# Macadamia

## Integrated Pest Management

### IPM of Insects and Mites Attacking Macadamia Nuts in Hawaii

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*—Vincent P. Jones*
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## Part 1

# Introduction to Macadamia Pest Management

## Insect growth and development

### Insect growth

Insects and mites possess an external skeleton called an *exoskeleton*. This exoskeleton acts as an attachment place for muscles (as do bones in humans) and protects the organism from the environment. The exoskeleton is composed of a number of proteins, but chiten is one of the most important. Chitin can be hardened into plates for protection and into mouthparts that are strong enough to chew through some of our softer metals.

The exoskeleton can be thought to be similar to a suit of armor. Because it is relatively rigid, when an insect feeds and begins to grow, the exoskeleton allows only a small amount of growth. To get around this problem, the insect sheds the exoskeleton periodically in a process called *molting*. To accomplish this, the insect lays down a soft, folded exoskeleton immediately underneath the outer exoskeleton. When this process is complete, the old exoskeleton splits, the insect emerges, and gulps air to expand the soft new cuticle to its maximum size. After a few hours, the new exoskeleton hardens and darkens to its final color. Often, the old exoskeleton is mistaken as a dead insect because it looks just like the insect, except it is typically clear and empty.

The process of molting means that when insects grow, they have only a few different sizes. Each of these sizes is relatively constant and roughly indicates the age of the insect. These different sizes are often called *instars*, and are numbered from youngest to oldest. For example, the stage that hatches from the egg is called the 1st instar, after the first molt it would be the 2nd instar, and so on.

### Insect development

Insects are cold-blooded animals. This means that the temperature of their immediate environment controls their developmental rate and activity. When temperatures increase, the insects can complete their life cycle quicker (within limits). Conversely, if temperatures are low enough that development ceases, the insect seeks shelter and stops moving. For pest management, the temperature-driven development means that damage and population growth is generally greatest in the warmest times of the growing season. However, in Hawaii's macadamia production areas, temperatures are relatively mild, and even at the coldest of times insect development can continue, although at reduced rates.

The relationship of insect growth and development to temperature can be used to help determine the maximum number of generations that a particular insect might complete at various growing areas around the state. By collecting historical weather data, models of the development rate can be run to give growers an idea of how severe a given pest will be in their locality. When combined with past damage records for an area, even better predictability is obtained. For a more detailed discussion of heat-driven models, see Appendix A.

### Types of insect metamorphosis

Three major types of development occur in insects. The first type is called "*no metamorphosis*" and does not occur in any of the pest insects associated with macadamia. It is characterized by simply an increase in body size at each molt, but no change in body form (metamorphosis means "change in body form"). Adults of insects of this group continue to molt as adults.

Figure 1.1. Incomplete metamorphosis in a stinkbug.

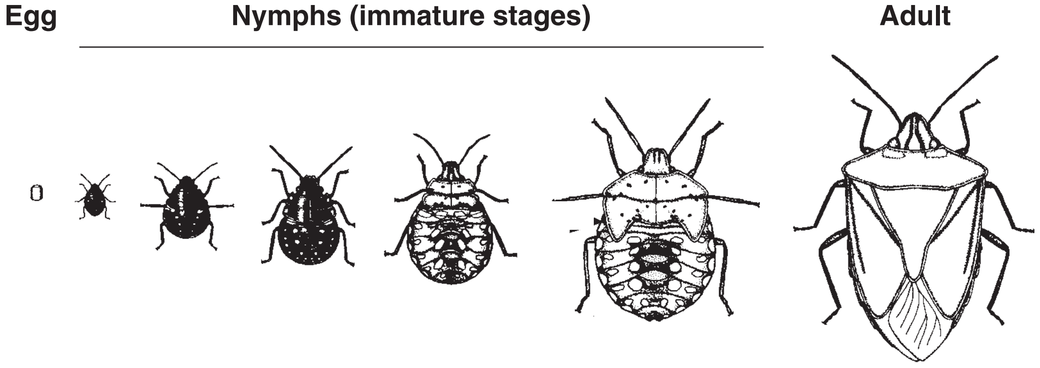
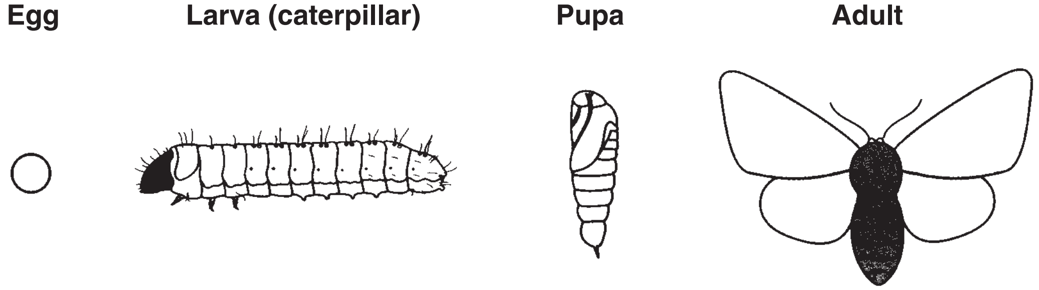


Figure 1.2. Complete metamorphosis in a moth.



The second type of metamorphosis is called "*incomplete metamorphosis*" (Fig. 1.1). Examples of insects in macadamia with incomplete metamorphosis include the southern green stinkbug, redbanded thrips, and black citrus aphid. Insects with incomplete metamorphosis have three distinct stages: egg, nymphal, and adult. In incomplete metamorphosis, as the insect molts it increases in size and the wing pads grow from small nubs to nearly adult size. The different immature stages in this type of development are called *nymphs*, and the number of instars typically varies from three to five. The last instar nymph then molts to the adult stage with fully functional wings. Thus, if fully developed wings are present on an insect, it must be an adult. Adults do not continue to molt.

The final type of metamorphosis is "*complete metamorphosis*" (Fig. 1.2). The insects that exhibit complete metamorphosis include the beetles (including the tropical nut borer), moths and butterflies (including the koa seedworm), ants, bees, wasps, and flies. Insects with complete metamorphosis have four distinct stages: egg, larval, pupal, and adult stages. The immature stages of these insects often have specialized names, like *caterpillars* (moths and butterflies), *grubs* (beetle larvae), and *maggots* (fly larvae), but they can be generally referred to as *larvae* (larva is the singular). In this group, the larvae do not resemble the adult stage. The larval stage is specialized for feeding, and as such, larvae frequently have a flexible exoskeleton that can be expanded considerably before molting is necessary. For some of these insects, the only hardened spot on the larva is the head capsule that contains the mouthparts. In some of the more advanced insects (such as flies, bees, ants, and wasps), the larva is rather featureless, with no visible legs or mouthparts, and there is no sign of wings in any of the larval stages (the wings develop internally). The number of larval stages varies with the type of insect, but again, three to five instars is typical. Once the last larval stage is completed, the insect forms a resting stage known as a *pupa* (pupae is the plural). This stage typically is hidden or camouflaged. During the pupal stage, the insect completely reorganizes its body shape, and the development of the wings is completed. The adult emerges from the pupal case and begins feeding and reproducing. As before, if wings are present, the insect is an adult. Once the adult stage is reached, molting stops.

For pest management, the different types of development can be important in determining the weak spot in the life cycle that can be targeted to reduce the insect population density or reduce damage. For example, if you treat weeds before southern green stinkbugs reach the adult stage, then the bugs cannot migrate to other areas. In addition, the different appearance of the larval and adult stages often makes identification more difficult.

## Types of insect damage

Insect and mite damage can be broadly divided into *direct* and *indirect* damage. Direct damage occurs when the insect feeds on the commodity that you are trying to sell and degrades its value. In macadamia, southern green stinkbug and tropical nut borer are good examples of insects that cause direct damage to the crop. Indirect damage occurs when the insect or mite feeds on some other part of the crop that is not marketed. Examples would be redbanded thrips or broad mite feeding on the outer surface of the husk. In addition to these two broad categories, insects may change their feeding site, or the effect of their feeding at different times may produce different symptoms. For example, broad mite feeding on the flowers causes distortion of the flower and results in reduced nut set. This means that its damage can be considered to be direct (because it prevents nut set), but once the nut is full size, it could be considered to be indirect because feeding on the outer surface of the husk has no effect on kernel quality.

In most cases, direct damage is of considerable concern, and very little direct damage is tolerated. Insects that cause direct damage are generally the primary focus of pest management practices.

Compared to direct damage, a larger amount of indirect damage can be tolerated. For example, redbanded thrips feeding on a few leaves is not a major problem for macadamia nut production. However, if the feeding becomes widespread on all the new leaves, then the tree becomes stressed. With many tree crops, the number of leaves present is in excess of the number required to bring the crop to harvest, so that indirect damage is most important when it continues for several growing seasons. This seems in part to be related to the ability of the tree to buffer its energy requirements by using stored reserves. However, once these reserves are exhausted, yield reductions can be severe. Although it is not known if macadamia has an excess of leaves, work does suggest that crop load is adjusted to what the tree can support. These facts suggest that the damage suffered by a plant depends on the number of insects present, how long they are present, and the initial stress level of the tree.

In designing pest management programs, it is critical to remember that using a pesticide or other control measure to kill the insect does not remove the damage. Thus we are primarily trying to prevent damage by changing the environment, the plant, or encouraging the natural enemies in ways that are detrimental to the pest.

## How insects become pests

Under natural conditions, insects are rarely found at extremely high levels. This is because of the action of various factors. These factors are either *abiotic* (nonbiological) factors specific to the environment (rainfall, temperature, etc.) or *biotic* (biological) factors such as natural enemies. Insects are classed as pests when these factors either do not act normally or are affected by external forces such as disruptive pesticide sprays that eliminate natural enemies, which allows the insect population to rise and cause economic damage.

In general, there are four major ways that insects can become pests that are related to human activities. These include moving a new crop into an area where the insect already exists, transporting the pest across natural geographical boundaries without its natural enemies, developing extensive monocultures of crops, and misuse of pesticides.

The first method occurred when macadamia was introduced into Hawaii from Australia and the koa seedworm (KSW) came into contact with macadamia plantings. KSW is a native species that was found on a number of native hosts, including koa. It generally does not cause a tremendous amount of damage on those trees. However, with the introduction of macadamia from Australia, KSW found a host plant that allowed it to complete up to 10½ generations per year and which had an abundance of susceptible nuts all year.

The second method by which pests are created commonly occurs in Hawaii. Studies have shown that since 1955, 17 new insects per year are accidentally introduced into the state. In macadamia, the tropical nut borer and the southern green stinkbug are the best examples of pests introduced without their natural enemies. In both cases, they arrived, spread to new areas, and rapidly increased in importance.

The third method has become more of a concern as our acreage under cultivation increased. We now have several orchards of a size in excess of 1000 acres that provide a good home for a number of pest insects. The large acreage means that the insects can channel more energy into reproduction because less energy is needed to find food. In addition, because we are trying to increase macadamia production, we eliminate (as much as possible) plant diversity in the area, and this reduces the number of generalist predators that typically help reduce the pest population.

The final method has not yet occurred in Hawaii's macadamia orchards, primarily because pesticides are rarely, if ever, used. The use of pesticides generally reduces the level of natural enemies and in some cases may actually increase the reproductive rate of some of the non-target insects. In other systems, the extensive use of pesticides has resulted in *pesticide resistance*, where the pest can no longer be killed by a pesticide application at a rate that initially would give excellent control.

