphs, then appears on the adults as a pouch on the abdomen. This parasitoid has been collected from cherry and apple orchards in the mid-Columbia area of Oregon, although it may be much more widely distributed. While substantial rates of parasitism have been reported, the potential of this parasitoid species as a biological control agent is unknown. Despite extensive examination of leafhoppers in Washington, this parasitoid species has not been found.

Management

Because leafhoppers are indirect pests, they should only be controlled when necessary. It is difficult to set treatment thresholds for white apple leafhopper since no fruit size, fruit quality, or return bloom reduction due to leafhopper damage has been observed. Other factors must be taken into account when deciding whether control is needed. Since the major form of biological control occurs during

Disparity in Control Timing for White Apple Leafhopper and Codling Moth

Year	Full bloom	Codling moth model timing	10% leafhoppers 4th and 5th instars	Difference, in days
1986	April 25	May 29	May 17	12
1987	April 23	May 10	May 11	-1
1988	April 19	May 20	May 5	15
1989	April 25	May 23	May 10	13

Optimum timing for leafhopper control is when about 10% of the leafhoppers are in the fourth or fiftrh instars, and the rest still in the first, second and third instars. The first cover spray, applied at the standard codling moth timing, will reduce leafhopper populations to some extent but is generally too late for optimum control. Observations above were made in Wenatchee.

Figure 169

the egg stage, this mortality is already accounted for when nymphal populations are assessed. If the trees are very young excessive damage to the relatively small leaf canopy could retard growth. In vigorous, mature trees with a high leaf-to-fruit ratio, moderate to heavy leafhopper damage will probably have little effect. Similarly, if the crop is very light, more foliar damage can probably be tolerated than if the crop load is heavy. The potential for drought because of light soils, inadequate irrigation schedules, or extremely hot, dry weather could also serve as a reason to consider controlling leafhoppers or other indirect pests. If substantial foliar damage by mites or leafminers has already been incurred, further damage by leafhoppers should probably be avoided.

White apple leafhoppers appear to have some resistance to the organophosphate insecticides commonly used in orchards. Tests at Wenatchee have shown up to 75% reduction of nymphal populations, depending on the material. Although most orchardists have come to expect much higher levels of control, this may be adequate to keep populations at a tolerable level. There also is some evidence of resistance to organochlorine insecticides, which varies from region to region, but carbamate insecticides still appear to be very effective in most areas. Insecticidal soaps, which are relatively new products in commercial orchards, are moderately effective against leafhoppers, and may be a tool for resistance management. In addition, these materials should have minimal impact on beneficials because of their short residual activity. The development of resistance to organophosphate insecticides indicates that resistance management should be of concern in the future.

Optimum timing for control of the first generation is when most of the overwintering eggs have hatched, but before the majority of the nymphs are in the last two instars, when they are harder to kill. A somewhat arbitrary target timing for this point in the leafhopper's phenology is when about 10% of the population in the fourth and fifth instars, with 90% still in the first, second, and third instars. This is usually at or slightly after petal fall. The first cover spray, applied at the standard codling moth timing, will also reduce leafhopper populations somewhat, as will carbaryl when used as a fruit thinning material. In general, however, first-cover timing is too late for optimum leafhopper control (*Figure 169*).

Control of the first generation is generally easier to achieve than control of the second generation, since the most susceptible stages are present at a specific period, and sprays can be targeted more precisely. An exception to the strategy outlined above is the use of insecticidal soaps.These materials appear to kill all nymphal instars equally well. Their residual activity is very short (probably only direct spray contact is effective), so egg hatch should be complete before application. For these reasons, timing will be slightly later than for conventional insecticides. Control of first generation nymphs with soap has been fairly successful, but control of the second generation has not.

Second generation white apple leafhopper populations can greatly exceed the first, often surprising producers and consultants by the size of a late-season infestation. Adults are quite mobile and during the first generation flight they can move into and rapidly reinfest a block that was treated for first generation nymphs. If a clean orchard is surrounded by infested ones, then second generation nymphs should be sampled. Because of a prolonged egg hatch in the second generation, multiple stages occur at any one time, making control of this generation less likely to be satisfactory than that of the first generation. However, if picker annoyance reduction is the primary concern, then it may be more appropriate to control this generation. Insecticide applications should be made before adult populations begin to rise sharply, which usually occurs in mid-to late August.

As leafhoppers occur largely on the undersides of the leaves and are well distributed throughout the canopy, spray coverage should be thorough to get adequate control. Limited tests using aerial applications have shown this method to be considerably less satisfactory than ground application. No information is available on the effect of concentrate versus dilute sprays although, assuming good coverage, both methods should be adequate.

Rose leafhopper

Edwardsiana rosae (Linnaeus)

(Homoptera: Cicadellidae)

The rose leafhopper is the second most common species of leafhopper on apple, and has also been found on pear. Because it is similar in appearance, feeding habits, and life cycle to white apple leafhopper, they have often been mistaken for each other. It can occur in mixed populations with white apple leaf hopper, or as the dominant species.

Hosts

The rose leafhopper appears to overwinter only on rose (woody plants in the genus *Rosa*), but can use other plants as hosts during summer generations. Tree fruit hosts include apple, pear, plum, and cherry.

Life stages

All life stages look similar to white apple leafhopper, but the two species can be distinguished in several stages. Rose leafhopper nymphs have rows of dark spots at the bases of strong setae, on the back of the thorax, including the wingpads. The spots are less distinct in the early instars, but are clearly visible in the older nymphs (*Figure 170*). Adult rose leafhoppers are the same size and color as white apple leafhoppers, but both males and females can be distinguished by differences in their genitalia (*Figure 171*). However, identification of females is difficult.

Figure 170: Rose leafhopper nymphs can be distinguished by their spots.

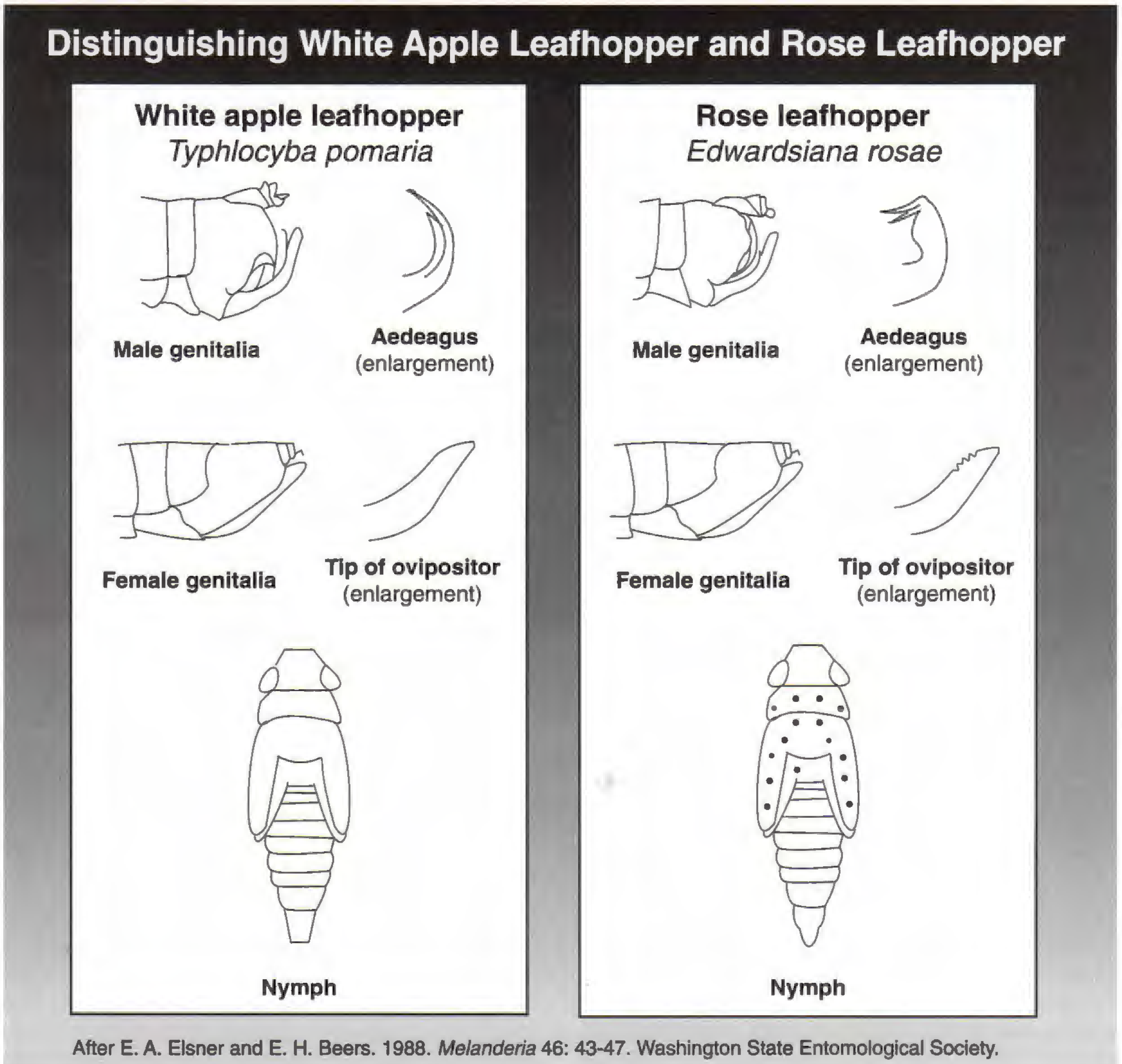


Figure 171

Life history

Unlike white apple leafhopper, which has two generations per year, rose leafhopper has three (*Figure 167*). This species overwinters in the egg stage on the stems of roses, which cause the same crescent-shaped swelling as white apple leafhopper. Eggs begin to hatch in early to mid-April, and nymphs are present until early June. First-generation nymphs are confined to the overwintering host. Adults of this generation are active from late May through late June. Second and third generations are produced either on rose or one of the tree fruit hosts. Second generation nymphs occur during July, with adults active from mid-July through mid-August. Third generation nymphs occur from late August through September and adults are active from early September through frost.

Damage, monitoring and natural enemies are the same as for white apple leafhopper. While little research information is available it appears insecticides used against white apple leafhopper will also be effective against rose leafhopper.

APHIDS ON POME FRUITS

(Homoptera: Aphididae)

Apple aphid

Aphis pomi De Geer

Spirea aphid

Aphis spireacola Patch
(= *Aphis citricola* van de Groot)

The apple aphid (often called the green apple aphid) is considered to be the most widespread aphid pest of apple around the world. Recently, entomologists have reported that a nearly identical aphid, the spirea aphid, has become more numerous than apple aphid on apple in Virginia, West Virginia and Maryland. The spirea aphid is the dominant aphid species on apple in Israel and China and is found more often than green apple aphid in some Washington State orchards. Because these two aphids are virtually impossible to separate in the field and little research has been conducted on the spirea aphid as a pest of apple, the biology, behavior, economic impact and management of these two species will be treated together in this section.

Hosts

The apple aphid can occasionally colonize pear and hawthorn, but its primary host is apple.

Life stages

Egg: The egg is shiny, black and roughly the shape of a rice grain but only about 1/50 inch (0.5 mm) long (*Figure 172*). It cannot be distinguished from the egg of two other species, rosy apple aphid and woolly apple aphid, that overwinter on apple.

Nymph: The nymph is yellowish green to dark green, about 1/16 inch (1.5 mm) long.

Adult: The wingless adult green apple or spirea aphid is bright green with black cornicles, legs and antennal tips (*Figure 173*). The winged adult has a black head and thorax with a yellow-green abdomen (*Figure 174*). Both winged and wingless forms are about 1/8 inch (3 mm) long.

Figure 173: The wingless apple aphid is green with black cornicles, legs and antennal tips.

Figure 172: Apple aphid eggs are black and the shape of a grain of rice, but only 1/50 inch long.

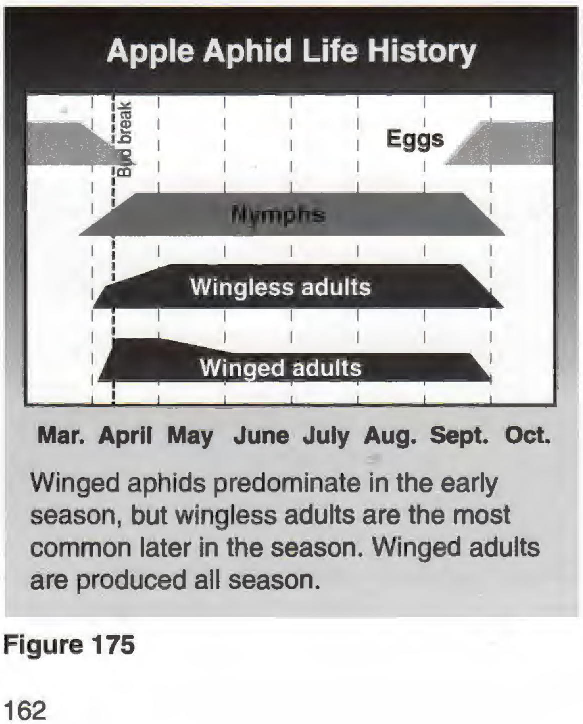
Figure 174: The winged adult has a black head and thorax, and a yellowish green abdomen.

Life history

Apple and spirea aphids overwinter as eggs laid on smooth twigs and watersprouts. Egg hatch begins about silver tip stage of bud development and is generally complete about the half-inch green stage. All the young are females, known as "stem mothers," which produce both winged and wingless female offspring. The winged forms predominate during this generation and although winged forms are produced almost continuously, wingless forms predominate through the rest of the season. The nymphs feed for 10 to 20 days (depending on temperature) before they become adults.

Through most of the season female aphids are produced parthenogenetically (without fertilization) from eggs held internally. Starting in August and throughout the autumn months, they are found almost exclusively on watersprouts or terminals of young trees that are still growing. Both male and female sexual forms are produced at this time of year.

These late-season sexual forms mate to produce the overwintering eggs. At least 9 generations have been reported on apple each year and up to 17 in warmer west coast locations (*Figure 175*). The ability of these insects to produce live young partially accounts for the rapid buildup of aphid populations. Unlike some aphid species, green apple aphid spends its entire life cycle on apple.



Winged aphids predominate in the early season, but wingless adults are the most common later in the season. Winged adults are produced all season.

Figure 175

Figure 176: When honeydew produced by aphids drips onto the fruit it is often colonized by a sooty fungus, which causes russeted areas, especially around the stem.

Damage

Both nymphs and adults suck phloem from their hosts, and prefer to feed on succulent, young tissue. Aphids may be found feeding on the undersides of leaves, on growing shoot tips or the shoot stem. When populations are high, the upper leaf surface will also be colonized. High populations early in the year may also feed directly on developing fruits, causing small bumps and red spots to appear at the feeding sites. Aphids feeding on fruit of Golden Delicious and Granny Smith later in the season can result in small circular red spots. These disappear by harvest.

The most important damage from these aphids is generally caused by the presence of copious amounts of honeydew excreted by the aphids. This honeydew is extremely annoying to harvesting crews. When honeydew drips onto the fruit (*Figure 176*), it is often colonized by a black, sooty fungus, *Fumago vagaus* Fries, which causes russeted areas on the fruit, especially around the stem. Although mechanical washing done in commercial packing lines removes most of the sooty mold from the fruit surface, some is left in the stem cavity. The black sooty mold is especially apparent on light colored cultivars like Golden Delicious.

Shoot growth can be stunted on young trees, but in older Red Delicious orchards there is generally no effect on growth, yield or fruit quality. Golden Delicious trees may be more susceptible to shoot growth reduction, but this is unlikely to have economic consequences on a large, mature tree.

Biological control

A number of natural enemies attack aphids. The most important predators are lady beetles, syrphid fly larvae, green lacewings and the predatory bug *Deraeocoris brevis* (see Natural Enemies and Pollinator, Part IV). Biological control may be disrupted by pesticide applications or weakened by poor synchrony between the development of aphid populations and their predators during June. Two species of parasitic wasps, *Lysiphlebus testaceipes* (Cresson) and *Praon* sp., attack apple aphid primarily early in the season, but neither species completes its development on apple aphid, so their potential usefulness in an IPM program may be limited. There appears to be a strong relationship between the availability and effectiveness of the parasites and the presence of other aphid hosts outside the orchard.

More research is required to understand this relationship. Success of the parasites and predators may depend more on seasonal factors, shoot growth patterns and cultural practices that slow aphid population growth rates without limiting the natural enemies. Environmental factors and cultural practices that encourage shoot growth will also create the potential for more severe apple aphid problems.

Monitoring

Begin monitoring for apple aphids and spirea aphids in late May to early June when shoot leaves are rapidly expanding. Most sampling schemes recommend sampling growing shoots and/or shoot leaves and are aimed at estimating when aphid infestations will reach a density that will result in honeydew related fruit russet.

However, many factors can influence the amount of potential damage, including tree structure, tree age, time of year, tree nutritional status and variety. Past recommendations were to sample and treat when 50% of the terminals were infested. This has resulted in overtreatment and the treatment threshold has since been raised to 75% of the terminals infested.

Recent research in both Washington and Pennsylvania suggests that the number of infested leaves per shoot is a better indicator of potential damage than just percentage infested shoots. In Washington 4 to 5 infested leaves per infested shoot signals a problem, which means that a population resulting in 2 to 3 infested leaves per randomly chosen shoot should be treated.

Pennsylvania research suggests an average of 1 to 3 infested leaves per randomly selected shoot would exceed the treatment threshold. Based on the Pennsylvania research, sampling 20 shoots from each of 5 trees, 10 shoots from each of 7 trees, 5 shoots from each of 10 trees, or 2 shoots from each of 20 trees would all give accurate estimates of aphid densities. The location of the infestation is critical. For example, thresholds would be lower if the infestations are on spur shoots rather than on terminal shoots. Young, non-bearing trees should probably be treated at lower infestation levels to insure proper growth.

Management

Delayed-dormant sprays targeting several insect and mite pests are still the first step in controlling apple aphid populations. Summer control of aphid populations that exceed the treatment threshold is still most quickly achieved by insecticides. However, the supply of insecticides effective against aphids is dwindling because of resistance and withdrawal of materials due to re-registration requirements.

Non-insecticidal approaches to tree fruit IPM, such as mating disruption, may help reduce the need for insecticide-based management of apple aphid. Reduced reliance on insecticides for control of other pests will help create a favorable environment for natural enemies and improve the efficacy of biological controls. Growers should pay closer attention to nitrogen fertility and water management to reduce shoot growth and set terminal buds early in the growing season.

Rosy apple aphid

Dysaphis plantaginea Passerini

Rosy apple aphid, introduced into the United States about 1870, is usually well controlled under conventional management programs, but can be severe in certain years or locations. In those years, rosy apple aphid is the most severe aphid pest, as its feeding causes small, deformed fruit and leaf curling. Curled leaves provide refuge for subsequent generations, making control difficult. Early recognition of a potential rosy apple aphid problem is necessary to obtain control.

Hosts

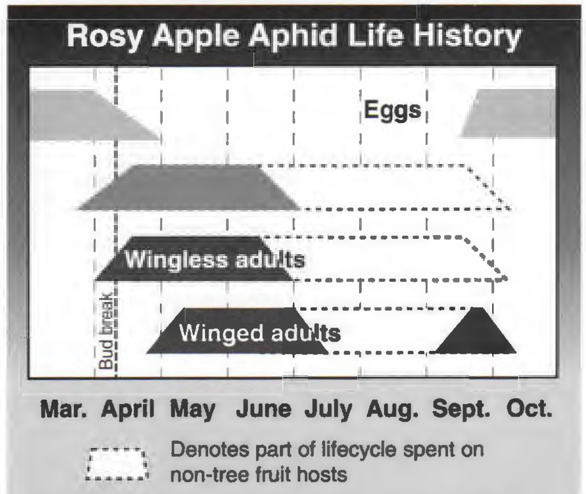
In the spring, the rosy apple aphid feeds on apple leaves and fruit. In summer, it moves to alternate herbaceous hosts, such as narrow-leafed plantain and dock. Rosy apple aphid will attack all apple varieties, but Golden Delicious and Rome Beauty are among the more susceptible to fruit deformation. Although it prefers apple, it also feeds on pear.

Life stages

Egg: The oval egg is pale green when first laid and turns shiny black. It is difficult to distinguish from the eggs of the apple grain aphid and apple aphid.

Nymph: The young rosy apple aphid passes through five nymphal instars. The nymph is rosy brown or purple with a powdery white covering.

Figure 177: The rosy apple aphid nymph has a pair of long cornicles, whereas the apple aphid has short cornicles.



Several generations are produced in the spring and early summer. Winged adults migrate to weed hosts in the summer. By late June or early July most rosy apple aphids have left apple trees. Winged adults fly back to apple in the fall to mate and produce overwintering eggs.

Figure 178

Its color and long cornicles, or protuberances, distinguish it from the apple aphid, which has short cornicles (*Figure 177*).

Adult: The winged adult, which migrates from host to host, is brownish-green to black, and about $\frac{1}{12}$ to $\frac{1}{8}$ inch (2 to 3 mm) long.

Life history

Rosy apple aphid overwinters as eggs on the bark of twigs and branches of apple trees. Eggs hatch in early spring as buds open (*Figure 178*). The eggs produce only female aphids. Nymphs feed on expanding buds, then move to the leaves of developing fruit clusters and become reproductive adults known as "stem mothers," during bloom. As soon as the blossom cluster begins to separate, the aphids work their way down among the clusters and are hard to see until petal fall. Young leaves are colonized as they unfold. Mature stem mothers give birth to live nymphs without mating. Second generation adults appear 2 to 3 weeks after petal fall. A few of these have wings. Several generations are produced in the spring and early summer. Each

Figure 179: Feeding by rosy apple aphid curls leaves and deforms shoots.

Figure 180: Toxic saliva injected into the tree as the aphid feeds can stunt and distort fruit.

succeeding generation has a higher percentage of winged forms. Winged adults migrate to summer weed hosts in the summer. By late June or early July most rosy apple aphids have left apple trees. Winged adults produce wingless asexual forms on weed hosts until early fall when winged adults are produced. These fly back to apple and give birth to egg-laying females. Males, which develop a little later, return to apple and mate with the females which lay overwintering eggs.

Damage

Feeding by rosy apple aphid causes leaves to curl and deforms shoots (*Figure 179*). Toxic saliva injected into the tree as the aphid feeds on the leaves of fruit clusters stunts and distorts fruit growth resulting in small, misshapen apples (*Figure 180*). Root growth and photosynthesis are also reduced. Damage can be most severe on young trees where shoots can be distorted so badly that tree shape is permanently altered. Feeding aphids produce honeydew which drips onto the foliage or fruit. A sooty mold, ***Fumago vagaus*** Fries, can grow in the honeydew.

Monitoring

Monitoring for rosy apple aphid is impossible until after egg hatch begins, since the eggs of apple grain aphid and apple aphid are identical to rosy apple aphid eggs. Following a standard delayed-dormant oil/organophosphate application, the Pennsylvania State University recommends monitoring at the early pink stage by examining 10 to 20 trees per block. It is essential to examine leaves and clusters carefully at this time, as it is difficult to detect the few aphids present. If an average of 1 to 2 infested clusters per tree is found, then a systemic insecticide effective against aphids should be applied at the pink stage of bud development. Samples should be taken from the upper parts of the canopy on the inside of the tree where rosy apple aphid colonies are most common.

Biological control

A large number of generalist predators and parasites help control rosy apple aphid but in many orchards substantial damage occurs before natural enemies become numerous enough to suppress aphid populations.

Management

Because rosy apple aphid is a sporadic pest in the Pacific Northwest and because of the difficulty of distinguishing its eggs from those of other species, it has been a challenge to study early season populations. According to research in Pennsylvania, egg hatch began when the first green bud tips appeared on Golden Delicious and was virtually complete by the half-inch green stage. Delayed-dormant sprays (half-inch green tip) may coincide with the end of rosy apple aphid egg hatch. It is not known if this pattern holds true in the Pacific Northwest, but every effort should be made to avoid treating too early.

Follow-up control treatments should be made from pre-pink to pink if sampling indicates a need.

Use an average of 1 to 2 infested clusters per tree sampling 10 to 20 trees per block as a guide in determining the need for a follow-up treatment. As the season advances and the leaves become tightly curled it becomes progressively more difficult to control this pest.

Apple grain aphid

Rhopalosiphum fitchii (Sanderson)

The apple grain aphid is the most conspicuous aphid in apple orchards in the early season. It appears at the green tip stage before eggs of other aphids have hatched. Though it can be alarming to see buds completely covered with the dark green aphids, they do little damage to apples. In fact, their presence encourages aphid predators to build up early in the spring, increasing the potential for natural control of other aphids that appear later. Its early appearance, its location on the buds, and the dark green stripe on its body help distinguish the apple grain aphid from other aphids found on apples.

Hosts

The apple grain aphid prefers apple as an overwintering site, but also overwinters on pear, hawthorn, plum and quince. Grasses and grains are preferred summer hosts.

Life stages

Egg: The egg is small, oval and shiny. Though dark green, it cannot easily be distinguished from other aphid species' eggs. Eggs are laid on small branches, fruit spurs and terminals.

Nymph: The newly hatched nymph is dark green at first but turns lighter green. It has short cornicles or protuberances at the end of its abdomen.

Adult: The older nymph and adult is light green with a darker green stripe down the middle of the back and crossbars of the same color (*Figure 181*).

Life history

The apple grain aphid overwinters as an egg near buds or on terminals, fruit spurs or larger branches. During the pruning season, eggs are often found by the hundreds. Eggs begin to hatch in spring when apple buds show the first green tissue (*Figure 182*). Nymphs feed on opening leaves, usually on spurs rather than watersprouts or terminals. Newly hatched aphids can be killed by unusually cold spring temperatures.

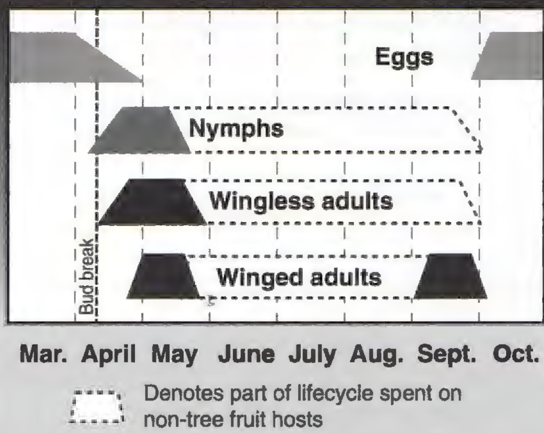
Figure 181: The older nymph and adult is light green with a darker stripe down the middle of the back.

The nymphs mature into wingless females that produce young without fertilization. One female can produce 100 offspring. Most second generation apple grain aphids have wings and migrate to summer hosts such as grain crops and grasses. The second generation aphids without wings produce a third generation. Those adults all have wings and begin to migrate from the apple trees about petal fall. By the end of May, what appeared to be a serious aphid problem will have vanished. The aphids produce several more generations on the summer hosts. Winged females return to apple trees in the fall. Males migrate back to the orchard in late fall and mate with the females, which lay overwintering eggs on apple twigs.

Damage

Although the bulk of aphid eggs found on the tree may be apple grain aphid and nymphs can completely cover opening buds, its feeding does not

Apple Grain Aphid Life History



Some second generation adults and all third generation adults have wings. They migrate from apple trees to summer hosts such as grain crops and grasses. By the end of May, what appeared to be a serious aphid problem will have vanished. Winged adults return to apple trees in the fall to mate and lay overwintering eggs.

Figure 182

damage the buds. When aphid numbers are high leaves may curl slightly. Occasionally large numbers of aphids may move to young fruit to feed, which can cause bumpy, distorted fruit.

Biological control

Little is known about biological control of this aphid except that it is a food source for many of the generalist predators and parasites that feed on other aphid species colonizing apple.

Management

The apple grain aphid usually does not need to be controlled. Its presence can be beneficial, as it may encourage aphid predators and parasites to build up in early spring, increasing chances of natural control of pest aphids appearing later.

Woolly apple aphid

Eriosoma lanigerum (Hausman)

This aphid, native to North America, was identified in the United States in 1842. It is now distributed throughout the apple growing regions of the world where its importance as a pest varies. The woolly apple aphid may occur on the above-ground portions or roots of the apple tree. Aphid forms inhabiting above-ground parts of the apple tree are most common in mid- to late summer and are usually detected in colonies on old pruning wounds and scars or at the base of buds on actively growing terminals and watersprouts. The aphids are covered with long white waxy filaments which give the colony a woolly appearance.

Hosts

The woolly apple aphid's most common host in the western United States is apple. It has also been discovered on pear, hawthorn, mountain ash and cotoneaster.

Life stages

Egg: The egg stage is not known to occur in Pacific Northwest orchards.

Nymph: The nymph is similar to the adult, but smaller.

Adult: The adult is reddish-brown to purple. The actual color, however, is usually concealed beneath a white, cotton-like substance secreted from the aphid's abdomen (*Figure 183*). This characteristic makes the aphid easy to identify.

Figure 183: The adult's purple or brown coloring is concealed beneath a white, cottony substance secreted from the aphid's abdomen.

Life history

Woolly apple aphid overwinters as a nymph on the roots of apple. It can also overwinter as a young nymph on the above-ground part of the tree in protected areas on the trunk or main limbs. In severe winters above-ground colonies may be killed.

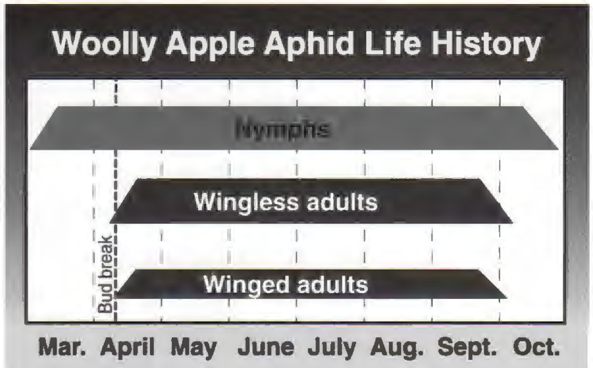
As temperatures warm in the spring, overwintering aphids produce live young that migrate up and down the tree (*Figure 184*). Nymphs on the roots move upward to provide a source of infestation if above-ground colonies do not survive the winter. Preferred feeding sites during the summer are leaf axils on terminal shoots. When populations are high, most leaves on a terminal will have a cottony mass at the base.

It is unclear whether winged adults are produced in the woolly apple aphid life cycle in the Pacific Northwest. British Columbia work indicates no winged adults are produced, but a 1966 USDA publication indicates the presence of winged adults. Research in Washington indicates that winged adults are present but relatively unimportant in the spread of this pest.

Damage

Galls, or swollen enlargements, form on the plant where aphid colonies feed on twigs or roots. These are not very noticeable after one year of feeding but increase in size as feeding continues in an area. Subterranean aphid colonies cause the most damage. Roots of infested trees have large, abnormal swellings (*Figure 185*). Continued feeding can kill roots and cause reduced growth or even death of young trees.

Figure 185: Roots of infested trees have large, abnormal swellings.



The woolly apple aphid's egg stage is not known to be present in Pacific Northwest orchards. The aphid passes the winter as a young nymph either on the above-ground part of the tree or on the roots.

Figure 184

The Malling-Merton series of rootstocks (e.g., MM.106 and MM.111) were developed to be resistant to woolly apple aphid, as is the Merton 793 selection, which is commonly used in the southern hemisphere.

Woolly apple aphids are attracted to sunken areas caused by the disease perennial canker. Galls caused by feeding of aphids are re-infection sites for the causal fungus of perennial canker, *Cryptosporiopsis perennans*. These galls are more sensitive to low temperatures than normal bark tissue and rupture at about 0°F or colder, providing an entry site for the fungus, continuing the perennial nature of the canker.

Honeydew produced by the woolly apple aphid can drip onto the fruit resulting in sooty mold and downgrading of fruit because of blackened or russeted areas. High populations of woolly apple aphid can create sticky and unpleasant working conditions for harvest crews. In some varieties with an open calyx, such as Hood River Pippin (Yellow Newton), woolly apple aphid can infest the core.

Monitoring

No specific monitoring procedures or treatment thresholds have been developed for woolly apple aphid. Generally, monitoring should begin in midsummer or perhaps earlier if the winter was mild. If many colonies are in the fruiting zone of the tree, treatment will probably be needed.

Biological control

The parasite *Aphelinus mali* is generally given the most credit for biological control of woolly apple aphid. Although *A. mali* may play a role, research in Washington has shown that a complex of generalist predators including lady beetles, syrphid fly larvae, *Deraeocoris brevis*, and green lacewings is more important.

Predators can destroy woolly apple aphid colonies, leaving the woolly residue but no trace of its activities. Woolly apple aphids parasitized by *A. mali* are black, persist on the tree and may have an exit hole where the parasite emerged. The persistence of these mummies has led to the conclusion that most biological control was by *A. mali*. (For more information on specific natural enemies, see Part IV.)

Management

Woolly apple aphid is not a serious pest in the Pacific Northwest. Low winter temperatures reduce overwintering populations substantially in most years, and the parasite and predator complex attacking woolly apple aphid along with insecticides used for other pests usually suppress its population below economic injury levels during the growing season. Outbreaks have been blamed on pesticide applications that disrupted biological control (particularly after a mild winter) and/or poor pesticide suppression from sprays aimed at other pests. Low populations are likely to persist on all rootstocks including the Malling-Merton series, as their resistance to woolly apple aphid infestation is not total.

STONE FRUIT APHIDS

(Homoptera: Aphididae)

Black cherry aphid

Myzus cerasi (Fabricius)

The black cherry aphid is found wherever cherries are grown throughout the United States. It infests leaves and deposits honeydew on leaves and fruit. Heavy populations can deform shoots, stunting young trees. Although not a serious pest under conventional orchard management programs, it can be a serious problem in young orchards and nurseries if populations are not properly controlled.

Hosts

The aphid prefers sweet cherry but will also attack tart cherries. On tart cherry it does not curl the leaves as it does on sweet cherries. Cherry is its winter host. In summer, it migrates to plants of the mustard family.

Life stages

Egg: The egg is small and shiny black.

Nymph: The nymph ranges in color from amber through various shades of dark brown to black

Adult: Both winged and wingless adults are shiny dark brown to black (*Figure 186*). They have a

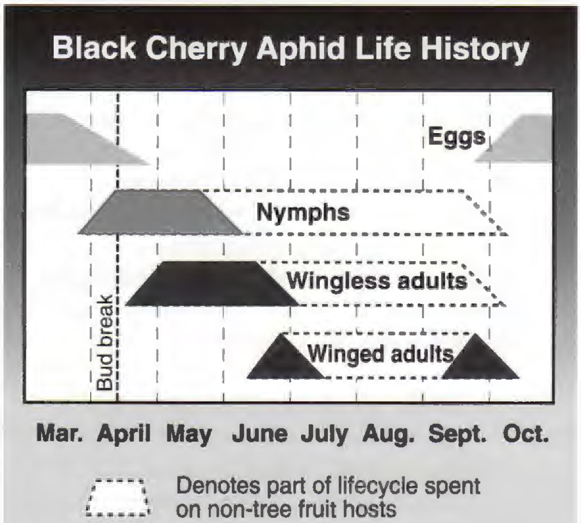
Figure 186: Both winged and wingless adults are shiny dark brown to black.

round abdomen and globular appearance. The black cherry aphid is larger than other fruit attacking aphids and is the only black colored aphid that attacks cherry.

Life history

The insect overwinters in the egg stage (*Figure 187*). Eggs are laid on the bark or buds of twigs and hatch before the buds open in late March or early April. The young aphids feed on unopened buds in the early spring. After bud break they attack the leaves. The leaves curl and protect the aphids as they continue feeding. Aphids mature within 2 or 3 weeks of hatching and begin to reproduce asexually. Two, three or more generations can be produced on cherry. The later generations often mature in less than a week. In each generation some winged adults are formed, which migrate to plants of the mustard family.

By early to midsummer few, if any, aphids remain on cherry. Succeeding generations occur on the summer host. In the fall, winged males and females fly back to the cherry where they mate and produce eggs that overwinter on the bark.



Early in the season, wingless aphids reproduce asexually. Two, three, or more generations are produced on cherries before winged aphids develop and migrate to summer hosts. Winged aphids return to cherries in the fall, where they mate and produce overwintering eggs. Timings are based on observations in Oregon.

Figure 187

Damage

Large numbers of black cherry aphids will colonize young terminal growth. Infested leaves curl severely and normal terminal growth is disrupted. In severe cases, injured leaves turn brown and die and the fruit is dwarfed. The aphids excrete large amounts of honeydew on leaves and fruit. Sooty mold can grow on the honeydew, making the fruit unmarketable. Heavy populations can distort and stunt growth of young trees and may reduce fruit set the following year on older trees.

Monitoring

It is important to monitor for black cherry aphid during and shortly after bud break. Management decisions should be made at this time, as the insect is more easily controlled when small and exposed. Once leaves curl, the aphid is more difficult to reach with insecticides.

Biological control

Lacewing larvae, lady beetles, syrphid flies, soldier beetles and predacious midges are among the predators that help keep populations of this aphid under control.

Management

Delayed-dormant applications of oil mixed with an insecticide applied to control other cherry pests will usually control the black cherry aphid. No criteria have been developed on what degree of infestation will cause significant economic loss. After the leaves curl it is difficult to achieve chemical control and sprays may disrupt predators.

Green peach aphid

Myzus persicae (Sulzer)

A native of Europe, the green peach aphid is now widely distributed across the United States and Canada. Though a common pest of stone fruits, primarily peaches, it is not usually considered a serious pest, except on nectarine. It is more destructive on vegetable crops, which are a summer host, because it is a vector of several important diseases.

Hosts

The green peach aphid attacks primarily peach and nectarine. In summer it moves to other hosts, which include a wide range of weeds and commercial vegetable crops.

Life stages

Egg: The eggs is shiny black and oval, similar to that of the apple aphid (See *Figure 172*).
Nymph: The nymph is slender and a pinkish color at first. As it develops, it becomes a yellowish-green color with three indefinite darker green stripes on the back of the abdomen (*Figure 188*).
Adult: The wingless adult resembles the nymph but is larger. The winged adult has a black head and thorax and a yellowish-green abdomen with a large dark-brown patch on the top of the abdomen.