## Integrated pest management

Our knowledge of macadamia insect pests has increased considerably over the past decade. This information has provided us with a strong foundation for the development of a comprehensive integrated pest management (IPM) system for the insect pests attacking macadamias in Hawaii. However, the development of integrated pest management is by definition a rather slow process. This is particularly true in a crop like macadamia that has only a few researchers working on it worldwide. IPM is not simply about applying pesticides correctly, although that may be an important component of the program. IPM is instead a broad-based approach to managing problems in the crop. One of the earliest definitions of IPM is "the intelligent selection and use of pest control that will insure favorable economic, ecological, and sociological consequences." The economic part means that whatever you do, the cost is important. The ecological consequences are crucial because they can increase other problems within the crop (insecticide resistance, resurgence of pest populations after their natural enemies are killed, etc.), and for the community at large (for example, groundwater contamination). The sociological aspects are becoming more critical for farmers as urban encroachment on agricultural areas increases, lawmakers make decisions that affect farming, and the public as a whole becomes more concerned with environmental issues.

The development of IPM therefore requires a very broad view of the crop system and must incorporate as many disciplines as possible, including entomology, horticulture, plant pathology, weed science, and economics. This manual will focus on insect problems and interactions with other factors in crop production that are important in insect management. For a general review of macadamia production practices, Nagao and Hirae (1992) provide an excellent guide to the physiology and cultivation of macadamia nuts.

## Economic thresholds, economic injury levels

The framework of IPM is based on the ideas of economic thresholds. An *economic injury level* (EIL) is the point at which economic damage occurs to the plant. The *economic threshold* (ET) is the point at which control measures need to be applied to prevent the pest population from exceeding the economic threshold. The *gain threshold* (GT) is a way of precisely defining the point at which economic damage occurs. It is the amount of the crop that must be saved for pest control to be profitable. Mathematically, the gain threshold is defined as

$$GT = \frac{\text{management cost (\$/acre)}}{\text{market value (\$/lb nuts)}} = \text{lb nuts/acre}$$

A second way to view the gain threshold is to simply consider that the gain threshold is equal to

$$GT = \frac{\text{management cost (\$/acre)}}{\text{total value (\$/acre)}} \times 100$$

where the total value is calculated as the total pounds of nuts per acre × the market value for the nuts. For example, if the management option costs \$100/acre, the total yield per acre is 6500 lbs, and the value is \$0.65/ lb,

$$GT = \frac{\text{\$100 (\$/acre)}}{\text{6500 lb/acre} \times \text{0.65 \$/lb}} \times 100$$

$$= \frac{\text{\$100/acre}}{\text{\$4225/acre}} \times 100$$

$$= 2.36\ \%$$

then the management practice must decrease the damage 2.36% to break even. Ideally, the savings will far exceed the gain threshold.

The economic injury level varies with the time of the year and for each pest. For example, small nuts are not attacked by koa seedworm, therefore early in the season the ET and EIL are very high. During the middle part of the season, when nuts have reached their full size, but have not reached full oil content, the ET and EIL would be much lower because early nut drop would result in immature nuts. Late in the season, when the majority of the crop is mature, the ET and EIL are again high, because early nut drop does not affect the nut quality.

Direct pests are often rather simple to set thresholds for because even a small amount of damage can result in a rejected nut. ETs and EILs for indirect pests are rather difficult to set because of the difficulty in standardizing the damage, and the trees' response to damage depends heavily on the stress they are under in a particular area. For this reason, ETs and EILs are often set by a process that monitors the response of the plant in different years and adjusts thresholds based on tree health and past experience.

### Natural control vs. biological control

Natural control and biological control (BC) are terms that are often used interchangeably. However, BC is generally a purposeful introduction of a natural enemy into an ecosystem to control a pest organism (that was generally introduced without its natural enemies). Natural control can be viewed as fortuitous control of a pest organism by natural enemies already present in the area.

### Natural enemies

What are natural enemies? Natural enemies are generally referred to as the "3 Ps": predators, parasitoids, and pathogens. Predators are animals that require several prey items to complete their development and are usually free-living. A wide range of insects and mites may be predators, and they can be either generalists that feed on virtually anything smaller than themselves or specialists that only feed on one to a few different types of insects. Common generalist predators include lacewings, ladybird beetles, certain predatory bugs, and phytoseiid mites.

Parasitoids are insects that require only one prey item to complete their development although they may ultimately be responsible for killing many prey items throughout their lifetime. Parasitoids are very common in the order Hymenoptera (wasps), but also occur in a few other orders of insects. Parasitoids nearly always have their immature stages intimately associated with a particular stage of their host (such as the larval or pupal stage). The immature stage of the parasitoid generally emerges from the pest and kills the pest at that point. The female parasitoids may kill many pests indirectly by depositing their eggs in the immature stage of the pest. However, females may also directly cause the death of a large number of pests by using their *ovipositor* (egg laying tube) to pierce the body of a host, and then suck up the blood (called *hemolymph*). The hemolymph contains nutrients that the female parasitoid then uses to help produce more eggs.

Pathogens are generally microbes that are specific to insects. They include viruses, fungi, bacteria, nematodes, and a number of miscellaneous bacteria-like organisms. Commercial formulations of most of these pathogens are either not registered for use on macadamia or their efficacy against our pests is unknown. The only one currently registered for use in macadamia is *Bacillus thuringiensis* (also known as *Bt*). *Bt* is a soil bacterium that is registered on a wide range of crops for caterpillar control (e.g., koa seedworm). The caterpillar must eat the bacteria for it to be effective. The bacterium enters the gut and causes it to lose integrity at the cellular level. The insect immediately ceases feeding and dies within a day or two.

## Biological control

### Types of biological control

There are four different types of biological control: augmentative and inundative releases, conservation, and classical biological control. *Augmentative and inundative releases* use laboratory-reared natural enemies to increase the number of natural enemies that are already present in the system. The difference between the two types of releases is that in inundative releases, the numbers of natural enemies released are so large that the pest population is controlled by the individuals that are released. For augmentative releases, the numbers released are smaller and the natural enemy is expected to multiply through the growing season. Thus, control is achieved not only by the number of natural enemies released, but also by the offspring of the released natural enemies. These two types of release are often used when the natural enemies have poor survival at certain times of the year (such as winter) that prevents them from establishing permanently in the environment and maintaining control of the pest. Inundative releases are the most common way that pathogens are used in agriculture and forestry situations, but this method is not limited to pathogens. For example, in some systems, lacewings, *Trichogramma* egg parasites (small wasps), and predatory mites may be commonly released in large numbers early in the crop season. Augmentative releases are more common with a variety of natural enemies that cannot be easily reared in large numbers.

*Conservation* involves manipulating the environment in some fashion to enhance or improve the activity and longevity of the natural enemy. Examples include growing certain plants that contain nectar or that harbor alternative hosts for the natural enemy to help

**Table 1.1. Rates of successful and unsuccessful biological control attempts based on historical data.** Data from Hall et al. (1980).

| | | Success of attempts at biological control (%) | | |
|---|---|---|---|---|
| **Order of insects** | **Common name** | **Complete success** | **Any success** | **Failure** |
| Homoptera | Scales, mealybugs, aphids | 30 | 80 | 20 |
| Hemiptera | Bugs | 15 | 38 | 62 |
| Lepidoptera | Butterflies and moths | 6 | 48 | 52 |
| Coleoptera | Beetles | 4 | 36 | 64 |
| Hymenoptera | Ants, bees, wasps | 0 | 56 | 44 |
| Dermaptera | Earwigs | 0 | 67 | 33 |
| Orthoptera | Grasshoppers, katydids, crickets | 0 | 43 | 57 |
| Diptera | Flies | 0 | 31 | 69 |
| Thysanoptera | Thrips | 0 | 10 | 90 |

sustain its population level during times when the pest population is low within the orchard.

The most widely used and important type of biological control is known as *classical biological control*, which is used when a pest is introduced into a new area without its natural enemies and its population level increases dramatically. Natural enemies from the native home of the pest are sought and imported into the new area. The intention is that these natural enemies will be able to suppress the population level of the pest to low levels with a single or only a few introductions.

### Success rates for classical biological control

The success of classical biological control is quite variable, depending on the type of pest, the number of natural enemies already within the area you are trying to protect, and the use of the commodity. By classifying the level of success by economic benefits (complete successes, partial or intermediate successes, and failures) and analyzing historical data on biological control introductions, we can determine the rate of success for the various types of insects. Table 1.1 shows that the best record is against the order Homoptera (scales, aphids, mealybugs, etc.), where the complete success rate is 30% and the partial success rate is 80%. The success with other orders is, however, much lower. For example, insects in the orders Lepidoptera (moths and butterflies) and Coleoptera (beetles) have only a 6% and 4% complete success rate, and a 48% and 36% partial success rate. Some of these failures are caused by release of a natural enemy poorly adapted for the new environment, too few individuals released, or introduction of the wrong species. Thus, if historic trends hold up, some of our most serious pests may require a greater effort for success.

In addition to the rates of control, the existence of several natural enemies already preying on the pest may reduce the establishment rate of new natural enemies. This is thought to occur at least partially through *competitive exclusion* of the new natural enemies. Competitive exclusion can occur when there are no available pests of the required stages because of already existing natural enemy action, when parasitized pests are preferentially eaten by another natural enemy, or when parasitized hosts are parasitized by a second, already established, parasite (called a hyperparasitoid).

### Environmental concerns associated with classical biological control

In addition to the possibility of failure, strong environmental concerns are associated with classical biological control. This is primarily because once released, the natural enemy may broaden its host range and attack nontarget pests. If these nontarget pests are rare or endangered species, unique native insects may be lost forever. This concern has slowed the rate of classical BC in Hawaii from 3.8 natural enemy species per year introduced from 1900 to 1980, to 2.3 species per year during 1981–1990, to one species every other year since 1990. Current regulations require that native species closely related to the pest be tested to determine the effect of the natural enemy on the nontarget pest. This means that the response time for action against new pests will be greatly extended and that biological control will almost certainly be initiated against well established populations of the pest.

## Monitoring programs

### Importance

Monitoring of pests and their natural enemies is a critical part of pest management. Knowing the population level or damage allows you to apply control measures before economic loss occurs and to intelligently plan ways to manage the orchard. Methods of monitoring for each pest differ because of the biology and behavior of the pest, the stage to be monitored, and the information desired. For example, just determining the presence of the insect can be sufficient to determine that the management program should be started.

### Definitions

Monitoring of an insect population or its damage is based on statistics but must take into account the biology of the insect, its distribution on the host plant, and the type of damage it causes. The terminology needed to explain sampling is thus partly based on statistics and partly on biology. For purposes of this manual, a *sampling unit* is the smallest part of the environment that is collected and examined for the presence of the pest or its damage. If it is a *natural sampling unit*, then the sampling unit is something like a twig, leaf, or nut. The use of a natural sampling unit is beneficial because it allows us to easily relate the damage level back to the plant. In contrast, the use of an *artificial sampling unit* (such as a trap) is convenient but more difficult to relate to damage on the plant. A *sample* is, then, a collection of a number of sampling units.

To give a valid estimate of damage, each sampling unit must be selected randomly. This means that unless specifically stated, the sampling unit should not be chosen because of the presence or absence of damage, or because it looks different from the other sampling units.

### Design of monitoring and methods

Important questions to be asked in designing sampling plans include:

- How far apart must the samples be taken to be representative of the entire area?
- How frequently should a sample be taken?
- What are the different sampling methods?

The first question is very important, because for the samples to be representative of an area, the damage level within the area should be similar. Examples of factors that disrupt this similarity are different cultivars (with different attractiveness to a pest), different soil profiles in an area, different weed hosts, or the presence of a border. Borders are particularly noticeable because if the pest is one that can move between host plants, the border is where the first effects on the orchard are normally visible. If the block to be sampled has these problems, the different areas should be sampled separately, unless the different areas are very small compared to the entire area of the block.

A second consideration for the first question is that samples taken in trees right next to each other are normally very similar. This means that there is a large amount of redundant data in the second sample and that it tells us little that the first sample did not. As the distance between two samples increases, the amount of redundant data decreases, and at some point the samples become truly independent of each other. To reduce monitoring as much as possible but still cover a large area, samples typically should be spaced evenly over the area of sampling. With tropical nut borer and koa seedworm, we have enough data to indicate fairly precisely how far apart these samples should be. With other pests, we will suggest various distances based on our best guesses from knowledge of their mobility and dispersal tendencies.

How often to sample depends on the type of pest (direct or indirect), the length of the life cycle, the mobility of the pest, and the reproductive capacity of the pest. Generally, sampling for pest management more often than once per generation wastes time and produces little new information. However, if the pest is highly mobile and migrates between host plants, then sampling must be performed more often. Sampling intervals are given for each of the pests in the sections on their biology and management.

Finally, the sampling method depends on the life stage that you need to sample for a particular pest. Adult insects can be trapped using light, pheromone, funnel, or colored panel traps (see Appendix C). These traps typically have a sticky surface (pheromone or colored panel traps) or a collecting jar (funnel or light traps) for collecting the insects. Adult traps are useful in surveying the level of the adult population but may not enable prediction of actual damage levels that are likely to be experienced at harvest.

Light traps are rarely used in the orchard because they are expensive to buy and maintain, and their efficiency is affected by the phases of the moon (a full moon makes the light trap less visible compared to a new moon). In addition, light traps attract many types of insects, making it difficult to count just the pests you are trying to monitor.

Pheromone traps use a female sex lure to attract males to the traps and are useful for determining when males are present. They are cheap, selective, and work very well when the species-specific pheromone has been identified. At present, koa seedworm and litchi fruit moth both respond to the pheromone for the oriental fruit moth (OFM), and so commercial OFM lures can be used to monitor male flight activity. However, the relationship between trap catch and final crop damage is yet not known.

### Types of samples

In most cases, monitoring is designed to determine that the population level of the insect is above or below an *economic threshold* or to obtain an estimate of the damage actually present in the field. The first method is often preferred for pest management because it allows for relatively quick decisions to be made and sampling plans can be less time consuming. The second type of monitoring program is more labor intensive, but it gives a precise estimate of the insect population level or damage experienced by the crop.

The simplest sampling method is one where the number of samples is fixed in advance. This proceedure is simple to explain and use, but if the insect population is either very high or very low compared to the economic threshold, it is very inefficent and wastes time and money.

Methods of reducing monitoring time include the development of presence-absence sampling and sequential sampling. Presence-absence sampling works best when the insect is small compared to the sampling unit (generally a leaf or nut) and reaches high population levels that are difficult to count. Because you simply look for the presence or absence of the pest, counting time is greatly reduced. In addition, presence-absence sampling is also useful when even a single insect can cause the entire nut to be damaged (for example, a single koa seedworm feeding in the husk is likely to cause the nut to fall). For ease of calculation, most presence-absence sampling plans require that a fixed number of nuts be inspected, and then the number of infested nuts is divided by the total number inspected to give a proportion of nuts damaged.

The second type of sample is a sequential sample, where the decision to continue or stop sampling is determined each time a nut is inspected. This system can drastically cut the sample sizes required to estimate the population level. Most of the time, the sequential samples are used to determine whether the population (or damage) level is above or below some pre-determined thresholds. However, sequential samples can also be developed to determine when a given precision of the estimate is reached. Sequential samples typically require a large amount of data to be processed and then validated before they can be used. At present, the only sequential sampling system we have developed on macadamia is for koa seedworm.

### Data recording

To aid in pest management, kernel quality assessments should be kept for each block within an orchard. The importance of this cannot be overstated; pest management is a process that should improve each year as more information about the orchard and the distribution, timing, and type of damage becomes available. Ultimately, this historic information can be used to fine-tune an IPM program and increase its profitability by decreasing management in areas or times of historically fewer problems and concentrate it in the most troublesome areas or times. The information for each block should also include the weed management frequency and method; weed species present; time, rate, and type of fertilizer; cultivars present in the block; irrigation timing (if any); and information on any management practices (e.g., harvest time and frequency) applied to the block. This information is invaluable because it allows the grower to look at when during the growing season a pest problem occurred and to consider other management practices that may have caused or helped reduce the problem in a particular section of the orchard.

## Insecticide and miticide application

Insecticides and miticides are rarely used in macadamia nut orchards in Hawaii. However, pesticides do have their place in IPM, and their correct use requires an understanding of the importance of droplet size, amount of water applied, and coverage. Often, “resistance” or poor pesticide performance can be directly related to poor application techniques or poor sprayer calibration.

For all pesticide application methods, drift of the pesticide can be both a problem and a benefit. Drift is directly related to the size of the pesticide droplet (the smaller the droplet, the greater the drift) and is important in determining coverage. Because smaller droplets tend to swirl around at application time, they are able to give partial coverage to all sides of the leaves. However, smaller droplets also tend to drift into other areas, particularly during windy weather.

**Figure 1.3. Air-blast sprayer used to treat macadamia orchards.**

### Orchard handguns

Orchard handguns can only be used for relatively small blocks or for spot spraying orchard borders. The pesticides are generally mixed in the tank on a per-100-gallon basis. Orchard handguns typically require from 350 to 800 gallons per acre (GPA) (3271–7482 liters per hectare) for good coverage, and their droplet size averages $100^+$ μ (μ is an abbreviation for micron, which is 1 millionth of a meter or 40 thousandths of an inch). This size droplet tends not to drift much, so for thorough coverage both sides of the leaves must be drenched with water until runoff occurs. The high gallonage per acre can cause soil saturation in areas with heavy soil.

Orchard handguns are most efficient for smaller trees where the top of the tree can easily be reached. The thorough coverage makes them very efficient for controlling insects and mites that are distributed throughout the canopy and for pesticides such as soaps that only have contact activity and no residual activity.

### Backpack mist blowers

Backpack mist blowers are useful primarily in the nursery, where a relatively small area needs to be treated. These sprayers use a small gasoline engine to spin a fan that blasts the pesticide-laden air mixture up to 25 feet (7.6 meters). The small droplet size of these sprayers allows fairly good coverage where the nursery trees are packed close together and the swirling action allows better coverage of the lower leaf surface than can normally be obtained with an orchard handgun in the same situation. In addition, the orchard handgun may damage young trees in the nursery if the pressure is too high, whereas the backpack mist blower does not cause this problem.

### Air-blast sprayers

Air-blast sprayers (Fig. 1.3) replace a portion of the water carrier with air by using large fans to propel the pesticide-laden mist to the target. This allows the GPA to be reduced to 75–150 GPA (700–1400 L/ha) and allows a much larger area to be treated without refilling the tank. Droplet size is still $100^+$ μ for airblast sprayers. To achieve the best coverage, the sprayer must be moving slowly enough to completely displace the air within the canopy of the tree with the pesticide-laden mist. If the sprayer is not traveling slowly enough, or if the trees are not pruned correctly, only the outer canopy receives the correct amount of pesticide. This allows insects from the center of the tree to move to the outer canopy as soon as the pesticide residue is degraded, and the pesticide may appear to be ineffective. To ensure proper coverage, air-blast sprayers should not be driven faster than 2½ mph (4 kph) except when spraying young trees under 10 feet (3 m) tall.

Macadamia growers in Australia spray much more often than growers in Hawaii. To overcome some of the problems mentioned above, they have developed ducting that directs the air under the edge of the canopy to help coverage on larger trees.

### Aerial application

Application of pesticides by airplane or helicopter is possible in macadamia, but the success of this method depends heavily on the type of insect or pest being targeted and the orchard growth pattern. For example, if the orchard is completely closed in (i.e., the canopies of adjacent trees touch), then little if any of the pesticide will penetrate the upper part of the canopy. If the canopies do not touch, the applications still may not penetrate into the center of the tree where insects may be located. In general, unless the pesticide has a fumigant action (like sulfur), is systemic, or the pest is concentrated in the upper canopy of the tree, aerial applications are not recommended. Helicopters may provide better coverage because of the disturbance of the canopy by the rotor blades, but in any case, coverage should be checked using water-sensitive cards that change color when water droplets hit them. These cards are placed in the tree before application and then removed later to determine pesticide application patterns.

### Inspection and calibration

Calibration of sprayers is critical for peak performance. First, the nozzles of the sprayer should be checked for the correct size and to be sure they are not clogged. Worn nozzles should be replaced, and plugged nozzles should

**Table 1.2. The number of tree spaces passed per minute at various speeds and tree spacings.**

| | Tree spacing within a row | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| mph | 10 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
| 1 | 8.8 | 6.3 | 5.5 | 4.9 | 4.4 | 4.0 | 3.7 | 3.4 | 3.1 | 2.9 |
| 1½ | 13.2 | 9.4 | 8.3 | 7.3 | 6.6 | 6.0 | 5.5 | 5.1 | 4.7 | 4.4 |
| 2 | 17.6 | 12.6 | 11.0 | 9.8 | 8.8 | 8.0 | 7.3 | 6.8 | 6.3 | 5.9 |
| 2½ | 22.0 | 15.7 | 13.8 | 12.2 | 11.0 | 10.0 | 9.2 | 8.5 | 7.9 | 7.3 |

be cleaned with a soft brush. A wire should never be used to unclog a nozzle because it can change the size of the opening and thus affect the calibration of the sprayer.

Calibration of air-blast sprayers is aimed at putting a constant amount of pesticide on a designated area (generally an acre). This means that the time required to drive over the acre and the amount of pesticide put out during that time are both important in applying the correct pesticide dose. If the sprayer is driven too fast over the acre, then the amount of pesticide applied to that acre is less and efficacy will be reduced.

Calibration of the sprayer output is done simply by setting up the sprayer so that the pump is operating at the desired pressure and determining how much water is pumped through during a constant time period (such as a minute). By combining this information with the speed through the orchard, the amount of pesticide applied per acre can be determined. Speed through the orchard can be determined by timing the speed of the sprayer over a measured 88-foot course. Divide 60 by the number of elapsed seconds to determine the mph. The number of gallons per minute required to put out the desired amount of pesticide can be calculated using the following equation:

$$\frac{\text{gallons / acre} \times \text{mph} \times \text{feet between rows}}{1000}$$

$$= \text{gallons / minute (per side)}$$

An example of the rate needed would be if 200 gallons/acre is desired at a 2 mph speed with a row spacing of 25 feet:

$$\frac{200 \times 2 \times 25}{1000} = 10 \text{ gallons / minute}$$

In this situation, set the nozzels on each side of the sprayer to 10 gallons per minute. In other tree crops, it is recommended to apply two-thirds of the spray from the upper half of the manifold to get the best coverage. The size and coverage of the nozzles is very important for optimal coverage.

Another method for determining the speed of the sprayer is to measure the number of trees passed in a row per minute. Table 1.2 provides the information necessary to determine mph in the orchard. To determine the number of tree spaces you should pass per minute at a particular speed, look at the top of the table for your tree spacing, then find the mph you would like to travel in the left column. The point where the speed row overlaps with the tree spacing column shows the number of tree spaces you should pass per minute. For example, if you want to travel 1 mph and you have a tree spacing of 10 feet, then you should pass 8.8 tree spaces per minute.

A second method of calibration called tree-row volume (TRV) is used in apple production and may be applicable to macadamia production. The advantage of TRV is that it takes the tree size into account in determining pesticide application rate. This may be extremely important in macadamia where tree size varies dramatically with orchard age. However, the method of TRV has not been tested in macadamia orchards, so it cannot be recommended at this time. However, growers interested in this method can read either Smith et al. (2002) or Unrath (1989).