Life history

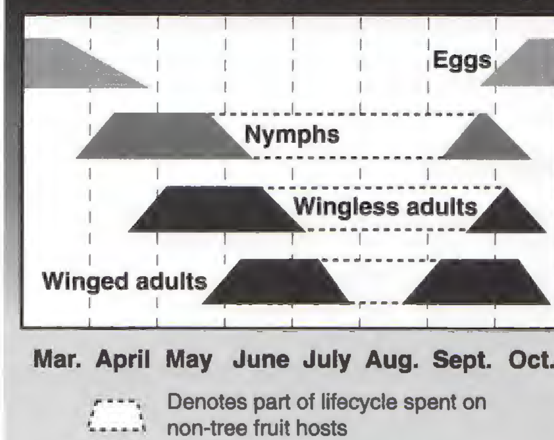
Overwintering eggs are laid in bud axils and bark crevices on twigs. They hatch just before bud break (*Figure 189*). The nymphs develop into wingless females, which produce young without mating. The aphids feed on the underside of the leaves. As the population increases, the leaves curl. After 2 or 3 generations, winged forms are produced, which migrate to summer hosts, where several generations are produced. In the fall, winged aphids return to peach and other stone fruits and give birth to nymphs. These develop into egg-laying females, which mate with males returning from summer host plants. They lay eggs that overwinter.

Damage

Peach crops can tolerate moderate infestations with little impact on the crop, but heavy infestations can cause serious damage. Where the aphid

Figure 188: Older nymphs and wingless adults are yellowish green with darker stripes.

Green Peach Aphid Life History



Early in the season, wingless aphids reproduce asexually. Two or three generations are produced on the tree fruit host before winged aphids develop and migrate to summer hosts. Winged aphids return to fruit trees in the fall, where they give birth to nymphs, which develop into egg-laying females. Those females mate with males returning from summer hosts to produce overwintering eggs. Timings are based on observations in Oregon.

Figure 189

Figure 190: Green peach aphids feed on young fruit of nectarines.

population is extremely heavy, leaves will become badly curled and flowers or newly formed fruit will abort. High populations can also reduce tree vigor and retard shoot growth. The most serious damage occurs on nectarine because aphids feed directly on young fruit. This feeding distorts normal growth and leaves fruit bumpy and unmarketable (*Figure 190*).

Monitoring

As most eggs hatch before bloom, begin monitoring at the delayed-dormant stage. Young aphids are easy to detect on the outside of open buds at this time. Examine several buds on 20 trees from throughout an orchard to determine the number infested by aphids. As soon as flowers open, aphids crawl inside and are more difficult to detect.

Biological control

The green peach aphid is attacked by several predators. Early season establishment of lady beetles, lacewings, syrphid flies, soldier beetles and predaceous bugs is important for successful biological control. On all crops but nectarine, natural enemies will often suppress green peach aphid populations below damaging levels. Chemical control sprays for the oriental fruit moth can be very disruptive of biological control of this aphid.

Management

Populations are suppressed by pre-bloom sprays, though resistance to many insecticides reduces the effectiveness of chemical controls. They are most susceptible just after hatching and before they have crawled into opening buds and flowers, just as buds are beginning to open. Dilute sprays, assuring good coverage, have provided good control during this period. Economic damage to peaches occurs only when populations are extremely high. However, significant losses can be sustained on nectarines even with low aphid populations, as the aphids feed directly on the fruit. After aphids have become protected by entering flowers or are concealed in curled leaves, chemical control is difficult. Post-bloom sprays for the aphid or other pests can kill predators, disrupting biological control, which in many orchards can suppress populations below damaging levels. Use of mating disruption for oriental fruit moth control should help encourage a build-up of natural enemies of the green peach aphid.

Hop aphid
Phorodon humuli (Schrank)

Leafcurl plum aphid
Anuraphis helichrysi (Kaltenbach)

Mealy plum aphid
Hyalopterus pruni (Geoffroy)

Rusty plum aphid
Hysteroneura setariae (Thomas)

Thistle aphid
Brachycaudus cardui (Linnaeus)

Several aphid species attack stone fruits in the Pacific Northwest. The black cherry aphid and the green peach aphid are the most important. However, the less common aphids listed above can cause occasional damage.

Hosts

Hop aphid: apricot and plum.
Leafcurl plum aphid: plum.
Mealy plum aphid: apricot, peach and plum, except Japanese hybrid plums.
Rusty plum aphid: cherry, peach and plum.
Thistle aphid: apricot and plum.

Life stages

Hop aphid: The wingless form is teardrop shaped and pale yellowish green to dark green. The winged female is pale yellowish green with a dark head and thorax. The male is smaller than the female. It has a black head and thorax and a dark green abdomen.

Leafcurl plum aphid: The stem mothers, which hatch from eggs in the early spring, are dark green or reddish with brown dorsal bands. Nymphs and adults born from the stem mothers are pale green. The female that lays eggs in the fall is dark green or reddish with brown bands on its back.

Mealy plum aphid: The adult is pale bluish green and has a white, powdery coating that makes it look gray to light green (*Figure 191*).

Rusty plum aphid: This aphid is rusty brown or deep purple with white bands on the legs.

Thistle aphid: This is a fairly large, shiny green aphid with black markings on its back.

Life history

Overwintering eggs are laid in crevices on twigs. They hatch just before bud break. The nymphs develop into wingless females, which produce young without mating. The aphids feed on the undersides of leaves. As numbers increase, the leaves curl.

After 2 or 3 generations, winged forms are produced. They migrate from tree fruits to summer hosts, which include weeds, ornamental plants and vegetables. There, they produce several more generations. In the fall, winged migrant aphids return to their tree fruit hosts and give birth to nymphs, which develop into egg-laying females. These females mate with males returning from summer host plants and produce eggs that overwinter.

Damage

The aphids colonize young terminal growth. Infested leaves may curl and terminal growth can be disrupted. The aphids produce copious amounts of honeydew, which coats leaves and fruit with a sticky film. A black fungus, known as sooty mold, grows on the honeydew, impairing fruit quality.

Monitoring

It is important to monitor for these aphids shortly before bud break, as management decisions must be made at that time. The aphids are best controlled when small and exposed.

Figure 191: The mealy plum aphid has a white, powdery coating.

Biological control

Several insect predators help to keep these aphids in check in a well balanced ecosystem. However, a certain number of aphids must be present to attract the predators, which means some damage can be expected. The most common aphid predators include lady beetles, lacewing larvae, syrphid fly larvae, soldier beetles and predacious midges. Since mealy plum aphid has only two summer hosts — reed grass and cattails — it may be feasible to control this aphid by eliminating the alternate hosts. However, as mealy plum aphids can migrate up to 30 miles, this is only practical where there are few alternate hosts around.

Management

These aphids are generally not a problem when a regular spray program is used to control other insects. The most effective of these programs would be a delayed-dormant spray of oil with an appropriate pesticide. After the aphids become active and leaves begin to curl they are more protected and harder to control. Attempts at late season control can disrupt predators.

Low populations in the orchard early in the season may be beneficial in attracting predators. Later in the season, predators and migration to summer hosts should keep populations at acceptable levels.

SCALES
San Jose scale
Quadraspidiotus perniciosus (Comstock)
(Homoptera: Diaspididae)

San Jose scale is a key pest in almost all the fruit growing districts of the United States. It was introduced to California from China on flowering peach in the early 1870s and soon became a serious pest in the San Jose area. By the late 1890s it had spread to all parts of the United States.

The scale is a tiny insect that sucks the plant juices from twigs, branches, fruit and foliage. Although an individual scale cannot inflict much damage, a single female and her offspring can produce several thousand scales in one season. If uncontrolled, they can kill the tree as well as make the fruit unmarketable.

San Jose scale is a problem particularly in large, older trees where it is difficult to achieve good spray coverage, but young, unsprayed trees may also be vulnerable. The pest has become of increasing concern to the Northwest tree fruit industry due to the importance of exports, as phytosanitary regulations bar infested fruit from some countries.

Although scale lives primarily on the tree bark, surviving under scales and in crevices, the first indication it is in the orchard may be small red spots on the fruit or leaves.

Hosts
San Jose scale is most destructive on apple and pear, but can be a serious pest of sweet cherry, peach, prune and other tree fruits. It also attacks nut trees, berry bushes and many kinds of shade trees and ornamental shrubs. Infestations in backyard or wild trees can spread to nearby orchards.

Life stages
Crawler: The female San Jose scale produces live young. The newly hatched crawler of either sex is yellow. It has six legs, two antennae and a bristle-like sucking beak that is almost three times the length of its tiny, oval body. The crawler seeks a suitable site to settle and immediately begins to secrete a waxy covering over its body, which hardens into a scale. The scale turns from white to black and then to gray and goes through several molts

Figure 192: Adult male is very small with wings and long antennae.

before maturing. The differences in sexes becomes apparent after the first molt, although the scales covering them are identical. The females are smaller and rounder than the males and have lost their eyes, legs and antennae. The males have eyes but no legs or antennae.

Adult: The mature male is a very small yellowish tan insect with wings and long antennae (*Figure 192*). The female is wingless and legless, and its yellow body is soft and globular. The covering of a full grown female is about the size of a pin head, with a central, nipple-like bulge. The color is often obscured by a sooty fungus.

Life history
San Jose scale has two generations a year in Washington (*Figure 193*). It overwinters in the black-capped, immature stage. Being unable to move, the scales must survive wherever they happen to be on the tree, and in severe winters many may be killed. Scales that are further developed than the black-cap stage in the fall are usually killed by cold weather. Increased scale problems can be expected after mild winters. In the spring, surviving scales continue to mature.

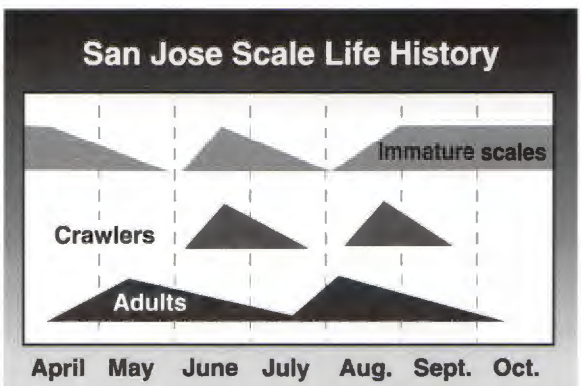
After developing through larval and pupal stages, the males mature and back out from their scales, about 4 to 6 weeks after birth. Adult males fly for only a few days and are capable of mating immediately with the females, which remain under their scales. Female scales release a pheromone to attract males for mating. Each female produces several hundred live crawlers over a 6-week period. Timing of the different stages varies from year to year, depending on temperatures. Usually, crawlers of the first generation appear in early June and may continue to be produced until early August.

The young crawlers move over the plant during the first few hours of their lives. They can be carried to other trees by the wind, on the feet of birds, on the clothing of farm workers or on orchard equipment. Within a few hours they settle on the bark, leaves or fruit, insert their long, bristle-like beaks, and begin feeding and forming a scale covering. Females of the first generation mature in late July, and second generation crawlers appear in August. Often, the two generations overlap and during the summer all stages can be found on the tree at the same time. Second generation crawlers continue to be produced until October or November.

Damage

If neglected, scale populations can quickly grow into a problem because the insect multiplies so rapidly. An infested apple can have 1,000 or more scale on it. A red spot will appear around the scales as they start to feed on the fruit (*Figure 194*), and often the feeding causes a slight depression. The spots are a brilliant red at first, but as the fruit grows and the spots increase in size, they fade to light red or pink. On red apples, spots are difficult to see. Trees infested with San Jose scale produce small, immature apples and infested apples do not color properly. If the trees are seriously infested, the apples crack and have a musty smell. The pest can be detected in an orchard bin or in the packing house by the odor.

Figure 194: Red spots form around the scales as they feed on fruit.



San Jose scale overwinters in the black-capped crawler stage. There are two overlapping generations a year. During the summer, all stages can be found on the tree at the same time. Timings are based on observations in Washington.

Figure 193

Besides making fruit unmarketable, San Jose scale kills twigs and limbs (*Figure 195*). If not controlled, it can kill the tree. More commonly, infestations of San Jose scale are light in commercial orchards. A small number of scales will infest an occasional fruit in or near the calyx. These scales may be difficult to locate on the sorting table. Packed fruit may rejected, particularly in export markets, if it has scale or markings from scale feeding.

Monitoring

It is usually not practical to sample to determine density or potential for fruit infestation, as the pest is seldom distributed uniformly throughout a tree and may infest only a few trees in an orchard block.

Figure 195: Besides making fruit unmarketable, San Jose scale kills twigs and limbs.

Scale may be noticed during pruning or on fruit as it is harvested. In cherry orchards, leaves of scale-infested trees do not drop in fall, making it easy to detect infested areas of the orchard. Mark infested areas as they are noticed so they can be given special attention when control treatments are applied. Place two-sided sticky tape on small limbs in infested areas to determine when crawlers are active or use the degree day model in Appendix 1 to time summer sprays.

Adult male flight can be monitored with pheromone traps. However, it has been difficult to relate trap catch with potential fruit damage. A biofix can be established using the traps, and development can be predicted using a degree day model.

Biological control

Several parasites and predators attack San Jose scale. Although they destroy many scales, they do not provide enough control to prevent damage. Natural enemies may become numerous in orchards that are not sprayed with insecticides, but even under these conditions biological control has not been adequate. Currently, biological controls are only a supplement to chemical control.

Management

San Jose scale was the first known insect in the United States to show resistance to a pesticide. Its resistance to lime-sulfur was reported in Washington in 1908. It caused tremendous damage and killed many trees before better chemical controls were found. Scale can develop rapidly in young, unsprayed trees, and scattered trees in the orchard may become encrusted with scale. New plantings should be checked annually. Where young trees are interplanted in old infested orchards, they quickly become infested. In older orchards, infestations may be spread to the top of the trees by birds and may go unnoticed for several years until scales are visible on the fruit.

The best approach to orchard protection is to prevent scales from becoming established. This can be done by treating the orchard annually before bloom when buds are beginning to open and good spray coverage of the tree can be achieved. If infestations become heavy, particularly on older, large trees, the insects may get under bark scales or on top of high leaders where they are difficult to target. Additional sprays, possibly by hand gun, may be needed for a few years to reduce populations. Summer sprays directed at the crawler stage help protect fruit but usually do not control infestations. For this reason, they are a supplement to the early-season spray, not a substitute.

A degree day model is helpful for timing crawler sprays in June. The lower and upper developmental thresholds of San Jose scale are 51°F and 90°F. A degree day look-up table based on these thresholds is given in Appendix 1. The model should be started at first male scale capture in a pheromone trap (the biofix), but because male scale flight is difficult to monitor accurately in commercial orchards, the regionally established biofix for codling moth is often used to start the San Jose scale model, as the flight of both insects commonly begins on the same day. If neither biofix is available, start the model at full bloom of Red Delicious. Apply sprays aimed at crawlers between 400 and 450 degree days after biofix. This timing is usually close to the second cover spray for codling moth. The degree day table given in Appendix 1 shows the relationship between degree days and the emergence of male scale and crawlers. It is important to examine young trees not receiving a full spray program. Control of infestations in the early stages will not only protect tree vigor but will prevent them spreading to other trees in the orchard.

Oystershell scale

Lepidosaphes ulmi (Linnaeus)

(Homoptera:Diaspididae)

Oystershell scale, as the name implies, looks like a miniature oyster encrusted on a small limb or twig. It is of European origin, but has been a common pest in the northwestern United States since 1850 and has since spread throughout the United States.

It infests trees of all sizes and ages and can kill young trees. However, it thrives on neglected trees and has rarely been an orchard pest. It lives primarily on bark, but can affect fruit also.

Hosts

Oystershell scale infests apple and a large number of other fruit, shade and ornamental trees and shrubs.

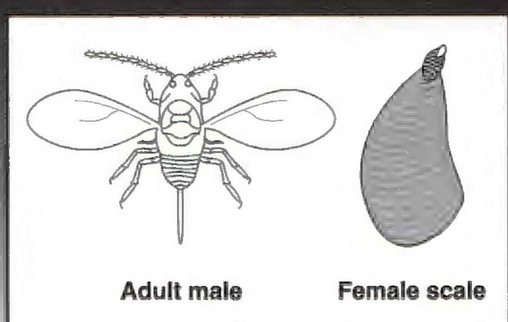
Life stages

Egg: The egg is oval and pearly white.

Crawler: The newly hatched crawler of either sex is pale yellow and has six legs. It resembles a San Jose scale crawler. After a few days it sheds its skin and loses its legs and antennae. After the second molt, the male develops wings. The female continues to grow in the same globular form and secretes a new, larger scale at each molt (*Figure 196*).

Adult: The adult scale resembles a miniature oyster shell. The female scale is shiny, light to dark grayish brown, with parallel ridges across and is from 1/16 to 1/8 inch (1.5 to 3 mm) long (*Figure 196*). The male is much smaller and has wings.

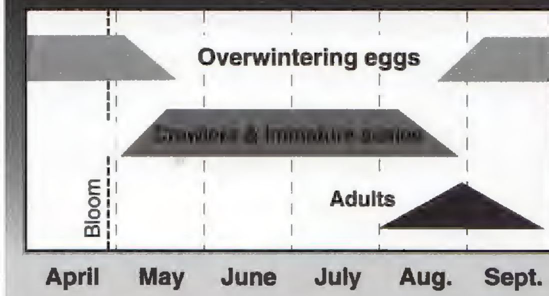
Oystershell Scale



The adult male scale has wings. The adult female remains in its scale, which resembles a miniature oyster shell.

Figure 196

Oystershell Scale Life History



Timings are based on observations on apples in central Washington.

Figure 197

Life history

The insect has one generation per year in the Northwest (*Figure 197*). It passes the winter in the egg stage under the scale of the mother. There can be from 40 to 100 eggs under one scale.

Crawlers emerge from the scale in May and June. They can crawl some distance before settling down on the bark. They then insert their long mouthparts into the host and secrete a waxy covering. Females never move again, but the males, which have wings, eventually emerge from their coverings and mate. Females continue to grow in the same form and mature in August or September. As eggs are laid, the body of the mother gradually shrinks into the smaller end of the scale and the eggs occupy the rest of the space. The female dies after the last eggs are laid.

Damage

Heavy oystershell scale populations on limbs and twigs weaken trees, but this damage is seldom seen in commercial orchards. Crawlers may settle on bark or fruit (*Figure 198*).

Monitoring

Look for scale on fruit and branches.

Figure 198: Oystershell scale lives primarily on bark but can affect fruit.

Biological control

Several predators feed on the scales but are rarely able to control them. Larvae of several parasites attack the eggs and some birds also feed on scales.

Management

This pest can be controlled with delayed-dormant sprays of oil or oil with an organophosphate insecticide. Oystershell scales are difficult to target with insecticides, as they spend almost 75% of their lives as eggs protected by the scale. The insect is most vulnerable in June when newly hatched young are crawling about. Generally, pesticides used in commercial orchards prevent the buildup of this pest.

European fruit lecanium

Parthenolecanium corni (Bouché)

(Homoptera:Coccidae)

European fruit lecanium, also known as brown apricot scale, is a common pest of tree fruits in the Pacific Northwest. The most common damage is russet and sooty fungus growth on the fruit caused by honeydew produced by the nymphs. It can also impair tree growth and even kill limbs.

Hosts

European fruit lecanium most often attacks stone fruits but may damage pome fruits and many other broadleaf plants. It is a common pest of landscape plants as well as commercial fruit trees.

Life stages

Egg: The egg is oval and pearly white.

Nymph: The newly hatched nymph, or crawler, is oval, flat and salmon colored. It later develops a hardened shell for protection.

Adult: The adult male has wings held flat over its abdomen. It emerges from under the protective covering after a short resting period or pseudo pupal stage. It can fly and crawl. The female cannot move, but remains under its shell where it deposit eggs. The mature female is the most conspicuous stage of this pest. The protective scale is hemispherical and chestnut brown (*Figure 199*). It measures between ⅛ and ¼ inch (3 to 5 mm) in diameter. Empty shells often remain attached to the tree bark throughout summer and fall. A few may still be found a full year after the female has died.

Life history

Overwintering nymphs mature into adults in April. After emerging from their coverings, males seek females for mating, and die within a few days. Females remain under their shells where they deposit eggs during May. Eggs loosely fill the mother's shell as she shrinks away during her egg-laying period.

Between mid-May and early June eggs hatch into crawlers, which are exposed and able to move about. After finding a suitable feeding site, usually on the undersides of leaves, crawlers settle and feed until early fall. Before leaf drop, the nymphs migrate back to current year shoots and settle again, this time developing a hardened shell for protection. They overwinter there and begin to feed and grow again during the following spring.

There is a single generation of European fruit lecanium per year (*Figure 200*). Crawlers can move from tree to tree on other insects or birds' feet, or may be blown by the wind. People thinning or doing other tasks involving close contact

Figure 199: The mature female is the most conspicuous stage of this pest.

with trees can also move crawlers between trees as they work.

Damage

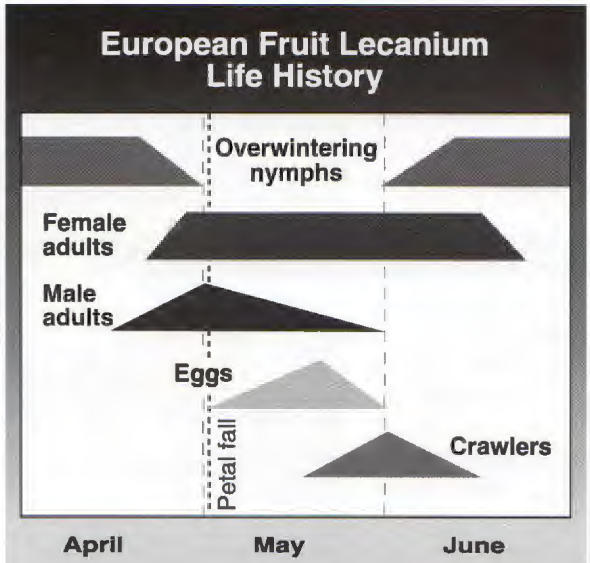
European fruit lecanium damages fruit trees in two ways. As with most sucking pests, it can devitalize the tree, resulting in reduced growth, poor fruit size and, in severe cases, dead limbs. The most common damage is due to honeydew, which is excreted by feeding nymphs and drips onto fruit and foliage. On fruit, honeydew leads to russet and is a medium for growth of sooty mold. Most honeydew is produced in late spring when nymphs are large and feed heavily on 1-year-old wood.

Monitoring

Large nymphs are easy to see during the dormant season on last year's growth. Once an infestation is detected, female development and egg hatch should be monitored by turning over the protective scales and examining the contents under magnification. Other indications of an infestation include sticky fruit and foliage, coarse russet on fruit, and sticky plants and ground under trees. When you notice these conditions, look for infestations on the bark.

Biological control

Natural enemies such as ladybird beetles, lacewings and predaceous bugs feed on crawlers as they emerge from under their mothers' scales and crawl to leaves to feed.



Timings are approximate and are based on observations on apricots in central Washington.

Figure 200

Management

Natural enemies normally keep European fruit lecanium at below damaging densities, but when pesticide sprays or other factors disrupt natural control, populations of this pest can reach damaging levels.

It is possible to control this pest with delayed-dormant sprays of oil and an organophosphate insecticide. Chemical sprays to control this pest are most effective when timed for the crawler stage. Time treatments by checking for crawlers hatching under female scales. Wait until most eggs have hatched or until a few crawlers have settled on leaves before applying the first spray.

If egg hatch is prolonged, a second application may be necessary for good control. As crawlers are active in late spring when there is lots of foliage on the trees, dilute sprays are more effective than concentrate applications.

Figure 201: The leafminer's round, flat eggs are laid on the undersides of leaves.

Figure 202: Sap-feeding larvae are wedge shaped and legless.

Figure 203: Tissue-feeding larvae are cylindrical and have legs.

Figure 204: The pupa is light tan when newly formed (bottom) but turns dark brown before the adult emerges.

Western tentiform leafminer

Phyllonorycter elmaella Doganlar & Mutuura

(Lepidoptera: Gracillariidae)

Since 1980, the western tentiform leafminer has been a serious problem in some Pacific Northwest apple orchards. However, it is not a new pest of tree fruits. Leafminers were pests in California and Oregon in the early 1900s and have been a sporadic problem ever since. Its recent resurgence in the Northwest is probably due to the spread of an organophosphate-resistant strain.

High populations in late summer can reduce fruit size and soluble solids in Red Delicious. However, the leafminer's main parasite, *Pnigalio flavipes*, often can keep leafminer densities below damaging levels. Leafminers are an indirect pest, and as such they present more management options than pests that damage the fruit directly.

Hosts

Of the pome fruits, apple has been the most severely affected. Pears do not appear to be as favored a host, but leafminer populations are probably suppressed by chemical controls applied for pear psylla. Cherry and prune also can be heavily infested.

Life stages

Egg: The egg is round, flat, and a yellowish green color. It is about 1/100 to 1/80 inch (0.25 to 0.3 mm) in diameter and is difficult to see without magnification (*Figure 201*). Eggs are laid on the undersides of leaves.

Larva: The larva develops through five instars. The first three instars, called sap feeders, are cream colored, flat, wedge shaped and legless (*Figure 202*). By the third instar the average larva measures 1/12 inch (2 mm) long. The fourth and fifth instars, called tissue feeders, are cylindrical and have legs. The fourth instar larva is cream colored and about 1/8 inch (3 mm) long, while the fifth instar is yellow and about 1/6 inch (4 mm) long (*Figure 203*).

Pupa: The pupa is cylindrical with abdominal segments that taper sharply towards the rear. Its color changes from light tan when newly formed to dark brown just before the adult emerges (*Figure 204*).

Figure 205: The adult has golden bronze forewings with white streaks edged in black.

Adult: The adult is ⅛ to ⅕ inch (3 to 5 mm) long, with wings held roof-like over the body. The forewings are golden bronze with white streaks edged with black (*Figure 205*).

Life history

The western tentiform leafminer has three complete generations and a partial fourth in most years (*Figure 206*). Adults emerge in spring from pupae that overwinter in fallen leaves. Eggs of the first generation appear shortly after the adults emerge, usually about the pink stage of flower bud development of Red Delicious. Egg laying peaks just before or during bloom of apple. Eggs are laid on the underside of leaves.

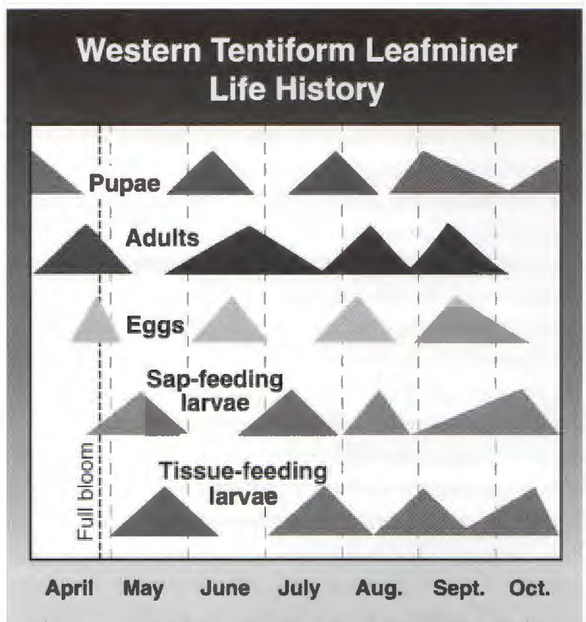
Larvae in the first three instars are referred to as sap feeders. They shear off the spongy, soft tissue inside the leaves with their sickle-shaped mouthparts and consume the cell contents. The first sap feeder mines appear in late April or early May. At first, the mine appears as a thin line, often following a leaf vein. Later, it forms a blotch visible only from the underside of the leaf (*Figure 207*).

The fourth and fifth instars, the tissue feeders, feed on the upper part of the leaf just to, but not through, the epidermis. As a result, the mines can be seen by examining the upper leaf surfaces. (*Figure 208*). Tissue feeders appear in early to mid-May. To accommodate its changing body form, the fourth instar larva increases the depth of the mine by spinning silken threads and attaching them to both sides of the mine. As the threads dry they contract, arching the mine and giving it its characteristic tentiform appearance.

Before pupating, the fifth instar larva moves to one end of the mine and spins a light silken chamber separating it from the rest of the mine. There is one spring flight of adults, in April, and three flights in the summer and fall. Adults of the first summer generation begin to emerge in late May or early June. After the first generation, the leafminer's life stages tend to overlap so that at any time several life stages might be present.

The pupa is the stage of western tentiform leafminer capable of surviving winter. However, in late summer, the leafminer does not stop development at the pupal stage. Adults emerge and another generation is begun, even though most of it will not reach the pupal stage before the onset of winter.

In different orchards in the same region, or even on different apple varieties in the same orchard, the proportion of leafminers in different life stages seems to vary considerably in the fall. In many orchards less than 5% of the leafminers will be in the pupal stage when freezing temperatures arrive, and the rest will be destroyed. High mortality due to the continuous development of the leafminer late in the season makes it very difficult to forecast populations from year to year.



Western tentiform leafminer has three and a partial fourth generations per year. Timings are based on observations in Washington.

Figure 206

Figure 207: Mines of sap feeders can be seen only on the underside of the leaf .

Figure 208: Tissue feeding mines can be seen from the upper leaf surface.

Damage

The leafminer's impact on production and quality of fruit depends on the time of infestation, apple variety, tree vigor, number of mines, and additional stresses, such as water stress or damage by other pests. No impact on fruit size or quality has been observed when populations average less than 2 tissue feeding mines per leaf in the second generation. While 2 mines per leaf would not cause damage to apple in late June, populations this high could result in damaging numbers of mines in the third generation. When the third generation has occurred late, at the end of August or in September, no impact on fruit size or quality has been documented where there were fewer than 5 tissue feeding mines per leaf. However, when the third generation has began early, in late July or early August, densities of eight or more tissue feeding mines per leaf have reduced fruit size and soluble solids in Red Delicious. The effect of the leafminer on fruit color has not been determined. In hot, dry summers when fruit is susceptible to sunburn, high leafminer infestations can aggravate this problem because infested leaves are curled or cupped, offering less shade.

Biological control

Biological control of western tentiform leafminer by parasitoids is common in commercial orchards. *Pnigalio flavipes,* a small parasitic wasp, is the principal biological control agent attacking the leafminer in the Northwest. It can kill more than 90% of the leafminers in a generation and often provides enough biological control that chemical controls are not required.

In most Washington apple orchards, leafminer populations in the spring are very low, less than 0.5 mines per leaf, because so few leafminers survive the winter. Parasitism levels of at least 35% in each leafminer generation, are usually sufficient to keep leafminer populations below treatment thresholds. If parasitism is below 20%, chances are good that the leafminer will exceed treatment thresholds at some time during the year.

Certain insecticides applied at the wrong time of year, when adult parasites are active, tend to disrupt the biological control of the leafminer. A hazard rating for different insecticides has been developed based on bioassays of their effect on *P. flavipes* together with observations following their use in the field and is given in *Figure 209.* Avoid

Toxicity of Insecticides to a Leafminer Parasite

Insecticide	Toxicity
Encapsulated methyl parathion	High
Chlorpyrifos	High
Esfenvalerate	Moderate
Endosulfan	Moderate
Phosphamidon	Moderate
Oxamyl	Moderate
Carbaryl	Low
Azinphos methyl	Low
Phosmet	Low

Toxicity of insecticides to *Pnigalio flavipes* adults, the major parasite of the western tentiform leafminer.

Figure 209

using insecticides with high or moderate hazard to *P. flavipes* during mid-June to early July when adults are active. Conservation of parasites is important for good biological control of the leafminer. See section on *Pnigalio flavipes* in Part IV, Natural Enemies and Pollinators.

Monitoring

Western tentiform leafminer can become a problem in almost any orchard, but particularly in those where it has recently become established. However, a high population one year does not mean it will be a problem the following year. A good sampling program and knowledge of treatment thresholds are keys to successful management of the leafminer.

As there is no known relationship between adults seen or trapped and the subsequent number of mines, sampling should be based on the number of mines. Though tissue feeding mines are the most obvious indication of a leafminer infestation, it is more important to sample sap-feeding mines to determine the need for treatment. Sap-feeding mines can be seen by picking the leaf, holding it toward the light and examining the undersurface.

1st generation:

It is not usually necessary to sample mines in the first generation except to assess the amount of parasitism. There are generally few mines as only a few of the earliest leaves were exposed to attack. The potential impact on tree vigor and fruit size or quality from mines in these leaves is low.

However, eggs of the first generation can be sampled at pre-pink or pink to determine the potential number of mines per leaf. Take at least 50 leaves (5 from each of 10 trees) and, using a hand lens or binocular microscope, examine the lower surface for eggs. Because the number of leaves on the tree increases rapidly during this period, it takes 3 eggs per leaf at pink to average 1 mine per leaf at the end of the first generation.

To determine the impact of parasitism, select 100 leaves from 25 trees that contain tissue feeding mines in late May or early June. Tear open each mine and determine if the leafminer larva or pupa is alive. If the leafminer is dead, determine if death was due to parasite attack by looking for a parasite egg, larva or pupa. If the leafminer larva seems normal but is not moving, it has probably been stung by a parasite but no egg was laid. This should be counted as death due to parasite attack.

Calculate the percentage of parasitized leafminers by adding up the number of mines affected by the parasite, dividing it by the total number of mines sampled and multiplying by 100. If more than 35% of the mines are parasitized, the potential for biological control is good. However, it may still be necessary to monitor parasitism levels in subsequent generations.

2nd generation:

A binomial sampling plan can be used for the second generation (*Figure 210*). This is based on a tally threshold of 2 or more mines per leaf (see Sampling section in Part I for more information on binomial sampling.) A total of 10 trees must be sampled to provide an accurate estimate of the population orchard-wide.

During late June and early July sample 20 leaves from the basal to mid-portion of a vegetative shoot and examine to determine how many contain 2 or more sap-feeding mines. Repeat this procedure for

10 trees in the orchard. The number of leaves over the tally threshold can be looked up in the sampling table in *Figure 210* to get the average mines per leaf. After values have been obtained for 10 trees, average the mines per leaf to determine the leafminer density for the orchard. In addition to the binomial sample, the second generation can be sampled using the same procedure as for the third generation. Pick a mid-shoot leaf on 5 shoots per tree, 20 trees per block, or 100 leaves.

3rd generation:
If the third generation occurs early, in late July or early August, sample sap feeding mines in early to mid-August. The same sampling scheme used in the second generation will *not* work for higher populations of leafminer. To determine the density of mines in the third generation, pick a mid-shoot leaf from 5 shoots and count the total number of sap feeding mines. Repeat this sample of 20 trees (100 leaves total), accumulating the number of mines as you go. Divide the total number of mines by 100 to get the number of mines per leaf. If the second generation was treated or if sap-feeders do not appear until late August or September, it should not be necessary to sample the third generation.

Treatment thresholds

The following treatment thresholds for the western tentiform leafminer are based on the limited experience with this pest in the western United States and from recommendations used in the eastern United States for controlling its close relative, the spotted tentiform leafminer.

1st generation:
The threshold of 1 sap feeder mine per leaf is seldom, if ever, exceeded. Pre-bloom treatments are suggested only if extremely high number of moths are seen at tight cluster to pink stage and eggs average more than 3 per leaf.

2nd generation:
Treatments should be applied if sap feeder mines exceed 2 per leaf, especially if first-generation parasitism was low, less than 35%. If the second generation develops early, new sap feeder larvae are present in early June, and parasitism in the first generation was low, the threshold for treatment should be reduced to 1 mine per leaf.

3rd generation:
If second generation treatments were applied, or if the third generation develops late, in late August or early September, no treatments should be required. However, if the third generation develops early with new sap feeders present in late July or early August, treatments should be applied if sap-feeder mines exceed 5 per leaf.

Management

Western tentiform leafminer is resistant to most organophosphate and chlorinated hydrocarbon insecticides. The only insecticides registered for use on apple that provide control are a carbamate and a pyrethroid, and use of either has negative side effects. Because both products are toxic to predatory mites, they can disrupt integrated mite control. Other natural enemies may be adversely affected, depending on the timing and the material used. Pre-bloom applications are recommended only in extreme situations where high number of moths are observed and egg counts exceed 3 per leaf. Even if orchards are treated early, the chances of reinfestation from untreated sources in the second and third generation are high. Controlling western tentiform leafminer during the first generation will greatly reduce any chance for biological control later in the season and all attempts should be made to delay control decisions until the second generation.

The best timing for chemical controls is after the eggs of a generation have hatched but before the tissue feeding larvae appear. Usually, this is in late June to early July for the second generation and early to mid-August for an early developing third generation. Using chemical control only when necessary will delay the development of resistance in leafminer populations and minimize the impact on predatory mites.

Taking maximum advantage of parasitoids will help reduce the need for chemical controls of the leafminer. Determine the potential for biological control by assessing parasitoid levels at the end of the first and second generations. Biological control of leafminer can be enhanced by avoiding chemical controls for other pests when adult parasitoids are active (roughly the same time as leafminer adults are active).

A Binomial Sampling Plan for Western Tentiform Leafminer

To estimate the average number of mines per leaf, collect a sample of 20 leaves and count the number of leaves with 2 or more mines. A total of 10 trees must be sampled for population predictions to be accurate within 1 mine per leaf.

Sampling table for western tentiform leafminer

No. of leaves with 2 or more mines	% of leaves with 2 or more mines	Average no. mines per leaf
1	5	0.33
2	10	0.51
3	15	0.67
4	20	0.81
5	25	0.96
6	30	1.10
7	35	1.25
8	40	1.40
9	45	1.57
10	50	1.73
11	55	1.91
12	60	2.11
13	65	2.33
14	70	2.57
15	75	2.86
16	80	3.21
17	85	3.66
18	90	4.28

Example

The first tree has 5 leaves with 2 or more mines, the second has 10, the third has 7 and the fourth through tenth trees have 8, 6, 5, 7, 10, 11 and 12, respectively. Use the table at left to estimate the average number of mines per leaf for each tree and then average across the 10 trees.