### Spray solution pH

The pH of the water used in mixing the pesticides is an important factor in pesticide effectiveness. The pH indicates whether the water is acid or alkaline. The pH scale goes from 1 (strong acid) to 7 (neutral) to 14 (strong base). Most pesticides are subject to acid or alkaline hydrolysis if the pH is extreme. Organophosphate insecticides are particularly susceptible to alkaline hydrolysis. The amount of breakdown is specific to the pesticide, the pH of the water, and the duration that the product is exposed to the water. Generally, if the spray water is higher than pH 7.5, it is alkaline enough to cause pesticide breakdown. A pH in the range of 4–6 is recommended for most pesticides. Some pesticides, however, especially those containing fixed copper, should not be acidified.

The half-life of a pesticide (the time for it to drop to half its potency) can radically change with increasing pH. For example, carbaryl (Sevin®) at pH 6 has a half-life greater than 100 days, at pH 7 it drops to 24–30 days, and at pH 8 the half-life is down to 2–3 days.

Malathion hydrolyzes rapidly in water above pH 7 and below pH 5. Iron will increase its decomposition. Endosulfan (Thiodan®) will undergo some breakdown at high pH.

The pH can be easily tested using test kits available from many agricultural chemical supply houses. If your water source has a pH outside the indicated range, various spray tank additives can readjust the pH in the spray tank, and these should be used to prevent pesticide failure.

### Hazards to bees

Only a few pesticides are currently registered for use in macadamia plantings in Hawaii. These include malathion and Thiodan on bearing crops. Thiodan is not considered a hazard to bees if it is applied in the evening or early morning, except if the temperature is high. Malthion is not considered a problem if applied in late evening, except during hot weather.

### Pesticide regulations

The regulations governing the use of a particular pesticide are indicated on the pesticide label. The pesticide label is a legal document and it spells out the crops on which it can be used, application methods, concentration of pesticide, and safety information. *Use of any pesticide in a manner inconsistent with the label is prohibited by law.* You are not allowed to use higher concentrations than listed on the label, increase the pesticide frequency over that stated on the label, or shorten the pre-harvest period compared to that on the label. According to the EPA definitions, you are allowed to decrease the concentration compared to the label, apply it less frequently than indicated on the label, and use it for a pest not on the label as long as the crop is listed on the label and all other safety precautions are observed.

If you have any questions about pesticide use, contact the Hawaii Department of Agriculture, which is responsible for enforcement. Pesticides should only be applied using appropriate safety equipment and by an individual who has been trained in pesticide application safety.

## Part 2

# Horticultural Factors Important in Integrated Pest Management

Macadamia trees grown in Hawaii are almost exclusively *Macadamia integrifolia*, also known as the smooth shell macadamia. The smooth shell variety is grown because the kernel has higher quality than the rough shell variety, *Macadamia tetraphylla*. Most macadamia trees in Hawaii are propagated by grafting the desired cultivar onto a seedling rootstock. Although in other crops the rootstock is often chosen for resistance to insects, nematodes, or plant pathogens, work in this area has not been done for macadamia. Ultimately this may be one of the more fruitful areas of research to help produce high quality trees and nuts. Nagao and Hirae (1992) suggested that there is already circumstantial evidence that rootstocks vary in their ability to absorb certain nutrients and that the variation in tree size and vigor within an orchard may be related to the variation in seedling rootstocks used in tree production.

Identification keys for the different cultivars have been published in both Australia and South Africa. The South African key is more recent. A reference to the keys is found in the *Further Readings and References* section.

### Flowering and fruiting patterns

The flowering and fruiting patterns of macadamia are important in developing management programs because they determine when and how long susceptible stages of the fruit are present. In Hawaii, multiple flowerings occur over an extended period for most cultivars in most locations. Time of year is important because insect population growth is quickest during the warmer times of the year. Thus a crop that drops primarily from August to December may experience more damage than a crop that drops from December to April. If the drop occurs over a short period, it means that the harvesting operations can be best timed to pick the crop up before significant damage has occurred. Unfortunately, the harvest period will change depending on the location and weather factors (rain, temperature) for a particular year. We also do not have good data for nut drop times from all the different regions where macadamia nuts are grown in the state. Our best data is from the CTAHR Kona Research Station in Kainaliu (Table 2.1). The other data comes from the patterns observed by growers with large orchards that contain multiple cultivars.

### Nut maturation process

Macadamia sets flowers on racemes that can contain up to 300 flowers (Fig. 2.1). Typically, more nuts are initially set on a raceme than can be successfully carried to maturity, and studies have shown that on average only one or two nuts are set per raceme. Small nuts are very susceptible to wind or mechanical damage and frequently fall off the raceme. Once the shell begins to form (when the nuts are about 20 mm or 0.8 inch in diameter), there is a marked tendency for the nuts to remain attached to the raceme. Virtually all the cultivars investigated had hardened shells when the nut was full size (about 30 mm or 1.2 inch) (Table 2.2). Once nuts reach full size, they require an additional 10–12 weeks for the kernel to mature and reach full oil content. Once nuts reach full oil content, the abscission layer in the stem matures and the nuts fall from the tree. The time from peak flowering to full size is about 18 weeks, with an additional 10–12 weeks to nut drop.

The nut maturation process is important in managing koa seedworm (KSW), southern green stinkbug

**Table 2.1. Effect of location on macadamia nut harvest period.**

| | | Kona Research Station[z] | Honomalino | |
|---|---|---|---|---|
| Cultivar | HAES[y] no. | Harvest period | Flowering period | Harvest period |
| Keauhou | 246 | — | Nov–March | Aug–March |
| Purvis | 294 | Sept–April | — | — |
| Ikaika | 333 | — | Nov–March | Aug–March |
| Kau | 344 | Oct–Jan | Nov– Feb | Aug–Dec |
| Kakea | 508 | — | all year | all year |
| Keaau | 660 | — | Nov–Feb | Aug–Dec |
| Mauka | 741 | Sept–Jan | Nov–Feb | Aug–Dec |
| Pahala | 788 | Sept–April | Nov–Feb | Aug–Dec |
| Makai | 800 | Sept–Jan | Jan–March | Oct–March |
| — | 816 | Oct–Jan | — | — |
| — | 835 | Sept–April | — | — |
| — | 856 | Sept–Dec | Dec– March | Sept–Feb |
| A4 | — | — | Nov–April | Nov–April |
| A16 | — | — | Nov–April | Nov–April |
| Honokaa Special | — | — | | |

[z] Data courtesy of Dr. Phil Ito, CTAHR, Univ. of Hawaii at Manoa. [y] Hawaii Agricultural Experiment Station.

(SGSB), and tropical nut borer (TNB). The length of the maturation process determines when harvest will occur and the length of time over which susceptible stages of the nuts are present. The importance of nut maturity for each pest species is different and will be discussed under each pests' section.

## Normal harvest operations

The method of macadamia nut harvest varies from grower to grower. Because of the prolonged flowering period, nut fall can extend more than 6 months for some cultivars. Most growers harvest the nuts from the ground at 6–12-week intervals depending on the time of year and the number of nuts on the orchard floor. Before the harvesting operation, typically the tree rows are treated with herbicide, the leaves are blown into the drive row, and the drive rows are mowed. These operations are necessary so the pickers can harvest the nuts and have easy access to the area.

Although rare, growers may also harvest directly from the tree. This is rarely done because the trees grow so tall that only a small fraction of the nuts are easily reached from the ground, and because it is difficult to determine nut maturity on the tree.

Mechanical harvesting using tree shakers or sweepers is used in some orchards. Shakers have padded jaws that attach to the trunk and shake the tree (Fig. 2.2). Most shakers have a canvas skirt that wraps around the tree during the shaking operation to catch the falling nuts. This allows the nuts to be immediately removed

**Figure 2.1. Macadamia raceme with the lower portion flowering.**

**Table 2.2. Macadamia nut husk diameter when shell hardening occurs for various cultivars.**

| Cultivar | Smallest size with shell present | Estimated size when 50% of shells are hardened | Estimated size when 90% of shells are hardened |
|---|---|---|---|
| Purvis | 0.66 (16.8) | 1.17 (29.7) | 1.40 (35.5) |
| Kau | 0.86 (21.8) | 0.89 (22.7) | 1.09 (27.8) |
| Pahala | 0.80 (20.3) | 0.94 (24.0) | 1.14 (29.0) |
| Makai | 0.89 (22.6) | 0.95 (24.2) | 1.14 (29.0) |
| 816 | 0.92 (23.7) | 0.96 (24.5) | 1.10 (28.0) |
| 856 | 0.79 (20.7) | 0.82 (20.9) | 1.03 (26.2) |
| Pooled | 0.82 (20.8) | 0.92 (23.5) | 1.13 (28.7) |

Size is given in inches first and in millimeters parentheses. See Jones (1994) for details.

from the field for processing. The elimination of the time nuts spend on the ground eliminates TNB damage, reduces SGSB damage, and increases nut quality. Use of shakers can reduce the number of weed-control activities but does not eliminate them. This is because, in general, shakers can be used only once a year (to prevent bark damage), and hand harvesting must be done either before or after the majority of the nuts are dropped with the shakers. In addition, weed control is still necessary for orchard health and management of some insect pests (such as SGSB).

Although shakers can be useful, there are several disadvantages, not the least of which is their high initial cost and on-going maintenance. In addition to the initial cost, their use requires several changes in orchard management. For example, the trees must be pruned so that the shaker jaws can reach the trunk, and the tree canopies must not touch. If the canopies touch, the force of the shaker is dampened by contact with the other tree. Secondly, the shaking must be timed so that the majority of the nuts are mature to prevent high levels of immaturity in the harvested nuts. This also means that some of the early crop will already be on the ground and subject to SGSB and TNB attack. Orchards planted on lava may also be more prone to damage from excessive shaking because of the lack of cushioning associated with normal soil. Shakers are also less efficient on larger trees because the flexibility of longer branches prevents the full force of the shake from reaching the nuts on the outer edge of the tree. This probably prevents immature nuts at the outer edge of the canopy from being dislodged, but this does not compensate for the lack of efficiency in shaking larger trees.

**Figure 2.2. Tree shaker with padded jaws and canvas skirt (retracted) that normally catches the falling nuts.**

Sweepers are another mechanical harvesting option, but in most cases, they can only be used if the orchard was initially designed for sweeper harvesting. As with tree shakers, there is an initial cost of purchasing the sweepers. In addition, the orchard floor must be reasonably flat and free of weeds and leaves. Thus sweepers do not reduce the need for mowing or herbicides.

Sweep harvesting usually requires two machines. The first is a blower/sweeper that moves the nuts and leaves into a drive row. The blower uses air to move nuts and leaves to the drive row, but the machine also has rubber paddles that sweep the nuts toward the drive row. The second machine picks up the leaves, nuts, and rocks and places them in a bin that is taken to the factory, where the rocks and leaves are removed before the nuts are husked.

Compared to shakers, an advantage of sweepers is that the harvest time for an area is relatively independent of the number of trees per acre. Thus in high-density plantings, sweepers become much more efficient than shakers because shakers must actually grab and shake each tree individually.

Perhaps one of the greatest disadvantages of sweepers is the possibility of damage to the small feeder roots near the soil surface. Root growth is generally thought to be highest during the fall when harvesting operations occur. If these young rootlets are damaged, it reduces the uptake of nutrients, minerals, and water and increases the overall stress on the tree, making it more susceptible to pathogens. A second problem is that the high-velocity air used to blow leaves and nuts also picks up small rocks and blows them into the tree trunk, damaging the trunk and providing an entry way for pathogens.

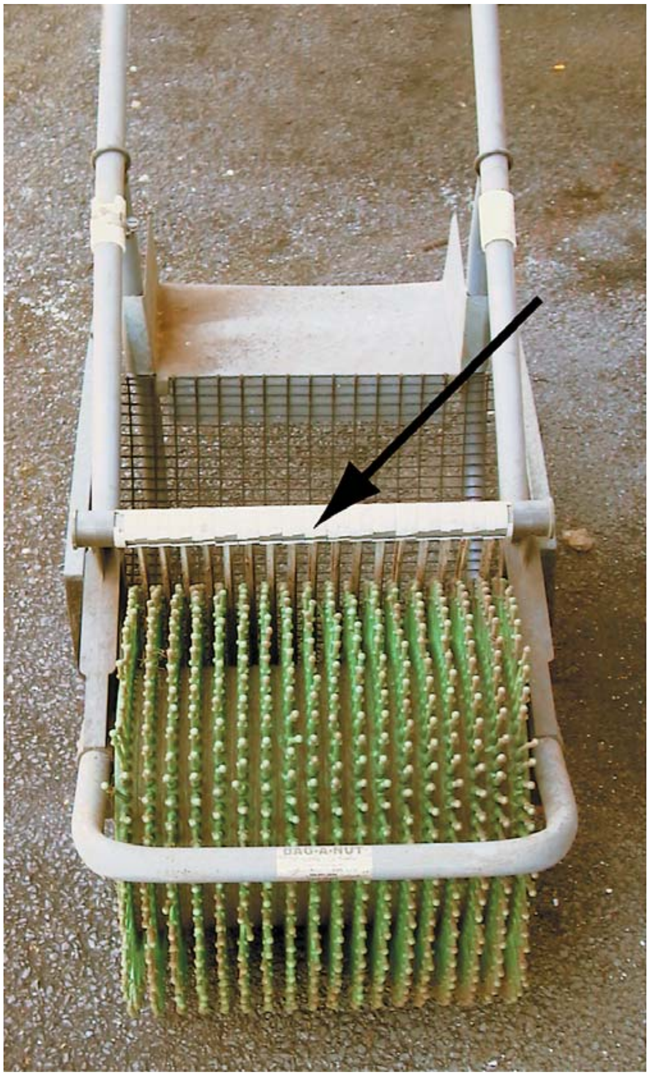
The final method of harvest is similar to the sweepers mentioned above. However, rather than using a sweeper that brushes the soil surface, it uses a drum covered with flexible plastic "fingers" that rolls over the nuts, and the nuts are trapped between the fingers (Fig. 2.3). The nuts are dislodged from the drum by a bar with projections that fit between the fingers on the drum. The nuts are then moved into a hopper. This sort of harvester can be a small hand-pushed unit about the size of a lawnmower or a larger unit towed behind a small tractor. The units work well if the ground is fairly flat and is relatively rock-free. Because they do not brush the soil surface like the sweepers, the damage to surface rootlets is minimized. These sweepers are available commercially and often called "Bag-a-Nut" after the company that manufactures them.

### Modified harvest operations

Smaller orchards will generally have little problem with cultivar mixtures, but this can have a severe impact on larger orchards where different cultivars may occur in different blocks. The differences in cultivar susceptibility should be used, along with the historic damage within each block, in planning and implementing pest management strategies. For example, the cultivar 800 is highly resistant to damage from the SGSB, and the cultivar 660 is extremely susceptible. If two blocks are planted side by side and have similar weed host plants and stink bug population levels, the 660 block should receive much more attention than the 800 block. In addition, the effect of mowing or weed control can cause SGSB to move from one site to another, so management in the block of 800 may result in increased damage within the 660 block. To reduce this problem, the most susceptible block should be harvested first if nut maturity occurs at the same time in both blocks. Further examples of cultivar susceptibility and the change in harvesting frequency to reduce damage are cited in the TNB section of this book.

**Figure 2.3. Hand-pushed Bag-a-Nut™ harvester.**

The fingers on the green drum trap the nuts, and the fingers on the bar (arrow) comb the nuts out and into the basket.



### Cultivar susceptibility

In addition to the differences in damage between locations, research has shown that there are major differences in susceptibility to the different insect pests. Much of the differences appear to be related to the thickness of the shell and the husk. In addition to differences in thickness that are cultivar-specific, there are also differences within a cultivar when it is grown at different elevations. Typically, the higher the elevation, the thicker the shell. This is probably related to rainfall, because in a study performed a few years ago, we observed shell thickness decreased steadily with elevation until we crossed into the irrigated lower portion of the orchard. At that point, the shell thickness was the same as at the top of the orchard for the same cultivar.

Cultivar selection for replants and new planting is critical for IPM. Incorrect decisions at planting time will result in higher damage and production cost throughout the life of the orchard. In addition to the susceptibility to damage, the length of the harvest period, and the time of year when harvest occurs can have marked effects on damage and ease of harvesting. The susceptibility of different cultivars to insects is cited in the different pest sections of this manual.

The combination of variability in cultivar susceptibility and geographical variation in insect severity means that it is critical to plant cultivars based on not just horticultural characteristics (yield, tree shape, etc.) but on the cultivar's susceptibility to insects and plant pathogens. Cultivar susceptibility to plant pathogens is not currently known except for a few pathogens, but as information becomes available, pathogen susceptibility should be incorporated into planting decisions in areas where pathogen infection is likely to occur.

### Fertilizer

Fertilizer recommendations for macadamia nuts are beyond the scope of this manual. However, fertilizer can have effects on the pest insects present. Over-application of fertilizers, particularly those high in nitrogen or phosphorus, have been shown on many crops to affect a wide range of insects and mites including aphids, whiteflies, spider mites, and the immature stages of moths (caterpillars). The general trends are for the plant to either become more attractive for feeding or egg-laying or for the insect or mite to experience greater reproduction because of better nutrition. High levels of fertilizer can also simulate longer and more intense growth flushes that may favor pests that occur on these flushes. Minor elements such as selenium can have direct negative effects on insect population growth.

### Pruning

Pruning can affect insect populations in several ways. The removal of old wood may cause the plant to be less stressed and more attractive to different insects. Pruning at different times may also stimulate a flush of growth that can be used by a particular insect. Insects often found on growth flushes in macadamia include broad mite, black citrus aphid, and redbanded thrips.

### Pollination

Macadamia flowers occur on long racemes that have from 100 to 300 perfect flowers (bearing both male and female flower parts). Studies in both Hawaii and Australia indicate that the flowers are mostly self-incompatible and require cross-pollination for good nut set. To insure cross-pollination and increase yields, most orchards are planted with pollinator cultivars spaced regularly throughout the block.

When choosing the pollinator cultivar used in an orchard, its susceptibility to insects as well as its suitability to cross-pollinate the main cultivar within the block should be considered. If possible, the pollinator cultivar should have at least as much resistance to the major pests as the main cultivar within the orchard. This is particularly important in areas that have a high risk for TNB damage and with cultivars that have a large number of sticktight nuts. Pollinator choice is probably also important in areas with high risk for KSW, but is less important if SGSB is the only pest present, because SGSB cannot complete development on macadamia nuts alone. Susceptibility of cultivars to other pest species is not well documented at this time.

In addition to similar pest susceptibility, fertilizer and irrigation requirements of the pollinator cultivars should be similar to reduce problems associated with overapplication of fertilizer or irrigation.

Studies have shown that honeybees, both feral and domesticated, are probably the most important pollinators of macadamia nuts in Hawaii. Honeybees have been shown to forage more than 1500 meters (4920 feet) from their hives and are important in cross-pollination of the different cultivars. Australian studies have shown that there is a tendency for honeybees to visit preferentially the flowers on the outer canopy of the tree, which may result in the highest nut set occurring there.

In addition to honeybees, syrphid flies have been cited as important for pollination, but their efficiency is thought to be considerably lower than that of the honeybee.

### Alternate hosts, ground covers

Many of our pest insects use a broad range of plants, and some of these host plants are commonly found near or within the orchard. In macadamia, broadleaf weeds tend to be very important for SGSB, KSW, and some of the minor pests. TNB has several alternate hosts, but macadamia is probably a better host than the alternate hosts we have found. Although legumes are often planted as ground cover with the idea that they will contribute to soil fertility, many legumes are also fair to excellent hosts for SGSB and KSW. In general, grasses are not hosts for any of the major pests of macadamia, and they can help prevent some of the insects' host weeds from spreading and becoming well established. In addition, for insects that require weed hosts for reproduction (such as SGSB), the grasses might prevent them from completing a generation.

In addition to grasses, some flowering plants provide pollen and nectar that can be important food sources for natural enemies. At present, we do not have information on any of the specific natural enemies that this might affect, but beneficial insects such as parasitic wasps and generalist feeders such as lacewings are known to use flowering plant nectaries to obtain nutrients that extend their life span and increase their effectiveness.

## Management of pests in nurseries

Macadamia trees in the nursery are often subject to insect and mite attack. Commonly, broad mite and redbanded thrips are the most serious pests. Their management in the nursery is easier in some instances but more difficult in others than in the field on bearing trees. Because of the importance of keeping the trees healthy and growing well, pesticides are the most commonly used method of management. In the nursery, it is easier to control pests because they occur in a very small area and because there are several pesticides that can be legally used on nonbearing trees but not in the field. The difficulty is that in the nursery the trees are packed together so tightly that achieving good coverage of the underside of the leaves (where both broad mite and redbanded thrips are more common) and lower parts of the plant is very difficult. If the trees are tightly packed and coverage of the lower leaves is not possible, the trees should be moved apart before treatment.

People working in the nursery should be careful not to transport the pests to other areas of the nursery on their clothes or by brushing the trees against one another when they are moved. Spray coverage in the nursery may be better achieved using a back-pack mist blower that puts out a smaller droplet size and is able to swirl the pesticide around and reach the lower surface of the leaves. If there are uncertainties about coverage, small cards that stain when water touches them can be placed before treatment in a few hard-to-reach areas and checked after treatment to determine the quality of the spray coverage.

## Part 3

# Major Pest Insects

### Overview of pest status

Among the four major pest insects of macadamia in Hawaii are two closely related moths, the native koa seedworm (KSW), *Cryptophlebia illepida*, and the accidentally imported litchi fruit moth (LFM), *Cryptophlebia ombrodelta*. In our studies, *C. illepida* has almost always been the dominant species and typically comprises around 80% of the individuals in the orchard. The other two major pests are the southern green stinkbug (SGSB), *Nezara viridula*, and the tropical nut borer (TNB), *Hypothenemus obscurus*, both of which were accidentally introduced.

Conservatively, these four insects probably damage about 10–15% of the crop delivered to processors industry-wide. Although these figures are higher than those reported by the Hawaii Agricultural Statistical Service (HASS), they are probably more accurate because the data reported by HASS are based on processor information. The reasons for the inaccuracy of HASS reported data include:

1. Culling of TNB damaged nuts in the orchard.
2. Culling of TNB damaged nuts after husking but before drying.
3. Use of an air curtain to blow small chunks of shell (and kernels damaged by TNB or KSW) off the production line.
4. The use of weight of damaged kernels compared to the weight of undamaged kernels in quality control assessments. By use of weight, any insect feeding that reduces kernel weight automatically results in an underestimate of damage from that factor. This underestimate can become extreme if the insect completely consumes the kernel, because it would be recorded as no damage. This is partially compensated for in the HASS estimates by conversion factors supplied by CTAHR, but there are no corrections for factors 1–3, and some of factors 1–3 may be processor- or grower-specific.
5. Finally, the data provided to HASS is further biased because not all processors record all damage categories. For example, in a survey of six processors in 1994, we found that three processors recorded Koa seedworm damage, five processors recorded SGSB damage, and three recorded TNB damage. In addition, immaturity, mold, and miscellaneous were recorded by six, six, and two processors, respectively. This means that misclassification is common, and lumping of damage classes can provide erroneous or useless information.