Tree	No. of leaves with 2 or more mines	Average no. of mines per leaf
1	5	0.96
2	10	1.73
3	7	1.25
4	8	1.40
5	6	1.10
6	5	0.96
7	7	1.25
8	10	1.73
9	11	1.91
10	12	2.11

Estimated mines per leaf = 1.44

Figure 210

SHOTHOLE BORERS

(Coleoptera: Scolytidae)

Shothole borer
(or fruittree bark beetle)
Scolytus rugulosus Müller

European shothole borer
(or ambrosia beetle)
Xyleborus dispar Fabricius

Lesser shothole borer
(or ambrosia beetle)
Xyleborus saxeseni Ratzeburg

Shothole borers are small beetles that were introduced from Europe and have spread over most of the United States and southern Canada. They were first reported in the Northwest in the early 1900s. They are destructive pests of forest trees but also attack fruit, shade and ornamental trees and shrubs.

The shothole borer (*Scolytus rugulosus*) is a bark beetle that lives between the bark and the surface of the wood, scoring the sapwood. It feeds on the tree's succulent phloem tissue. Ambrosia beetles bore into the wood of trees, forming galleries in which both adults and larvae live. They feed on an ambrosia fungus, which they cultivate.

All shothole borers are attracted to injured or stressed trees. As chemical controls have not proven very successful, the best management approach is to keep trees healthy.

Hosts

Apple, pear, cherry and plum are among the fruit trees attacked by shothole borers.

Life stages

Shothole borer:

Egg: The egg is oval or round and a shiny, pearly white color.

Larva: The larva is white, legless and about ⅛ inch (4 mm) long (see *Figure 211*). The body is slightly enlarged just behind the head.

Pupa: The pupa is white with sparse hairs and numerous large, think tubercles. It is about ⅛ inch (4 mm) long.

Adult: The adult beetle is about $\frac{1}{12}$ inch (2 mm) long (*Figure 212*). It is brownish black with brown legs and antennae and has a short, stubby snout with chewing mouthparts. The thorax is shiny and

Figure 211: Larvae are white and legless. Pictured is *Xyleborus dispar.*

Figure 212: The adult shothole borer has a short, stubby snout with chewing mouthparts.

elongated. The wing covers are dull and the interstices (the parts between the body sections) are wrinkled.

Ambrosia beetles:

Egg: The egg is oval or round and shiny, pearly white.

Larva: The larva is pinkish white, cylindrical and legless. It passes through five instars and when mature is about 1/6 inch (4 mm) long (*Figure 211*).

Pupa: The pupa is white.

Adult: The adult female *Xyleborus dispar* is about 1/8 inch (3 mm) long and winged (see *Figure 212)*. It has a dark brown or black body covered with yellowish hairs and pale brown legs and antennae. The adult male is wingless and shorter, with a relatively small thorax and short abdomen. The adult *Xyleborus saxeseni* is only about 1/10 inch long. It can be pale brown to black.

Life history

Shothole borer:

Larvae overwinter in burrows beneath the bark, where they pupate. Adults emerge in the spring or early summer and often feed at the base of leaves or small twigs (*Figure 213*) before they tunnel into the tree through the bark). They then excavate narrow galleries running parallel to the wood grain. Each female deposits about 50 eggs in niches along the walls of the gallery. As the eggs hatch, the larvae excavate slender mines or burrows, usually at right angles to the maternal gallery, occasionally crisscrossing over one another between the bark and the sapwood (*Figure 214*).

The larval burrows are filled with excrement and get wider as the larvae grow. When fully grown, about 6 to 8 weeks later, the larvae construct pupal cells at the ends of the mines. When they emerge as adults, they build exit burrows from the pupal cells to the outside. The numerous exit and entrance holes give the shothole effect (*Figure 215*). There are usually two generations a year in the northern states (*Figure 216*). Larvae of the second generation complete development during late winter and early spring as temperatures rise.

Ambrosia beetles:

Ambrosia beetles overwinter as adults (*Figure 217*). In spring, when daily temperatures exceed 65°F (18°C), females become active and search for

Figure 213: Ambrosia beetle adults often feed at base of leaves before tunneling into the tree through the bark.

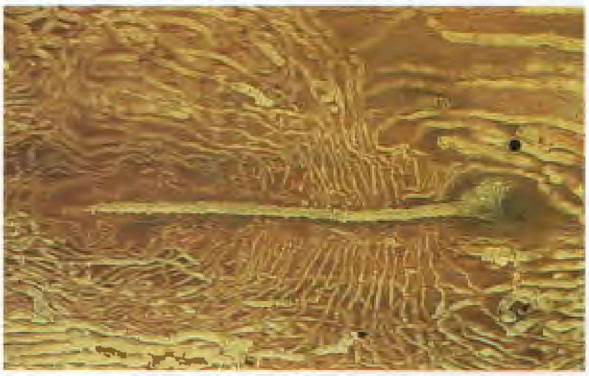


Figure 214: Burrows of shothole borer larvae run at right angles to the central maternal gallery.

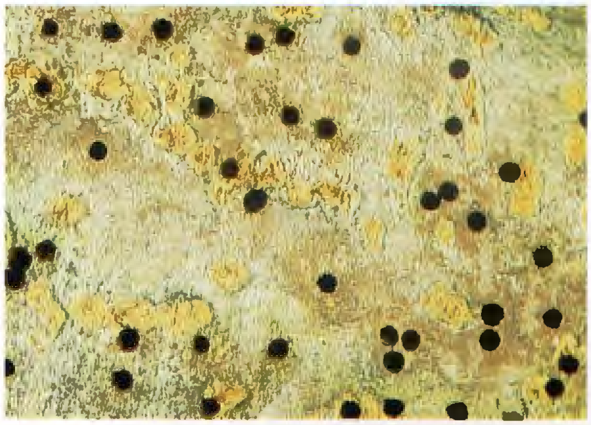
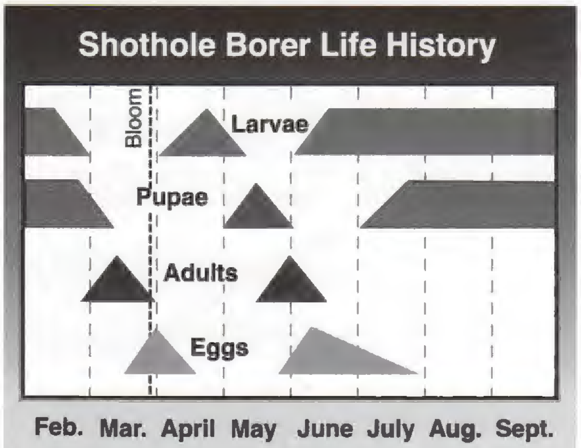


Figure 215: When adults emerge they build exit burrows from the pupal cells. Entrance and exit holes give a shothole effect.



Timings based on observations on pears in Oregon.

Figure 216

a suitable host. They are attracted to weak trees. Once they find a suitable tree, they bore into the bark, burrowing down to the sapwood or heartwood before excavating shorter tunnels to either side. Each female deposits between 40 and 50 eggs at the entrance of the shorter galleries, where the larvae are reared.

As eggs are laid over a period of several weeks, both young and old larvae live together in the same gallery. The female tends her young as they develop through May and June, carefully cultivating ambrosia fungus in the galleries for them to eat. The females have special organs for storing and carrying the fungal spores. The ambrosia fungus develops on a mixture of wood fibers and excrement and spreads to the various galleries, staining them dark brown or black. Unless consumed regularly, the fungus may close off the galleries, killing the larvae inside.

Female beetles usually remove any excrement pellets or debris produced by the larvae. Galleries of ambrosia beetles can be distinguished from those of other wood borers by the lack of wood dust and other refuse as well as their uniform size. Young adults, tightly packed one behind the other, may be found in the galleries starting in July and August where they remain in a state of diapause until the following spring. When temperatures warm in the spring, the adults mate and females leave galleries in search of a new host.

Damage

Shothole borer:

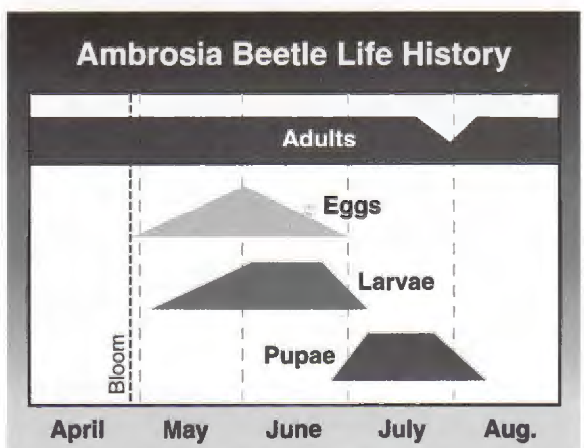
The mining of the shothole borer can interfere with the movement of fluids through the cambium layer between the wood and the bark. Infested trees are usually weak and will be further weakened by the damage. Eventually, the tree will be girdled and killed. Young, healthy trees may also be attacked if they are close to a large source of beetles, such as a pile of prunings. A typical scenario is where an old orchard is removed in the fall, the cut wood is stacked near the edge, and new trees are planted in the spring.

Ambrosia beetles:

Branches and stems of infested apple and pear trees will wilt and die. The damage is often mistaken for fire blight. Usually the beetle attacks weak or damaged trees, but young, vigorous trees can also be infested. Trunks and large branches may become completely riddled with galleries.

Monitoring

Examine trunks and branches in late May or early June. On infested trunks and limbs, there often will be holes about 1/12 inch (2 mm) in diameter, oozing sap and sawdust. Holes without fresh sawdust are most likely from previous years and no longer contain beetles. On stone fruits, the entrance and exit holes are usually covered and sealed with a gummy



Timings based on observations in Oregon.

Figure 217

ooze or dried droplets of gum, which hang from the twigs and branches like teardrops. Pay special attention to areas that have a history of attacks, that are near hedges, brush piles or wooded areas, or that have had freeze damage. Bear in mind that the beetles attack primarily unhealthy trees.

Ambrosia beetle flights can be monitored with traps such as the one described in *Figure 218*. Small pails filled with the alcohol bait can also serve as traps. Beetles attracted to the trap drown in the liquid and can easily be counted.

In areas previously attacked, begin trapping in late March or early April using 2 to 4 traps per acre. Place traps in the tree near the trunk, about 4 to 5 feet (1.5 meters) from the ground. During warm weather, flights last 3 to 4 weeks. In cold or variable weather, they can last up to 6 weeks. If fewer than 20 beetles are caught per trap per season, little or no damage is likely. If catches exceed 20 beetles per trap per season there is potential for serious damage and control measures should be taken.

Biological control

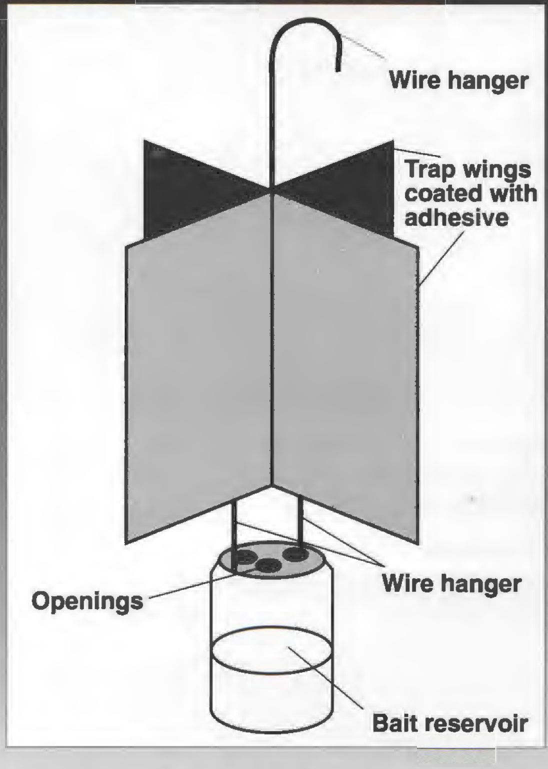
Shothole borers are preyed upon by birds (chiefly woodpeckers), checkered beetles, hymenopterous parasites and parasitic bacteria and fungi.

Management

Healthy, vigorous trees that are well cared for are less subject to attack. Give sickly trees adequate water and fertilizer. In areas prone to sunburn or winter damage, paint trunks with a solution of equal parts of latex paint and water to prevent damage to the trees. Sanitation is the key to successful shothole borer control. In winter, remove and burn infested and diseased trees or branches of both orchard trees and other nearby hosts. This will prevent beetle populations building up to the point where they might attack healthy wood.

Baited traps like those used for monitoring can be used to control ambrosia beetles. Space traps evenly throughout areas previously attacked, using at least 8 per acre. The success of the trap depends primarily on how attractive the alcohol bait is to the beetle. Several chemicals are registered for use against shothole borers, most of which are directed at adult beetles. Chemical controls can be applied whenever adults are present, from late March to September. However, they are of limited value and the best control method is to keep trees healthy.

Ambrosia Beetle Trap



The wings of the trap are made from two pieces of brown or black plastic, 10 inches square, fixed in a cross design and coated with a polybutylene adhesive such as Tanglefoot, which is available through suppliers of agricultural products. The bait reservoir or bottle hangs below the wings and has holes for the bait to evaporate. It is filled one third full with 95% ethyl alcohol mixed with an equal volume of water.

Figure 218

Figure 219: The larva of the Pacific flatheaded borer is a yellowish-white grub. The front of the body is broad and flat.

Figure 220: The beetle is brown with irregular markings and a coppery luster.

Pacific flatheaded borer

Chrysobothris mali Horn

(Coleoptera: Buprestidae)

The Pacific flatheaded borer has been a serious pest throughout the United States and southern Canada in the past, but is rarely seen in commercial orchards. It attacks many trees and shrubs. The larvae kill or weaken trees by girdling the trunks and lower branches. Stressed plants are most vulnerable. Newly planted nursery stock, drought stressed trees, sunburned trees and trees whose trunks are exposed to the sun usually are the most seriously affected. One borer can kill or severely weaken a small tree.

Hosts

The borer attacks apple, pear, peach, apricot, plum, prune and cherry as well as many other trees and shrubs.

Life stages

Egg: The egg is pale yellow, disk shaped and wrinkled, and is about $\frac{1}{20}$ inch (1 mm) in diameter.

Larva: The larva is a yellowish white, slender grub, which can grow up to 1 inch (25 mm) long. The front part of the body is broad and flat, prompting the insect's common names of flat-headed borer (*Figure 219*). The larva usually lies curled on one side in a U shape.

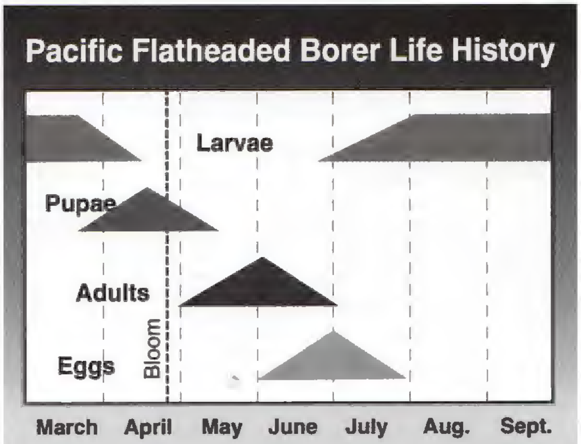
Pupa: The pupa is about $\frac{1}{2}$ inch (13 mm) long. It is pale yellow at first but later turns brown.

Adult: The adult is a broad, flat beetle about $\frac{1}{4}$ to $\frac{1}{2}$ inch (6 to 13 mm) long (*Figure 220*). It is brown with irregular grey markings and has a coppery luster. Its back beneath the wing covers is brilliant green.

Life history

Adults emerge soon after bloom of apple (*Figure 221*). Females lay eggs from early June through July in crevices in the bark, usually on the sunny side of tree trunks below the lowest branches. Females prefer to lay eggs on sickly, dying or recently transplanted trees. The eggs hatch from mid-June to mid-August.

Newly hatched grubs burrow into the bark and feed between the bark and sapwood until full grown. If the tree is vigorous and full of sap, the



The flatheaded borer overwinters as a larva inside a pupal cell. Timings are approximate.

Figure 221

borer cannot thrive within the growing tissue and it may die or stop growing.

When mature, the grubs burrow a short distance into the wood and build cells where they overwinter and pupate in the spring. The adults' emergence holes in the bark or exposed wood are oval and about $\frac{1}{4}$ inch in diameter, and are usually near the base of the tree.

Damage

The burrows are broad and irregular. The wound can encircle and kill a young tree, but on larger trees the injury is usually confined to the sunny side.

Monitoring

The grubs throw out very little frass. Injured spots can be detected by a dark colored depression in the bark and by cracks in the bark through which the frass shows.

Biological control

Birds, such as woodpeckers, peck the larvae from the trees with their sharp beaks. Carpenter ants will eat both larvae and pupae while they are in the wood. Hymenopterous parasites also attack the borer.

Management

As the borer attacks mainly weakened or injured trees, the best way to prevent infestations is to keep trees healthy and vigorous.

To prevent sunburn, paint the trunk with a mixture of white latex paint and water.

Keeping weeds, grass and trash away from the base of the trees makes it easier to detect and remove borers and exposes them to natural enemies such as birds. Where possible, remove wild host plants, such as hawthorn, shadbush, mountain ash and wild apple seedlings that are near the orchard.

Larvae cannot be controlled after they have entered the bark, so the best strategy is to prevent egg laying. As the adults only lay eggs in direct sun on the trunk below the branches, barriers or sun shades will help to stop them laying eggs. Use loose paper or another type of tree protector. Wrap the trunk loosely with paper, cloth or burlap. Paper should be water resistant and be resilient enough to allow for trunk growth.

Insecticide applications should be timed to kill newly hatched larvae before they enter the bark. Residues must remain on the trunk during egg hatching. Spray the trunk up to the lower limbs about June 1 and again on July 1.

Peachtree borer

Synanthedon exitiosa (Say)

(Lepidoptera: Sesiidae)

Peachtree bore is a clear-winged moth native to North America and common in the Northwest. Its larvae can kill trees by feeding on the trunk near or below ground level.

Hosts

Before peaches were grown commercially, the peachtree borer survived on wild plum, cherry and related plants. It will attack commercial peach, cherry, prune, apricot, nectarine and plum orchards.

Life stages

Egg: The egg is a flattened disk shape, about $\frac{1}{50}$ inch (0.5 mm) in diameter. It is reddish brown and is deposited singly or in small groups, usually near the base of the tree.

Larva: The larva is white or cream with a yellow-

Figure 222: The peachtree borer larva is about 1½ inches long when fully grown.

Figure 223: The male moth is bluish black with bands of light yellow scales on the abdomen.

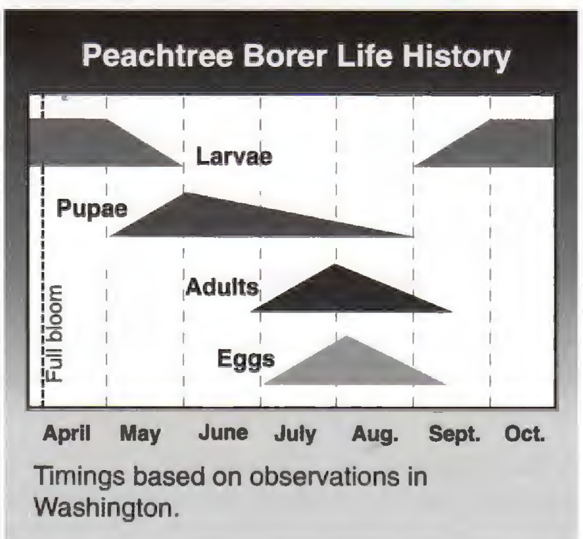


Figure 224

brown to dark brown head and three pairs of segmented legs. It measures about 1½ inches (38 mm) long when fully grown (*Figure 222*).

Pupa: The female pupa is about ¾ inch (18 mm) long, slightly larger than the male pupa. It is darker colored than the male and develops an orange band on the abdomen.

Adult: The adult is a dark-blue, clear-winged moth. The female is slightly larger than male and has bands of bright orange scales on the fourth and fifth abdominal segments. On the male, some abdominal segments may be fringed with white or yellow scales (*Figure 223*).

Life History

The peachtree borer overwinters as a larva on or under tree bark, usually below ground. It becomes active when soil temperatures reach 50°F and feeds on live tissue under the bark. When full grown, the larva builds a cocoon and pupates in May and June (*Figure 224*). Moths begin to emerge in late June to early July and continue into September. Female moths mate shortly after emerging and within 30 minutes start laying eggs. Most eggs are deposited the day of emergence and mating. Females live about 6 or 7 days but lay few eggs after the third day. Eggs hatch in 9 to 10 days and the young larvae bore into the bark at the base of the trunk. Once beneath the bark, they feed in the cambium layer.

Damage

The main damage is done by larvae feeding on the cambium tissue, which is the layer of living cells between the wood and the bark. Damage is usually confined to the trunk, from a few inches above to a few inches below ground level (*Figure 225*). Young trees can be killed if they are completely girdled by larval feeding. Older trees are less likely to be girdled, but injury can lower vigor, making them vulnerable to other insects, diseases and conditions that contribute to their death. Infested trees bleed frass infested gum from damaged areas during the growing season.

Monitoring

Initial and peak emergence of adult males can be monitored with pheromone traps. Larval feeding is difficult to detect because much of it is at or below ground. The only way to positively identify the borer, apart from trapping, is to dig out the sus-

Figure 225: Base of dead peach tree, showing signs of heavy peachtree borer infestation.

pected attack using a knife or heavy screwdriver. A light brown frass and soft, sticky sap will be found where there is fresh feeding activity.

Biological control

Several species of parasitic hymenoptera have been reared from larvae or pupae of the peachtree borer. They include *Bracon sanninoideae* and *Macrocentrus marginator* (Braconidae); *Cryptus rufovinctus, Phaeogenes ater*, and *Venturia nigricoxalis* (Ichneumonidae); *Syntomophyrum clisiocampae* (Eulophidae); and *Telenomus quaintacei* (Scelonidae).

Management

Summer insecticide treatments are effective in controlling this pest. Apply sprays by handgun to the tree trunk and ground around the base of the tree. Normally, two applications are needed, one in early July and another one month later. Do not apply pesticides to cultivars that are scheduled to be harvested within the pre-harvest interval. The use of pheromones in a mating disruption program is an effective control.

Cherry bark tortrix

Enarmonia formosana (Scopoli)

(Lepidoptera: Tortricidae)

Cherry bark tortrix has been a pest in Europe and Siberia for many years and is widespread throughout the British Isles. It was first discovered in North America in 1990 in southern British Columbia and in Washington state in 1991.

Hosts

The common name is somewhat misleading as this insect attacks most tree fruits, not just cherry. Its hosts also include plum, peach, nectarine, apricot, almond, apple, crab apple, pear and ornamental cherry. In England, it is primarily a pest of older trees that are more likely to have winter injury or wounds. Stone fruit trees, which tend to have more bark injury, may be more vulnerable than other fruit trees.

Life stages

Egg: The egg is round, flat and slightly dome shaped and measure about $\frac{1}{40}$ inch (0.7 mm) in diameter. It is white when laid, but turns pink with a deeper colored center it develops. Eggs are usually laid singly, although sometimes in groups of two or three, slightly overlapped.

Larva: The larva is about $\frac{3}{8}$ inch (8 to 11 mm) long and has a yellowish brown head and pale gray body. The anal plate is the same color as the rest of the body, but with a grayish brown spot.

Pupa: The pupa is yellowish brown with bands of spines on the dorsal side of the abdomen.

Adult: The adult has ochre-yellow forewings, which are intricately patterned with dark brown and metallic grey and have white lines on the outer margin The hind wing and abdomen are dark grayish brown.

Life history

In Washington, the adult moth is active from April to September and has one generation a year (*Figure 226*). It flies mainly in the early morning, but also during the day.

Mated females lay eggs on the bark of the tree, often near wounded or previously infested areas. Pruning scars and winter damaged areas are likely targets. Each female lays about 90 eggs, which hatch within 2 to 3 weeks. The larvae, which pass through five instars, feed beneath the bark, making irregular tunnels. Cherry bark tortrix overwinters as a larva, which pupates the following spring. After the adult has emerged, the cast pupal skin protrudes from the tunnels in the bark.

Damage

The feeding tunnels of larvae loosen and crack the bark. Gummosis, often mixed with silk and frass (small pellets of insect excrement) oozes from the

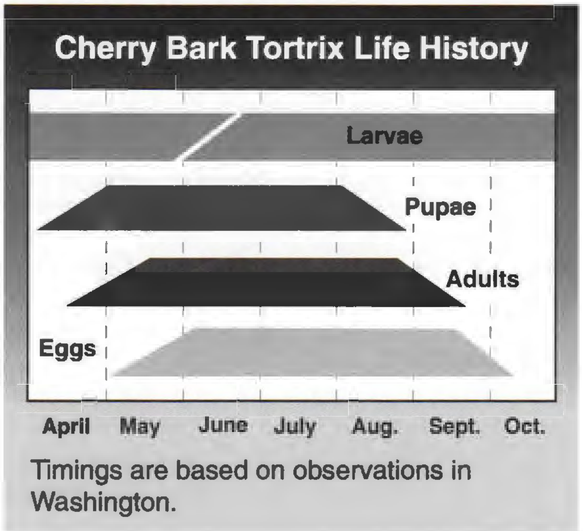


Figure 226

cracks. The bark sustains most of the damage, although there can be some damage to the cambium layer. Heavy infestations cause swellings and cankers and can eventually kill limbs or entire trees. On apple, damage is usually confined to the undersides of the main scaffolds. On cherry, the base of the trunk is more often attacked. Larvae often attack pruning scars on branches or any area on the trunk or limbs that has been damage, such as limb rubs caused by support wires.

Monitoring

A simple, but time consuming method of monitoring is to examine injured bark for signs of gummosis and frass. Frass can easily be seen at tunnel openings in late winter and early spring. However, several native clear-wing moths in the Sesiidae family cause similar damage to the trunk and scaffold limbs. To identify the pest, the larvae must be collected and examined.

Cherry bark tortrix is attracted to a blend of tortricid pheromone components. Use of pheromones can simplify monitoring in regions not know to be infested, but they are not useful in managing established infestations due to the long flight period of adults.

Management

Control aimed at adults is not practical, because of the prolonged flight period. Most of the available information on control of the pest is outdated. In England, spring treatments aimed at killing larvae as they came to the surface of the bark to pupate were not successful. Another approach in England in the 1960s was a dormant-season treatment aimed at the overwintering larvae using materials such as tar oil, creosote or insecticides. However, the treatments were extremely labor intensive, as the materials were brushed onto the tree after the bark had been scraped, and the insecticides used are no longer available. Materials currently used for sesiid borers, such as the peachtree borer, may be effective.

Tent caterpillars

(Lepidoptera: Lasiocampidae)

Western tent caterpillar
Malacosoma fragilis (Stretch)

Forest tent caterpillar
Malacosoma disstria Hübner

The western tent caterpillar is found throughout the western United States and Canada. The species found in the East is the common eastern tent caterpillar, *Malacosoma americana* (Fabricius). There are several species of tent caterpillars in the western United States, but all have similar life histories, habits and appearances. They are not common in most commercial orchards but tents are conspicuous in abandoned trees or native habitats. They are considered a minor pest of fruit trees.

The forest tent caterpillar is found throughout North America. While the larvae do trail webbing wherever they go, this webbing does not function as a true tent. However, the webbing may completely cover limbs and foliage. When not feeding, the larvae gather in masses on branches or the tree trunk.

Hosts

The western tent caterpillar attacks a wide range of hosts including apple, peach, plum, cherry, pear, wild rose, poplar and willow. The forest tent caterpillar prefers maple, but will also feed on the foliage of most types of fruit trees.

Figure 227: Young larvae move to a crotch and spin a dense web.

Life stages

Egg: The egg is elongated and about 1/25 inch (1 mm) long. Eggs are laid in masses of as many as 400. The masses are covered with a brownish gray material that protects them from the weather.

Larva: The fully grown western tent caterpillar larva is about 2 inches (50 mm) long and covered with fine, soft yellowish brown hairs. The body is pale blue-gray on the sides with a distinctive light stripe down the middle of its back and bluish spots to either side of the mid-line. The fully grown forest tent caterpillar larva can be distinguished from the western tent caterpillar by the row of wedge- or club-shaped cream spots down its back in place of the stripe.

Pupa: The pupa is brown and about 3/4 inch (19 mm) long. It is enclosed in a silken cocoon of loosely woven white silk, which is commonly dusted over with a fine yellowish powder.

Adult: The western tent caterpillar moth is a dull, reddish brown with a pair of parallel oblique whitish bands crossing the front wing. On the forest tent caterpillar the bands are brown.

Life history

Tent caterpillars have one generation a year. Tent caterpillars overwinter as eggs, which hatch in spring when new foliage starts to appear. The young larvae move to a crotch and spin a dense web (*Figure 227*). This web gradually expands as the larvae grow and the feeding area required to sustain the colony increases. Larvae mature in 4 to 6 weeks and by mid-May through June can be seen wandering in search of places to pupate. Moths emerge in June and July, then mate and lay eggs, which hatch the following spring (*Figure 228*).

Damage

Larvae of a single tent caterpillar colony can strip the leaves from a small tree if allowed to develop and are more of a threat in nurseries or newly planted orchards. On larger trees they are only a serious problem if there are several colonies on the same tree. While fruit is not directly attack, fruit on branches that have had leaves consumed will not develop normally.

Monitoring

Check for tents or webbing of these insect, which are easy to spot in the orchard.

Biological control

Tent caterpillars are attacked by numerous natural enemies, including birds, predaceous beetles and bugs, and parasitic wasps and flies. They are at times devastated by outbreaks of bacterial or viral diseases, especially if local populations become extremely dense. The potential for biological control

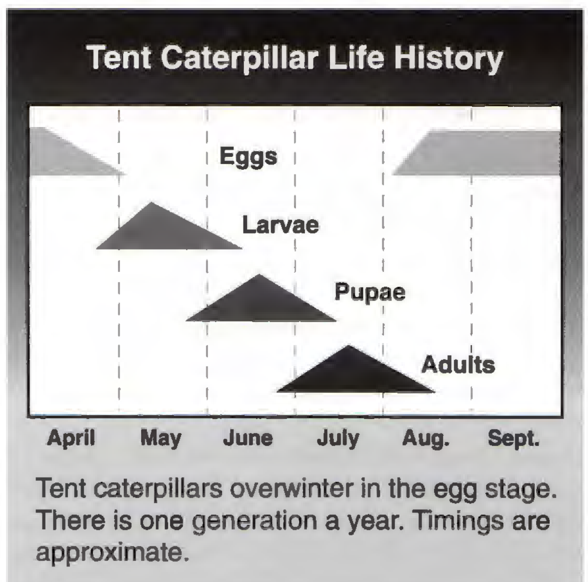


Figure 228

of tent caterpillars is great and probably accounts for much of the mortality in native habitats.

Management

Small tents of the western tent caterpillar can be pruned and removed from the orchard. Spot treatments with insecticides are also a viable option for control.

Fall webworm

Hyphantria cunea Drury

(Lepidoptera: Arctiidae)

The fall webworm is native to North America and is found throughout the United States, Canada and Mexico. It inflicts the most damage on shade trees, but can cause problems in apple and pear orchards. Its larvae spin large webs in the trees, which may enclose entire branches. The larvae are primarily leaf feeders, but if fruit is enclosed in the webs they will feed on it. These webs are formed in August, whereas those of the tent caterpillar appear in the spring.

Hosts

The fall webworm feeds on almost all fruit, forest and shade trees, except conifers.

Life stages

Eggs: The egg is round about 1/50 inch (0.5 mm) in diameter. It is pale green or yellow. Eggs are laid in masses on both sides of leaves and are partly covered with white hairs from the female's body.

Larva: The mature caterpillar is yellowish or tawny, with a dark stripe down the back and rows of distinctive black and orange-yellow tubercles on each side. The body is covered by long, fine, light colored hairs. When fully grown it is about 1 inch (25 mm) long (*Figure 229*).

Pupa: The reddish brown pupa is about ½ inch (12 mm) long.

Adult: The adult moth is satiny white, with long, soft hair, and may have brown or black spots on the wings. It measures 1 to 1¼ inches (25 to 30 mm) across with the wings expanded.

Life history

The fall webworm has one generation in the Pacific Northwest (*Figure 230*). It overwinters as a pupa in a cocoon under debris on the ground, in bark crevices, or in the soil. Adults emerge in summer and females deposit eggs on leaves in masses of 300 to 400. Eggs hatch in about 10 days. The young larvae live as a colony within balloon-like webs, which contain leaves on which they feed. The webs expand as the larvae grow and can measure up to 2 feet long. When almost full grown, caterpillars often feed outside the web at night. As food becomes scarce on a branch, caterpillars may migrate to another branch or tree. Larvae mature and pupate in the fall.

Damage

The larvae eat foliage and fruit within their webs. They can strip all the foliage off small trees, but usually attack only certain limbs or parts of limbs on larger trees (*Figure 231*). Larvae make broad, shallow feeding tracts on the fruit surface. Fruit on defoliated limbs may be stunted and shriveled.

Monitoring

Because of the webs, fall webworms are conspicuous even in small numbers.

Biological control

The fall webworm has many natural enemies including the braconid wasps *Meteorus hyphantria* and *Apanteles hyphantria*.

Figure 229: The caterpillar of the fall webworm has distinctive black and orange-yellow tubercles on each side.

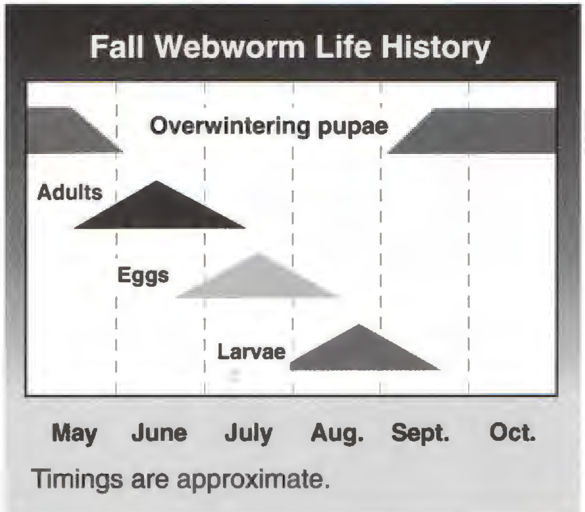


Figure 230

Figure 231: Larvae of the fall webworm eat foliage and fruit within their webs. They usually attack only certain limbs or parts of limbs on larger trees.

Management

Prune small webs out of the tree when they appear and dispose of by burning or freezing. Webs can also be spot treated with a hand gun or backpack sprayer. Fall webworm is susceptible to insecticides used for other fruit pests and is primarily a problem in young or unsprayed orchards. However, with increased use of mating disruption and other soft pesticide programs, this insect may become more common in commercial orchards.

Redhumped caterpillar

Schizura concinna (J. E.Smith)

(Lepidoptera: Notodontidae)

The redhumped caterpillar is found throughout the United States and Canada. Though not common in most orchards of the western United States, it is more often seen than the yellownecked caterpillar. In large numbers the caterpillars can severely defoliate trees.

Hosts

The redhumped caterpillar's wide range of hosts includes apple, pear, cherry, plum, apricot, blackberry and many forest trees.

Life stages

Egg: The egg is pearly white and almost round but slightly flattened.
Larva: The fully grown larva is about 1 to 1½ inches (25 to 35 mm) long. The head is a dull red, along with the hump on the first abdominal segment (just after the thorax), the reason for its common name. The body is a yellowish color with black and white stripes (*Figure 232*). There are black tubercles on the top of several body segments. When at rest, the larva will often raise its posterior tip.
Pupa: The pupa, a typical brown lepidopteran pupa, is found in a lightly woven cocoon under litter on the ground.
Adult: The adult redhumped caterpillar is an inconspicuous grayish brown moth.

Figure 232: The redhumped caterpillar larva is more than an inch long.

Life history

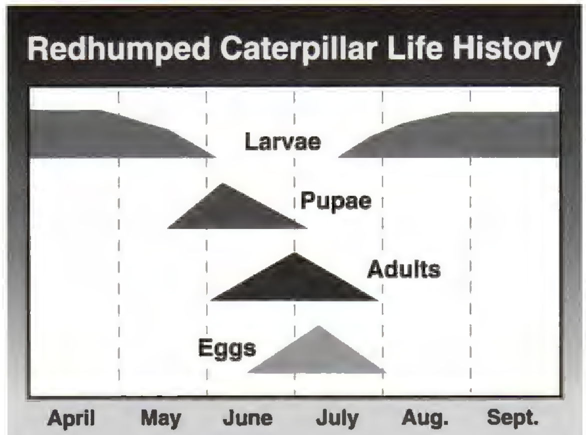
The redhumped caterpillar spends the winter as a full grown larva in a cocoon in the ground. It pupates in early summer and adult moths begin to emerge in June and July (*Figure 233*). Females lay eggs in clusters of 40 to 100 on the lower surfaces of leaves. Young larvae feed on the undersurfaces of leaves, but as they grow they consume entire leaves. Caterpillars from the same egg mass usually remain together on the same limb and feed in groups. They do not construct a tent or a nest. Caterpillars mature by August or September when they move to the ground and spin a cocoon under litter. The larvae remain in their cocoons during the winter. There is only one generation in the northern United States, though there may be two generations in the South.

Damage

Larvae of the redhumped caterpillar can consume large quantities of foliage in a relatively short time when they are nearly full grown. They strip all the leaf, leaving only the mid-vein, and may strip several branches on a tree before maturing (*Figure 234*). They do not attack the fruit and are not usually a problem on larger trees, but can completely defoliate a young tree.

Monitoring

The first sign of a redhumped caterpillar infestation is feeding damage. While few feeding sites are found in commercial fruit orchards, they may be more common in nurseries or orchards where few insecticides are used. Examine foliage for damage in late July or early August.



The redhumped caterpillar has only one generation in the northern United States, though two generations may occur in the South.

Figure 233

Figure 234: Larvae of the redhumped caterpillar strip leaves, leaving only the mid-veins and may strip several branches before maturing.

Biological control

Little is known about the potential for biological control of this pest. However, Ichneumonids in the genera *Enicospilus* and *Aphanistes*, and Braconids in the genera *Apanteles*, *Hypomicrogaster* and *Netelia* are reported to attack it. In addition 10 species of Tachinids have been reared from it.

Management

Insecticides used to control other fruit pests will usually keep the redhumped caterpillar under control. Spot treatments with insecticides is also a viable option.

Yellownecked caterpillar

Datana ministra Drury

(Lepidoptera: Notodontidae)

This insect is found throughout the United States and Canada on a wide variety of host plants. It is uncommon in most orchards of the western United States but is found periodically in large numbers. The reason for its normal scarcity and sudden appearance is poorly understood. It can cause severe damage when present in large numbers, but is easily controlled.

Hosts

Besides apple, pear, cherry and most other fruit trees, the yellownecked caterpillar also uses numerous shade and forest trees as hosts.

Life stages

Egg: The egg is small and round. It is light colored when first laid but turns darker. Eggs are laid in clusters of up to 100 on the undersides of leaves.

Larva: The young larva is chestnut brown with obscure darker stripes. The fully grown larva is almost 2 inches (50 mm) long, and has a bright yellow or orange band just behind the head. The body is distinctly striped black and yellow and is sparsely covered with long, whitish hairs. When disturbed, the caterpillar raises up both ends of its body, clinging to the plant with only its abdominal prolegs (Figure 235).

Pupa: The pupa is brown and about 1 inch (25 mm) long. It is found in the soil.

Adult: The yellownecked caterpillar moth is a cinnamon brown color with 3 or 4 dark lines crossing each wing. The thorax is a reddish brown and the hind wings are a pale straw color.

Yellownecked Caterpillar

When at rest, the yellownecked caterpillar stands only on its four middle pairs of legs with both extremities raised. If disturbed, the caterpillar jerks up its head and tail until they almost meet.

Figure 235

Yellownecked Caterpillar Life History

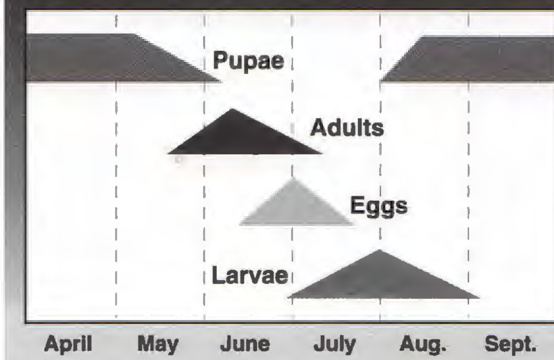


Figure 236

Life history

The yellownecked caterpillar spends the winter in the ground as a pupa. Adults appear in June and July, and fly to host trees where they deposit egg masses. Eggs hatch in 10 to 14 days and the young larvae remain on the same leaf, all feeding with their heads pointing towards the edge of the leaf. They skeletonize the underside of the leaf until they molt to the next instar, at which time they move to other leaves and begin consuming the entire leaf, eating from the edge inward. They tend to remain together as a colony, but do not produce a web, as does the tent caterpillar or fall webworm. The larvae mature in about three weeks. They then burrow 2 or 3 inches into the ground and pupate. The caterpillar has only one generation per year (*Figure 236*).

Damage

Larvae of the yellownecked caterpillar can consume large quantities of foliage. They strip the leaf, leaving only the mid-vein, and may strip several branches on a tree before maturing. This is not often a problem on larger trees, but a young tree can be defoliated.

Monitoring

The first sign that the yellownecked caterpillar may be in the orchard is usually feeding damage. While few such sites are found in commercial fruit orchards, they may be common in nurseries or in orchards where few insecticides are used. Examine foliage in late July or early August.

Management

Insecticides used to control other fruit pests will usually keep the yellownecked caterpillar under control. If infestations are detected early, before larvae have grown and spread, colonies can be cut out of the tree, removed from the orchard and destroyed.

Figure 237: Egg masses turn from light yellow to bright red.

Apple ermine moth

Yponomeuta malinellus (Linnaeus)

(Lepidoptera: Yponomeutidae)

Apple ermine moth originated in Eurasia. It was identified in British Columbia in 1981 and was first found in the United States in Bellingham, Washington, in 1985. By 1992 the pest had spread throughout Washington and northern Oregon. Its larvae feed mainly on leaves and can seriously defoliate apple trees. It primarily attacks abandoned and neglected backyard trees, but could be a threat to commercial orchards using non-conventional pest control techniques such as mating disruption.

Figure 238: The larva is a gray, green or cream caterpillar with dark spots along its sides.

Hosts

Apple ermine moth attacks apple and crab apple (*Malus* spp.)

Life stages

Egg: Freshly laid egg masses are light yellow. They change to bright red within about two weeks, then fade to a cryptic gray, which is difficult to see on apple tree bark (*Figure 237*).

Larva: The larva is a caterpillar varying from gray to dark green or cream in color, with dark spots along its sides. It develops through five instars and when mature is about ¾ inch long. The caterpillars feed within a communal web (*Figure 238*).

Pupa: The pupae, which have white cocoons, hang in clusters within the web (*Figure 239*).

Adult: The adult has silvery white forewings with rows of small black spots. Its wingspan is about ¾ inch (*Figure 240*).

Figure 239: Pupae are inside white cocoons suspended in clusters within the web.

Figure 240: The apple ermine moth has silvery-white forewings with small black spots.

Life history

Apple ermine moths overwinter as young larvae underneath egg masses that the females deposited on tree bark the previous summer. The larvae sometimes feed on bark under the egg mass. In early spring, larvae emerge from the protective covering, or hibernaculum, and move to nearby developing leaves (*Figure 241*). At first, they mine the leaves, but towards the end of the bloom period they begin to feed within communal webs, like tent caterpillars. The webs expand to engulf more and more leaves, and can be as large as a tennis ball. Apple ermine moth caterpillars may spin several tents in each tree, whereas the tent caterpillar may produce one or very few large ones.

The larvae continue feeding in this fashion until June, when they pupate. Pupating caterpillars line themselves up neatly in tightly packed clusters. Adult moths begin to emerge in June and females lay eggs from July into September.

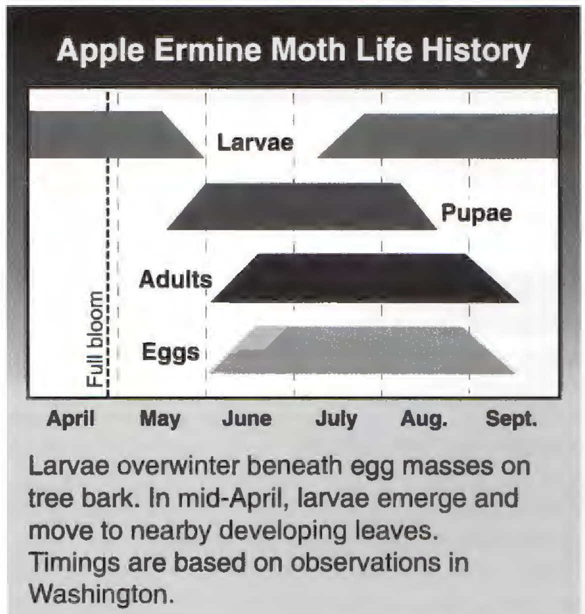


Figure 241

Damage

If tents and larvae are numerous enough, a tree can be seriously defoliated.

Monitoring

The best way to detect apple ermine moth is to trap adults. Bait wing traps with the commercially available apple ermine moth sex pheromone and place shoulder high in apple or crab apple trees. Check every 2 weeks to avoid damage to the wing pattern by stickum. Change the lure every six weeks, or more often in hot weather. The lure is effective only within about 200 feet. In May and June you can see webs containing larvae and pupae. The webs are about the size of a tennis ball or smaller and can be difficult to detect without close scrutiny, especially in large trees. Look for a gold cast on leaves that have been mined within the web. Do not confuse these webs with those of the tent caterpillar, which get much larger and extend along the branch. Searching for overwintering egg masses on the bark during fall and winter is not recommended, as the color of the hibernaculum blends in well with the bark.

Biological control

Generalist predators such as tachinid flies, birds and spiders can help control apple ermine moth. One of the moth's most important parasites, *Ageniaspis fuscicollis*, a wasp from Eurasia, has been introduced and established in the Bellingham area of Washington to reduce populations and slow its spread.

Management

Apple ermine moth is not a threat where broad-spectrum insecticides are used regularly but could be a persistent pest in orchards where codling moth is controlled by mating disruption. Tents with caterpillars inside can be removed from the tree and disposed of if they are easily accessible and not too numerous. The best time for this is May. Most chemicals used to control tent caterpillars or leafrollers should control apple ermine moth also. The bacterial insecticide Bt (*Bacillus thuringiensis*) gives good control if applied to actively feeding caterpillars in April and May.

Rain beetles

Pleocoma crinita
Pleocoma minor
Pleocoma oregonensis
(Coleoptera: Scarabaeidae)

Rain beetles is the collective name for the small group of beetles in the genus *Pleocoma*. These beetles are found only in western North America. The above species have been found in fruit-growing areas in the Pacific Northwest. Adults are called rain beetles because they usually fly after fall rains. The larvae are called white grubs. They feed on roots of forest and orchard trees.

Root damage to fruit trees in California by *Pleocoma* larvae was reported in the 1920s and 1930s. An orchard survey in the Mid-Columbia area of northern Oregon and southern Washington in 1953 found that rain beetle grubs seriously damaged roots on bearing trees and made it difficult to establish new plantings. Populations of five or more larvae per square foot have been found in some orchards in northwest Oregon. Affected trees go into slow decline.

Hosts

Pleocoma larvae will attack most deciduous fruit trees. Root damage by rain beetle larvae has been reported in apple, pear and other orchard trees in California, and in apple, pear and cherry trees in the Mid-Columbia area. Native hosts in the Mid-Columbia area include Douglas fir, Ponderosa pine, white fir, white oak, Oregon maple, vine maple and black cottonwood. *P. oregonensis* also feeds on sagebrush.

Life stages

Egg: The egg is white with a yellowish tinge and has a smooth, dull surface. It is oval and is usually about 1/6 inch (4.5mm) long.

Larva: The larva is grub-like with a curved, whitish body and pale yellow-brown head. Mature larvae are from 1¾ to 2¼ inches (45 to 55 cm) long. In the prepupal stage they are creamy white, flaccid and immobile *(Figure 242)*.

Pupa: The female pupa is white and measures from 1½ to 1¾ inches (35 to 45 mm) long, depending on the species. The male pupa is generally smaller.

Adult: The adult is a typical scarabaeid beetle with strong legs for digging (*Figure 243*). It is dark or reddish brown and hairy. Its antennae have oval clubs at the end made up of several lamellae, or plate-like structures. The male's antennae have longer lamellae than the female's. The female *P. oregonensis* is about ⅞ to 1 inch (22 to 25 mm) long. Female *P. crinita* and *P. minor* are about ⅝ inch (15 mm) long. Males are smaller than females.

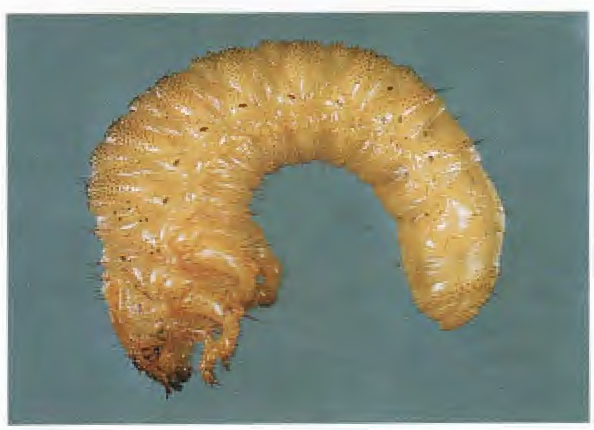


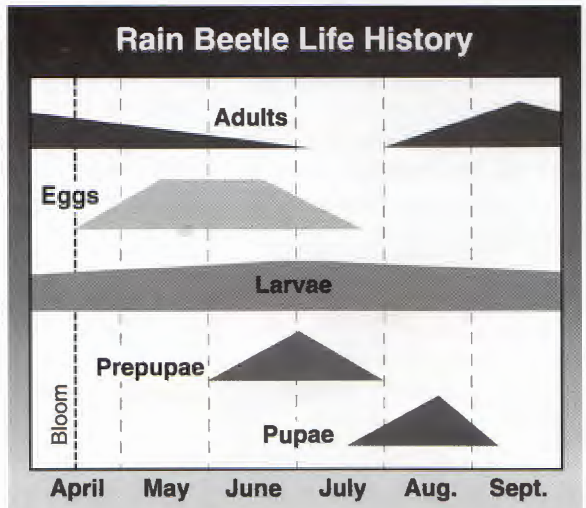
Figure 242: The grub-like larva is about 2 inches long.

Life history

Rain beetles appear in the field at different times according to species. Generally, pupae transform to adults in August and September, when beetles leave their pupal cells and burrow to the surface. Adults can live for many months, but do not feed. Only male beetles can fly. After surfacing, the wingless females reenter their burrows a short distance or dig new holes where they wait for males. Males fly in the early morning and after fall rains. They are attracted to females in their burrows by a sex pheromone given off by females.

After mating, females move deeper in the soil. They start laying eggs in April and continue until early July. Eggs are laid in a spiral pattern in the burrow from 10 to 30 inches (25 to 75 cm) deep. A females produces up to 60 eggs. Eggs hatch from July to August. Larvae molt only once a year and remain as larvae for 9 to 13 years before they pupate.

When mature, the larvae build pupal cells and enter an inactive prepupal stage. Pupae form between late June and mid-August. The pupal stage lasts from 40 to 50 days (*Figure 244*).



Larvae are always present, as they live for 9 to 13 years. Timings based on observations on pear in northern Oregon.

Figure 244

Damage

Larvae live in the soil in the root zone and feed on fibrous roots, main roots and underground portions of the trunk. Feeding injury may be shallow or deep and looks like patches or winding bands on the root. Affected bearing fruit trees are low in vigor and have sparse foliage and low yields.

Figure 243: Rain beetle females (right) are larger than males and have no wings.

Monitoring

Male *Pleocoma* beetles are attracted to light when they emerge. Blacklight traps can be used to determine their distribution and to track flight periods. The only way to find *Pleocoma* larvae in the soil is to dig down to the root zone where most larvae feed and examine roots for damage. Densities are expressed in terms of the number of larvae per square foot of soil. The soil should be checked if trees show signs of stress and other possible reasons for poor vigor have been eliminated. It is particularly important to inspect the soil and roots for larvae and feeding damage in woodland that is being converted to orchard or in old orchards that are being replanted.

Biological control

Rodents, such as moles, shrews and field mice feed on larvae. Raccoons and skunks are effective predators of adult rain beetles.

Management

Rain beetles are difficult to control in established orchards. Chemical control of adult beetles has not proven successful, but fumigation of grub-infested soil with methyl bromide has been effective in small replant areas. The success of this treatment depends on soil type and moisture. The fumigant penetrates best in dry, light soils. The injector should reach down 4 feet. Apply water to the soil surface after fumigation to create a mud cap and prevent the fumigant escaping. With time, fumigated soil may become infested again as larvae move into the area.

The best time to control rain beetle larvae is before an orchard is planted. Old orchard that is being replanted or woodland that is being converted to orchards should be fumigated if the soil is infested and the trees are to be planted within a year of clearing the land.

Fumigation may not be necessary if the land is allowed to lay fallow for a time or if it is planted with a crop that is not a host, such as alfalfa or cereals, before the orchard is established. However, it is not known how long larvae can survive in the soil without food.

Tenlined June beetle

Polyphylla decemlineata (Say)

(Coleoptera: Scarabaeidae)

The tenlined June beetle is widely found in sandy soils west of the Rocky Mountains. Larvae feed on plant roots and can weaken or kill the plant. Adults feed on foliage but do not cause economic damage to fruit trees. Infestations spread slowly because of a lack of movement by mated females and the long time span of each generation, which can be up to four years in the Northwest.

Hosts

Hosts of the tenlined June beetle larvae probably include all deciduous tree fruits grown in the Pacific Northwest. Infestations in Washington tree fruits have mostly been associated with apple. The tenlined June beetle has also been well studied as a pest of almonds in California. Other hosts include strawberries, cane fruits, roses, potatoes, corn, and possibly willow and poplar.

In Washington, grubs have been found in areas of sagebrush on sandy soils, although the exact hosts are undetermined. Adults feed on leaves of many broadleaf trees and some conifers.

Life stages

Egg: Eggs are large, oval and a dull, creamy white. They can measure up to ⅙ inch (4 mm) long.

Larva: The grub is a typical C-shaped scarab larvae. The first instar is less than ½ inch (12 mm) long, while the full-grown third instar is 1 to 2 inches (25 to 50 mm). It has a brown head and three pairs of legs on the thorax. The dark brown contents of the gut can often be seen through the exoskeleton at the tip of the abdomen (*Figure 245*).

Pupa: The pupa is preceded by a prepupal stage. The pupa is cream to light tan, about 1½ inches (25 mm) long, with external wing pads.

Adult: The adult beetle is ¾ to 1½ inches (20 to 35 mm) long. It is brown with conspicuous white stripes on the elytra, pronotum and head. Its antennae are distinctly clubbed (*Figure 246*). On the male, the lamellae of the club are long, flat, tongue-shaped plates and the club is one and a half times as long as the rest of the antennae. The female has a shorter, more compact club, about ½ to ⅓ as long as the rest of the antenna.

Life history

The larval period can last 2 to 4 years in the Northwest, depending on the site and the length of the growing season. Most older grubs are found in the top foot of the soil, where they feed on woody roots, while younger grubs live deeper in the soil and eat the finer and more tender roots. Most of the damage to the tree is done by the older grubs. The grubs begin to pupate in May and June in pupal

Figure 245: The larva has a brown head and three pairs of legs.

cells a few inches below the soil surface. The cells are about 2 inches (50 mm) long and ¾ inch (18 mm) wide. The pupal period lasts about 5 weeks. Adult activity begins in June or July and continues until fall (*Figure 247*). The adult bores an emergence hole from the pupal cell to the soil surface, but may not emerge immediately. Adults stay under cover during the day, hiding in weeds or grass in the orchard. They make a peculiar wheezy, hissing noise when disturbed. They become active around dusk and are active longer on warm nights. There is little activity when temperatures are below 60°F. Males are attracted to females by a sex pheromone. They mate at or near the female's emergence hole, and she often lays eggs in the same hole. Dispersal of females may be very limited.

Females lay 60 to 70 eggs in the soil. The eggs hatch in about 3 to 4 weeks. Young larvae feed on decaying vegetable matter or fine roots. They take 3 to 4 years to develop fully. In cold-winter climates, larvae may move deeper in the soil to avoid frost, and move closer to the surface again in the spring to continue feeding.

Damage

The grubs' feeding on the roots can weaken or kill the tree. Adults feed on plant foliage, but cause little damage.

Monitoring

Problems with tenlined June beetle have most often occurred when a sandy, virgin soil, formerly with sagebrush as the dominant plant, has been planted to orchard. Young trees in this situation that grow poorly, despite adequate irrigation and nutrients, should be examined for grubs. An untreated problem may persist many years after the orchard is planted. Severely affected trees can sometimes be pulled easily from the ground, because there are no longer enough roots to anchor them. Sample several trees that appear to be stunted or water stressed. Dig up an area around the tree about 3 feet in diameter and a foot deep, and sift through the soil and roots for grubs. With older trees, dig a trench in the herbicide strip in the tree's root zone and look for grubs.

Adult males can be monitored with a blacklight trap and will also be attracted to ordinary lights during flight. They can be found in large numbers gathered around lights in heavily infested areas in mid- to late summer.

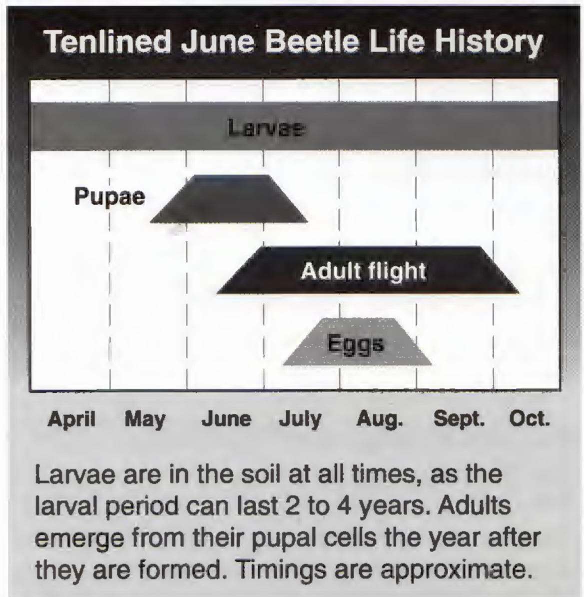


Figure 247

Figure 246: The beetle has conspicuous white stripes on its head, pronotum and wing covers.

Biological control

Birds eat exposed grubs, while bats and owls attack adults. The grubs are parasitized by a large tiphiid wasp and adults are parasitized by the flesh fly.

Management

Check for grubs when planting trees into virgin soil where sagebrush has grown. In unirrigated soil, the grubs may have moved down deep to obtain moisture. Where feasible, tilling the soil when grubs are near the surface in spring and summer helps expose them to predators and parasites. Where infestations are severe, trees may have to be removed and the soil fumigated.

Pear leafcurling midge

Dasyneura pyri Bouché

(Diptera: Cecidomyiidae)

The pear leafcurling midge is of European origin. It was first detected in New York in 1931 and has since spread to other pear growing areas of North America including the Pacific Northwest. Although pear leafcurling midge has not become a major annual pest in commercial orchards in the Northwest, it can cause concern in nurseries or new plantings. It attacks growing terminals and damages the leaves. On young trees with few terminals it can stunt growth.

Hosts

The pear leafcurling midge is a pest only on pear. A closely related species, the apple leaf curling midge, *Dasyneura mali*, causes similar leaf damage on apple trees in Europe, but has not been introduced into North America. Pear varieties differ in susceptibility to attack by the pear leafcurling midge. Clapps Favorite, Red Bartlett and Alexander appear to be very susceptible; d'Anjou, Bosc and Bartlett moderately susceptible; and Conference and Passe Crassane slightly susceptible. Young trees and vigorous older trees with excessive terminal growth are particularly susceptible to attack.

Life stages

Egg: The egg is yellow, elongated and about $\frac{1}{100}$ inch (0.3 mm) long. A bright red eye spot appears soon after an egg is laid.

Larva: The small, legless larva is orange at first but later turns white. The mature maggot is $\frac{1}{12}$ inch (2 mm) long and develops into a small brown pupa.

Pupa: The pupa is roughly the same size as the mature maggot, and is brown and cylindrical.

Adult: The adult is a gray midge (small fly) and measures $\frac{1}{25}$ to $\frac{1}{12}$ inch (1 to 2 mm) long.

Life history

The pear leafcurling midge overwinters as a pupa in the soil. Adults begin to emerge around bloom time and lay eggs on young, still unfolded leaves. Larvae hatch from eggs after 3 to 5 days and feed on leaves. Infested leaves can harbor up to 30 larvae. After feeding within the curled leaves for about two weeks, larvae make exit holes and drop to the ground where they pupate in the top 1 or 2 inches ($2\frac{1}{2}$ to 5 cm) of soil. The number of generations in an area depends on seasonal temperature and on the amount of terminal growth, as eggs are laid only on newly developed leaves. There are 4 or 5 generations in most pear growing areas of the Pacific Northwest (*Figure 248*). On long shoots, infested and healthy leaves alternate, indicating the number of completed generations.

Damage

Feeding by larvae curls infested leaves. Affected leaves are tightly rolled parallel to the midrib and have red, gall-like swellings. Later, infested leaves turn black and fall. Extensive feeding damage can stunt young trees. It is of less concern on mature trees, where excess vegetative growth is not desirable.

Monitoring

Adult midges appear on developing foliage at bloom time. However, because of their small size they are easily overlooked, especially when their density is low. Yellow sticky boards placed in the tree canopy may be useful for monitoring adults.

Leaves infested by larvae are easily recognized by the characteristic damage symptoms. No treatment thresholds are available for this pest. However, thresholds used for apple aphid on pears can be used for pear leafcurling midge infestations as both pests attack growing terminals.

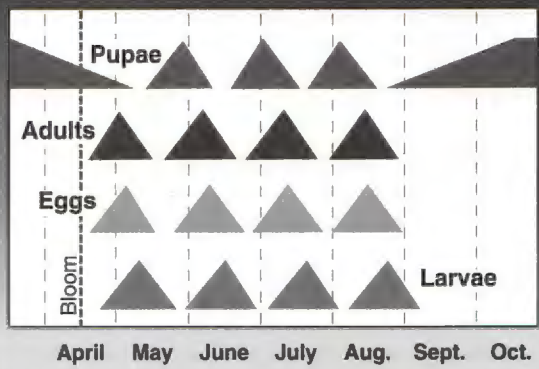
Biological control

Little is known about natural enemies of the pear leafcurling midge. Leaves curled by the larva provide shelter for generalist predators such as predaceous bugs and ladybird beetles, which contribute to biological control of pear psylla and other pests.

Management

This pest is not common, and should not be a consideration in most pest management programs.

Pear Leafcurling Midge Life History



Timings based on observations in Hood River, Oregon.

Figure 248

Where infestations are severe, especially on young trees, control may be considered. The midge can be controlled with post-bloom applications of organophosphate insecticides. The first spray should be applied at or shortly after the petal fall stage to control adult midges and young maggots. Subsequent sprays should be timed to coincide with adult emergence and egg laying of later generations.

GRASSHOPPERS

(Orthoptera: Locustidae)

Redlegged grasshopper

Melanoplus femur-rubrum (De Geer)

Clearwinged grasshopper

Camnula pellucida (Scudder)

Migratory grasshopper

Melanoplus sanguinipes (Fabricius)

Although there are more than 100 species of grasshoppers in Washington, few damage crops. The redlegged, clearwinged and migratory grasshoppers are the species most likely to be found in orchards in the Pacific Northwest. The redlegged grasshopper is one of the most common species of grasshopper and has the widest geographical distribution. It is found anywhere from the Arctic Circle to Central America. Grasshoppers, also known as locusts, are very destructive insects and are sporadic orchard pests. They can strip trees of foliage and may damage fruit and small wood. Young trees are particularly vulnerable.

Major outbreaks only occur when conditions are ideal for their growth and development, usually only once every 7 to 10 years. Populations build up slowly so it is fairly easy to predict bad grasshopper years. Outbreaks are worst when spring weather is warm and dry, and predators, parasites and diseases of grasshoppers are at low levels.

Hosts

The **redlegged** grasshopper feeds on many fruit trees, grasses, grains, field and forage crops, vines and native plants. It prefers low, moist ground. The **clearwinged** grasshopper usually feeds in meadows at over 2,000 feet in elevation. The **migratory** grasshopper is particularly destructive to small grains and alfalfa, but will also attack tree fruits. It can fly long distances in search of food.

Life stages

Egg: The egg is white and elongate.

Nymph: The nymph is similar to the adult but without wings.

Adult: The **redlegged** grasshopper is ¾ to 1 inch (18 to 25 mm) long. It is gray-green to yellow brown above, and is yellow beneath (*Figure 249*).

Figure 249: The redlegged grasshopper is gray-green to yellow-brown and has distinctive red hind legs.

The hind tibiae (*Figure 250*) are red. The similar-sized **clearwinged** grasshopper is slender and light brown with dark markings. Its hind wings are transparent. The femur is yellowish brown with 2 or 3 darker bars. The **migratory** grasshopper is 1 to ½ inches (25 to 37 mm) long. It is grayish to reddish brown above and yellow beneath. It has dark flecks in the center of the forewing.

Grasshopper Leg

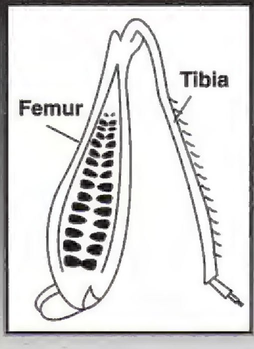
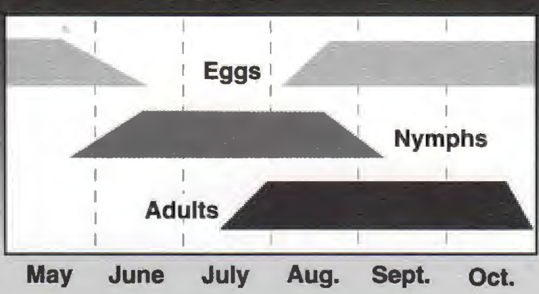


Figure 250

Life history

There is usually one generation annually, although a partial second generation may develop some years (*Figure 251*). After the grasshoppers mate in late summer, females lay eggs in the ground in masses with a gummy coating that hardens and binds them together. The coating protects the eggs from cold during the winter. Eggs hatch in May and June. Nymphs develop through five or six instars, during which they shed their skins, and mature in summer or fall, about 40 days after hatching. Adults continue to feed and lay eggs until they are killed by cold weather. Only adults can fly.

Grasshopper Life History



Only adult grasshoppers can fly. They move into orchards from breeding grounds in late summer. Timings are approximate.

Figure 251

Most grasshoppers live in the same general area throughout the year and are non-migratory. The redlegged grasshopper makes rapid flights of only about 10 to 30 feet. They often breed in sagebrush surrounding orchards or along ditch banks and move into orchards in late summer when the grass begins to dry up. Migratory species are stronger fliers. They leave their breeding grounds when the wings are fully developed and migrate in vast swarms, setting in orchards or other cultivated areas, often devastating everything in their path.

Grasshoppers are voracious eaters and have powerful jaws and sharp mandibles for chewing up all kinds of plant life. They particularly like grasses and flowering plants.

Damage

Feeding damage increases as the young grasshoppers mature. Grasshoppers will strip trees of foliage. Damaged trees may be more prone to winter injury.

Monitoring

Look in summer for feeding damage around or on the borders of the orchard.

Biological control

Grasshoppers have many natural enemies that play an important part in keeping them in check. Eggs are destroyed by some species of pediculid mites, parasitic wasps and flies, and the larvae of many predatory insects.

Nymphs and adults are preyed upon by wasps, ground beetles and robber flies. Some parasitoids, such as hairworms and tachinid and flesh flies attack nymphs and adults. Diseases can also keep populations down.

Management

Many chemicals used in orchards will kill grasshoppers. Insecticides are most effective against young grasshoppers. The best strategy is to control grasshoppers in the nymphal stages by spraying or baiting areas around the orchard.

Natural Enemies and Pollinators

Natural enemies are divided into two main groups: predators and parasites.

A **predator** lives by capturing and feeding on another species. Predators are usually larger and more powerful than their prey. Both adults and immature stages feed by devouring the prey or sucking the body juices. They can quickly destroy many pest insects or mites, but may also require high pest populations to continue to survive.

A **parasite** lives in, on or with another organism and obtains food and usually shelter at the host's expense. An example of a parasite are the fleas that live on a dog. An insect that parasitizes other insects is most appropriately called a **parasitoid.** This term defines an organism that is parasitic in its immature stages but is free-living as an adult. Unlike a predator, a parasitoid kills its host over a long period of time and needs only one individual host to complete development. For example, a parasitic wasp might lay an egg in a caterpillar. The wasp larva hatches inside the caterpillar and feeds at first only on its fatty tissue, allowing the host to continue to grow and develop. As the wasp larva nears the end of its development, it feeds on the caterpillar's vital organs, killing it. After leaving the remains of its victim, the wasp larva pupates and later emerges as an adult. Most parasitoids attack only one or a few host species. Predators generally attack a wider range of insects.

Monitoring

Natural enemies can be monitored while sampling for pests. For example, predatory mites can be counted in leaf brushing samples collected for spider mites, and parasitism of tentiform leafminer can be determined during field counts of leafminer densities. A beating tray sample is a useful way to estimate the abundance of several kinds of predators. Predators are usually sampled using a beating tray or counted while sampling for other pests. Their periods of highest activity are outlined in *Figure 252*. Successive samples can show how pest populations are changing in relation to their natural enemies.

Management

Use control tactics that are the least harmful to natural enemies. If insecticides must be used, select those that are known to be less toxic to predators and parasitoids. Spray when pests are most vulnerable and natural enemies are least vulnerable. For example, insecticides applied early in the growing season, before many natural enemies have become active or moved into the orchard, tend to be less disruptive than those applied later in the summer. Biological control can be promoted as an important tactic in pest management by using reduced rates where possible and spot treatments or delayed applications when it appears natural enemies might be able to provide control.

Natural enemies can be established or reestablished in the orchard more easily when natural habitat is provided near the orchard as a refuge. However, there is also the risk that natural habitats will be sources of pest infestations. Several species of predators and parasitoids can be bought for release in orchards. A list of the names and addresses of suppliers of natural enemies in North America can be obtained by contacting the California Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management, 1220 N Street, P. O. Box 942871, Sacramento, California 94271-0001.

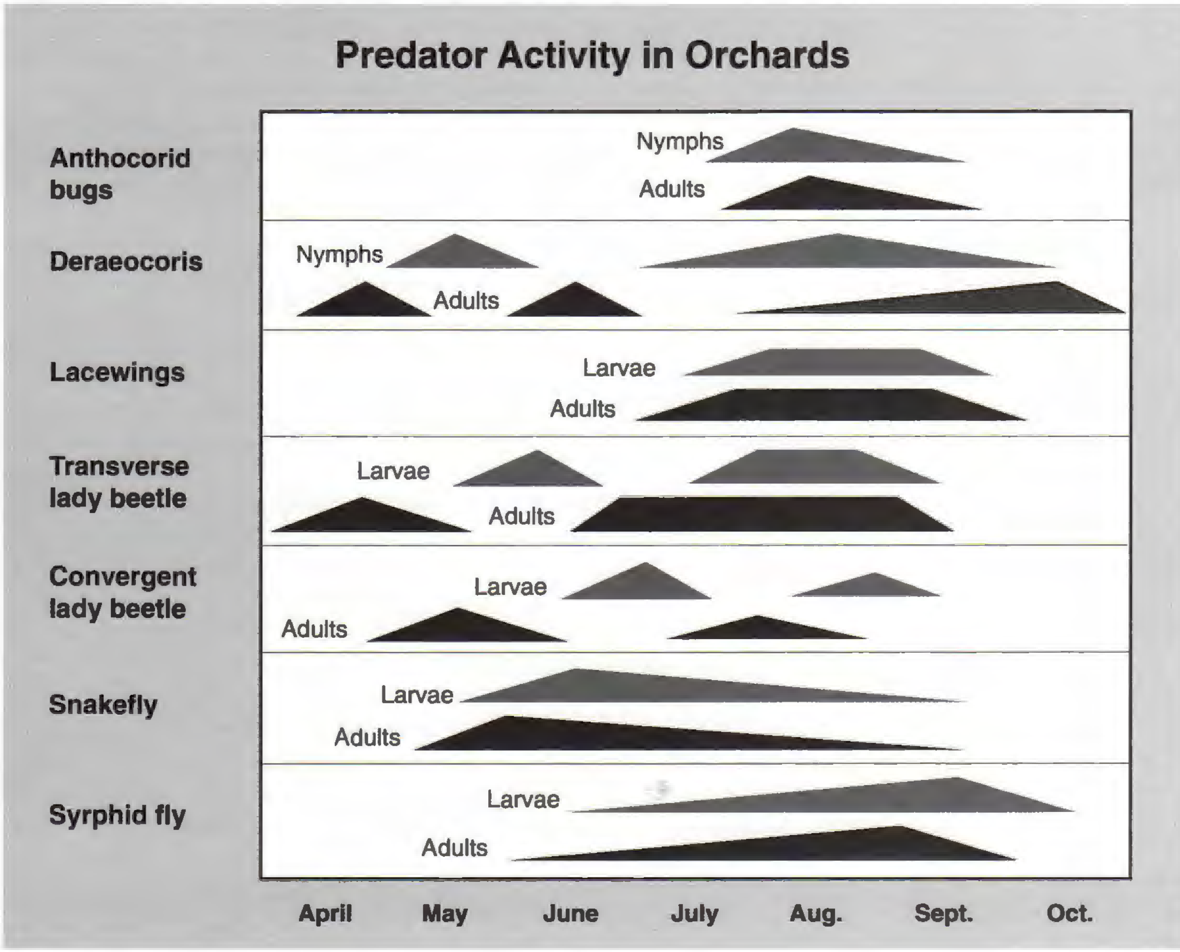

Predator Activity in Orchards
Anthocorid bugs
Nymphs
Adults
Deraeocoris
Nymphs
Adults
Lacewings
Larvae
Adults
Transverse lady beetle
Larvae
Adults
Convergent lady beetle
Larvae
Adults
Snakefly
Larvae
Adults
Syrphid fly
Larvae
Adults
April
May
June
July
Aug.
Sept.
Oct.

Figure 252

PREDATORS

Green lacewings

Chrysoperla carnea (Stephens)
Chrysopa nigricornis Burmeister
(Neuroptera: Chrysopidae)

Brown lacewings

Hemerobius humulinus Linnaeus
Hemerobius neadelphyus Gurney
Meleoma dolichartha (Navas)
Micromus variolosus Hagen
(Neuroptera: Hemerobiidae)

The lacewings listed here, and other less common species, are important natural enemies native to the Pacific Northwest. Green lacewings are widely distributed and are important generalist predators. They are often abundant in orchards where IPM is practiced and feed on a variety of insects. Although less well known, brown lacewings can also become abundant in orchards where soft pesticide programs are used. Lacewing larvae are active earlier in the season than many other predators and are good biological control agents for early season pests. Inundative releases of lacewings have been used to control mealybugs and variegated leafhoppers in California.

Hosts

Both green and brown lacewing larvae prey mostly on aphids but also attack scale insects, mealybugs, leafhoppers, thrips, mites, pear psylla and many other small sedentary insects. Adults of *Chrysopa nigricornis* are also carnivorous, but adults of most species feed on aphid honeydew and plant fluids.

Life stages

Green lacewings:

Egg: The egg is green or white and oval, and is suspended on a long, hair-like stalk. The egg is about 1/50 inch (0.5 mm) long, while the stalk is about 1/4 inch (6 mm) (*Figure 253*). Eggs are laid singly or in groups.