Although there are no easy fixes for the current reporting system, the industry can and should fix factors 4 and 5 above. Factor 4 can be fixed by having the quality-control people calculate damage by counting the number of damaged kernels and dividing this by the total number of kernels examined. Having all the processors using the same damage categories to classify nut damage would fix factor 5. If these two fixes were implemented, we would markedly improve the current reporting system at minimum cost.

Why are accurate damage estimates critical to the industry? First, accurate assessment of damage allows us to implement management practices that reduce the damage and increase profitability. Second, if damage is classified incorrectly, the incorrect management practices may be applied or the damage may be accepted as inevitable and no action would be taken. Incorrect classification of damage has occurred and still occurs in the industry. For example, we found that 25% of the nuts classed as "moldy" by a major processor were caused by SGSB feeding. Previously, it was thought that moldy nuts were related to rainfall keeping moisture high and favoring the growth of mold. However, island-wide surveys show mold incidence is well correlated with SGSB damage and is highest in the dry areas, not in the high rainfall areas. Another example is the classification of nuts as "immature" which is discussed under "Cultivar Susceptibility" in the KSW section. Finally, accurate damage estimates are necessary for the industry to prioritize research to keep competitive in the increasingly global marketplace.

### Patterns of damage

In discussions with growers, it is clear that each of the major growing areas has different problems. Data collection for various projects over the past 10 years easily substantiates grower observations. In general, dry areas such as Kona, Kau, and Wailuku tend to have more problems with SGSB and TNB. Wet areas such as Hilo and the Hamakua coast tend to have more problems with KSW and fewer with SGSB and TNB. The intermediate areas, such as Kohala, tend to have SGSB and TNB damage and an intermediate amount of KSW damage. However, it is important to remember that during periods of drought or excess moisture, these general patterns can be distorted. For example, during drought periods, TNB has been reported in high numbers in the normally wetter areas near Hilo, but in typical weather years it is almost undetectable in those areas.

## Tropical nut borer

***Hypothenemus obscurus*** **(Coleoptera: Scolytidae)**

### History

TNB was first noticed in North Kona in 1988, and surveys conducted in 1990 showed that it was concentrated in orchards close to Kainaliu. The following year it had spread in low numbers to Kohala, a few locations along the Hamakua coast, and one or two locations in Hilo. However, it was not present on Maui, Oahu, Kauai, or the South Kona and Pahala areas of the Big Island. Damage was highest in the dry areas and barely detectable in the wetter areas.

By the year 2000, the distribution was much different. TNB was found at Wailuku on Maui, Waimanalo on Oahu, South Kona, and Pahala. The damage from TNB was still highest in the Kona (north and south) areas, followed by Kohala, and was increasing in Pahala and Wailuku. Our best estimate was that it had been found on 16,000 of the 22,000 acres of macadamia grown in the state. However, damage was still most serious in the dry areas, and even in wet areas where it was recovered, damage was considerably lower.

Movement of TNB to different areas occurs naturally by flight or by wind. However, the rapid spread of TNB was probably aided by processors buying Wet in Shell nuts from infested areas. In addition, during the early 1990s, the benefits of using husks as fertilizer resulted in some growers buying husks from processors or husking plants and inadvertently spreading infested husks in their orchards. Husks that have been composted are not a source of TNB because the high temperatures attained in the composting process cause complete mortality of all stages.

From the distribution and damage experienced in the drier infested areas, it is clear that TNB will continue to be a serious pest of macadamia. The damage from TNB is substantial, and its life cycle makes it well adapted to macadamia production practices. Areas that have only recently become infested, such as Pahala and Wailuku, are major production areas, and damage will certainly increase if the problem is not dealt with correctly.

### Life cycle and description

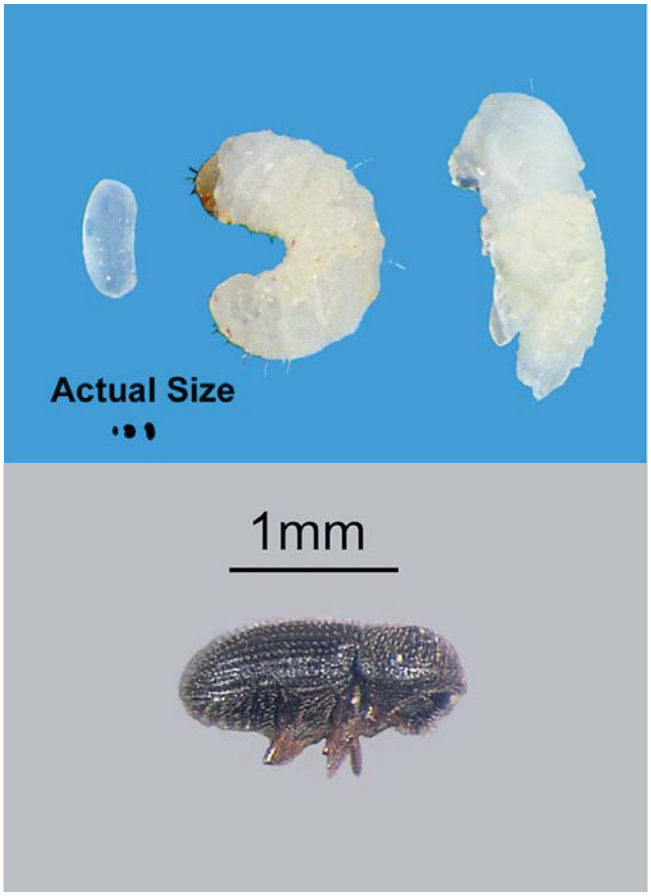
TNB eggs are oblong and measure 0.03 inch long by 0.01 inch wide (0.76 mm x 0.25 mm) (Fig. 3.1). They are pearl colored and are generally laid in the husk or kernel. Studies show that they hatch in about 4.5 days at 78°F.

There two larval stages as determined by head capsule measurements. The larvae tend to chew through the husk or kernel, depending on where the eggs are laid, and they can complete development in either place. Studies show that the average development time of the larva is about 3–4 weeks. Larvae are "C"-shaped with a darkened head capsule and no obvious legs (Fig. 3.1).

The pupal stage is a resting stage where the insect transforms into an adult beetle. There are two distinct size classes of pupae, with the more numerous female pupae measuring about 0.07 inch long (1.8 mm) and the males measuring about 0.05 inch (1.27 mm long). Both sexes have a similar, white, torpedo shape (Fig. 3.1). The pupal stage lasts about 1 week at 78°F.

The adults initially are light brown, but after a day or so they become dark brown. Females average 0.06

**Figure 3.1. Tropical nut borer egg, larva, pupa (top, left to right), and adult (bottom).**



inch long (1.5 mm) and are more than 50% larger than the males (average 0.04 inch long, or 1 mm). Wood (1982) described the beetles as "partly parthenogenic." This means that the females either mate with their siblings (brothers) or can produce fertile eggs without mating. Field studies show the sex ratio highly favors females, and the lab studies show the ratio is about eight females to one male.

Adults either can remain in the nut where larval development occurred and lay eggs for a subsequent generation or leave and attack another nut that is partially dry. We have seen up to 190 beetles within a single sticktight nut, which suggests that many generations can use the same nut for development. Sticktight nuts are very favorable sites for reproduction and development. Green nuts are rarely attacked, but the current season's nuts that have fallen to the ground and dried for about 2–3 weeks are highly attractive.

Females lay eggs in groups of three to four, and probably lay about 30 eggs over their life span.

### Identification

Identification of TNB to the species level is complicated by the presence of a closely related species, *Hypothenemus seriatus*. *H. seriatus* is commonly found in the husk but rarely is found in the kernel. Any infested kernel can reasonably be considered to be caused by TNB. Distinguishing between TNB and *H. seriatus* requires an expert using a high quality microscope with up to 80x magnification. The differentiating character is that the hairs on the back of *H. seriatus* are fan-shaped (bigger at the top than bottom), while those on TNB are narrow all the way up and are generally pointed at the top. Other characters are also used, but they are mainly used to confirm the differences in hair shape.

### Alternate hosts

We collected twigs and fruits (or pods) from nine host plants and examined about 20 other plant species. In general, TNB is not associated with twigs, but low numbers of beetles were collected from carob (*Ceratonia siliqua*) and fairly high numbers from hog plum (*Spondias mombin*). Carob pods, asoka fruit (*Saraca asoca*), and castor bean (*Ricinus communis*) fruit were shown to support populations of TNB and thus should be removed from the immediate vicinity of the orchard. TNB has also been collected in low numbers from dried coffee cherry left over from the previous season. Of all these host plants, castor bean is probably the most common host throughout the macadamia production area and it is also a host plant for SGSB reproduction.

### Damage

TNB damage is normally seen as small holes through the husk, shell, and kernel (Fig. 3.2). In severe cases, many holes are found in the shell and no kernel remains. Damage from TNB can be distinguished from KSW damage by the presence of numerous small TNB beetles about 0.06 inch (1.5 mm) long and the many small holes they make in the shell and kernel. Beetle entry also typically results in moldy nuts, so the damage can potentially be misclassified at the processor level.

### Time of damage

Studies have shown that nuts must be on the ground 2–3 weeks for kernel damage to occur. At 3 weeks, our studies showed 2.5% damage when averaged across the different cultivars. By 4 weeks, damage increased to about 13.4%, and by 5 weeks it was 22%. Different cultivars have different susceptibility to attack, and thus they can have higher or lower damage. Our most susceptible cul-

**Figure 3.2. TNB damage to macadamia kernel.**

tivar (660) experienced 4.8, 25.6, and 41% damage at 3, 4, and 5 weeks, respectively. In all our tests with all cultivars, there was a marked increase in damage (about 5.6 fold increase) between 3 and 4 weeks after nut fall.

Our studies of susceptibility of different cultivars have been extended over several years and in different orchards. The studies indicate the rate at which nuts are damaged after nut drop but should not be used directly to predict nut damage at different harvest intervals. The reason for the difference is that nuts drop throughout the time between harvests, and the rate at which they drop and the time at which they drop can have a huge impact on the amount of damage seen in the field. For example, if all nuts were collected in the last harvest, then if no nuts fell until 2 weeks before the next harvest, the damage would be undetectable. Conversely, if the day after harvest a large portion of the remaining crop dropped but no more dropped after that, the result would be a damage estimate similar to those seen in the bag studies.

The effect of different nut drop patterns can be calculated using an average rate of damage (averaged over all the cultivars) and examining the effects of different patterns of nut drop that could reasonably occur. For the simulated scenarios, we used four patterns of nut drop and simulated the damage for harvest intervals up to 10 weeks. The first drop pattern was a uniform nut drop every day between the two harvest periods. The second assumed a heavy initial nut drop (about 40% of total drop) over the first 4 days after the last harvest and a uniform low level drop during the remaining period. The third simulation used the uniform nut drop until about the middle of the 10-week period, then dropped 40% of the crop during the next 4 days and went back to a uniform low drop level until harvest. The final simulation used a low level of nut drop until 4 days before the next harvest and then dropped 40% of the total crop. When the results of these simulations are plotted, it is apparent that none of the drop patterns result in as high a damage level as predicted by the bag studies (Fig. 3.3). Again, this is because at harvest time, not every nut has been on the ground since the previous harvest period. Examination of Fig. 3.3 shows that, as expected, the highest damage occurs when there is a heavy early drop and the least when the drop occurs later in the season. When a heavy drop occurs either in the middle or end of the season, an immediate noticeable drop in percentage damage occurs. This is caused by an increase in the total number of nuts on the ground that are undamaged, effectively diluting the number of older, damaged nuts with new, undamaged ones.