Larva: The larva's alligator shaped body is yellow

Figure 253: Green lacewing eggs are suspended on long stalks and are laid singly or in groups.

Figure 254: The lacewing larva is alligator shaped.

Figure 255: The adult has large, lace-like wings.

or mottled gray with red or brown and has clumps of bristles. Its prominent sickle-like mandibles, or jaws, are longer than the head and are used to capture the prey and extract the body juices (*Figure 254*). The larva develops through five instars and is about ⅗ inch (15 mm) long when mature.

Pupa: The larva pupates in an opaque white or yellow tightly woven, spherical cocoon. The pupa is green with many features visible externally.

Adult: The adult is mostly green with gold markings and large, lace-like wings (*Figure 255*). It is about ⅗ to ¾ inch (15 to 20 mm) long. Its flight is fluttery and weak.

Brown lacewings:

Egg: The egg is pink or white and does not have a stalk. Eggs are attached to the leaf surface and are less noticeable than green lacewing eggs.

Larva: The body is alligator shaped but narrower than that of the green lacewing. It has few bristles and the mandibles are shorter than the head. It is white at first, but turns brown as it matures.

Pupa: The cocoon is loosely woven and transparent.

Adult: The adult is brown, beige or dark green with lace-like wings covered with hairs. At ⅜ to ½ inch (10 to 12 mm) long, it is smaller than the green lacewing.

Life history

Most lacewings complete 3 or 4 generations per year in the Pacific Northwest. As different species develop at different rates, all life stages may be present during the late season. Most lacewings overwinter as pupae in cocoons, although *Chrysoperla carnea* overwinters as an adult. Adults emerge in early spring and disperse. Breeding continues throughout the summer.

Monitoring

Lacewing adults and larvae can be monitored in orchards with beating trays. The active adults are best sampled in the cool morning hours. The number of lacewing larvae needed for effective pest control has not been established Larvae can be most easily detected by examining active aphid colonies on the undersides of leaves. Eggs are usually laid near aphid colonies, and can be monitored at the same time as the larvae.

Management

Lacewing adults will move into the orchard from uncultivated vegetation. To augment local populations of lacewings, preserve unsprayed vegetation near the orchard. Eggs of *Chrysopa* spp. are available commercially for mass release. Because of the tendency of adults to disperse after they emerge, introduction of eggs or larvae is more effective than adults. Adults of most species are attracted to honeydew rather than the pest.

Snakeflies

(Neuroptera: Raphidiidae)
(Neuroptera: Inocelliidae)

Snakeflies are related to lacewings. The adult has a long thorax and is able to raise the head above the rest of the body, which gives it the appearance of a snake ready to strike. Snakeflies are found only in western North America. Larvae live under the bark of forest, ornamental and fruit trees and can be very helpful predators in fruit orchards. Adults also are predaceous.

Hosts

Larvae feed on wood-boring insects, small insects such as aphids and caterpillars, and various insect eggs. Snakefly adults feed on aphids or other small, weak prey. In pear orchards, they are important predators of pear psylla, especially in the early season.

Figure 256: The snakefly feeds on small prey.

Life stages

Egg: The egg is elongated and cylindrical with a small appendage at one end.

Larva: The larva is long and flattened with a black shiny head and prothorax and three pairs of legs. It can be from ½ to almost 1 inch (12 to 25 mm) long and is a mottled reddish or grayish color.

Pupa: The pupa is active and not enclosed in a cocoon.

Adult: Snakeflies have four membranous wings, which are held rooflike over the body when at rest (*Figure 256*). The wings, which have many veins, are from ¼ to ⅔ inch (6 to 17 mm) long. The prothorax is elongated. The female is usually slightly larger than the male and has a long, tail-like ovipositor.

Life history

Most species have one generation a year, but take 2 to 3 years to complete their life cycle. The larva overwinters in a small depression on the bark surface covered by small pieces of bark. After pupation under the bark, adults emerge and disperse in search of prey. They can be seen in orchards throughout the season.

Eggs are laid in clusters in bark crevices. Larvae are usually found under the bark in galleries of various wood-boring insects. They also feed on small insects such as aphids, caterpillars and insect eggs deposited on the bark.

Monitoring

A beating tray is only moderately effective for monitoring snakeflies, since adults are fairly active and often will not drop when a limb is tapped. However, because of their large size and unusual appearance, adult snakeflies are easy to see on the foliage.

Management

Snakeflies are most likely to be found in orchards where woodland or wild habitat is close by. As larvae feed on wood-boring insects, maintaining unsprayed vegetation close to the orchard that is infested with such insects will provide snakeflies with an additional food source. However, there is the risk that the wood-boring insects will also invade the orchard.

LADY BEETLES

(Coleoptera: Coccinellidae)

About 400 species of lady beetles are found in North America. Several species have been introduced to control pests. Almost all lady beetles prey, as both larvae and adults, on soft-bodied pests, such as aphids, mites and scales.

One larva can consume hundreds of prey during its development. Because of their voracious appetites and ability to multiply rapidly, lady beetles can control even large infestations of pests. They are important predators of orchard pests, especially aphids. The two most common species in the Northwest are the convergent and transverse lady beetles.

Convergent lady beetle

Hippodamia convergens Guérin-Méneville

Hosts

Larvae and adults will feed on most small, soft-bodied insects, but prefer aphids.

Life stages

Eggs: The egg is bright yellow, elongated and pointed at one end. It is about $\frac{1}{16}$ inch (1.5 mm) long. Eggs are laid in clusters, usually on the bark or leaves of tree infested with prey (*Figure 257*).

Larva: The alligator shaped larva is dark gray with two small, often indistinct, orange spots on the prothorax and four larger ones on the back. It develops through four instars and when mature is between ¼ and ⅜ inch (7 to 10 mm) long.

Pupa: The pupa is orange and black and almost hemispherical. It is most often found attached to the upper surface of a leaf.

Adult: The adult is ¼ inch (6 to 8 mm) long. While the body is black, the forewings, which cover most of the body, are orange to red with 12 black spots. Just in front of the forewings, or elytra, is the prothorax, which is black with two oblique (converging) white stripes and white edges (*Figure 258*). Its small head is almost covered by the front of the thorax. Legs and antennae are short.

Figure 257: Lady beetle eggs are spindle shaped and are laid in clusters.

Figure 258: The convergent lady beetle adult has 12 black spots on the elytra, and two convergent white stripes on the prothorax.

Figure 259: The transverse lady beetle larva is blue-black, whereas the larva of the convergent lady beetle is gray.

Life history

Convergent lady beetles are effective predators in spring. They overwinter as hibernating adults, usually in mountainous regions. Large concentrations are often found in the same area each year. In spring, the beetles return the valleys. After mating, females seek out a good location for their offspring, usually a tree infested with aphids that ensures a plentiful food supply for the larvae. Eggs are laid only after adults have fed on prey. One female can lay between 200 and 500 eggs, depending upon the availability of prey. Eggs hatch in 5 to 7 days. The young larvae devour prey as fast as they can find them. The life cycle from egg laying to adult takes 4 to 7 weeks, depending on the temperature and amount of food available. There are typically 1 or 2 generations per year. Populations are higher in the first generation. In late summer, adults migrate to mountain areas to hibernate.

Transverse lady beetle

Coccinella transversoguttata richardsoni Brown

Hosts

The transverse lady beetle attacks aphids of apples and stone fruits and other soft-bodied insects such as pear psylla.

Life stages

Egg: The egg is yellowish orange and spindle shaped, similar in size and appearance to that of the convergent lady beetle.
Larva: The larva is blue-black with orange markings and is alligator shaped (*Figure 259*).
Adult: The adult is ¼ inch (6 to 7.5 mm) long. It is more rounded in shape than the convergent lady beetle and has fewer spots on the elytra. While the body is black the dominant color is the orange of the elytra, which covers most of the body.

Life history

The transverse lady beetle has 1 to 3 generations in the Pacific Northwest. It is one of the first predators to arrive in orchards in the spring. Overwintering adults may be observed as early as March. Eggs and larvae appear from mid-May to June and new adults emerge in late June and July. Larvae can often be seen in orchards as late as mid-September.

Monitoring

The beating tray is the most widely used method of monitoring lady beetle adults. Densities of larvae and pupae can be estimated while making visual counts of pest populations.

Management

Avoid using broad-spectrum insecticides that are toxic to lady beetles. Supplies of adults can be bought for release in orchards but they often disperse when aphid populations are low. Releases of lady beetles in the orchard in mid- or late summer are unlikely to be very beneficial.

Black lady beetles

Stethorus picipes Casey

These small lady beetles prey chiefly on mites. *S. picipes* is usually found in orchards with heavy spider mite or rust mite populations, and generally does not appear in orchards until mite populations are quite high.

Distribution of black lady beetles is patchy and they generally are not as closely associated with their mite prey as are predatory mites. Although they may be useful in reducing high mite populations, they cannot be relied upon to maintain phytophagous mites at a low level on a long-term basis.

Life stages

Egg: The egg is gray, tiny and spindle shaped. Eggs are laid singly in mite colonies.

Larva: The larva is about 1/20 inch (1 to 1.5 mm) long and is dark brown or black with short spines (*Figure 260, bottom*).

Pupa: The pupa is mahogany colored and usually attached to a leaf surface.

Adult: The adult is black and covered with silvery hairs (*Figure 260, top*). It is about 1/25 inch (1 mm) long, much smaller than the transverse or convergent lady beetles.

Figure 260: The *Stethorus* adult (top) and larva are much smaller than other lady beetle species.

Scymnus spp.

The genus *Scymnus* includes many species of small black, brown, mottled or spotted beetles. The larvae are usually covered with a white wax and are often mistaken for mealybugs. They feed on mealybugs, scale insects, aphids, red spiders, mites and insect eggs. Adults are about 1/12 inch (2 mm) long.

Mealybug destroyer

Cryptolaemus montrouzieri Mulsant

This introduced species of lady beetle can be an effective predator of mealybugs and will also feed on soft scales and aphids. Both adults and larvae are predaceous. Adult beetles are black with orange markings on the head, thorax and tip of the elytra, and are about 1/8 inch (1 mm) long. Larvae are covered with white waxy filaments giving them an appearance similar to their host. The small orange eggs are laid within mealybug colonies. A single generation can be completed in as little as 30 days during the summer.

Cryptolaemus are raised primarily as a control agent for the citrus mealybug in California. They are generally released as adults in the early spring when mealybugs become active. *Cryptolaemus montrouzieri* is being evaluated as a potential biological control for the grape mealybug in pear and apple in Washington.

Figure 261: Syrphid flies lay eggs in the midst of aphid colonies.

Figure 262: Despite being blind and legless, syrphid fly larvae can easily locate prey, such as these aphids.

Figure 263: The adult looks similar to a wasp, but has a flatter body and only one pair of wings.

PREDATORY FLIES

Syrphid flies or flower flies

Scaeva pyrastri (Linneaus)
Eupeodes volucris Osten Sacken
(Diptera: Syrphidae)

Syrphid flies are also known as flower or hover flies because they visit flowers to feed on nectar and pollen. The most common species in Pacific Northwest orchards is *Scaeva pyrastri*. Adults are not predaceous, but the larvae prey on aphids, scale insects and thrips. Syrphid fly larvae may quickly suppress aphid infestations, as each is capable of destroying hundreds of aphids during its development. Where lady beetles are not abundant, syrphid fly larvae usually become the dominant predator.

Syrphid fly larvae can be important predators of the green peach aphid in Washington. They are effective in cooler conditions than most aphid predators and in the fall are the most effective predator of aphids on peach trees.

Hosts

Syrphid fly larvae prey primarily on aphids of apples and stone fruit but also will attack other soft-bodied insects such as scales. Some species prey on thrips.

Life stages

Egg: The egg resembles a small grain of rice. Eggs are laid singly on leaves, usually in or near an aphid colony (*Figure 261*).

Larva: The larva is yellowish, legless and blind. It has a typical maggot shape, tapering to a point at the head end and broadly rounded at the rear (*Figure 262*). Its mouth has a triple-pointed dart with which it seizes and pierces its prey before sucking it dry. It has dark colored breathing tubes on the tail end.

Adult: The adult superficially resembles a bee or wasp, but has a more flattened body and, like other flies, only one pair of wings. It does not sting. It is usually yellow and black, and in some species the black parts have a greenish metallic sheen (*Figure 263*). It is ⅜ to ½ inch (10 to 12 mm) long. It is a fast and agile flyer, often hovering over plants.

Life history

Although most syrphid flies overwinter as larvae in leaf litter, *S. pyrastri* overwinters as an adult. There are usually three generations per year in Washington, although in very warm years or areas there may be more. Adults need pollen from wild flowers or weeds in order to produce eggs. They move into the orchard relatively late in the season, usually about mid-May. Adults often hover around flowers where they feed on nectar and honeydew from aphids and scale insects. Females lay eggs on leaves near or in aphid colonies, where the young maggots will locate prey easily. Despite being blind and legless, the larvae move about and locate prey very efficiently. Often a larva will lift an aphid off the leaf surface while sucking out its body fluids. When mature, larvae go to the ground to transform into pupae and eventually to adult flies. The life cycle takes 2 to 4 weeks to complete.

Monitoring

Adult syrphid flies are easy to see in flight, but are often mistaken for wasps or bees. Syrphid flies have just one pair of wings, whereas wasps and bees have two, but it may be hard to distinguish them when the insect is at rest with the wings folded over the back. Black oily smears, the excrement of syrphid fly larvae, on plant foliage are typical signs of active syrphid fly populations. Larval densities can be determined in conjunction with visual counts of aphids.

Management

Syrphid flies are highly susceptible to insecticides. Avoid insecticidal control of aphid infestations if you see syrphid fly larvae in them.

Cecidomyiid flies

Aphidoletes aphidimyza (Rondani)
Anthrocnodax sp.

(Diptera: Cecidomyiidae)

Most species of cecidomyiid flies (or gall gnats) are plant feeders that produce galls in which their larvae live. However, a few species are predaceous. Predaceous species are common and reliable predators in the eastern United States and Midwest, but appear to be more sporadic in Pacific Northwest orchards. The most abundant species is the aphid predator *Aphidoletes aphidimyza*. Like other cecidomyiids, *A. aphidimyza* pupates in moist soil and its scarcity in some Northwest orchards may be due to the dry soil surface between irrigations. Another cecidomyiid, *Anthrocnodax* sp., has been detected feeding on mites in pear orchards.

Hosts

Predaceous cecidomyiid larvae attack spider mites, eriophyid mites, aphids, pear psylla, thrips and scale insects. They also feed on eggs of mealybugs.

Life stages

Egg: The egg is orange, oval and about $\frac{1}{80}$ inch (0.3 mm) long.
Larva: The larva is pink or orange and about $\frac{1}{8}$ inch (3 mm) long when mature (*Figure 264*). Its shape is similar to that of a syrphid fly larva.
Adult: The adult is a delicate, light brown fly with long legs and is about $\frac{1}{16}$ inch (1.5 mm) long. It is nocturnal and rarely seen.

Life history

Aphidoletes aphidimyza overwinters in the ground as mature larvae or pupae sheltered inside a cocoon. As the weather warms, adults emerge and mate. Females lay eggs either singly or in small clusters among aphid colonies. As larvae are not very mobile, they feed on aphids where the eggs were laid. They suck out the body contents of the aphids. The life cycle from egg laying to adult emergence takes about 18 to 20 days. There are several generations per year.

Monitoring

Cecidomyiid larvae can easily be detected by examining active aphid colonies. The bright pink or orange color makes the predaceous maggots quite visible despite their small size.

Management

In the eastern United States some cecidomyiid species have developed tolerance to organophosphate insecticides and are important predators of aphids in commercial orchards. However, species common in the Pacific Northwest appear to be susceptible to insecticides.

Figure 264: The cecidomyiid larva is pink or orange and about ⅛ inch long when mature.

Some species of cecidomyiids are available from biological control insectaries for release in orchards. The efficacy of these species in controlling aphids in Pacific Northwest orchards is unknown.

Leucopis spp.

(Diptera: Chamaemyiidae)

The family Chamaemyiidae comprises a group of flies with larvae that are predators of soft-bodied insects, including aphids, mealybugs and scales. Within the largest genus, *Leucopis*, at least one species is known to attack the green apple aphid and grape mealybug in the Pacific Northwest.

Information on the life history of this predator is limited. Adults are small, grayish flies with pale stripes on their backs. The white, cylindrical eggs are laid in or near colonies of aphids and mealybugs. Larvae hatch in a few days and feed on nearby prey by breaking through the skin with their mouthhooks and sucking out the body contents. They are not very mobile and generally complete their development within a single aphid or mealybug colony.

Mature larvae are yellowish, almost cylindrical but gradually tapering toward the head end, and about ⅛ inch (3 mm) long. Larvae preying on mealybugs pupate within destroyed colonies, but those in aphid colonies usually drop to the ground to pupate. The life cycle from egg laying to adult takes about 30 to 40 days. Pupae formed late in the summer enter diapause and overwinter. There are probably 2 to 3 generations per year.

PREDATORY BUGS

Mirids

Deraeocoris brevis piceatus (Knight)
Deraeocoris fasciolus Knight
Campylomma verbasci (Meyer)
(Hemiptera: Miridae)

Deraeocoris

Deraeocoris brevis piceatus often is the most abundant predaceous true bug found in Pacific Northwest apple and pear orchards. Where insecticides are used judiciously, it can have a major impact on a variety of pests. Most organophosphate insecticides are highly toxic to deraeocoris adults and nymphs when applied directly, but older residues of these chemicals are only moderately toxic. Other spray compounds such as insect growth regulators and oils are not very toxic.

Hosts

Deraeocoris adults and nymphs prey on many species including spider mites, aphids, leafhoppers and scale insects and are considered to be a very important predator of pear psylla.

Life stages

Egg: The egg is elongate and is inserted into plant tissue. Only a small part of the egg is visible. During summer, eggs are most often laid in the leaf midrib.
Nymph: The nymph is a mottled whitish gray, with long gray hairs on the thorax and abdomen and a cottony-looking secretion covers much of the body (*Figure 265*).
Adult: Deraeocoris adults are shiny black and ⅛ to ¼ inch (3-6 mm) long (*Figure 266*).

Life history

Deraeocoris overwinters as adults, both in and outside orchards. Overwintering females lay eggs in April or May. Nymphs of the first generation are found 2 to 3 weeks later.

They pass through five instars. A second generation is produced in most areas of the Pacific Northwest. Under laboratory conditions development from first instar to adult takes about 25 days at 70°F.

During that time, a single deraeocoris nymph can eat as many as 400 pear psylla eggs or nymphs.

Monitoring

Deraeocoris can be monitored by the beating tray method, but predator-prey relationships have yet to be established to help decide when densities are sufficient to ensure biological control.

Management

Deraeocoris is often abundant in a variety of non-orchard habitats in the Pacific Northwest. Other vegetation that is known to provide food and shelter for this predator includes service tree, tobacco brush, mountain mahogany, white fir, madrona, black oak, manzanita and several species of pine. Deraeocoris adults are most likely to colonize orchards where woodland or wild habitat is close by. Maintaining unsprayed vegetation close to the orchard may play an important role in the natural control of orchard pests by this mirid.

Figure 265: During its development, a single deraeocoris nymph can eat up to 400 pear psylla eggs or nymphs.

Campylomma

The mullein plant bug, *Campylomma verbasci*, is primarily recognized as a pest of apple and its biology is discussed in detail in Part II, Direct Pests. However, adults and nymphs are also predaceous, feeding on many orchard pests including aphids, mites and pear psylla.

At present, losses caused by campylomma feeding on fruit outweighs the potential of this bug as a biological control agent for aphids in apple. Its usefulness in pear is also limited if the orchard is adjacent to apple blocks, but in a more isolated setting campylomma can have a major impact on pear psylla populations. In addition, this mirid appears to be tolerant to many insecticides and is one of the few predators found in heavily sprayed orchards.

Figure 266: The deraeocoris adult is between ⅛ and ¼ inch long.

Anthocorid bugs

Orius tristicolor (White)
Anthocoris nemoralis (Linnaeus)
Anthocoris melanocerus Reuter
Anthocoris antevolens White
(Hemiptera: Anthocoridae)

There are about 70 species of anthocorid bugs in North America. These tiny predators, also known as flower bugs, reproduce more rapidly than do most other common predaceous insects. They can develop from egg to adult in as little as 15 days. Both adults and nymphs suck body fluids from their prey. The most common predaceous anthocorid is the minute pirate bug, *Orius tristicolor,* but three species of *Anthocoris* may also be abundant in fruit orchards. *Anthocoris nemoralis* is a European species introduced into North America as a predator for pear psylla.

Hosts

Anthocorid bugs attack spider mites, thrips, aphids, young scales, pear psylla and eggs of various insects. *Anthocoris* spp. are particularly well adapted for feeding on pear psylla and can play a major role in the biological control of this pest.

Life Stages

Egg: The egg is elongate and creamy white when first laid, and is about ¹⁄₂₅ inch (1 to 2 mm) long. It is inserted into leaf tissues just beneath the epidermis, causing a bump. The white cap, or operculum, is the only part of the egg that is visible. The pattern on the cap is unique for each *Anthocoris* species.
Nymph: The young nymph is yellowish to orange. The older nymph has a yellow to orange head and thorax with an amber colored abdomen, and grows to about ¼ inch (5-6 mm) in length (*Figure 267*).
Adult: The adult is mostly black with white markings on the wings. *Orius tristicolor* (*Figure 268*) adults are about ¹⁄₁₆ (1.5 mm) long, while *Anthocoris* spp. adults are ⅛ inch (3 mm) long.

Life history

Anthocorids overwinter as adults in sheltered places, such as in trash, under tree bark, or under boards. They appear early in the spring and females insert eggs into plant tissue. There are 3 to 4 generations a year. Nymphs and adults have piercing and sucking mouthparts enclosed in a long beak. They will occasionally probe the plant with their beaks, but this does not appear to cause damage.

Monitoring

Adults and nymphs can be monitored in orchards with beating trays.

Management

Anthocorids can be released in orchards and often will remain there year after year. They appear to have developed a tolerance to some insecticides, such as azinphosmethyl, chlorpyrifos, amitraz and oxythioquinox, but they are very susceptible to pyrethroids.

Figure 267: *Anthocoris* nymphs attack pear psylla.

Figure 268: *Anthocoris* adults also are predaceous.

Other Predatory Bugs

Other kinds of predaceous bugs are often found in beating tray samples throughout the year. As a group, they prey on most tree fruit pests. Alone, they are rarely numerous enough to provide effective biological control of pests, but collectively they can have an important impact.

Bigeyed bugs

Geocoris spp.

(Hemiptera: Lygaeidae)

Bigeyed bugs prey on lygus bugs, aphids, leafhoppers and spider mites. Both adults and nymphs feed by sucking body fluids from their prey. They are most commonly found on alfalfa but occur in fruit trees when abundant in the orchard cover crop. The adult is dark gray or black and about ⅛ to ¼ inch (3 to 6 mm) long, with prominent eyes (*Figure 269*). The nymph is similar but is smaller and lacks wings. Bigeyed bugs overwinter as adults in litter or other protected areas on the ground. Adults appear in spring. Females deposit eggs, which are ribbed and pink or pale yellow, in plant tissues. Nymphs feed on prey for several weeks before maturing. There are usually two generations a year.

Damsel bugs

Nabis spp.

(Hempitera: Nabidae)

Damsel bugs (also called nabids) prey on aphids, lygus bug nymphs, leafhoppers, scales, mites, and the eggs and larvae of moths. They also prey on other natural enemies.

The adult is tan or gray with piercing-sucking mouthparts and enlarged front legs for grasping its prey. It has a slender body, tapering at the rear, and is about ⅜ to ½ inch (10 to 12 mm) long (*Figure 270*). The nymph is similar to the adult but is smaller and lacks wings. Damsel bugs are often found in large numbers on the cover crop and will occasionally climb trees and prey on fruit pests. Although they are swift and aggressive, their feeding rate is fairly low. They can play an important role in biological control of tree fruit pests because they appear in the orchard as early as March and occasionally are abundant throughout the summer. They overwinter as adults in weeds, grain or alfalfa fields. Adults begin laying eggs soon after emerging in the spring. Eggs are flat on top and are deposited in soft plant tissue. There are 3 or 4 overlapping generations each year in the Northwest.

Figure 269: A bigeyed bug attacks a lygus bug. It feeds by sucking body fluids from its prey.

Figure 270: The damsel bug has large front legs for grasping its prey.

Figure 271: Assassin bugs will feed on other predators as well as pests.

Assassin bugs

(Hemiptera: Reduviidae)

Assassin bugs are fairly large brown to black bugs (*Figure 271*). Nymphs and adults prey on aphids, leafhoppers and caterpillars. They are not selective predators and will feed on other predators such as lady beetle larvae.

Rough plant bugs

Brochymena spp.

(Hemiptera: Pentatomidae)

Although many stink bugs species are pests, those of the genus ***Brochymena*** are predaceous as both nymphs and adults. Predaceous stink bugs are most often found on forest trees and shrubs but also occur on fruit trees, where they prey on caterpillars, beetles, pear psylla, aphids and other insects. They puncture the prey with their stylets (mouthparts) and suck out the juices. Eggs are pearly white, oval and about 1/25 inch (1 mm) long and are laid on twigs or leaves in small groups. Both the nymph and adult are a steely gray with white specks. The coloring distinguishes the predaceous species from the consperse stink bug, an orchard pest, which has black specks. The adult is about ½ inch (12 to 15 mm) long. Brochymena has one generation a year and overwinters as an adult.

PREDATORY MITES

Western predatory mite

Typhlodromus occidentalis (Nesbitt)
(Acari: Phytoseiidae)

Typhlodromus occidentalis is a predaceous mite native to the western United States. It probably moved from native host plants to fruit trees shortly after the latter were invaded by the pest mite species. It has long been observed on fruit trees but before 1951 was identified as *Seius pomi. T. occidentalis* also goes under the names of *Metaseiulus occidentalis* and *Galandromus occidentalis.*

Until the 1940s, pesticide sprays aimed at codling moth prevented *T. occidentalis* from being an effective predator. The greatly improved control of codling moth, scales and aphids after the advent of synthetic organic chemicals in the 1940s and 1950s allowed the fruit industry to focus greater attention on mite problems. Several miticides were used during the 1950s and early 1960s, but the selection of mites quickly developed resistance to each material. Soon, the mite problem was difficult and expensive to control and mite damage was widespread and sometimes severe. On apple, plum, peach and cherry, the most promising biological control agent was *T. occidentalis.* An integrated program was developed, which relied on this predaceous mite for mite control and selective insecticides for control of other pests. Biological control of mites on apples has been used effectively on a commercial scale since 1965. However, the usefulness of predatory mites on pear has been limited due to the harmful effect of chemicals needed to suppress pear psylla.

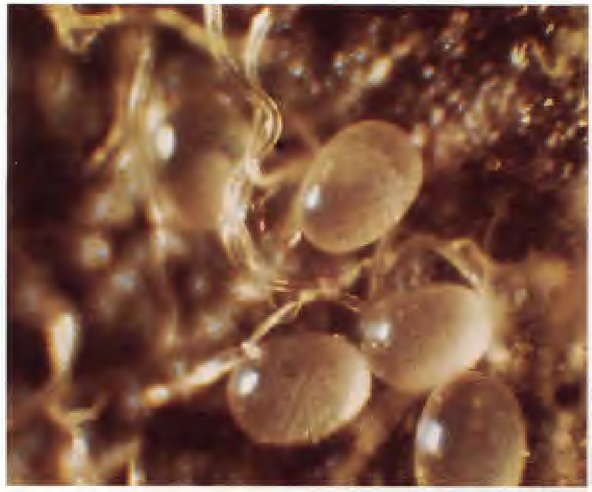


Figure 272: Eggs of *Typhlodromus occidentalis* are oval, whereas eggs of McDaniel and twospotted spider mites are round.

Benefits of biological control of mites

Biological control of mites has been used in commercial orchards since about 1965 and has provided major benefits to the fruit industry, including:

- Reduced use of miticides and costs of materials and applications.
- Less downgrading of fruit due to mite injury.
- Improved storage life of fruit.
- Virtual elimination of live mites in fruit calyces and related quarantine problems.

Hosts

T. occidentalis feeds on the spider mites and rust mites that attack deciduous tree fruits, including the European red mites, twospotted spider mites, McDaniel spider mites, yellow spider mites, apple and pear rust mites, *Prunus* rust mites, and blister mites that are exposed on the surface of the leaf.

Life stages

Egg: The egg is oval and about $\frac{1}{120}$ inch (0.2 mm) long. It is transparent at first but turns translucent white after a couple of days (*Figure 272*). It is easy to distinguish from eggs of the McDaniel or twospotted spider mites, which are round and smaller.

Immatures: The larva is wedge shaped with three pairs of legs. It is generally opaque white and about the same size as the egg. The protonymph is oval, about $\frac{1}{100}$ inch (0.24 mm) long, and has four pairs of legs. The deutonymph is similar but slightly larger.

Figure 273: *T. occidentalis* are opaque white when they have not fed recently, but take on the color of the prey for about 24 hours after feeding.

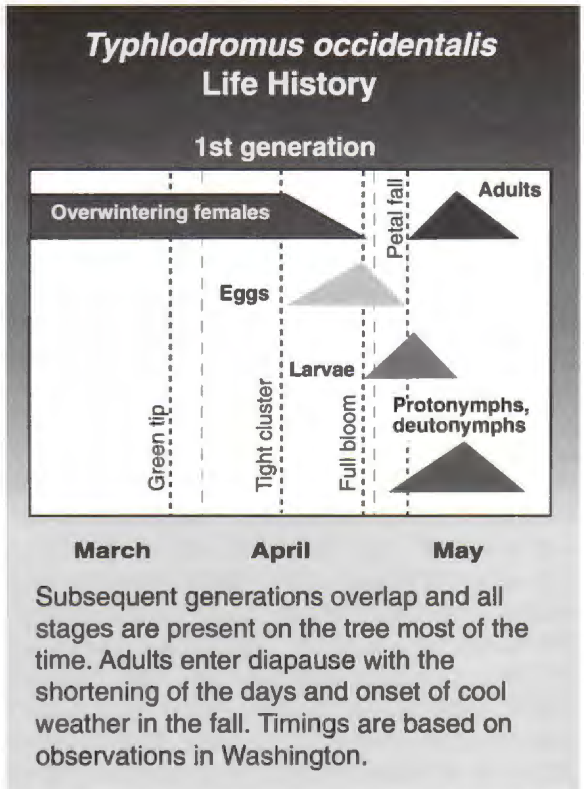


Figure 274

Adult: The adult female is about 1/70 inch (0.36 mm) long and about half as wide, and has four pairs of legs (*Figure 273*). The body is broader toward the rear and tapered at the head. The male is similar but only 1/80 inch (0.3 mm) long. All active stages are opaque white when they have not fed recently, but take on the color of the prey for about 24 hours after feeding. Generally, *T. occidentalis* can be distinguished from plant-feeding mites by the color difference, the spots on the twospotted and the McDaniel spider mites, or differences in shape. All spider mites are broader at the front, while *T. occidentalis* is broader at the rear.

Life history

T. occidentalis overwinters as mated adult females in duff at the base of trees, under bark scales, or in crevices on tree trunks. In mild winters, the females can survive in similar places higher in the tree. Many can be killed in very cold winters, particularly if the weather is dry.

Overwintered females begin to emerge at the green tip stage of apple tree development (*Figure 274*). Emergence peaks between half-inch green and tight cluster stages on apple. The females disperse in search of prey. If spider mites are on the tree, *T. occidentalis* will be found on foliage of opening buds in the low, central part of the tree. If apple rust mites are the main prey, the females will move to terminals or other areas where these mites are found. They do not seek out European red mites. Females begin to lay eggs at about tight cluster stage. Eggs are deposited on the undersides of leaves, between the leaves of opening buds or on flower parts, and hatch in 1 to 4 days, depending on the temperature. Immature mites are found in the same areas as the eggs. Development time, from egg laying to adult emergence, depends on temperature, but averages 6½ days at 75°F (24°C). At this temperature, females survive about 30 days and deposit about 21 eggs. Males survive for a shorter time and consume fewer prey than females.

Because of the mite's rapid development, there can be many generations per year — usually 8 to 10 — and good potential for increases in population. Later in the season, *T. occidentalis* are generally found along the midveins on the lower surfaces of leaves during the day. As the light fades towards the evening, they search the entire leaf surface for prey.

During late summer and early fall, some mated females leave the foliage in search of overwintering sites. Others remain on the foliage, consuming the remaining mite prey, and drop with the leaves.

A Sampling Scheme for *Typhlodromus occidentalis*

Sampling table for *Typhlodromus occidentalis*

No. of leaves with 2 or more mites	% of leaves with 2 or more mites	Average no. mites per leaf
1	4	0.04
2	8	0.10
3	12	0.16
4	16	0.22
5	20	0.29
6	24	0.37
7	28	0.46
8	32	0.55
9	36	0.65
10	40	0.75
11	44	0.87
12	48	1.00
13	52	1.14
14	56	1.30
15	60	1.47
16	64	1.67
17	68	1.89
18	72	2.15
19	76	2.45
20	80	2.84
21	84	3.32

The average number of mites per leaf cannot be estimated accurately when 85% or more of the leaves are infested with 2 or more mites.

Courtesy of V.P. Jones, University of Hawaii at Manoa

To estimate the average number of *Typhlodromus* mites per leaf, collect 25 leaves from each of 10 trees and count the number that have 2 or more mites. (See Sampling section in Part I for details.) **Example:** On the first tree 15 of the 25 leaves have 2 or more mites. The second through tenth have 10, 7, 18, 6, 5, 17, 10, 11 and 12 leaves respectively with 2 or more mites. Use the table (left) to estimate the average number of mites per leaf for each tree, then average across the 10 trees, as shown below.

Tree	No. of leaves with 2 or more mites	% of leaves with 2 or more mites
1	15	60
2	10	40
3	7	28
4	18	72
5	6	24
6	5	20
7	17	68
8	10	40
9	11	44
10	12	48
	Average	= 44

The table shows when 44% of the leaves have 2 or more mites, the average number of mites per leaf is 0.87.

Figure 275

Monitoring

Examine the undersurface of several leaves where mites are likely to be. Examine leaves on terminal shoots if apple rust mites are the primary prey, or spur leaves if other mite species predominate. The predators will usually be found along the midvein during daylight. Mite and predator densities are usually determined by brushing leaves in a leaf brushing machine. Samples can be taken at intervals to monitor changes in the relative abundance of predators and prey. Leaf samples can also help determine which pest control measures might be causing persistent mite problems.

A binomial sampling plan for *T. occidentalis* is given in *Figure 275*. The sample can be done at the same time as the sample for spider mites. However, look carefully if using this type of sample, as the predator is hard to find and may easily be overlooked. Predator levels of 1 or more per leaf are an indication of good distribution. Mites will usually be controlled within 7 to 10 days if their densities do not exceed 25 per leaf.

Insecticide Selectivity Guide for *Typhlodromus occidentalis* Management

Compound	*Typhlodromus* toxicity	Apple rust mite toxicity	Comments
azinphos methyl	1	1	
Bacillus thuringiensis (Bt)	1	1	
carbaryl	1-3	1-2	Usually no problems if applied before June 1. Toxicity will vary with history of use in a given orchard.
chlorpyrifos	1-2	1	Toxic to predatory mites if multiple applications are made.
diazinon	1	1	
dimethoate	2	1	
encapsulated methyl parathion	1	1	
endosulfan	1	1-3	May be relatively nontoxic to apple rust mite in orchards where it has been frequently used.
esfenvalerate	4	1	Use on apples not recommended because of toxicity to *Typhlodromus.*
fenbutatin-oxide	2-3	4	
formetanate hydrochloride	2-3	2-3	
lime-sulfur	1-2	3	If weather is hot, lime-sulfur may kill rust mites. There should be no problem, however, with the dormant spray.
methidathion	3	1	
methomyl	4	1	Use only as a trunk spray prebloom
oxamyl	2-3	—	Toxic to tetranychid mites also.
permethrin	4	1	Use on apples not recommended because of toxicity to *Typhlodromus.*
phosmet	1	1	
phosphamidon	1	1	
propargite	1	2-3	

Rating system:
4 Highly toxic, likely to cause mite populations to flare up
3 Fairly toxic, will cause mite population flare-up at high rates or with frequent use
2 Somewhat toxic, will reduce population to some degree
1 Relatively nontoxic
— Toxicity unknown

This table is a guide to preserving and managing the predatory mite *T. occidentalis.* Because rust mites are its primary alternate prey and an important part of overall mite management, information on preserving rust mites is given also. Although developed for *T. occidentalis* and apple rust mite on apples, much of the information will also apply to other predatory mites and their alternate rust mite prey.

Figure 276

Management

Three main factors limit the number of *T. occidentalis* in an orchard:

• Number of prey

Since apple rust mites usually become numerous during May and June, numbers of predatory mites can increase rapidly during that period as they feed on the rust mites, reproduce and disperse over the tree. *T. occidentalis* usually does not control rust mites but will reduce their numbers. As moderate populations of apple rust mites do little damage, it is not advisable to control them unless numbers are extremely high, as they help stabilize biological control of the more damaging mite species. Large numbers of predators in May and June prevent the build up of spider mite and European red mite populations. If the number of rust mites is low in the early season, predator numbers will also remain low and populations of other mite species can grow before the predators respond. Though acaricide applications may not be directly toxic to *T. occidentalis*, they may starve if their food supply is destroyed.

• Winter mortality

Cold, dry winter weather can drastically reduce the numbers of overwintering predators. However, if there are plenty of rust mites as food, populations can build up again within several weeks.

• Toxic pesticides

Applications of pesticides that are highly toxic to predators have the most devastating effect on biological control of mites (*Figure 276*). High spider mite populations can develop during the several months it takes for predator populations to build up again after the pesticide application.

It is important to conserve *T. occidentalis* and manage apple rust mites properly. If no *T. occidentalis* are in the orchard, it may be due to use of a non-selective pesticide. To help establish biological control, eliminate the pesticide from the management program and bring foliage with predators into mite-infested areas. If acaricides are used, it is best to apply them before introducing the predators and only introduce the predators where mites have survived the treatment.

Typhlodromus pyri Scheuten

(Acari: Phytoseiidae)

Typhlodromus pyri is a predatory mite found in fruit-growing regions throughout the world, including Europe, North America and New Zealand. It preys on the apple rust mite, European red mite, and twospotted spider mite.

T. pyri closely resembles *T. occidentalis*, but there are important differences between the two. For example, *T. pyri* is a more effective predator in cool, humid conditions, whereas *T. occidentalis* increases most rapidly and is most effective in dry, hot climates. The two can work well together. *T. pyri* is effective at the start and end of the season when the weather is cooler and prey densities are low, and *T. occidentalis* works best during midseason when prey are abundant.

In the arid areas of eastern Oregon and Washington, *T. occidentalis* is the predominant of the two predatory mites. In the more humid growing areas of western Oregon and Washington, *T. pyri* is the more prevalent. *T. pyri* is also found in British Columbia.

Both predatory mites have become resistant to a range of agricultural pesticides, including organophosphate insecticides, which has led to their successful use in tree fruit IPM programs. A strain of *T. pyri* that is resistant to pyrethroids has been patented in New Zealand.

Hosts

Unlike *T. occidentalis,* which is an obligate predator of mites, *T. pyri* feeds on pollen as well as pest mites. *T. pyri* prefers to prey on European red mite, whereas *T. occidentalis* prefers McDaniel or twospotted spider mite.

T. pyri is the most important predatory mite on blackberries in western Oregon and Washington. It also inhabits fruit trees, many rosaceous plants and occasionally hops.

Life stages

T. pyri looks very similar to *T. occidentalis*. Adults are difficult to distinguish without a microscope or 30-power lens. The main difference is that *T. occidentalis* has long setae, or hairs, on its back. The setae on *T. pyri* are much shorter and less conspicuous (See *T. occidentalis* in *Figure 273*).

Life history

Adults overwinter in diapause and emerge in early April. Female *T. pyri* tend to begin laying eggs earlier than *T. occidentalis*, perhaps because they are better adapted to cool temperatures and will feed on other foods when prey is scarce. During the summer, several generations develop and the population is usually made up of equal number of adults, nymphs and eggs.

T. pyri females lay eggs for about 2 to 3 weeks longer than *T. occidentalis* in the fall. *T. pyri* numbers may increase with the onset of cool weather, whereas *T. occidentalis* populations tend to decline. *T. pyri* adults are active until October. Winter mortality can be high.

Monitoring

Examine the undersurface of leaves where mites are likely to be. Use a leaf-brushing machine to count both pest and predatory mites. Repeat samples at intervals to monitor changes in their relative abundance. Though *T. pyri* numbers may not be high in midsummer, it can be an effective predator towards the end of the season when the weather cools off and *T. occidentalis* numbers begin to wane.

Research shows that *T. pyri* requires a ratio of about 1 predator per leaf (all life stages) to about 5 to 10 European red mites per leaf before biological control can be highly successful. This is a higher predator ratio than required for *T. occidentalis*.

Management

T. pyri is less inclined than *T. occidentalis* to emigrate to other leaves, trees or habitats in search of prey. For this reason, it can take several years for the mite to move into an orchard from nearby habitat.

To introduce it to an orchard, bring in water sprouts or clippings from trees where the mite is known to occur. Because *T. pyri* does not move very much, populations outside orchards may not have built up resistance to pesticides like those inside orchards. Although *T. pyri* is unlikely to thrive in very dry conditions, it may be able to survive in orchards in arid areas that have overtree irrigation systems.

Zetzellia mali (Ewing)

(Acari: Stigmaeidae)

Zetzellia mali is a predatory mite that attacks European red mite and apple rust mite. It is found throughout the United States and is in most orchards at some level. It can contribute to biological control of pest mites, although a drawback of this mite is that it also preys on eggs of the predatory phytoseiid mites *Typhlodromus occidentalis* and *T. pyri*.

Z. mali may not be able to control high pest mite populations, but where populations have been lowered by other predatory mites, it alone can keep European red mites at low levels for long periods of time, perhaps several years, if undisturbed by harmful pesticides. When the food supply is low, *Z. mali* is better able to survive than *T. occidentalis* or *T. pyri*.

Hosts

Z. mali is commonly found on tree fruits, particularly apples. It preys on eggs and immature stages of European red mite and on active stages of apple rust mite. It will also feed on other predatory mites and other *Z. mali*.

Life stages

Egg: The egg is round, lemon yellow and smaller than that of a spider mite.
Nymph: The nymph is lemon yellow but turns reddish yellow after feeding on European red mites.
Adult: The adult is lemon yellow to reddish and slow moving. It is almost oval but is more pointed at the rear and slightly smaller than a spider mite (*Figure 277*).

Life history

Females overwinter in cracks or crevices on twigs or bark, or under empty scales of San Jose scale. They emerge in April and infest unfolding leaves of developing buds. The mite develops through several generations during the summer. Females begin to search for overwintering sites in September, but may be found on leaves as late as November. Populations depend to some extent on the numbers of apple rust mites available as prey.

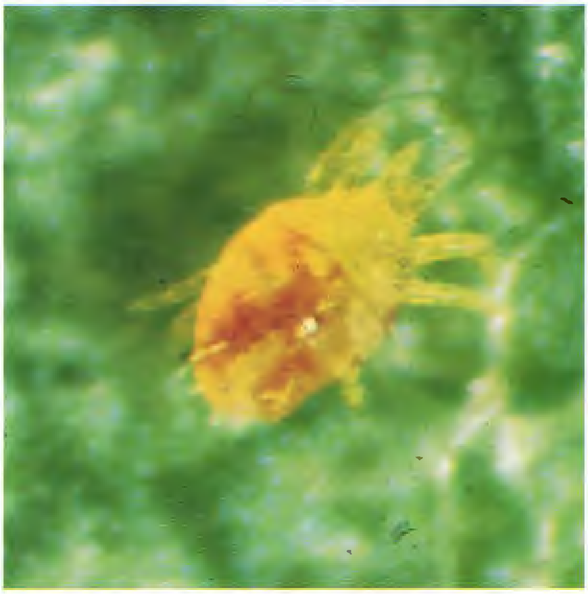


Figure 277: *Zetzellia mali* is more pointed at the rear and slightly smaller than a spider mite. It can easily be distinguished by its yellow color.

Monitoring

Z. mali is easy to see and can be monitored by sampling leaves. However, no optimum predator-prey ratios have been established.

Management

Z. mali is sometimes found in large numbers in unsprayed orchards. It is resistant to organophosphate insecticides but, unlike *T. occidentalis* and T. *pyri*, is susceptible to endosulfan.

Z. mali can be introduced into an orchard on shoots from inhabited trees but the potential benefits should be weighed against the risk that it will prey to some extent on other predatory mites.

PREDATORY THRIPS

Sixspotted thrips

Scolothrips sexmaculatus (Pergande)

(Thysanoptera: Thripidae)

Black hunter thrips

Aelothrips sp.

(Thysanoptera: Aelothripidae)

Thrips are primarily phytophagous but some are predaceous. Two species, the sixspotted thrips (*Scolothrips sexmaculatus*) and the black hunter thrips (*Aelothrips* sp.) are found in tree fruit crops. They mainly prey on the eggs and young of spider mites and do not harm trees. Predatory thrips are rarely found in regularly sprayed orchards, but where soft pesticide control programs are used, they can become abundant and control spider mites. The adult of the sixspotted thrips is about $\frac{1}{30}$ inch (0.8 mm) long (see Western flower thrips section in Part II, Direct Pests, for general appearance). It is pale yellow with three brown spots on each forewing. The adult of the black hunter thrips is larger, about $\frac{1}{15}$ inch (1.6 mm) long, and has a dark body and legs. The forewings of this species are clear with two dark crossbands joined by a dark bar along the hind margins. Adults of both species can be counted along with other insects in beating tray samples.

Earwigs

Forficula auricularia Linneaus.

(Dermaptera: Forficulidae)

The beneficial role of the European earwig is often overlooked, due partly to its pest status (See Part II, Direct Pests for description). It is, however, considered an important predator of some fruit pests, with aphids, pear psylla, mites and insect eggs (including those of codling moth), forming a significant part of the diet. Artificial nesting sites are used in European orchards to increase the abundance of the European earwig.

Ants

(Hymenoptera: Formicidae)

Ants are the most efficient and numerous of all predaceous insects. Some ants, such as certain species of *Formica*, can be used in orchards to help control pests and reduce reliance on pesticides.

Hosts

Ants can prey on a wide variety of insects. Their primary role in orchards is as predators of pear psylla on pear.

Life stages

Egg: The egg is white and oval.
Larva: The larva is shiny white and elongated.
Pupa: The pupa is a dull white or tan.
Adult: Adults range in size from about 1/12 inch (2 mm) to ½ inch (12 mm). Many are black but there are also red, brown and yellow species (*Figures 278 and 280*). The head is large with long, elbowed antennae and is joined to the thorax by a thin neck. The thorax is connected to the abdomen by a narrow, flexible waist, or petiole. In some species, the petiole is just one segment, while in others it is two segments. The swollen part of the abdomen behind the petiole is known as the gaster. During part of their life cycle, when they mate and disperse, the reproductive ants have wings.

Life history

A typical ant colony consists of sterile female workers and soldier ants governed by one or more queens. The queen lays eggs. Worker ants forage for food, maintain the nest and care for the queen and her developing brood. Soldiers defend the colony and its resources from enemies. Ants overwinter as adults in a colony. In the spring, the queen resumes egg laying. A queen can lay thousands of eggs each year. Workers carry the eggs to nursery chambers in the nest. Larvae are fed and cared for by workers.

After several weeks, the larvae develop into pupae from which worker and soldier ants later emerge. Once or twice a year, usually in the late spring and early fall, a special brood of eggs develops into winged male and female reproductive ants. Swarms of these ants leave the nest to mate and disperse. After mating, new queens either move away to establish new colonies or, in species that have more than one queen per colony, they may stay in the nest. Once established in a nest, the queen sheds her wings. Males die or are killed soon after mating. Queens usually mate only once and use stored sperm to fertilize eggs for the rest of their lives.

Why ants are good natural enemies

Ants can be very effective biological control agents for several reasons:

- Colonies contain large numbers of ants that consume large quantities of food.
- A colony with multiple queens can have an enormous number of workers, perhaps 300,000 or more. Often, there are networks of colonies containing millions of foraging workers.
- Predation is not limited to a particular prey species or stage.
- Worker ants will continue to forage even when satisfied. They hunt for the brood, the queens, and other workers in the nest.
- Ants can survive temporary food shortages by living on stored food reserves.
- Ants forage throughout the orchard and can efficiently exploit new food sources through chemical communication.
- Ants are active for long periods, both on a daily and seasonal basis.

Management

Ants as biological control agents

Over the centuries, predaceous ants have been exploited in countries around the world to control a variety of pests. Ants can be used in orchards to help control pests, such as pear psylla, and reduce reliance on pesticides. Ants eat psylla nymphs and young adults and also remove honeydew, reducing fruit russet.

Some ant species will farm, or tend, other plant-damaging insects. For example, the ants may feed on sugar produced by aphids and protect the aphids from predators and parasites in return. But some researchers believe that honeydew-producing insects such as aphids help scatter the ants throughout the tree, enabling them to protect the plant better from other, more damaging pests. If undisturbed, ants will establish permanent colonies and build up to large numbers.

Introducing ant colonies

In most orchards, ants have been eradicated by pesticides. However, ant colonies can be collected and reintroduced (see instructions in *Figure 279*). If the mosaic can be preserved in an orchard, predatory ants can contribute significantly to pest control within two years of introduction.

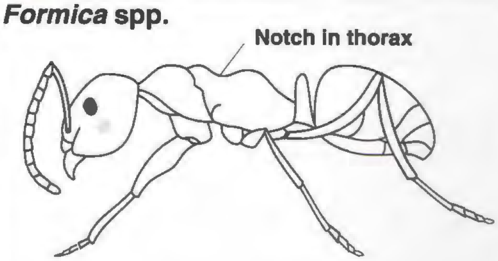
Formica neoclara and *Formica podzolica* are appropriate species to use in orchards. Both are indigenous to Washington's pear growing regions. They have more than one queen, which greatly increases the reproductive capacity of the colonies and lessens the risk of a colony failing to become established if a queen dies. They are not aggressive, do not sting, and seldom tend aphids. Both species nest in the soil, forming low mounds that are easy to excavate and do not interfere with orchard equipment. Other, closely related species, such as *Formica montane,* could also be used.

Protecting ant colonies

After ant colonies have been introduced, they must be protected and allowed to spread throughout the orchard. The two greatest threats to ant colonies, particularly new ones, are pesticides and physical damage to the nests. Most orchard practices do not harm ant colonies, with the exception of disk tillage to control weeds, which destroys nests.

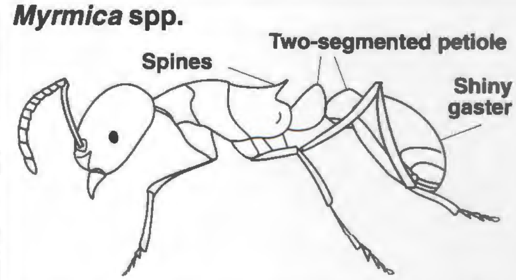
Distinguishing Ant Species

***Formica* spp.**



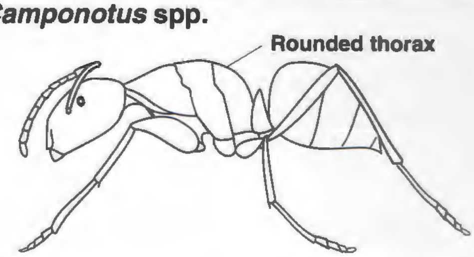
Workers of *Formica neoclara* and *Formica podzolica* are medium-sized ants, about 1/4 inch long. They look similar, except *F. neoclara* is brown and *F. podzolica* is black. All *Formica* ants have a one-segment petiole, or waist, and a conspicuous notch in the thorax. Their color and size distinguish them from many other ant species.

***Myrmica* spp.**



Myrmica spp. are similar in color to *F. neoclara* but have a two-segment petiole and a shiny gaster, or abdomen. They have prominent spines in front of the petiole.

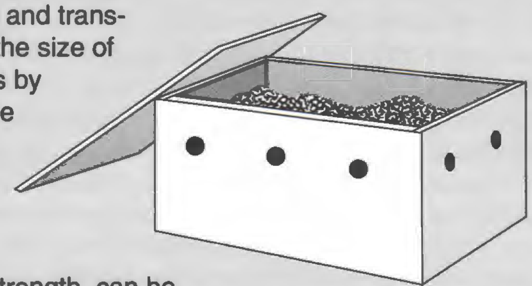
***Camponotus* spp.**



Camponotus workers are often larger than *Formica* and can be as long as 3/8 inch. Some are black, like *F. podzolica*, but they have a smoothly rounded thorax.

Figure 278

Transplanting an Ant Colony



Use wooden nesting boxes to collect, transport and transplant ant colonies. The box size depends on the size of the colony, but usually a box measuring 12 inches by 24 inches and 16 inches high is large enough. The best material is a low-grade white pine. Do not use treated lumber and wood products, such as particle board and plywood, as they contain compounds that could harm the ants.

Heavy plastic garbage bags, doubled for extra strength, can be used instead of wooden boxes, but they do not protect the colony very well during handling.

To stop ants escaping, make sure the box's joints fit tightly. Use duct tape as a sealant. Collect the colonies by carefully shoveling nests directly into the nesting boxes.

During collection, separate and discard empty nesting material, rocks and debris from material containing brood and workers and discard. It is best to collect colonies in the early spring before they become active. Also, more ants will survive transplanting during mild spring weather.

Before sealing the boxes, put cotton saturated with honey and water inside with each colony. If the nesting material is very dry spray a little water into the box. After sealing the boxes, try not to disturb them. Keep boxed colonies for one to two days in a cool, dry, shady place before burying them in the orchard. Holding the ants increases the chances of successful introduction.

In the orchard, dig a hole for the box in an area that will not be disturbed or flooded by irrigation. Ideally the site should be exposed to morning sunlight but shaded in the afternoon. Drill several exit holes, about 1 inch (2.5 cm) in diameter, through each side of the box before lowering it into the hole and burying it under 3 to 4 inches (7 to 10 cm) of soil.

Ant colonies usually do not stay in the nesting boxes, but establish new nests nearby. The box protects the ants during transit and their early days in the orchard. With careful handling, most ant colonies will survive.

Figure 279

Figure 280: *Formica neoclara* is an appropriate ant species to use in an orchard.

Other weed controls, such as herbicides, should be used if ants are in the orchard.

It is relatively easy to conserve ant populations in organic orchards as pesticides such as *Bacillus thuringiensis* (Bt), granulosis virus, rotenone and other products certified for use in organic orchards are not toxic to ants.

In conventional orchards, apply pesticides when ants are least active and use compounds that are the least toxic to ants. Ants are not yet active when dormant sprays are applied. Later in the season, ants are least active between about 10 p.m. and 4 a.m. They are also relatively inactive from about 11 a.m. to 4 p.m., particularly on hot days.

Organophosphate and carbamate insecticides are highly toxic to ants and their residual effect can last for up to two weeks. Synthetic pyrethroids also are toxic to ants but they are effective for only about a week. The best compounds to use with ants for pear psylla control would be insect growth regulators, which have little effect on foraging ants. Good dormant control of pear psylla is essential where ants are used as biological control agents. Pear psylla begin to reproduce at least a month before ants become active in the spring. Early season chemical control is needed to keep psylla populations below damaging levels until the ants begin foraging.

Vespid wasps

(Hymenoptera: Vespidae)

Vespid wasps such as the yellow jacket, *Vespula pennsylvanica*, and the baldfaced hornet, *V. maculata*, can occur in large number in orchards. Their potential as biological control agents is probably limited since they will feed on other natural enemies. In addition, their aggressive behavior and painful sting make them undesirable in orchards any time people are working. There are reports that large number of vespids can suppress pear psylla populations, presumably by feeding extensively on psylla honeydew, causing the death of exposed nymphs by desiccation. Using vespid wasps in an IPM program would be difficult since it would require that wasps be removed from the orchard prior to harvest.

Spiders

(Araneae)

There are over 8,000 species of spiders in North America. They are predaceous and are commonly found on apple and pear trees, particularly where IPM is practiced, but their role in suppressing pest populations in orchards is not well understood. Jumping spiders (Salticidae), crab spiders (Thomisidae), and web-spinning spiders (many families) are known to feed on insects such as pear psylla, aphids and leafhoppers.

PARASITOIDS

Parasitic wasps

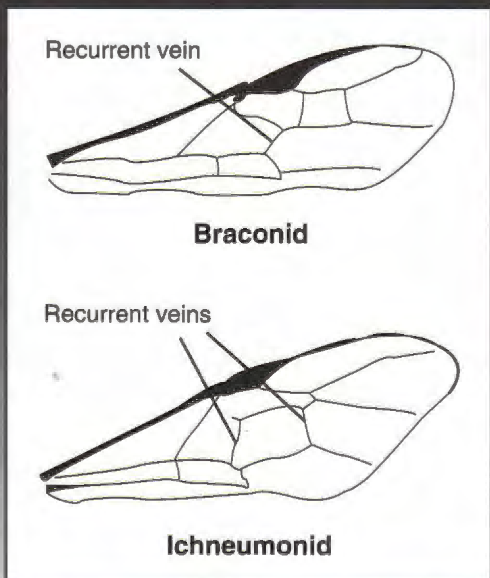
Ichneumonids

Ichneumonidae (Ichneumon wasps) is one of the largest insect families, with over 4,000 species throughout North America. They are slender-bodied wasps with long antennae and vary considerably in form, size, and coloration. In some species there are considerable differences in size and coloration between sexes. Many species have a sickle-shaped abdomen. The ovipositor can be hidden within the abdomen or be external and as long or many times longer than the body.

Ichneumon wasps attack larvae or pupae of flies, caterpillars, beetles, and sawflies. Eggs are usually placed inside the host and larvae and develop internally, though a few are ectoparasitoids, feeding on the outside of the host. Members of the Ichneumonidae look similar to the Braconidae but are generally larger. The main distinguishing feature is the venation on the forewing. The ichneumonids have two recurrent veins forming a cell in the lower part of the wing which is lacking in the braconids (*Figure 281*).

Ichneumonid wasps have been reported from several fruit pests but none are specifically discussed here because there is not sufficient information to recommend how they might be managed and what their impact on the pest is likely to be. As mating disruption and soft insecticide programs gain wider acceptance the occurrence and impact of ichneumonid wasps on certain pests will likely increase.

Distinguishing Braconid and Ichneumonid Wasps



The main distinguishing feature of ichneumonid and braconid wasps is the pattern of veins on the forewings. The ichneumonids have two recurrent veins, forming a cell in the lower part of the wing, which the braconids lack.

Figure 281

Braconids

Braconid wasps are parasitic and do not sting humans. There are more than 1,700 species in North America. Most are about ⅛ inch (3 mm) long. Their bodies, though slender, tend to be shorter than those of ichneumonid wasps. Many species are important biological control agents of crop pests. Although hosts vary according to species, most prey on larvae of Lepidoptera. Some also attack beetle larvae and adults, fly larvae, sawflies and aphids. Most braconid larvae develop inside the host's body. However, when the hosts are concealed, like leafrollers or wood-boring beetles, the wasp larva may remain outside the host's body and feed externally.

Ascogaster quadridentata Wesmael

(Hymenoptera: Braconidae)

Ascogaster quadridentata is an efficient parasitoid of codling moth. It is a strong flier, good searcher, and its life cycle is synchronized with that of codling moth. This parasitoid is native to Europe and was evidently accidentally introduced into North America, probably on shipments of fruit. In 1919, *A. quadridentata* was introduced to the west coast from eastern United States. Insecticides used in commercial orchards eliminate *A. quadridentata.*

Hosts

A. quadridentata uses codling moth, oriental fruit moth and lesser appleworm as hosts.

Life stages

Egg: The minute egg is laid inside the host egg.
Larva: The first instar larva, which is 1/12 inch (2 mm) long, remains inside the host larva until it is nearly mature. It does not begin to develop until the host is in the fourth instar. Then, the parasitoid larva grows, consuming the entire host larva. The almost mature larva exits the the body of the host larva (but still within its cocoon) and soon spins a glossy white cocoon about 1/8 inches (3 mm) long.
Pupa: The pupa is inside the cocoon, which is within the cocoon of the host.
Adult: The adult is a small wasp, 1/8 to 1/5 inch (3 to 5 mm) long, with a black to dark brown robust body and long antennae (*Figure 282*).

Life history

A. quadridentata overwinters as a first instar larva inside a host larva that has spun a hibernacula beneath bark of apple or pear. In spring, when unparasitized codling moth larvae continue development and change to the pupal stage, the development of parasitized larvae is blocked. Instead, the parasitoid larva begins to grow and consumes the contents of its host.

When the parasitoid larva is mature it pupates and its emergence as an adult coincides with the emergence of codling moth adults. Adult *A. quadridentata* search out codling moth eggs, or other host eggs, and deposit their egg inside. When the codling moth egg hatches the first instar *A. quadridentata* larva is inside. The host's larva develops normally through the first three instars but development is blocked at the fourth instar. The parasitized codling moth larvae leaves the fruit and seeks a cocoon site. *A. quadridentata* then develops inside the host, leaving when mature and ready to pupate. There are at least two generations of *A. quadridentata* in the Northwest.

Figure 282: *Ascogaster quadridentata* lays its eggs inside codling moth eggs.

Monitoring

Parasitized larvae are smaller than unparasitized ones and this can be used to an advantage in monitoring and managing populations of *A. quadridentata.* Banding with openings less than 1/20 inch (1.3 mm), will selectively collect parasitized codling moth larvae.

Management

Healthy codling moth larvae can be collected in banding with larger diameter openings. The banding can be destroyed. A second cultural practice that can be used to favor parasitized larvae is to place infested fruit in special containers or bins with openings that are of a size that will allow parasitized larvae to escape while confining healthy ones. Healthy larvae can then be destroyed, and parasitized ones returned to the orchard.

A. quadridentata can be reared easily in the laboratory, and can be forced into diapause by regulating the photoperiod. Dormant hosts can be accumulated during winter and held at 40°F for several months. When they are transferred to long days (16 hours light) and warm temperatures (80°F) dormancy ends. The breaking of dormancy can be programmed so that large numbers of parasitoids are available for mass release in the spring. In unsprayed trees releases of *A. quadridentata* have resulted in parasitism levels of 35 to 40%. It is possible to place parasitized codling moth eggs on wild apple trees. When these eggs hatch the codling moth larvae would attack fruit but all would eventually produce adult *A. quadridentata* that would be available to attack codling moth of following generations. This approach could also be used on crab apple pollinizers in commercial orchards to increase the level of parasitoids naturally without mass releases of adults. The use of insecticides in orchards for control of codling moth has eliminated populations of *A. quadridentata.* It can, however, be an important component in a pest management program where mating disruption and soft insecticides are used. It can also be important in reducing codling moth populations in wild or backyard trees, thus reducing the number of immigrating moths from these sources.

Apanteles sp.

(Hymenoptera: Braconidae)

This genus contains several members that are important larval parasitoids of lepidopteran pests. Several species of *Apanteles* attack leafrollers. *Apanteles* sp. (possibly *A. atar*) is one of the most common attacking leafrollers in commercial orchards and may play a key role in biological control of leafrollers when combined with mating disruption or soft insecticides.

Hosts

Apanteles attacks the four leafroller species known as pests of fruit crops in the Northwest. It is likely that larvae of other Lepidoptera serve as alternate hosts for *Apanteles* outside orchards.

Life stages

Larva: The larva of *Apanteles* spends most of its life inside the host larva. It is usually only observed after it leaves the host when ready to pupate. At this time it is a typical maggot form and is a creamy white to light green.

Pupa: The pupa is the life stage most commonly seen. It is contained within a white fuzzy cocoon (*Figure 283*). It is oblong and about $\frac{1}{8}$ inch (3 to 4 mm). Usually more than one, and as many as 15, cocoons will be found within the leaf shelter constructed by the doomed host larva.

Adult: The adult *Apanteles* wasp is about $\frac{1}{8}$ to $\frac{3}{16}$ inch long (3 to 5 mm) with a black body and long antennae. The female has a short ovipositor at the end of the abdomen.

Life history

Apanteles overwinters inside the leafroller host larva. As the leafroller larva matures in spring the *Apanteles* larva begins to grow and feeds on its hosts organs, eventually killing it. When mature, *Apanteles* larvae leave their host and spin individual cocoons in the leaf shelter that contained the host.

Apanteles cocoons can be found in late May and early June when unparasitized leafroller larvae are beginning to pupate. The host larva's remains are usually visible as a black, shriveled mass near the

Figure 283: Usually several *Apanteles* cocoons will be found within the leaf shelter of the doomed leafroller larva.

parasitoid cocoons. Adult parasitoids emerge in 7 to 10 days. When leafroller eggs of the summer generation hatch, in late June to early July, the adult parasitoids attack newly hatched larvae. Cocoons are again found in late July or early August, and adult *Apanteles* parasitize small leafroller larvae in the fall before they move to overwintering sites and construct hibernacula.

Monitoring

The presence and abundance of *Apanteles* can be determined by examining leaf shelters of leafroller larvae in late May and again in late July. Even if the parasitoid has already emerged from the cocoon its remnants provide evidence of a successful attack.

Management

Apanteles adults are susceptible to broad-spectrum insecticides, which probably accounts for the reduced level of parasitism of summer generation leafroller larvae in commercial orchards. Since *Apanteles* has not been successfully reared in the laboratory, artificial release in orchards to augment populations does not seem to be an option. However, *Apanteles* could be conserved and encouraged in orchards where broad-spectrum insecticides are replaced with mating disruption and soft insecticides for pest control.

Macrocentrus ancylivorus Rohwer

(Hymenoptera: Braconidae)

The genus *Macrocentrus* includes several species that have been reported attacking pests of fruit. They are only known to attack first instar through nearly full grown larvae of Lepidoptera. *M. ancylivorus*, which is native to North America, historically has been recognized as being one of the most important in the genus and has provided effective control of the oriental fruit moth. In California, the release of *M. ancylivorus* plus minimal insecticide use have been reported to give as good control of the oriental fruit moth as a heavy insecticide program.

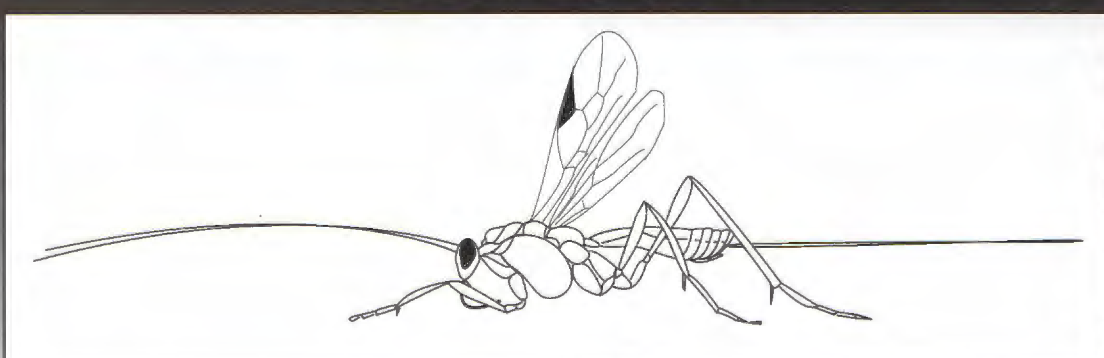
Hosts

M. ancylivorus attacks the strawberry leafroller and oriental fruit moth. It uses fruitworms, stemborers and other leafroller species as alternate hosts.

Life stages:

Egg: The egg is 1/250 inch (less than 0.1 mm) long and is deposited inside the host larva.
Larva: There are four larval stages. The first three instars occur inside the host body, while the fourth feeds externally, consuming the host body con-

Macrocentrus ancylivorus



The antennae and ovipositor of the female *Macrocentrus ancylivorus* are as long as its body. *M. ancylivorus* is an important parasite of the oriental fruit moth.

Figure 284

tents. The last instar is 1/6 to 1/5 inches (4 to 5 mm) long.

Pupa: The pupa is contained inside a cocoon spun by the last larval instar near to or within the cocoon of the host. It is about 1/6 inch (4 mm) long and is a glistening brown color.

Adult: The adult female is 1/6 to 1/5 inches (4 to 5 mm) long with an equally long ovipositor and antennae (*Figure 284*). The body is slender and reddish brown to yellowish in color. The male is 1/8 to 1/6 inches (3 to 4 mm) long.

Life history

The egg hatches soon after being deposited in the host larva. Any larval stage of the host may be attacked, though eggs are not laid until there is some webbing or frass. When the host larva matures, stops feeding, and spins a cocoon, the parasitoid larva completes development. The fourth instar *M. ancylivorus* leaves the host's body and feeds externally until ready to pupate. The parasitoid's larva spins a cocoon within the cocoon of the host. *M. ancylivorus* takes about 7 days longer than its host to develop, on average. Because of this, emergence of the adult parasitoid coincides with the egg hatch of the host, so the adults have host larvae available to attack. There are as many generations of *M. ancylivorus* as its host, usually 3 to 4 for the oriental fruit moth.

Monitoring

Presence and abundance of *M. ancylivorus* can be monitored by collecting twig strikes and infested dropped fruit, placing them in a container and counting the number of oriental fruit moths and parasitoids that emerge.

Management

M. ancylivorus was mass reared on the potato tuberworm, *Gnorimoschema operculella*, for release in orchards in the 1940s and 1950s. While this research was mostly conducted in the eastern United States, the results were encouraging. Release of 3 to 5 *M. ancylivorus* adults per tree, either alone or in combination with a reduced insecticide treatment schedule, effectively reduced damage by the oriental fruit moth on peaches. *M. ancylivorus* is evidently a strong flyer and will readily disperse from the release orchard, so regional release programs might be the best strategy to follow. Extensive use of insecticides in Northwest peach and nectarine orchards has probably prevented *M. ancylivorus* from having a significant effect on oriental fruit moth populations. *M. ancylivorus* could be used to enhance control of oriental fruit moth in orchards using mating disruption and where soft insecticides, such as Bt products, are used to control peach twig borer.

Chalcidoids

Chalcidoids are 1/10 to 1/8 inch (2 to 3 mm) long, and are often a dark metallic blue or green. They have clear wings with few veins, and in some families (such as Mymaridae) the wings are merely stalks with hairs. These small wasps attack the eggs, larvae or pupae of many different insects, including important fruit pests. It is estimated that there are over 25,000 described species and probably many more that are undescribed. There are more than 2,000 species of chalcid wasps in North America. Many species have been imported into the United States to control pests.

Pnigalio flavipes (Ashmead)

(Hymenoptera: Eulophidae)

This small eulophid wasp is the most common parasite of the western tentiform leafminer in the Pacific Northwest. Its life history is well synchronized with that of the leafminer. *P. flavipes* can kill more than 90% of the leafminers in a generation. Its activities against the leafminer are usually so effective that chemical controls are not needed. It is an ectoparasite, which means it feeds externally on its host rather than within the host's body.

Life stages

Egg: The egg is white and cylindrical, and is laid inside the leafminer mine (*Figure 285*).

Larva: The larva is maggot-like, with a legless, elongated body that is 1/100 to 1/10 inch (0.3 to 2.5 mm) long. It is generally white, though the brown contents of the gut may be visible through the skin, especially in larger larvae (*Figure 286*).

Pupa: The pupa is black and is from 1/20 to 1/10 inch (1.3 to 2.5 mm) long. Unlike the pupa of the western tentiform leafminer, its head, thorax and abdomen are visible. It can also be distinguished by its shorter, more robust shape and darker color (*Figure 287*).

Adult: The female *P. flavipes* usually has a dark-colored thorax with blue metallic reflections and a yellow and black abdomen. The male has similar coloring but is smaller than the female and has branched antennae (*Figure 288*).

Life history

There are at least three complete generations of the parasitoid a year. It overwinters primarily as a pupa within mines of leaves on the orchard floor. In some years it may also overwinter as a larva. Unlike its host, *P. flavipes* seems to anticipate the change of seasons and in the fall stops development at the pupal stage. Thus, proportionally more parasitoids may survive the winter in an orchard than leafminers, giving the parasitoids a distinct advantage in the spring, which is usually when parasitism levels are highest.

Adult parasitoids emerge in the spring at about the same time as the leafminer. Female parasitoids search leaves for mines and attack the larvae. Female parasitoids lay eggs primarily in the mines of tissue feeding larvae. Parasitoids are in the orchard 2 to 3 weeks before most tissue feeders and survive during this period by feeding on sap feeders, an activity known as "host feeding." After the first generation, *P. flavipes* generations tend to overlap, so all stages of the parasitoids are in the orchard at any time. Leafminer generations also tend to overlap later in the season, providing a constant source of tissue feeders for the parasitoids to attack.

When a female parasitoid finds a sap feeding mine, it will most often sting the larva, paralyzing it. As its stinger is withdrawn from the sap feeding mine, a material is secreted that forms a tube connecting the larva to the surface of the mine. The parasitoid then feeds on the contents of the sap-feeder larva through this tube. Host feeding can account for 10 to 25% of the deaths caused by *P. flavipes*. The female parasitoid may deposit an egg in the mine after stinging the larva, but only if the last sap feeder stage (third larval instar) is present. Adult parasitoids produced from eggs laid in sap feeder mines are always males.

Figure 285: Eggs of the parasitoid are white and cylindrical and are laid inside the leafminer mine.

Figure 286: A *Pnigalio flavipes* larva is pictured feeding on a western tentiform leafminer larva.

Figure 287: The black pupa of the parasitoid (top) is pictured with the larger, lighter colored pupa of the leafminer.

When a female parasitoid finds a tissue feeding mine, it will sting the larva, paralyzing it. Usually an egg is deposited within the mine, but not necessarily on the leafminer larva. When the egg hatches, the parasitoid larva crawls to the paralyzed leafminer and feeds. Parasitoids emerging from tissue feeding mines are about half males and half females. Between 40 and 75% of leafminers are killed this way. Occasionally, the female parasitoid will sting a tissue-feeding larva, paralyzing it without depositing an egg. The leafminer larva eventually dies but no parasitoid is produced. This type of attack usually accounts for less than 10% of leafminer mortality. Larvae of the parasite pupate inside the mines. Emerging adults escape from the mine by chewing a small, circular hole through the leaf. This evidence can help determine the level of parasitism in an orchard.

Management

Assess parasitoid levels at the end of the first and second leafminer generations to determine the potential for biological control. Parasitism levels of 35% or greater in each leafminer generation are usually sufficient to keep leafminer populations below treatment thresholds. If parasitism is below 20%, it is likely the leafminer will exceed treatment thresholds at some time during the year. Biological control can be improved by avoiding chemical controls for other pests when adult parasites are active, which is roughly the same time as leafminer adults are active. Certain insecticides applied at the wrong time of year, when adult parasitoids are active, tend to disrupt biological control of the leafminer (*Figure 289*). See western tentiform leafminer in Part II, Indirect Pests.

Figure 288: A male *P. flavipes* adult caught on a sticky trap.

Toxicity of Insecticides to a Leafminer Parasite

Insecticide	Toxicity
Encapsulated methyl parathion	High
Chlorpyrifos	High
Esfenvalerate	Moderate
Endosulfan	Moderate
Phosphamidon	Moderate
Oxamyl	Moderate
Carbaryl	Low
Azinphos methyl	Low
Phosmet	Low

Toxicity of insecticides to *Pnigalio flavipes* adults, the major parasite of the western tentiform leafminer.

Figure 289

Colpoclypeus florus (Walker)

(Hymenoptera: Eulophidae)

Colpoclypeus florus is a common ectoparasitoid attacking leafrollers in European orchards. It was first reported from North America when it parasitized nearly 80% of the leafroller larva in two unsprayed apple orchards in Washington during 1992.

Hosts

In Europe, *C. florus* has been reported from several leafroller species from orchards and other crops. In Washington, it has been reared from the pandemis and obliquebanded leafroller. It could potentially attack all leafrollers found on fruit crops.