Simulations done using different statistical distributions (such as a normal, or bell-shaped curve) showed results very similar to the uniform drop simulations. Thus in normal situations, the assumption of uniform drop may be the most reasonable assumption to make. However, if storms occur with either large amounts of rain or winds that blow nuts off, then the assumption of heavy early, mid, or late drop may be more reasonable.

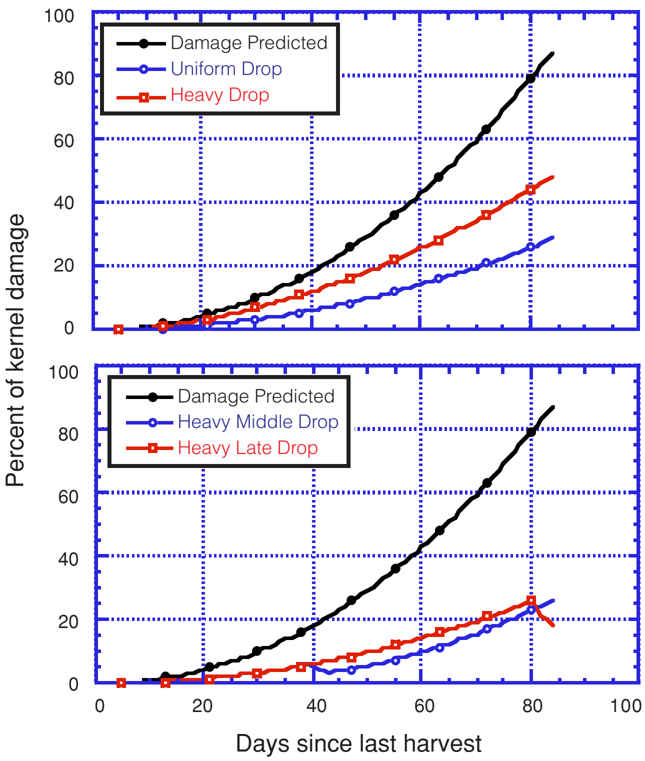
## Monitoring

Sticktight nuts tend to have the highest population level of TNB, but there is no simple way to relate the percentage of infested sticktights to the damage at harvest. This is because the current season's crop is not suitable for TNB attack until it has been on the ground for 2–3 weeks and because different cultivars have different levels of susceptibility to attack. Sampling sticktights thus provides a direct indication of the presence and population level of TNB, but only an indirect estimate of how much damage will be detected at harvest.

Monitoring for damage within an area should be done separately on the pollinator and main cultivar planted in an orchard. Because nuts constantly fall over the course of the season, to get an indication of damage if you harvested on a particular day, randomly sample 20 nuts from under 10 trees within a block of up to 50 acres. The nuts should not be discriminated in terms of color (green nuts on the ground fell within 2 weeks,

## Figure 3.3. Simulations of TNB damage at different times after a harvest.

Top: effect of 40% of total nuts dropping in the first 4 days after harvest, a uniform nut drop, and the damage if all nuts dropped the first day after harvest (damage predicted). Bottom: effect of having 40% of the total nuts dropping at days 41–44 (heavy middle drop) and 40% dropping the last 4 days before harvest (heavy late drop).



brown nuts fell more than 3 weeks before). If the sample is composed of only green nuts, no damage is likely to be recorded because TNB typically does not attack nuts until 2–3 weeks after they fall. Likewise, sampling only brown nuts will bias the damage estimate toward higher levels because they will be more likely to have already been attacked by TNB. The sample trees should be a minimum of 300 feet apart to give the best estimate of damage over a fairly large area. In small orchards, the samples should be spread evenly over the whole orchard block, but for farms smaller than 10 acres, one tree per acre should give a reasonable estimate of damage. Inspect each nut for the presence of TNB holes. Nuts with holes should be cracked to determine whether the kernel is actually damaged, because not all holes in the shell extend into the kernel. Data should then be recorded in a data form similar to Table 3.1.

## Table 3.1. Example calculation of TNB damage.

| Tree | Number of nuts damaged |
|---|---|
| 1 | 5 |
| 2 | 3 |
| 3 | 14 |
| 4 | 10 |
| 5 | 4 |
| 6 | 16 |
| 7 | 10 |
| 8 | 11 |
| 9 | 8 |
| 10 | 12 |
| **Total** | **93** |

Average percent of nuts damaged
= 93 / (20 nuts/tree x 10 trees)
= 93 / 200
= 45.5%

Adult population levels can be monitored with funnel traps baited with ethanol (Appendix C, Fig. 6.5). These traps were originally developed for trapping bark beetles in forest trees, and the trap simulates a tree trunk. However, these traps are both expensive and cumbersome to use. In addition, at present, there is no way to predict nut damage from the number of beetles trapped. Thus their primary use is for research or population detection and to determine population trends within the orchard. For most purposes, the sticktight sample method discussed above is an easier and cheaper method.

### Cultivar susceptibility

Macadamia cultivars show marked differences in susceptibility to TNB attack. This is probably because different cultivars grown in the same area tend to display fairly consistent differences in shell thickness. If we measure the shell thickness on a large number of nuts and determine the average percentage of nuts of the same shell thickness that are damaged by TNB, we find that damage decreases as shell thickness increases. If we plot the data from several different locations on the same graph, we see that the data are consistent within a location, but between locations the damage is shifted higher or lower depending on the level of TNB present in the orchard (Fig. 3.4). We also find that in examining a husked nut damaged by TNB, many of the holes do not extend all the way into the kernel. If the beetle bores into the shell and does not reach the kernel within 1.5 mm (its body length), only 20% of them will continue

**Figure 3.4. Effect of shell thickness on kernel damage observed at three sites.**

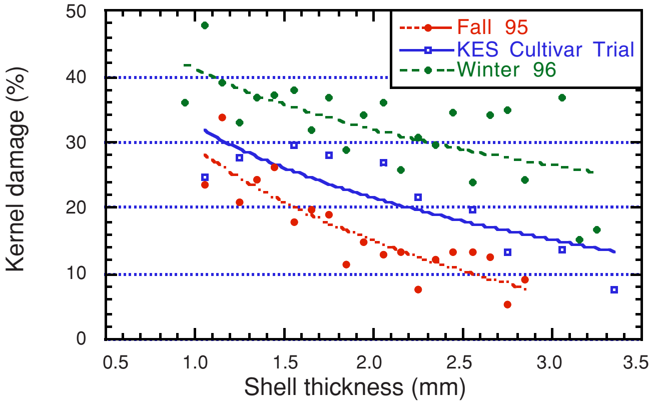
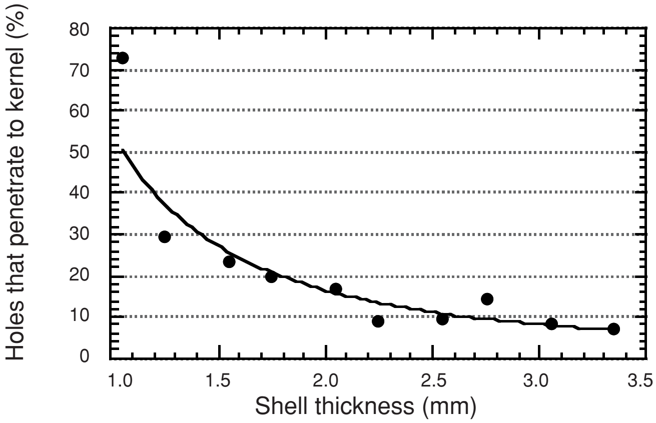


**Figure 3.5. TNB penetration through the shell as a function of shell thickness.**



toward the shell (Fig. 3.5). At 2.5 mm (about 1.7 times its body length), only about 10% will continue toward the kernel. Instead, they tend to back out and start another hole in a different location.

Rainfall and altitude both affect shell thickness measured at any given time of the year. In an orchard irrigated only in the lower portion, we measured shell thickness for a particular cultivar from the top to the bottom of the orchard. We found that the shell thickness was highest at the top of the orchard and gradually decreased until we crossed into the irrigated part of the orchard at low elevation, where it increased to a value similar to that at the top of the orchard. The change in shell thickness right at the point where irrigation starts suggests that the differences we saw were caused by rainfall, because the orchard normally experiences higher rainfall at higher elevations. However, elevation can also affect the rate of nut development, so that at any given time of the year, the nut development may be different at different elevations. This means that damage could be different at different elevations, even though the TNB population levels are the same throughout. The effect of water availability on shell thickness helps explain why damage tends to be higher in drier years.

Table 3.2 shows the relative susceptibility of different cultivars to TNB damage. For cultivars that are relatively "resistant," our studies indicated that if populations of TNB are high, even these cultivars can suffer damage of greater than 40% if left in the orchard more than 6 weeks. The economics of control using frequent harvest is discussed below. As stated previously, if the time since nut fall is constant, the thickness of the shell is the most important factor in determining susceptibility to TNB.

### Sticktight nuts

Sticktight nuts occur when the abscission layer in the nut dies before the nut matures. This prevents the nut from falling off the tree (Fig. 3.6). Typically such nuts

**Figure 3.6. Sticktight nuts from the current crop year that have not yet started to break down.**

**Table 3.2. Susceptibility of different cultivars to tropical nut borer.**
Cultivars are in approximate order of susceptibilty, with the most resistant at the top and the most susceptible at the bottom.

| Cultivar | HAES no. | Susceptibility to TNB | Shell thickness | Sticktights |
|---|---|---|---|---|
| Ikaika | 333 | low | thick | low/high |
| Makai | 800 | low | thick | low |
| — | 856 | low | thick | intermediate |
| Keauhou | 246 | intermediate | thick/variable | low |
| A16 | — | intermediate | high/low variable | high |
| — | 835 | intermediate | low/intermediate | low |
| Kau | 344 | intermediate | low/intermediate | low |
| Kakea | 508 | intermediate | intermediate | high |
| Honokaa Special | — | intermediate | high | high |
| Pahala | 788 | high | thin | very high |
| — | 816 | high | thin | high |
| Mauka | 741 | high | thin | high/low |
| Purvis | 294 | high | thin | very high |
| Keaau | 660 | high | thin | intermediate |
| A4 | — | high | thin | very high |

**Table 3.3. Tendency for sticktights at four locations observed in a normal year.**

| Cultivar | HAES no. | Kona Res. Station | Honomalino | Pahala | Hilo |
|---|---|---|---|---|---|
| Keauhou | 246 | — | — | low | — |
| Purvis | 294 | high | — | high | — |
| Kau | 344 | medium | medium | low | low |
| Kakea | 508 | — | — | — | high |
| Keaau | 660 | — | — | medium | low |
| Mauka | 741 | high | — | medium | low |
| Pahala | 788 | high | medium | low | — |
| Makai | 800 | low | low | — | low |
| — | 816 | high | — | high | — |
| — | 835 | medium | — | low | — |
| — | 849 | high | — | low | — |
| — | 856 | medium | low | low | — |
| — | 863 | low | — | — | — |
| A16 | — | — | high | — | — |
| A38 | — | — | high | — | — |
| A4 | — | — | high | — | — |

remain on the tree into the next season until the husk rots sufficiently for the nut to fall. The cause of sticktights is presently unknown, but water stress and cultivar are known to have significant effects. In the drier areas where TNB is present, cultivars known to have high levels of sticktights should be avoided as replants or new orchard plantings.

As mentioned above, sticktight nuts are the primary site of TNB reproduction. Sticktights are important for pest management because they fall among the current year's nuts during the harvest period. This means that sticktight nuts with high levels of TNB are found right next to the current years' crop. High levels of sticktights can have a dramatic effect on the damage seen at harvest time. Our studies were primarily in orchards with high sticktight levels, so the damage estimates given previously are for areas with relatively high levels of TNB and sticktights.