Life stages

Egg: The egg is slender and slightly curved and is less than 1/25 inch (1 mm) long. It is a creamy white color. Several eggs are laid by a single female on the webbing spun by the host larva within the leaf shelter.

Larva: The larva feeds externally and is found almost anywhere on the host's body. It is maggot-like and usually bright to dull green in color. The first stage larva is less than 1/25 inch (1 mm) while the fully grown larva measures about 1/8 to 1/6 inch (3 to 4 mm) (*Figure 290*).

Pupa: The pupa is found within the webbing spun by the host. It is light brown when first formed, gradually turns black and is 1/8 to 1/6 inch (3 to 4 mm) long. It has no cocoon and its appendages appearing to be glued to together (*Figure 291*).

Adult: The female has a black thorax with a light brown to golden abdomen. On the underside of the female's abdomen are two small dark spots at the base of the ovipositor. The antennae are short. The male is slightly smaller than the female and has a black thorax and abdomen. It has a creamy white area on the underside of the abdomen.

Figure 290: *C. florus* larvae feed almost anywhere on the host's body.

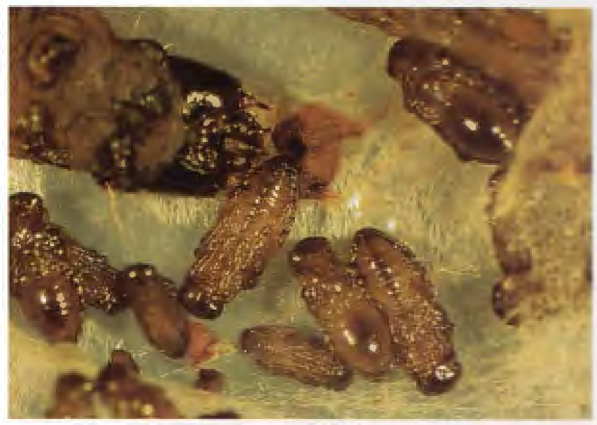


Figure 291: The pupa has no cocoon. Its appendages appear to be glued together.

Life history

The life history in the Pacific Northwest has not been studied but information from European literature should be appropriate for conditions and hosts here. *C. florus* overwinters as a mature larva on the consumed host larva. They pupate in spring and adults are present when leafroller larvae are present. The female stings a fourth or fifth instar larva, and then remains with the larva inside the webbed leaf shelter. The host larva spins an abnormally dense web and the female lays eggs on this webbing. When the eggs hatch, the parasitoid larva locates the host and begins to feed on the outside of the host. The host larva remains alive until the final instar of *C. florus* begins feeding. Up to 50 or more *C. florus* may be produced from a single host larva. The development time from egg to adult is about 15 days at 75°F. There appear to be only two generations of *C. florus* in the Pacific Northwest but more could be produced if hosts of suitable size were available.

Monitoring

C. florus can be sampled by searching shelters of mature larvae. The first sign that *C. florus* might be present is the density of the webbing in the shelter. The webbing of a leafroller larva stung by *C. florus* is 3 to 4 times denser than a normal leafroller larva. Even if adult *C. florus* have emerged, the pupal skins remain and are a good clue to the presence of this parasitoid.

Management

Broad-spectrum insecticides are toxic to *C. florus* in Europe but insect growth regulators and Bts are not. *C. florus* may not overwinter in high numbers because none of the leafrollers that are pests in orchards overwinter as late instar larvae, its preferred host size. Because *C. florus* is easily reared, it may be a candidate for augmentative release. This technique has been used in Europe with mixed results.

Aphelinus mali Haldemann

(Hymenoptera: Eulophidae)

This small wasp, native to the northeastern United States, parasitizes woolly apple aphid by laying its eggs directly into the body of the aphid. *A. mali* was introduced into the Pacific Northwest in 1928 at Hood River and has been introduced or has spread naturally to other Pacific Northwest fruit districts. It has been introduced successfully in many apple growing areas of the world, and was considered one of the early success stories of biological control.

Hosts

While it has been reported to parasitize other aphid species, its primary economic value is as a woolly apple aphid parasitoid.

Life stages

Egg: The egg, which measures about 1/600 to 1/200 inch (0.07 to 0.21 mm), is inserted singly into the body of the woolly apple aphid.

Larva: The larva, which develops inside the aphid's body, is elongated or shield shaped.

Pupa: The pupa is generally smaller than the larva. The thorax is black and the outlines of legs and other appendages become visible as the pupa develops. The pupal stage is also spent inside the aphid's body.

Adult: The adult is a tiny black wasp (slightly shorter than the woolly apple aphid) with short antennae (*Figure 292*). The membranous wings are folded flat over the back, and extend beyond the tip of the abdomen. It is inconspicuous in the orchard, jumping rather than flying and preferring to hide under leaves.

Figure 292: *Aphelinus mali* is slightly shorter than its host, the woolly apple aphid.

Life history

A. mali overwinters as a full grown larva or pupa inside a dead body of a woolly apple aphid. Emergence of adults corresponds with the start of nymph production by the woolly apple aphid in the spring.

The most visible signs of parasitism by *A. mali* are hardened, black, woolly apple aphid mummies with a characteristic circular exit hole cut by the adult parasite as it emerges from the aphid. The female inserts her egg into the lower surface of the abdomen, sometimes feeding on the body fluids that exude from the puncture. The egg hatches in about 3 days, and larval development takes about 10 to 12 days. The parasitoid pupates in the body of the aphid, and the emerging adult chews a neat, round exit hole in the back. The total life cycle takes 20 to 25 days. There are 6 to 7 generations of *A. mali* per year. Peak activity of adult parasitoids corresponds with peaks in woolly apple aphid nymph production in the spring and fall. *A. mali* only parasitizes woolly apple aphids on the above-ground parts of the tree.

Monitoring

Look for woolly apple aphid mummies with circular exit holes. Mummies are usually noticed after the pest has been controlled and no predator/prey ratios have been established to predict future control based on the number of mummies.

Management

Unmanaged, *A. mali* provides commercial control or suppression of woolly apple aphids in most years. *A. mali* may not provide acceptable control after mild winters, when large woolly apple aphid populations survive. Recent research indicates that a large complex of generalist predators, including lady beetles, syrphid fly larvae, *Deraeocoris brevis* and green lacewings is as or more important. Cultural practices that encourage these predators will enhance biological control of woolly apple aphid. Control of woolly apple aphid may be disrupted by pesticides that are toxic to *A. mali*.

Trechnites insidiosus (Crawford)

(Hymenoptera: Encyrtidae)

Trechnites insidiosus is the dominant parasitoid of pear psylla throughout western North America. It has been little studied because of its small size and because it is rarely found in pear orchards sprayed with organophosphate insecticides and other quick-acting nerve toxins. Because *T. psylla* from western Europe is morphologically indistinguishable from the so-called native *T. insidiosus*, it is likely that the *Trechnites* species found in North America is *T. psylla*. It probably colonized along with pear psylla during the 19th century. This would be consistent with collection of *T. insidiosus* in California before its intentional importation and release.

Figure 293: After attack by *Trechnites insidiosus*, the pear psylla nymph is mummified. The mummy is a shiny pale brown.

Hosts

Trechnites attacks pear psylla, its only host in orchard environments.

Life stages

Egg: The egg is laid inside the host, and is about 1/250 inch (0.1 mm) long.

Larva: There are two larval instars. The mature larva is about 1/16 inch (1.5 mm) long.

Pupa: The pupal stage occurs in the body of the host, and is roughly the same size as the fourth instar psylla.

Adult: The adult wasp is predominantly black with yellow legs and has a distinctive iridescent-blue patch on its back. It is about 1/25 inch (1 mm) long.

Life history

The parasitoid overwinters as a fully developed larva inside the host mummy. The larva pupates in early spring, and the adult wasp emerges from the mummy around bloom time. The race of *Trechnites* in the Northwest reproduces parthenogenetically (asexually) and males are rare. Females of the spring generation search for psylla nymphs on buds and flowers. Females of later generations search both surfaces of the leaves and up and down the petioles.

Upon encountering a psylla nymph, the female wasp taps it with her antennae and may sting it and lay an egg inside the host body. As the second instar larva reaches full size (10 to 20 days after parasitism) it devours the internal organs of the psylla nymph and the nymph becomes mummified. The mummy is characteristically shiny and pale brown (*Figure 293*). It is about the shape of an engorged fourth instar psylla nymph.

In summer generations the mummy forms on the leaves and small branches. Parasitized psylla nymphs of late summer or fall crawl down from the leaves, often into bark crevices, before transforming into the immobile mummy. There are 3 to 4 generations per year.

Monitoring

Monitoring the activity of *Trechnites* is difficult because of its size and biology. Yellow sticky cards may be of some use to detect adults but the relationship between trap catch and parasitism rate has not been established. The only reliable method is to dissect psylla nymphs under 30- to 50-power magnification. Such dissections are too tedious to be a useful field management tool. However, a relative abundance of characteristic psylla mummies on the leaves give an idea of the presence and activity of this parasitoid.

Management

Trechnites is known to be easily killed by most synthetic insecticides commonly used in pear orchards. Only insecticidal soaps and oils, species-specific pheromones and microbial insecticides will not harm this natural enemy. Parasitism rates in unsprayed orchards can reach levels of 70 to 90%, and season-long averages of 50% have been observed in orchards using soft pesticide programs. However, even high rates of parasitism may not prevent pear psylla from causing significant damage. Although *Trechnites* alone may not provide sufficiently high levels of biological control, their activities will augment the effect of other natural enemies.

Trichogramma minutum Riley
Trichogramma praetiosum Riley

(Hymenoptera: Trichogrammatidae)

These minute wasps parasitize the eggs of many different insects, particularly Lepidoptera. As early as 1912, trichogrammatid wasps were used as a biological control agent against codling moth. However, even where parasitism rates have reached 50% or more, reduction in fruit damage has not been significant or consistent. In warm growing areas of the Northwest, the common species are *Trichogramma minutum* and *T. praetiosum.*

Hosts

T. minutum are notoriously indiscriminate in their choice of host eggs and have often been seen trying to lay eggs in specks of dust or other inanimate objects about the same size as host eggs. However, *Trichogramma* species are known to produce locally adapted strains, which may have narrow host ranges. The degree of host specialization of species in Northwest orchards is unknown.

Life stages

Egg: The egg is deposited into the egg of its host.
Larva, pupa: The larva and pupa develop inside the host egg.
Adult: The adult is a yellow wasp with red eyes and is 1/25 inch (1 mm long) or smaller (*Figure 294*).

Life history:

Trichogramma overwinter as pupae inside host eggs in leaf litter either in or outside the orchard. Low parasitoid activity early in the growing season suggests that they most often overwinter on a non-pest host outside the orchard and move into orchards again in May and June. The female deposits one or more eggs into the egg of its host. The wasp larva hatches and develops inside the host egg, consuming its contents. The pupa is also contained within the host egg. The host egg turns black when the pupa is nearly ready to emerge as an adult (*Figure 295*). The larva transforms into a pupa, then into an adult wasp, which leaves the remains of the host egg and mates. The species

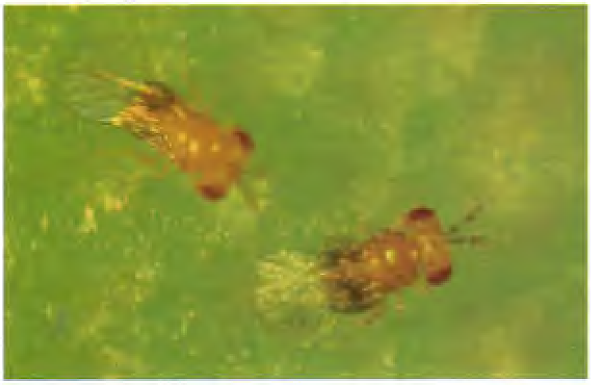


Figure 294: *Trichogramma* wasps are yellow with red eyes.

Figure 295: A parasitized codling moth egg. Note emergence hole and the *Trichogramma* wasp in the foreground.

found in the Pacific Northwest produce 6 to 10 generations a year.

Monitoring

The best way to determine if trichogrammatid wasps are in the orchard is to collect codling moth eggs during mid-summer and late-summer moth flights and examine them. However, the eggs, which are laid singly on leaves or fruits, are extremely difficult to find. Parasitized eggs will turn black and the microscopic wasps will later emerge.

Management

Trichogramma wasps are sensitive to most commonly used pesticides. Even botanical pesticides such as pyrethrum and rotenone are harmful to them. Studies in Europe and the former Soviet Union have shown that some species of *Trichogramma* gave better control of codling moth and leafrollers than *T. minutum*. In these studies, large numbers of wasps, roughly 10,000 per tree per season, were needed to reduce codling moth or leafroller damage by 60%.

Although alone *Trichogramma* wasps may not be able to suppress fruit damage to acceptable levels, they can contribute to biological control of orchard pests and should be conserved where possible. *T. minutum* eggs can be bought from commercial suppliers for release in orchards. However, keep in mind that large numbers will be needed and, even if parasitism rates are high, alone they are unlikely to suppress fruit damage by codling moth below commercially accepted standards.

Anagrus sp.

(Hymenoptera: Mymaridae)

Anagrus spp. are egg parasitoids of leafhoppers, and have been studied since the 1930s as biological control agents. More recently, they have been studied for their potential in biological control of white apple leafhopper in Michigan and Washington, and grape leafhoppers in California. The taxonomy of this group is complex, and species identification is difficult. *A. epos* is presumed to be the species of interest in the west.

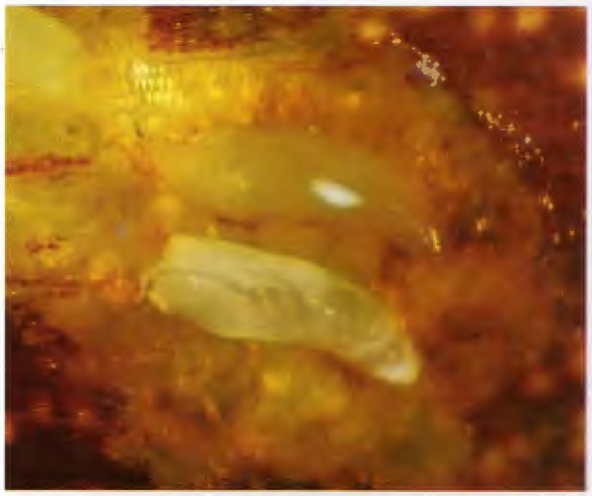


Figure 296: A parasitized rose leafhopper egg (top) is pictured with a normally developing embryo, which is opaque white.

Hosts

Known overwintering hosts include the white apple leafhopper and the rose leafhopper. Summer hosts include grape leafhoppers (*Erythroneura elegantula* and *E. ziczac*), as well as the rose leafhopper and white apple leafhopper.

Life stages

Larva: The larva of *A. epos* is initially seen as an opaque white oval shape (reported to be the fat body of the larva) inside the translucent egg of the white apple leafhopper. As it develops, the larva becomes light tan and appears segmented. Eventually it fills the entire egg chamber. Normally developing embryos of white apple leafhopper will be more opaque white, and as hatch nears, legs, abdominal segmentation and red eyes can be distinctly seen (*Figure 296*).

Pupa: In the pre-pupal stage, some light brown pigmentation appears, and segmentation becomes evident. The pupal form is a distinct, medium to dark brown. It is about $\frac{1}{60}$ inch (0.4 mm) long and completely fills the egg chamber. During the summer generation of white apple leafhopper, the dark pigmentation in the parasitized egg can be seen through leaf tissues in which they are laid, whereas healthy white apple leafhopper eggs will be invisible at this time.

Adult: The adult is a tiny, delicate wasp about $\frac{1}{50}$

inch (0.5 mm) long. The distinctive characters are the lack of wing veins and a fringe of hairs bordering both pairs of wings (*Figure 297*). The hind wings are small and very narrow. The antennae are long and thread-like. Color is variable, but generally dark brown.

Life history

A. epos passes the winter as a partially grown larva inside the egg chamber of its host. This species must overwinter in a host that overwinters in the egg phase, although it can parasitize eggs of other leafhoppers during the growing season. The fat body of the larva can be seen shortly after the egg is deposited, and remains in this stage until late April of the following year. Development speeds up as weather warms in the spring, and pre-pupal and pupal forms occur during late April to mid-May. Adults emerge from about May 10 to 20 to the first week in June. The emerging parasite leaves a distinctive, round hole in the bark. Emergence coincides with the appearance of adult white apple leafhoppers. Eggs of the second generation of leafhoppers, which are laid in the leaf tissue, are also parasitized by *A. epos*. The adult leaves an exit hole in the leaf tissue when it emerges. Although adults are present from mid-May to mid-November, there are 2 or 3 peaks of activity. The first occurs about June 1; the second, smaller peak is in late July to mid-August; and a third peak is from late September through mid-October. Females deposit their eggs in the overwintering eggs of *A. epos*, which are inserted beneath the bark of woody host plants.

Anagrus spp.
(Leafhopper parasitoid)

Anagrus spp. are egg parasitoids of leahoppers. White apple leafhopper and rose leafhopper are overwintering hosts of *A. epos*. The parasitoid is susceptible to broad-spectrum pesticides. Egg parasitism rates of up to 25% have been found in moderately sprayed orchards and up to 70% where no insecticides were used.

Figure 297

Monitoring

A. epos can be monitored most readily in two phases: as a larva or pupa in the overwintering eggs of leafhoppers, or as an adult. To monitor larvae or pupae, the thin layer of bark overlying the leafhopper egg can be carefully cut off with a scalpel without disturbing the egg beneath. From early spring through the time the adult parasites emerge, either the larva, pre-pupa or pupa can be distinguished from a normal leafhopper embryo. The round exit hole left by the adult parasite (and at one end of the egg chamber) can be seen without dissection.

Adult parasitoids can be monitored with the same unbaited yellow sticky trap used for white apple leafhopper adults. Although this gives some idea if the parasite is in the area, it does not identify the host. Calculating the percentage of parasitism in overwintering eggs gives a more definitive assessment of biological control.

Management

Preliminary data suggests that parasitism by *A. epos* is adversely affected by increasing numbers of applications of broad-spectrum insecticides. Soft pesticide programs should allow this parasite to provide sufficient levels of control for the two main species of leafhoppers on apples. Parasitism levels of up to 25% have been found in moderately sprayed orchards, suggesting some tolerance to insecticides. Levels of 50 to 70% parasitism of overwintering eggs have been found in unsprayed orchards.

Aphelopus typhlocyba Muesebeck
(Hymenoptera: Dryinidae)

A. typhlocyba is a parasitoid of leafhoppers that feeds internally on nymphs and later appears externally on adults. As the species name implies, it parasitizes the white apple leafhopper, *Typhlocyba pomaria*, but it may also use other leafhopper species as hosts. *Aphelopus* species were studied as early as the 1930s but have not been exploited as a biological control agents to any degree. Parasitized adult leafhoppers have been found in samples from a mixed population of rose leafhopper and white apple leafhopper from apple and sweet cherry orchards in the Mid-Columbia area of Oregon. Although thousands of adult leafhoppers from central Washington have been examined, no evidence of this parasitoid has been found.

Figure 298: A white apple leafhopper with a sac-like protrusion on the abdomen containing a larva of the parasitoid *A. typhlocyba*.

Hosts

Little is known about the specific host range of *A. typhlocyba*. Other species of *Aphelopus* are reported to parasitize only *Typhlocyba* leafhoppers. Some species of Dryinidae are know to be species specific or limited to a very small number of hosts.

Life stages

Larva: Early stages of the larvae are not visible without dissection of the host. The latter stages are grub-like and can be seen inside a sac-like protrusion on the abdomen of the leafhopper (*Figure 298*). The sac is formed from the cast larval skins of the parasitoid larva and is attached to the side of the host's abdomen between two abdominal segments. When the larva is mature (about 2 to 4 weeks after the sac becomes visible), the oval sac is nearly as large as the host's abdomen. Mature larvae are white, about ⅛ inch (3 mm) long, pointed at the head end, and have a rounded posterior.

Pupa: The larva spins a cocoon in which to pupate. The cocoon is white, oval, and about 1/12 to ⅛ inch (2 to 3 mm) long.

Adult: The adult is a small wasp about 1/12 inch (2 mm) long. The primary body color is dark brown to black, but the first two pairs of legs, clypeus and mandibles are pale colored. The forelegs are adapted for grasping leafhoppers during egg laying. The antennae are filiform, or thread-like.

Life history

A. typhlocyba overwinters in the larval stage in a silken cocoon in the ground. Adults emerge in late spring and search out hosts. Eggs are laid in leafhopper nymphs and develop inside the body, where they consume the internal organs. The sac becomes visible in the adult stage of the leafhopper, often pushing the wings out of position. Visibly parasitized adult leafhoppers occur in June and July. The leafhopper remains alive and active until a few days before larva matures. The mature larva emerges from the host, drops to the ground, spins a cocoon, and pupates in the soil. The remains of the leafhopper mummy may stay attached to the leaf for a considerable period. The combined cocoon and pupal period lasts from 24 to 48 days. The adult parasitoids emerge during late July and August. This brood attacks the second generation of white apple leafhopper. Parasitized leafhoppers often exhibit reduced or deformed external genitalia. Although they reach adulthood they are incapable of reproduction.

Monitoring

A. typhlocyba may be monitored by checking for parasitized adult leafhoppers. These should be easily seen by aspirating adults from the trees, or examining adults caught on sticky traps. See *Figure 3* in Part I for information on how to use an aspirator for monitoring.

Management

This species is probably sensitive to many orchard pesticides, and is kept at low levels where broad-spectrum pesticides are used routinely, especially during the periods of adult activity. Discing when the larvae and pupae are in the ground will kill a high proportion of the population. Softer programs may allow populations to build. It is not known if *A. typhlocyba* is established in some regions of Washington, or if it may be successfully introduced to supplement biological control by *Anagrus epos*.

PARASITIC FLIES

Tachinid flies

(Diptera: Tachinidae)

Tachinid flies are a large and valuable group of parasitic insects. There are more than 1,000 species in North America. They are endoparasitoids, which means they develop inside their hosts. They tend to have a wider range of hosts than parasitic wasps. These flies can be very important natural enemies of leafrollers, cutworms and other Lepidoptera that feed exposed on foliage in the Northwest.

Hosts

Tachinid flies attack the larvae of moths, beetles, sawflies, stink bugs and other insects and are effective biological control agents because they can increase their populations rapidly. Tachinids from five different genera have been reared from leafroller larvae.

Life stages

Egg: The egg is white, oval and flat. It is not unusual to see a caterpillar with several tachinid eggs attached to its body or a stink bug nymph or adult with eggs on its shoulders.

Larva: The maggot develops inside the host body. In some species, the adult keeps the larvae within its abdomen and deposits them directly on or near the host.

Pupa: The pupa is dark reddish brown and oval, like a large grain of wheat *(Figure 299)*.

Adult: The size and appearance of the adult varies depending on the species. It is usually hairy or bristly and dark gray or black (*Figure 300*). Many are about the size and color of a housefly.

Life history

The life history of different species can vary considerably. Some tachinid flies complete only one generation a year, spending much of the season in the pupal stage. Others have several generations and complete the life cycle in 3 to 4 weeks.

The life cycle of some tachinid flies corresponds closely with that of the host. If the victim — usually a caterpillar — overwinters as a larva, the tachinid larva also spends the winter at rest inside the host. Some species of tachinid flies overwinter as pupae

Figure 299: A pandemis leafroller pupa (top) is pictured with the smaller pupa of a tachinid fly.

Figure 300: Tachinid flies vary in size and appearance but are usually hairy or bristly.

in the soil or in leaf litter.

Adults emerge in the spring and feed on insect honeydew and flower nectar. After mating, the female begins searching for hosts. Many tachinid fly species that lay eggs deposit them directly on or in the body of their host. However, some simply deposit their eggs on the host's food plant and leave it up to the larvae to find suitable victims. Many tachinid flies do not lay eggs. Instead, they deposit young larvae on, in or near their hosts. The young larvae feed their way into their hosts, where they chew on the gut wall. Usually, a single larva develops inside an individual host insect. Many tachinid larvae almost totally consume the host insect before they bore out of the host to pupate and complete the generation. Usually the tachinid larva will leave the host pupa, forming its own pupa close by.

Monitoring

Adult flies can often be seen visiting flowers in the orchard or on plants near to the orchard. They can be recognized by the thick bristles on the abdomen. Often the large white eggs of tachinid fly species that deposit eggs on the host can be seen on the head or thorax region of caterpillars that have been attacked. Usually, the presence of tachinid flies will become evident during sampling for pests. The parasitoid's pupa, or the empty pupal case, often remains beside the dead body of the host.

Management

The impact of tachinid flies on pests in the Northwest is not well understood. Broad-spectrum insecticides are probably highly toxic to these natural enemies.

Honeybee

Apis mellifera Linnaeus
(Hymenoptera: Apidae)

Honeybees play a vital role in the pollination of all tree fruits. They are indispensable pollinators. Bee colonies were first brought to North America by early European settlers. Beekeepers keep honeybees for honey production and rent them to orchardists for crop pollination.

There are about 100,000 managed bee colonies in Washington. Beekeepers move colonies to various locations so that sufficient bees are available to pollinate crops adequately.

Life stages

Egg: The egg is cylindrical and is about 1/16 inch (1.5 mm) long.
Larva: The larva is a white, legless grub, which lies curled up on the bottom of the wax cell of the honey comb. When first hatched it is about 1/16 inch (1.5 mm) long. It develops through four molts before maturing.
Pupa: The head, eyes, antennae, mouthparts, thorax, legs and abdomen are visible and resemble the adult's. Only the wings are not yet developed.
Adult: The adult is covered with dull yellow and black hairs arranged in alternating stripes across the abdomen (*Figure 301*). The hairs trap pollen as the insect moves from flower to flower, so the workers are often covered with a dusting of orange or yellow pollen granules. The worker bee (female) averages ½ inch (13 mm) in length, the drone (male) about ⅝ inch (16 mm), and the queen about ¾ inch (18 mm). The queen, whose main function is to lay eggs, has a long, tapered abdomen.

Life history

Honeybees are social insets. A colony of bees is a family unit containing a queen, drones and female workers. During spring and summer, there will be several thousand drones in a healthy colony. Their main role is to mate with new queens. Most bees in a colony are sterile female workers. The population of a colony varies from 10,000 to 15,000 in winter to as many as 60,000 in midsummer.

A colony of honeybees needs food. Workers forage for pollen and nectar, and bring it back to the hive

Figure 301: The adult bee is yellow and black, and covered with dense hairs. Workers forage for pollen and nectar.

where it is stored in combs. Workers also keep the hive clean and take care of the brood. Brood is a collective term for eggs, larvae and pupae. The queen lays eggs in cells in the combs in the colony and the workers feed royal jelly and nectar to the larvae. Most larvae are only fed royal jelly for a few days, but a future queen will be fed royal jelly during the entire larval period. When the larvae are mature, workers cap the cells and the larvae change to pupae. About 12 days later, adult bees emerge. The life cycle from egg to adult takes 21 days.

Pollination

Pollination is the transfer of pollen from the anther (the male part of the flower) to the stigma (the female part). Without pollination there is little or no fruit. While foraging for nectar and pollen, bees touch the anthers and stigma of flowers, transferring the pollen.

Protection from pesticides

Most fungicides, most herbicides, plant growth regulators and nutrients can be applied to bloom because they are not harmful to bees. However, bees are vulnerable to insecticides used in orchards. A bee that picks up insecticide residues on open bloom is almost certain to be killed. Bee kills can be avoided by never applying insecticides when any blossoms are open or when the spray may drift to open bloom in adjoining orchards or interplants. However, there may be times when orchard pests need to be controlled when there is bloom in the orchard or blooming weeds.

There are real differences in the bee hazard and toxicity of the different insecticides used in orchards. Some are hazardous at any time on blooming crops, while others (mainly miticides and fungicides) are not hazardous to bees at any time. See *Figure 302* for indications of the hazard of pesticides to bees. The toxicity of those rated as hazardous at certain times depends primarily on how quickly the residues break down. The residues of some break down in within a couple of hours, which means they can be applied in the evening or early morning. Those with residues that take several hours to break down should only be applied in the evening.

During the growing season, mow or beat down blooming orchard cover crops before applying insecticides that are hazardous to bees. This is especially important before tree bloom, as this is during a critical foraging period when bees will fly several miles to obtain pollen and nectar from even a few blooms of plants such as dandelion or mustard.

Toxicity of Pesticides to Bees

Hazardous at any time	Not hazardous If applied in late evening except during high temperatures [1,2]	Not hazardous If applied in evening or early morning except during high temperatures [1,2,3]	Not hazardous at any time
azinphos methyl carbaryl (Sevin 50 WP) chlorpyriphos diazinon dimethoate encapsulated methyl parathion malathion ULV methidathion methyl parathion phosmet phosphamidon	esfenvalerate formetanate malathion EC mevinphos permethrin oxamyl	carbaryl (Savit 4F) carbaryl (Sevin XLR Plus) endosulfan methoxychlor trichlorfon	amitraz *Bacillus thuringiensis* (Bt) clofentezine dicofol dodine fenbutatin-oxide fenarimol lime-sulfur myclobutanil superior oils oxythioquinox propargite sulfur triadimefon

1 If temperature is below 45˚F, spray any time.
2 If temperature is above 60˚F, do not spray until after 7 p.m.
3 For early moming spray, stop at 7 a.m.

Figure 302

Appendices

Degree Day Look-up Table for Codling Moth and Peach Twig Borer

Lower threshold: 50°F Upper threshold: 88°F Horizontal cut-off

Maximum temperature	Minimum temperature: 15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81
49	0	0	0	0	0	0	0	0	0	0	0	0											
52	0	0	0	0	0	0	0	0	0	0	0	1	2										
55	1	1	1	1	1	1	1	1	1	1	2	2	3	5									
58	1	2	2	2	2	2	2	2	2	3	3	3	5	6	8								
61	2	2	3	3	3	3	3	3	4	4	4	5	6	8	9	11							
64	3	3	4	4	4	4	4	4	5	5	6	6	8	9	11	12	14						
67	4	4	5	5	5	5	5	6	6	6	7	8	9	11	12	14	15	17					
70	5	5	6	6	6	6	7	7	7	8	8	9	11	12	14	15	17	18	20				
73	6	7	7	7	7	8	8	8	9	9	10	11	12	14	15	17	18	20	21	23			
76	8	8	8	8	9	9	9	10	10	11	11	12	14	15	17	18	20	21	23	24	26		
79	9	9	9	10	10	10	11	11	12	12	13	14	15	17	18	20	21	23	24	26	27	29	
82	10	10	10	11	11	11	12	12	13	14	14	15	17	18	20	21	23	24	26	27	29	30	32
85	11	11	12	12	12	13	13	14	14	15	16	17	18	20	21	23	24	26	27	29	30	32	33
88	12	13	13	13	14	14	15	15	16	16	17	18	20	21	23	24	26	27	29	30	32	33	35
91	13	14	14	14	15	15	16	16	17	18	18	19	21	22	24	25	27	28	30	31	32	34	35
94	14	15	15	15	16	16	17	17	18	18	19	20	22	23	24	26	27	29	30	32	33	34	36
97	15	15	16	16	16	17	17	18	19	19	20	21	22	24	25	27	28	29	31	32	33	35	36
100	16	16	16	17	17	18	18	19	19	20	21	22	23	24	26	27	28	30	31	32	34	35	36
103	16	16	17	17	18	18	19	19	20	21	21	22	23	25	26	28	29	30	32	33	34	35	36
106	17	17	17	18	18	19	19	20	20	21	22	23	24	25	27	28	29	31	32	33	34	35	36
109	17	17	18	18	19	19	20	20	21	22	22	23	24	26	27	28	30	31	32	33	34	36	36
112	18	18	18	19	19	20	20	21	21	22	23	24	25	26	27	29	30	31	32	34	35	36	37
115	18	18	19	19	20	20	21	21	22	22	23	24	25	26	28	29	30	31	33	34	35	36	37

To find the total degree days for a day, locate the low and high temperatures and follow the rows to where they intersect. For temperatures between those listed, use the nearest shown. This chart can be photocopied for easy reference in the field.

Table 1

Degree Day Look-up Table for Oriental Fruit Moth

Lower threshold: 45˚F Upper threshold: 90˚F Vertical cut-off

Maximum temperature	Minimum temperature																						
	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81
46	0	0	0	0	0	0	0	0	0	0	1												
49	1	1	1	1	1	1	1	1	1	1	2	4											
52	1	1	1	2	2	2	2	2	2	3	4	5	7										
55	2	2	2	2	3	3	3	3	4	4	5	7	8	10									
58	3	3	3	4	4	4	4	5	5	6	7	8	10	11	13								
61	4	4	4	5	5	5	6	6	6	7	8	10	11	13	14	16							
64	5	5	6	6	6	6	7	7	8	8	10	11	13	14	16	17	19						
67	6	7	7	7	7	8	8	9	9	10	11	13	14	16	17	19	20	22					
70	8	8	8	8	9	9	10	10	11	11	13	14	16	17	19	20	22	23	25				
73	9	9	9	10	10	10	11	11	12	13	14	16	17	19	20	22	23	25	26	28			
76	10	10	11	11	11	12	12	13	14	14	16	17	19	20	22	23	25	26	28	29	31		
79	11	12	12	12	13	13	14	14	15	16	17	19	20	22	23	25	26	28	29	31	32	34	
82	12	13	13	14	14	15	15	16	16	17	19	20	22	23	25	26	28	29	31	32	34	35	37
85	14	14	15	15	15	16	17	17	18	19	20	22	23	25	26	28	29	31	32	34	35	37	38
88	15	15	16	16	17	17	18	19	19	20	22	23	25	26	28	29	31	32	34	35	37	38	40
91	13	13	14	14	15	15	16	16	17	18	19	20	21	23	24	25	26	28	29	30	31	31	32
94	11	11	11	12	12	12	13	13	14	15	16	17	18	19	20	21	22	23	24	25	25	25	25
97	10	10	10	10	1	11	12	12	13	13	14	15	16	17	18	19	20	21	21	22	22	22	21
100	9	9	9	10	10	10	11	11	12	12	13	14	15	16	17	18	19	19	20	20	20	20	19
103	8	8	9	9	9	10	10	10	11	11	12	13	14	15	16	17	17	18	18	19	19	18	17
106	8	8	8	8	9	9	9	10	10	11	12	12	13	14	15	16	16	17	17	17	17	17	16
109	7	8	8	8	8	9	9	9	10	10	11	12	13	14	14	15	16	16	16	16	16	16	15
112	7	7	7	8	8	8	9	9	9	10	10	11	12	13	14	14	15	15	16	16	16	15	14
115	7	7	7	7	8	8	8	9	9	9	10	11	12	12	13	14	14	15	15	15	15	14	13

To find the total degree days for a day, locate the low and high temperatures and follow the rows to where they intersect. For temperatures between those listed, use the nearest shown. This chart can be photocopied for easy reference in the field.

Table 2

Degree Day Look-up Table for Pandemis Leafroller

Lower threshold: 41˚F   Upper threshold: 85˚F   Vertical cut-off

Maximum temperature \ Minimum temperature	16	19	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79
41	0	0	0	0	0	0	0	0	0													
44	0	0	0	1	1	1	1	1	1	3												
47	1	1	1	1	1	2	2	2	3	4	6											
50	2	2	2	2	3	3	3	3	4	6	7	9										
53	3	3	3	4	4	4	4	5	6	7	9	10	12									
56	4	4	4	5	5	5	6	6	7	9	10	12	13	15								
59	5	5	6	6	6	7	7	8	9	10	12	13	15	16	18							
62	6	7	7	7	8	8	9	9	10	12	13	15	16	18	19	21						
65	8	8	8	8	9	9	10	11	12	13	15	16	18	19	21	22	24					
68	9	9	9	10	10	11	11	12	13	15	16	18	19	21	22	24	25	27				
71	10	10	11	11	12	12	13	14	15	16	18	19	21	22	24	25	27	28	30			
74	11	12	12	13	13	14	14	15	16	18	19	21	22	24	25	27	28	30	31	33		
77	13	13	13	14	14	15	16	17	18	19	21	22	24	25	27	28	30	31	33	34	36	
80	14	14	15	15	16	16	17	18	19	21	22	24	25	27	28	30	31	33	34	36	37	39
83	15	16	16	17	17	18	19	20	21	22	24	25	27	28	30	31	33	34	36	37	39	40
86	13	14	14	14	15	15	16	17	18	19	20	22	23	24	26	27	28	29	30	31	31	30
89	11	11	12	12	12	13	13	14	15	16	17	18	20	21	22	22	23	24	24	24	24	23
92	10	10	10	11	11	12	12	13	13	15	16	17	18	19	19	20	21	21	21	21	21	19
95	9	9	10	10	10	11	11	12	12	13	14	15	16	17	18	19	19	19	20	19	18	17
98	8	9	9	9	10	10	10	11	12	13	13	14	15	16	17	17	18	18	18	18	17	15
101	8	8	8	9	9	9	10	10	11	12	13	14	14	15	16	16	17	17	17	16	16	14
104	7	8	8	8	9	9	9	10	10	11	12	13	14	14	15	15	16	16	16	15	15	13
107	7	7	8	8	8	8	9	9	10	11	12	12	13	14	14	15	15	15	15	15	14	12
110	7	7	7	8	8	8	8	9	10	10	11	12	13	13	14	14	14	15	14	14	13	12

To find the total degree days for a day, locate the low and high temperatures and follow the rows to where they intersect. For temperatures between those listed, use the nearest shown. This chart can be photocopied for easy reference in the field.

Table 3

Degree Day Look-up Table for Western Cherry Fruit Fly

Lower threshold: 41˚F   Upper threshold: None

Maximum temperature \ Minimum temperature	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81
40	0	0	0	0	0	0	0	0	0														
43	0	0	0	0	0	0	0	0	1	2													
46	1	1	1	1	1	1	1	2	2	3	5												
49	2	2	2	2	2	2	3	3	3	5	6	8											
52	3	3	3	3	3	4	4	4	5	6	8	9	11										
55	4	4	4	4	4	5	5	6	6	8	9	11	12	14									
58	5	5	5	5	6	6	6	7	8	9	11	12	14	15	17								
61	6	6	6	7	7	7	8	8	9	11	12	14	15	17	18	20							
64	7	7	8	8	8	9	9	10	11	12	14	15	17	18	20	21	23						
67	8	9	9	9	10	10	11	11	12	14	15	17	18	20	21	23	24	26					
70	10	10	10	11	11	12	12	13	14	15	17	18	20	21	23	24	26	27	29				
73	11	11	11	12	12	13	14	14	15	17	18	20	21	23	24	26	27	29	30	32			
76	12	12	13	13	14	14	15	16	17	18	20	21	23	24	26	27	29	30	32	33	35		
79	13	14	14	15	15	16	16	17	18	20	21	23	24	26	27	29	30	32	33	35	36	38	
82	15	15	16	16	17	17	18	19	20	21	23	24	26	27	29	30	32	33	35	36	38	39	41
85	16	16	17	17	18	19	19	20	21	23	24	26	27	29	30	32	33	35	36	38	39	41	41
88	17	18	18	19	19	20	21	22	23	24	26	27	29	30	32	33	35	36	38	39	41	42	44
91	19	19	20	20	21	22	22	23	24	26	27	29	30	32	33	35	36	38	39	41	42	44	45
94	20	21	21	22	22	23	24	25	26	27	29	30	32	33	35	36	38	39	41	42	44	45	47
97	21	22	22	23	24	24	25	26	27	29	30	32	33	35	36	38	39	41	42	44	45	47	48
100	23	23	24	24	25	26	27	28	29	30	32	33	35	36	38	39	41	42	44	45	47	48	50
103	24	25	25	26	27	27	28	29	30	32	33	35	36	38	39	41	42	44	45	47	48	50	51
106	26	26	27	27	28	29	30	31	32	33	35	36	38	39	41	42	44	45	47	48	50	51	53
109	27	28	28	29	29	30	31	32	33	35	36	38	39	41	42	44	45	47	48	50	51	53	54
112	28	29	30	30	31	32	33	34	35	36	38	39	41	42	44	45	47	48	50	51	53	54	56
115	30	30	31	32	32	33	34	35	36	38	39	41	42	44	45	47	48	50	51	53	54	56	57

To find the total degree days for a day, locate the low and high temperatures and follow the rows to where they intersect. For temperatures between those listed, use the nearest shown. This chart can be photocopied for easy reference in the field.

Table 4

Degree day Look-up Table for San Jose Scale

Lower threshold: 51˚F Upper threshold: 90˚F Vertical cut-off

Maximum temperature \ Minimum temperature	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81
49	0	0	0	0	0	0	0	0	0	0	0	0											
52	0	0	0	0	0	0	0	0	0	0	0	0	1										
55	1	1	1	1	1	1	1	1	1	1	1	1	2	4									
58	1	1	1	1	1	2	2	2	2	2	2	3	4	5	7								
61	2	2	2	2	2	2	3	3	3	3	4	4	5	7	8	10							
64	3	3	3	3	3	4	4	4	4	5	5	6	7	8	10	11	13						
67	4	4	4	4	4	5	5	5	6	6	6	7	8	10	11	13	14	16					
70	5	5	5	5	6	6	6	6	7	7	8	8	10	11	13	14	16	17	19				
73	6	6	6	7	7	7	7	8	8	9	9	10	11	13	14	16	17	19	20	22			
76	7	7	8	8	8	8	9	9	10	10	11	11	13	14	16	17	19	20	22	23	25		
79	8	8	9	9	9	10	10	10	11	11	12	13	14	16	17	19	20	22	23	25	26	28	
82	9	10	10	10	11	11	11	12	12	13	14	14	16	17	19	20	22	23	25	26	28	29	31
85	11	11	11	12	12	12	13	13	14	14	15	16	17	19	20	22	23	25	26	28	29	31	32
88	12	12	12	13	13	14	14	15	15	16	16	17	19	20	22	23	25	26	28	29	31	32	34
91	10	10	11	11	11	12	12	13	13	14	14	15	16	17	19	20	21	22	24	25	26	26	27
94	8	9	9	9	9	10	10	10	11	11	12	12	13	14	16	17	18	19	20	20	21	21	21
97	7	8	8	8	8	9	9	9	10	10	10	11	12	13	14	15	16	17	17	18	18	18	18
100	7	7	7	7	8	8	8	8	9	9	10	10	11	12	13	14	15	15	16	16	17	17	16
103	6	6	7	7	7	7	7	8	8	8	9	9	10	11	12	13	14	14	15	15	15	15	15
106	6	6	6	6	7	7	7	7	8	8	8	9	10	11	11	12	13	14	14	14	14	14	14
109	6	6	6	6	6	6	7	7	7	8	8	8	9	10	11	12	12	13	13	14	14	13	13
112	5	5	6	6	6	6	6	7	7	7	8	8	9	10	10	11	12	12	13	13	13	13	12
115	5	5	5	6	6	6	6	6	7	7	7	8	8	9	10	11	11	12	12	12	12	12	11

To find the total degree days for a day, locate the low and high temperatures and follow the rows to where they intersect. For temperatures between those listed, use the nearest shown. This chart can be photocopied for easy reference in the field.

Table 5

Degree Day/Development Table for Codling Moth

Accumulated degree days	% moth flight	hatch	Accumulated degree days	% moth flight	% egg hatch	Accumulated degree days	% moth flight	% egg hatch
0	1	0	780	100	94	1560	81	46
20	2	0	800	100	95	1580	83	50
40	4	0	820	0	96	1600	85	53
60	7	0	840	0	97	1620	87	56
80	10	0	860	1	97	1640	88	60
100	15	0	880	1	98	1660	90	63
120	19	0	900	1	98	1680	91	66
140	24	0	920	2	99	1700	92	69
160	29	0	940	2	99	1720	93	71
180	35	0	960	3	99	1740	94	74
200	40	0	980	4	99	1760	95	76
220	45	1	1000	5	100	1780	96	79
240	50	2	1020	6	100	1800	97	81
260	52	3	1040	7	0	1820	98	83
280	54	4	1060	9	0	1840	98	85
300	59	6	1080	11	0	1860	99	86
320	63	9	1100	13	1	1880	100	88
340	67	12	1120	15	1	1900	0	89
360	70	20	1140	18	2	1920	1	91
380	73	25	1160	20	2	1940	2	92
400	77	30	1180	23	3	1960	2	93
420	80	35	1200	26	3	1980	3	94
440	83	40	1220	29	4	2000	4	95
460	85	45	1240	33	5	2020	5	96
480	88	49	1260	36	7	2040	6	97
500	90	54	1280	39	8	2060	8	97
520	91	58	1300	43	10	2080	9	98
540	93	62	1320	46	11	2100	10	99
560	94	66	1340	50	14	2120	12	100
580	95	70	1360	53	16	2140	14	100
600	96	73	1380	56	18	2160	15	1
620	97	77	1400	60	21	2180	17	2
640	98	80	1420	63	24	2200	20	3
660	98	82	1440	66	27	2220	22	3
680	99	85	1460	69	30	2240	24	4
700	99	87	1480	72	33	2260	26	5
720	99	89	1500	77	36	2280	29	7
740	100	91	1520	77	40	2300	31	8
760	100	92	1540	79	43	2320	34	9

This table shows the relationship between accumulated degree days after biofix and moth flight and egg hatch. See section on codling moth in Part II for recommended timings of controls.

Table 6

Degree Day/Development Table for Peach Twig Borer

Degree days	% male flight	% egg hatch
0 (405)	1	
20	1	
40	2	
60	4	
80	7	
100	10	
120	15	
140	20	
160	26	
180	34	
200	38	
220	49	1
240	57	1
260	64	2
280	70	3
300	76	5
320	81	8
340	85	11
360	89	16
380	92	22
400	94	28
420	96	34
440	97	42
460	98	49
480	98	56
500	99	63
520	99	69
540	100	75
560		80
580		84
600		88
620		91
640		93
660		95
680		96
700		97
720		98
740		99
760		99
780		99
800		100

Degree days	% male flight	% egg hatch
820		
840		
860	1	
880	1	
900	2	
920	2	
940	3	
960	4	
980	6	
1000	8	
1020	10	
1040	13	
1060	16	
1080	19	1
1100	23	1
1120	27	1
1140	32	2
1160	36	3
1180	41	4
1200	46	5
1220	51	6
1240	56	8
1260	61	11
1280	66	13
1300	70	16
1320	74	20
1340	78	23
1360	81	28
1380	84	32
1400	88	37
1420	89	41
1440	92	46
1460	94	51
1480	95	56
1500	96	61
1520	97	65
1540	98	69
1560	98	73
1580	98	77
1600	99	80
1620	99	83

Degree days	% male flight	% egg hatch
1640	99	86
1660	100	88
1680		90
1700		92
1720		94
1740		95
1760	1	96
1780	1	97
1800	1	97
1820	2	98
1840	3	99
1860	3	99
1880	4	99
1900	5	100
1920	7	
1940	8	
1960	10	
1980	12	
2000	14	1
2020	17	1
2040	20	1
2060	23	2
2080	26	3
2100	29	3
2120	33	4
2140	37	5
2160	41	7
2180	45	8
2200	49	10
2220	53	12
2240	56	14
2260	60	17
2280	64	19
2300	68	22
2320	71	26
2340	74	29
2360	77	32
2380	80	36
2400	82	40
2420	85	44
2440	87	48

Degree days	% male flight	% egg hatch
2460	89	52
2480	90	56
2500	92	59
2520	93	63
2540	94	67
2560	95	70
2580	96	73
2600	97	76
2620	98	79
2640	98	82
2660	99	84
2680	100	86
2700		88
2720	1	90
2740	1	91
2760	2	93
2780	2	94
2800	3	95
2820	4	96
2840	5	97
286	6	97
2880	7	98
2900	9	99
2920	11	99
2940	12	100
2960	14	1
2980	16	1
300	19	2
3020	21	3
3040	24	3
3060	27	4
3080	30	5
3100	33	6
3120	36	8
3140	39	9
3160	43	11
3180	46	13
3200	49	15
3220	53	17
3240	56	19

This table shows the relationship between accumulated degree days after biofix (first moth capture) and moth flight and egg hatch.

Table 7

Degree Day/Development Table for Western Cherry Fruit Fly

Accumulated degrees	% flies emerged	% mature flies	Accumulated degrees	% flies emerged	% mature flies	Accumulated degrees	% flies emerged	% mature flies
900	0	0	1600	46	32	2300	95	90
920	0	0	1620	48	34	2320	96	91
940	0	0	1640	51	36	2340	96	91
960	1	0	1660	53	38	2360	97	92
980	1	0	1680	55	40	2380	97	93
1000	2	0	1700	57	42	2400	97	93
1020	2	0	1720	59	44	2420	97	94
1040	3	0	1740	62	47	2440	98	94
1060	3	1	1760	64	49	2460	98	95
1080	4	2	1780	66	51	2480	98	95
1100	4	2	1800	68	53	2500	98	96
1120	5	2	1820	69	55	2520	99	96
1140	6	3	1840	71	57	2540	99	96
1160	7	3	1860	73	59	2560	99	97
1180	8	4	1880	75	61	2580	99	97
1200	9	4	1900	76	63	2600	99	97
1220	10	5	1920	78	65	2620	99	97
1240	11	6	1940	79	67	2640	99	98
1260	12	7	1960	81	68	2660	99	98
1280	14	8	1980	82	70	2680	99	98
1300	15	8	2000	83	72	2700	99	98
1320	17	10	2020	85	73	2720	100	98
1340	19	11	2040	86	75	2740		99
1360	20	12	2060	87	76	2760		99
1380	22	13	2080	88	78	2780		99
1400	24	14	2100	89	79	2800		99
1420	26	16	2120	90	80	2820		99
1440	28	17	2140	91	82	2840		99
1460	30	19	2160	91	83	2860		99
1480	32	21	2180	92	84	2880		99
1500	35	22	2200	93	85	2900		99
1520	37	24	2220	93	86	2920		99
1540	39	26	2240	94	87	2940		100
1560	41	28	2260	94	88			
1580	44	30	2280	95	89			

This table shows the relationship between accumulated degree days and the percentage of flies emerged. Chemical control sprays should be applied on or before 1060 degree days to target mature, egg-laying flies. The table can be photocopied for easy reference.

Table 8

Degree Day/Development Table for San Jose Scale

Accumulated degree days	% males	% crawlers	Accumulated degree days	% males	% crawlers	Accumulated degree days	% males	% crawlers
0 (275)	20	0	560	0	55	1120	64	0
20	36	0	580	0	61	1140	69	0
40	52	0	600	0	67	1160	74	0
60	68	0	620	0	73	1180	78	0
80	80	0	640	0	78	1200	82	1
100	89	0	660	0	82	1220	85	1
120	94	0	680	0	86	1240	88	1
140	97	0	700	0	89	1260	91	2
160	99	0	720	0	92	1280	93	3
180	100	0	740	0	94	1300	94	4
200	100	0	760	0	95	1320	96	5
220	100	0	780	1	96	1340	97	6
240	100	0	800	1	97	1360	98	8
260	100	0	820	2	98	1380	98	10
280	100	0	840	3	99	1400	99	13
300	100	1	860	4	99	1420	99	16
320	100	1	880	6	99	1440	99	19
340	100	2	900	8	100	1460	100	22
360	0	4	920	11	100	1480	100	26
380	0	6	940	15	100	1500	100	30
400	0	9	960	19	100	1520	100	35
420	0	12	980	23	100	1540	100	39
440	0	17	1000	29	100	1560	100	44
460	0	22	1020	34	100	1580	100	49
480	0	28	1040	40	100	1600	0	53
500	0	34	1060	46	100	1620	0	58
520	0	41	1080	52	0	1640	0	62
540	0	48	1100	58	0	1660	0	67

This table shows the relationship between accumulated degree days, and emergence of male scales and crawlers. The first males emerge about 275 degree days after January 1. Sprays aimed at crawlers should be applied between 400 and 450 days after biofix.

Table 9

Scientific names

Common name	Scientific name	Order: Family
Ambrosia beetle (European shothole borer)	*Xyleborus dispar* Fabricius	Coleoptera: Scolytidae
Apple aphid	*Aphis pomi* De Geer	Homoptera: Aphididae
Apple ermine moth	*Yponomeuta malinellus* (Linnaeus)	Lepidoptera: Yponomeutidae
Apple grain aphid	*Rhopalosiphum fitchii* (Sanderson)	Homoptera: Aphididae
Appleleaf blister mite	*Phytoptus mali* (Burts)	Acari: Eriophyidae
Apple maggot	*Rhagoletis pomonella* (Walsh)	Diptera: Tephritidae
Apple rust mite	*Aculus schlechtendali* (Nalepa)	Acari: Eriophyidae
Bertha armyworm	*Mamestra configurata* Walker	Lepidoptera: Noctuidae
Black cherry aphid	*Myzus cerasi* (Fabricus)	Homoptera: Aphididae
California pear sawfly	*Pristophora abbreviata* (Hartig)	Hymenoptera: Tenthredinidae
Campylomma	*Campylomma verbasci* (Meyer)	Hemiptera: Miridae
Cherry bark tortrix	*Enarmonia formosana* (Scopoli)	Lepidoptera: Tortricidae
Cherry fruit fly	*Rhagoletis indifferens* Curran	Diptera: Tephritidae
Clearwinged grasshopper	*Camnula pellucida* (Scudder)	Orthoptera: Locustidae
Codling moth	*Cydia pomonella* (Linnaeus)	Lepidoptera: Tortricidae
Consperse stink bug	*Euschistus conspersus* Uhler	Hemiptera: Pentatomidae
Dock sawfly	*Ametastegia glabrata* (Fallén)	Hymenoptera: Tenthredinidae
European earwig	*Forficula auricularia* (Linnaeus)	Dermaptera: Forficulidae
European fruit lecanium	*Parthenolecanium corni* (Bouché)	Homoptera: Coccidae
European leafroller	*Archips rosanus* (Linnaeus)	Lepidoptera: Tortricidae
European red mite	*Panonychus ulmi* (Koch)	Acari: Tetranychidae
Eyespotted bud moth	*Spilonota ocellana* (Denis & Schiffermüller)	Lepidoptera: Torticidae
Fall webworm	*Hyphantria cunea* Drury	Lepidoptera: Arctiidae
Forest tent caterpillar	*Malacosoma disstria* Hübner	Lepidoptera: Lasiocampidae
Fruittree leafroller	*Archips argyrospilus* (Walker)	Lepidoptera: Tortricidae
Grape mealybug	*Pseudococcus maritimus* (Ehrhorn)	Homoptera: Coccidae
Green fruitworm	*Lithophane antennata* (Walker)	Lepidoptera: Noctuidae
Green peach aphid	*Myzus persicae* (Sulzer)	Homoptera: Aphididae
Green stink bug (green soldier bug)	*Acrosternum hilare* (Say)	Hempitera: Pentatomidae
Hop aphid	*Phorodon humuli* (Schrank)	Homoptera: Aphididae
Leafcurl plum aphid	*Anuraphis helichrysi* (Kaltenbach)	Homoptera: Aphididae
Lesser appleworm	*Grapholitha prunivora* (Walsh)	Lepidoptera: Tortricidae
Lesser shothole borer (Ambrosia beetle)	*Xyleborus saxeseni* Ratzeburg	Coleoptera: Scolytidae
Lygus bug (Tarnished plant bug)	*Lygus lineolaris* (Palisot de Beauvois)	Hemiptera: Miridae
McDaniel spider mite	*Tetranychus mcdanieli* McGregor	Acari: Tetranychidae

Common name	Scientific name	Order:Family
Mealy plum aphid	*Hyalopterus pruni* (Geoffroy)	Homoptera: Aphididae
Migratory grasshopper	*Melanopus sanguinipes* (Fabricius)	Orthoptera: Locustidae
Obliquebanded leafroller	*Choristoneura rosaceana* (Harris)	Lepidoptera: Tortricidae
Oriental fruit moth	*Grapholitha molesta* (Busck)	Lepidoptera: Tortricidae
Oystershell scale	*Lepidosaphes ulmi* (Linnaeus)	Homoptera: Diaspididae
Pacific flatheaded borer	*Chrysobothris mali* Horn	Coleoptera: Buprestidae
Pandemis leafroller	*Pandemis pyrusana* Kearfott	Lepidoptera: Tortricidae
Peach silver mite	*Aculus fockeui* (Nalepa & Trouessart)	Acari: Eriophyidae
Peach twig borer	*Anarsia lineatella* Zeller	Lepidoptera: Gelechiidae
Peachtree borer	*Synanthedon exitiosa* (Say)	Lepidoptera: Sesiidae
Pear leafcurling midge	*Dasyneura pyri* Bouché	Diptera: Cecidomyiidae
Pear rust mite	*Epitrimerus pyri* (Nalepa)	Acari Eriophyidae
Pear sawfly (pear slug)	*Caliroa cerasi* (Linnaeus)	Hymenoptera: Tenthredinidae
Pearleaf blister mite	*Phytoptus pyri* Pagenstecher	Acari: Eriophyidae
Pear psylla	*Cacopsylla pyricola* (Foerster)	Homoptera: Psyllidae
Prunus rust mite	*Aculus fockeui* (Nalepa & Trouessart)	Acari: Eriophyidae
Pyramidal fruitworm	*Amphipyra pyramidoides* (Guenée)	Lepidoptera: Noctuidae
Rain beetles	*Pleocoma* spp.	Coleoptera: Scarabaeidae
Redhumped caterpillar	*Schizura concinna* (J.E. Smith)	Lepidoptera: Notodontidae
Redlegged grasshopper	*Melanoplus femur-rubrum* (De Geer)	Orthoptera: Locustidae
Rose leafhopper	*Edwardsiana rosae* (Linnaeus)	Homptera: Cicadellidae
Rosy apple aphid	*Dysaphis plantaginea* Passerini	Homptera: Aphididae
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Homoptera: Aphididae
San Jose scale	*Quadraspidiotus perniciosus* (Comstock)	Homoptera: Diaspididae
Shothole borer	*Scolytus rugulosus* (Müller)	Coleoptera: Scolytidae
Speckled green fruitworm	*Orthosia hibisci* (Guenée)	Lepidoptera: Noctuidae
Spirea aphid	*Aphis spiraecola* Patch	Homptera: Aphididae
Spotted cutworm	*Xestia (Amathes) c-nigrum* (Linnaeus)	Lepidoptera: Noctuidae
Tenlined June beetle	*Polyphylla decemlineata* (Say)	Coleoptera: Scarabaeidae
Thistle aphid	*Brachycaudus cardui* (Linnaeus)	Homoptera: Aphididae
Twospotted spider mite	*Tetranychus urticae* Koch	Acari: Tetranychidae
Variegated cutworm	*Peridroma saucia* (Hübner)	Lepidoptera: Noctuidae
Walnut husk fly	*Rhagoletis completa* Cresson	Diptera: Tephritidae
Western boxelder bug	*Leptocoris rubrolineatus* Barber	Hempitera: Rhopalidae
Western flower thrips	*Frankliniella occidentalis* (Pergande)	Thysanoptera: Thripidae
Western tent caterpillar	*Malacosoma fragilis* (Stretch)	Lepidoptera: Lasiocampidae
Western tentiform leafminer	*Phyllonorycter elmaella* Doganlar & Mutuura.	Lepidoptera: Gracillariidae
White apple leafhopper	*Typhlocyba pomaria* McAtee	Homoptera: Cicadellidae
Woolly apple aphid	*Eriosoma lanigerum* (Hausman)	Homoptera: Aphididae
Yellownecked caterpillar	*Datana ministra* Drury	Lepidoptera: Notodontidae
Yellow spider mite	*Eotetranychus carpini borealis* (Ewing)	Acari: Tetranychidae

Metric conversions

To convert to metric:

	Multiply by	To get
Inches	2.54	centimeters
Feet	30	centimeters
Yards	0.91	meters
Square feet	0.09	square meters
Square yards	0.8	square meters
Acres	0.4	hectares
Ounces	28	grams
Pounds	0.45	kilograms
Short tons	0.9	metric tons
Pints	0.47	liters
Quarts	0.95	liters
Gallons	3.8	liters

To convert from metric:

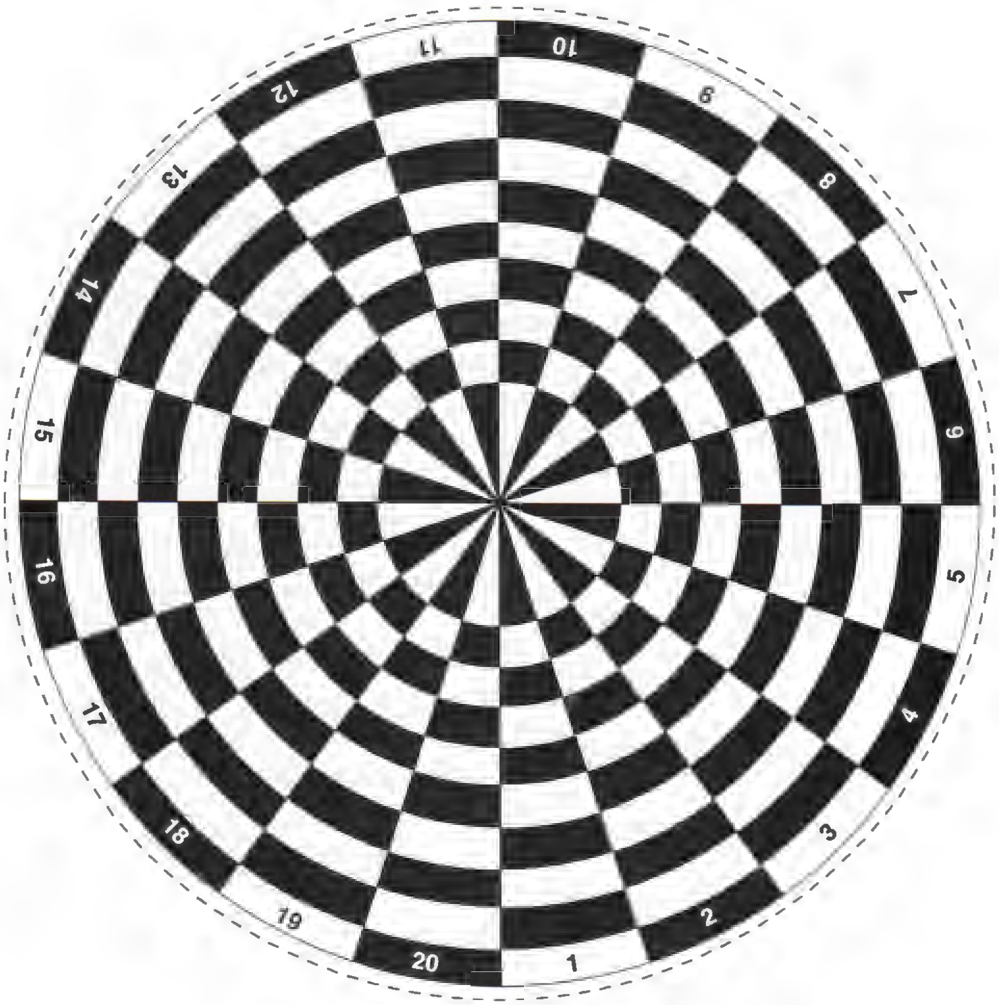
	Multiply by	To get
Millimeters	0.04	inches
Centimeters	0.4	inches
Meters	3.3	feet
Square meters	0.16	square yards
Hectares	2.47	acres
Grams	0.035	ounces
Kilos	2.2	pounds
Metric tons	1.1	short tons
Liters	2.1	pints
Liters	1.06	quarts
Liters	0.26	gallons

Temperature

To convert from Fahrenheit to Celsius:
Subtract 32, then multiply by $\frac{5}{9}$ths.

To convert from Celsius to Fahrenheit:
Multiply by $\frac{9}{5}$ths, then add 32.

Mite Counting Grid



A leaf-brushing machine and microscope are generally used to count mites. The leaf-brushing machine is a device with rollers covered with soft bristles that brush mites from the leaf onto a revolving glass plate coated with a slightly sticky substance. A microscope is used to distinguish individual species and stages. A paper grid like the one above is placed beneath the glass plate to help keep track during the count. This grid can be photocopied and used for this purpose.

Glossary

A

Abscission: the normal separation of fruit and leaves from plants by the development of a thin layer of pithy cells at the base of their stems.

Acaricide: a chemical used to control mites; also called a miticide.

Adeagus: the intromittent organ of a male insect; the penis.

Analog: that which is similar or corresponds with something else; in chemistry, two compounds with similar compositions and structures.

Arachnid: any of a large class of arthropods that have four pairs of legs and breath through lung-like sacs or breathing tubes. Some, such as mites, have bodies without exterior segmentation. Others, such as spiders, have bodies divided into two segments. Others have bodies of several segments.

Arrhenotoky: parthenogenesis in which only male offspring are produced.

Arthropod: any member of a large taxon of invertebrate animals with jointed legs and a segmented body, such as insects, crustaceans and arachnids.

Axil: the upper angle formed by a leaf and the stem from which it grows.

B

Biofix: a biological fix point used to synchronize a degree-day model with insect development, such as the first capture of moths in a pheromone trap.

C

Cambium: the layer of formative cells between the wood and bark in woody plants. The cells grow to form new wood and bark.

Chalcid wasp: a large family of very small wasps. In many cases the larvae are parasites on the eggs, larvae or pupae of other insects.

Clypeus: a shield-like plate on the anterior part of the head of certain insects.

Confidence interval (CI): in statistics, the estimated mean, plus or minus a range within which one is confident that the true mean occurs. For instance, for a 95% confidence interval of 2.0 plus or minus 0.4, the estimate of the mean is 2, and if you were to repeat the experiment 100 times, in 95 of those experiments the estimated mean would fall between 1.6 and 2.4.

Cornicles: the protruding dorsal tubes on aphids that secrete a waxy substance.

D

Deutonymph: third instar of an immature tetranychid mite.

Diapause: a period of delayed development or growth accompanied by reduced metabolism and inactivity.

Dorsal: on, of or near the back of an insect.

E

Ecosystem: a system made up of a community of animals, plants and bacteria, and its interrelated physical and chemical environment.

Ectoparasitoid: a parasitoid that lives on the outside of its host.

Elytra (plural of elytron): the front pair of thickened wings in beetles, which form a protective covering for the rear wings.

Endoparasitoid: a parasitoid that lives inside its host.

Epidermis: the outer layer of skin of an insect, or the outermost layer of cells of a plant.

Exoskeleton: the hard, external, secreted supporting structure of an insect; an external skeleton.

F

Filiform: thread-like.

Flagging: wilting of foliage.

Frass: refuse or excrement left by insect larvae.

G

Gaster: the abdomen of Hymenoptera; also, the final 7 to 8 segments of the abdomen of an ant, just behind the petiole.

Genus (plural, genera): a classification of insects with common characteristics; the main subdivision of a family, made up of a group of closely related species or of a single species.

Gummosis: the giving off of gummy substances as a result of cell degeneration.

H

Hibernaculum (plural, hibernacula): a case or covering for protection during the winter.

Honeydew: the liquid excrement of certain phloem-feeding insects, such as aphids, mealybugs and pear psylla. It is composed of water, plant sugars and amino acids.

Host: an organism on or in which another (called a parasite) lives for nourishment or protection.

I

Induced pest: an insect or mite raised to pest status by destruction of natural enemies.

Instar: a stage of an insect between molts; a growth stage.

K

Key pest: pest around which management programs are built. Examples are codling moth, oriental fruit moth and cherry fruit fly.

L

Lamella (plural lamellae): a series of overlapping plate-like structures; used to refer to the type of antennal club in some beetles.

Larva (plural larvae): a comprehensive term for the immature stages of insects with complete metamorphosis (e.g. flies, beetles, moths, wasps). Often specific names are given to the larvae of some orders or families: fly larvae are called maggots, scarab beetle larvae are called grubs.

M

Margin: Edge.

Mesophyll: The soft green tissue inside a leaf, between the lower and upper epidermis, chiefly concerned in photosynthesis.

Metamorphosis: the series of changes from the egg to the adult stage whereby insects grow and develop. Metamorphosis is said to be complete when the pupa is inactive or does not feed, and incomplete when the pupal stage is lacking, or is active and feeds.

Micron: one thousandth of a millimeter; one millionth of a meter.

Mine: a hollow under the surface of a leaf made by an insect.

Molt: the process by which insects shed their outer skin (exoskeleton), in order to increase in size.

Morphology: the branch of biology that deals with the form and structure of animals and plants.

Mycelium: the vegetative part of a fungus, made of a mass or network of thread-like tubes.

N

Neurotoxin: a poison that interferes with nerve function.
Nymph: a comprehensive term for the immature stages of insects with incomplete metamorphosis (e.g. true bugs, aphids, leafhoppers and grasshoppers).

O

Operculum: a lid-like structure, usually over an egg.

Ovate: shaped like the longitudinal section of an egg.

Ovicide: an insecticide effective on the egg stage.

Ovipositor: an organ of many female insects for depositing eggs, often in a host.

P

Parasite: an organism that lives on or in one of another species, from which it derives sustenance or protection. It usually does not benefit the host, and often does it harm. It may complete its life cycle without killing the host.

Parasitoid: a parasite that destroys its host, such as various wasp larvae that feed on the tissues of an immature stage of a host.

Parthenogenesis: asexual reproduction by means of the development of an unfertilized egg. For example, in aphids a number of parthenogenetically produced generations of females succeed a sexually produced generation. Finally, males are produced (also by parthenogensis) and sexual reproduction again occurs.

Petiole: in a plant, the stalk of a flower cluster or leaf; in an insect, the slender, stalk-like part between the thorax and abdomen of the body.

Phenology: the study of the effects of climate on recurring natural phenomena, such as insect or plant development.

Phenology model: a model based on accumulated heat units used to predict significant events in the life cycle of a plant or insect (e.g. full bloom, egg hatch).
Pheromone: a chemical substance secreted by an insect to convey information to others of the same species.

Phylum: a principal division of the animal kingdom.

Physiology: science of the functions and phenomena of living organisms and their parts.

Phytophagous: herbivorous, or plant-feeding.

Predator: an organism that lives by capturing and feeding upon another. Unlike parasitoids, predators consume many hosts during their development.

Prolegs: the stubby limbs on the abdomen of the larvae of Lepidoptera, sawflies and some other insects

Prothorax: the first segment of the thorax of insects, bearing the first pair of legs.

Protonymph: second instar of an immature mite.

R

Race: a population that differs from others in the relative frequency of some gene or genes.

Recurrent vein: small veins running transversely between major veins on the wings of Hymenoptera.

Refugium (plural, refugia): a small, isolated area that has escaped changes undergone by the surrounding area.

S

Scutellum: a feature on the dorsum of an insect, made up of one or more of the thoracic segments; a prominent feature of Hemiptera (true bugs), where it is a triangular-shaped part of the middle thoracic segment enclosing the angle of the forewings at rest.

Secondary pest: a pest that is less important than a key or primary pest. Examples are aphids, mites and leafhoppers.

Selection: a process by which certain organisms or characters are favored or perpetuated in preference to others.

Seta (plural setae): a bristle or bristle-like part or organ.

Species: the basic unit of classification of living organisms. A class of similar insects that generally interbreed only among themselves; a subdivision of a genus.

Spermatophore: a case or capsule containing a number of spermatozoa, expelled whole by the male of certain animals, including rust mites.

Spiracle: a breathing pore.

Stipe: a usually short, thick stem such as found on certain mite eggs.

Stoma (plural, stomata): minute holes in leaves through which trees exchange gases.

T

Taxonomy: the system of arranging animals and plants into natural, related groups based on some factor common to each. The basic taxonomic categories are, in descending order: kingdom, phylum, class, order, family, genus and species.

Thoracic shield: the dorsal plate of the prothorax; a plate on the insect's upper side just behind the head.

Thorax: the middle of the three main divisions of an insect's body; the body part between the head and abdomen that bears the legs and wings.

Tubercle: a small, rounded projection.

V

Ventral: underside of the body.

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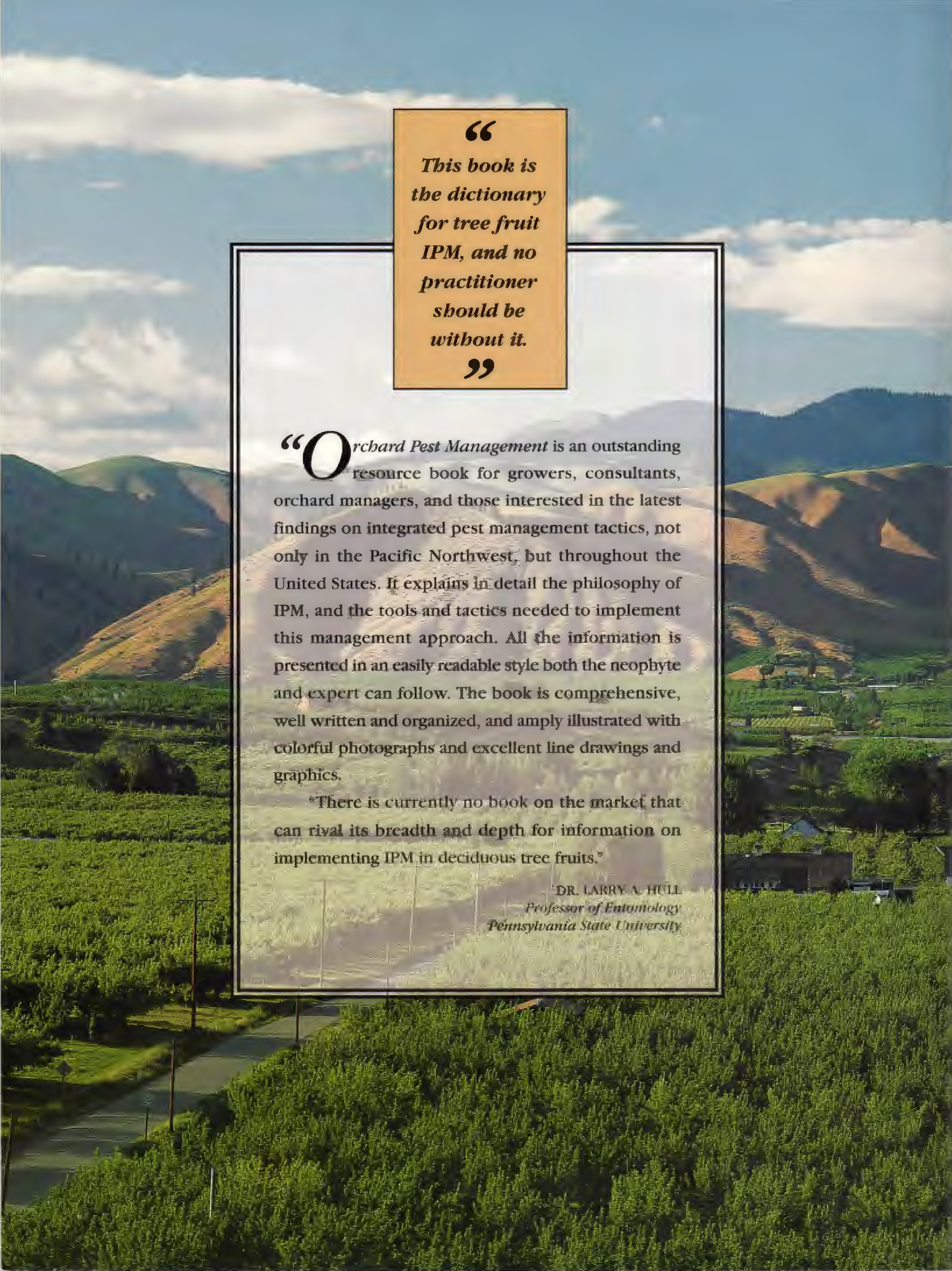

"*This book is the dictionary for tree fruit IPM, and no practitioner should be without it.*"

"*Orchard Pest Management* is an outstanding resource book for growers, consultants, orchard managers, and those interested in the latest findings on integrated pest management tactics, not only in the Pacific Northwest, but throughout the United States. It explains in detail the philosophy of IPM, and the tools and tactics needed to implement this management approach. All the information is presented in an easily readable style both the neophyte and expert can follow. The book is comprehensive, well written and organized, and amply illustrated with colorful photographs and excellent line drawings and graphics.

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Professor of Entomology
Pennsylvania State University