In most areas, removal of sticktight nuts is impractical. If done manually, the cost would be excessive, and for the few orchards that can afford tree shakers, the larger trees cannot be shaken sufficiently to reduce the numbers of sticktights enough to make a difference in TNB damage without causing damage to the tree. However, Table 3.3 indicates which cultivars are prone to sticktights, and areas with those cultivars should be checked frequently to prevent excessive damage from occurring. Cultivar selection for replants or new sections in the orchard should avoid those with high sticktight levels if the orchard is in a dry area or if there have been problems with TNB in other orchard blocks nearby.

## Management strategies

### General

No single method of TNB control will work in all situations; therefore, an IPM program requires the use of several methods. Several methods are available, but their usefulness depends on farm size and the economics of the operation. For these methods to be most effective, they need to be undertaken while considering several parts of TNB biology. The critical points are

- TNB reproduces primarily within sticktight nuts on the tree and in nuts that have been on the ground for more than 2–3 weeks. In general, the longer the nuts are on the ground, the greater the damage.
- TNB can move more than 200 yards away from an infested area into a new area and within 3–4 weeks can cause kernel damage there.
- A single sticktight nut can have up to 190 beetles present.
- Cultivars have significant differences in their "resistance" to TNB attack.

The management strategies are discussed separately, but in designing a management program, use as many as necessary to reduce damage. The methods for TNB reduction can be broken down into harvest modification, natural enemies, pesticides, and cultivar choice.

### Harvest modification

For small farms, the best control measure for TNB is frequent harvest. Nuts of any cultivar harvested at 3-week intervals should have less than 3% kernel damage. Because the borer reproduces and feeds in the husk as well as the kernel, removal of the husk removes a large portion of the population. Leaving the husks on, or husking the nuts and holding them in harvest bags until there are enough to take to the processor, greatly increases damage because TNB reproduction and damage continues in the bags. Damaged nuts should not be left in the orchard but should be removed and destroyed by burning (check whether restrictions apply to your area), composting, burying, or transporting them to the dump. Because TNB is found throughout most of the macadamia growing areas, taking them to the dump will not infest a new area (if in doubt contact your CTAHR Cooperative Extension Service agent). Finally, do not buy raw husk for composting around your home or orchard. If you are lucky enough not to have TNB, this is a certain way to bring it to your orchard. If you are buying the completely composted husk material, it is not a problem, because the temperature of the compost piles typically reaches over 120°C for relatively long periods, and our tests showed 100% beetle mortality in compost piles.

For large farms, management depends in part on whether TNB is recently established or has been there for several years. If it is a newly established pest, aggressively harvest in the infested areas and in adjacent areas which have thin-shelled cultivars. Keeping the population low for as long as possible will allow you to get a reasonable management program in place and decide which areas historically have the most damage. If the pest is well established, knowing which areas have susceptible cultivars allows you to concentrate harvest rounds in those areas. The harvest frequency to minimize damage is discussed under the section on cultivar damage and harvest frequency.

Large operations with a husking plant should consider methods to dispose of the husk. TNB can complete development in the husk, and thus spreading the uncomposted husk spreads TNB within the orchard. A husking plant is therefore a prime area to survey for TNB presence, and orchard blocks nearby may require a more intensive management program than blocks further removed from the plant.

### Early season harvest

Early season harvest should be beneficial for several reasons. First, a thorough harvest just before the current year's crop comes off would remove last year's nuts, which act as a food source for TNB. Secondly, although the damage will probably be higher than for later harvests when harvest intervals are shorter, it should provide an estimate of damage for the different sections of the orchard. However, our studies show that the reduction in damage in subsequent harvest rounds was insignificant compared to the effect of an additional harvest round during the normal harvest season. The lack of effect in our studies was probably because the plots we used had extremely high sticktight levels and TNB population levels.

### Mechanical harvest

Shakers are rarely used in Hawaii, but they can be used alone or in conjunction with ethephon (Ethrel®) to speed harvest operations. With respect to TNB and SGSB attack, this eliminates the time on the ground where most of their damage occurs. The shakers thus can speed harvest, reduce the time and labor required to harvest a given block, and increase nut quality.

In addition to the benefits mentioned above, there are other benefits of using shakers. First, shakers can reduce the number of sticktights remaining in the tree and thus reduce feeding sites for TNB. Our studies with shakers show that the normal shaking for harvest reduces the number of sticktights by about half. At this level, it is not economical to shake the trees just to remove sticktights, but it is a good bonus of the normal shake-harvesting method. The 50% sticktight drop may increase in smaller trees or with some of the newer shaker models. Second, the use of shakers reduces the cost of weed control because nuts are not collected from under the tree, and the use of leaf blowers, mowing, and herbicides can be greatly reduced for that particular harvest.

Sweepers are another mechanical harvesting method, but they also have limited applicability to many Hawaii orchards. First, the orchard floor must be prepared for sweeping, and this preparation generally must happen before the orchard is planted. Second, unlike shakers, sweepers do not eliminate the period when nuts are on the ground, so the reduction in insect damage is primarily because sweepers allow harvest rounds to be more frequent, thus reducing the time nuts are on the ground compared to hand harvesting. However, if used with ethephon to reduce the length of the harvest season, sweepers may reduce the overall level of pest damage in the orchard.

### Use of ethephon

Large orchards can also use ethephon (Ethrel®), a plant growth regulator that causes nut drop within a few weeks of application. Ethephon vaporizes and releases ethylene gas, which causes the abscission layer in the nut to mature, resulting in nut drop. As a management tool, ethephon is useful because it can decrease the length of time over which nuts drop. This allows harvesting to be scheduled so nuts can be removed before TNB damage occurs. Use of ethephon can dramatically affect the economics of harvesting by reducing TNB damage and eliminating at least one harvest round per season.

Our studies show that ethephon concentrations should be about 250–300 ppm for optimal nut drop. Concentrations lower than this result in erratic nut drop, and higher concentrations can cause excessive leaf drop. Our studies also show that ethephon is not very efficient when trees are water-stressed, and excessive leaf drop also occurs under those conditions. When trees were not under water stress, we found that up to 90% of the nuts dropped within 3 weeks of application, and no effect on return bloom was noted the following year.

Studies in other areas show that the addition of a surfactant and adjusting the spray solution to pH 7.0 increases the effectiveness of ethephon and reduces the amount of leaf drop that occurs. See the section on spray solution pH in the introduction for more information.

The use of ethephon requires careful attention to timing. Studies have shown that flowers and small nuts (3–7 weeks after flowering) are sensitive to ethephon, mid-size nuts are insensitive, and full-size nuts nearing maturity (28–30 weeks after flowering) are again sensitive (maximum nut size is reached at about 18 weeks after flowering). Because macadamia trees in Hawaii tend to flower several times a year, it is important to apply ethephon only when the majority of nuts are mature and new flowers or small nuts are not present.

Ethephon used in conjunctions with tree shakers has been shown to be a particularly effective method to shorten the harvest period. Nut drop is typically higher than when either ethephon or shakers alone are used. In some situations, only a single shake/ethephon treatment may be required along with a single hand harvest to collect early season nut drop. For large trees that are especially difficult to shake, ethephon may dramatically increase the efficiency of shaker harvest by reducing the force needed to remove the nuts from the tree. Ethephon in conjunction with sweepers could also be a particularly effective method of shortening the harvest period, reducing TNB damage, and decreasing the number of harvests necessary per year.

### Natural enemies

In 1995–96 we conducted an 18-month survey for natural enemies of TNB found in sticktight nuts. When the data were analyzed, only one predator (a small beetle) was found and at only one site (Honomalino). Further analysis showed that 96% of the time, when the predator was found it was in conjunction with TNB, indicating that it was probably a specific predator of TNB.

On closer examination, the apparently single species was found to be two species: *Cathartus quadricollis* (Coleoptera: Sylvanidae), and *Leptophloeus* species (Coleoptera: Laemophloeidae), both of which are new records for the state (Fig. 3.7, 3.8). The larger of the two beetles is the square-necked grain beetle, *C. quadricollis*. This insect is known to feed on stored grains (such as

**Figure 3.7. Adults of *Leptophloeus* species (left) and *Cathartus quadricollis* (right).**

**Figure 3.8. Larval (top) and pupal (bottom) stages of *Cathartus quadricollis*.**

corn) and is considered a pest in many areas. However, our studies showed that it can eat an average of 21.7 TNB eggs per day or 7.7 TNB pupae per day. When given a choice between TNB eggs or pupae and macadamia nut kernels, the consumption of eggs dropped slightly to 20.7 eggs/day and 6.1 pupae per day. We have also not seen any indication that *C. quadricollis* can penetrate into the kernel by itself, so it should not cause damage above and beyond that caused by TNB. When given a choice of TNB eggs, larvae, or pupae, *C. quadricollis* did not show marked preference for any stage. *C. quadricollis* has also been reported as an effective predator of the immature stages of the coffee berry borer, *Hypothenemus hampei*, in Colombian coffee fields.

Our studies have not yet progressed to the same level with *Leptophloeus*. However, we find they also are predators of eggs, larvae, and pupae of TNB. We found that if three *Leptophloeus* adults were placed with 10 TNB eggs or larvae, 80% of the eggs and 70% of the larvae were eaten within 1 day. In general, *C. quadricollis* appears to have a higher feeding rate on TNB than *Leptophloeus*.

Overall, the two predators show great promise for reducing TNB population levels within sticktight nuts. This means that the overall level of TNB within an orchard should decline and the damage caused by TNB should eventually be reduced.

### Use of pesticides

Pesticides can reduce TNB populations inside sticktight nuts if coverage is thorough. We have tested pesticides in small trials, and endosulfan (Thiodan®) was found to reduce TNB levels by about 50% in sticktight nuts compared to the untreated control. This is probably not enough to justify its use alone, but it may be useful if other methods of reducing sticktight nuts (shaking or hand removal) are also used in areas planted with highly susceptible cultivars. Endosulfan application did not cause significant mortality to *Cathartus* that were present in the study.

In contrast to using pesticides for control of TNB inside sticktight nuts, pesticides can play a role in protecting nuts from damage. Our small trials showed endosulfan had good efficacy when treating recently fallen nuts. In our trial, nuts were collected from the tree, then treated with endosulfan and examined 5 and 8 weeks later. We found that there was no damage at 5 weeks and 5% kernel damage at 8 weeks in the endosulfan-treated plots, whereas the control plots had 24.5 and

Table 3.4. Average rate of damage across all cultivars tested, based on the assumption of uniform nut drop between harvest periods.

| Days since last harvest | Nut damage (%) | Days since last harvest | Nut damage (%) | Days since last harvest | Nut damage (%) | Days since last harvest | Nut damage (%) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 22 | 1.8 | 43 | 7.1 | 64 | 16.2 |
| 2 | 0 | 23 | 2.0 | 44 | 7.4 | 65 | 16.8 |
| 3 | 0 | 24 | 2.1 | 45 | 7.8 | 66 | 17.3 |
| 4 | 0.1 | 25 | 2.3 | 46 | 8.2 | 67 | 17.9 |
| 5 | 0.1 | 26 | 2.5 | 47 | 8.5 | 68 | 18.4 |
| 6 | 0.1 | 27 | 2.7 | 48 | 8.9 | 69 | 19.0 |
| 7 | 0.2 | 28 | 2.9 | 49 | 9.3 | 70 | 19.6 |
| 8 | 0.2 | 29 | 3.1 | 50 | 9.7 | 71 | 20.2 |
| 9 | 0.3 | 30 | 3.4 | 51 | 10.1 | 72 | 20.8 |
| 10 | 0.4 | 31 | 3.6 | 52 | 10.5 | 73 | 21.4 |
| 11 | 0.4 | 32 | 3.9 | 53 | 11.0 | 74 | 22.0 |
| 12 | 0.5 | 33 | 4.1 | 54 | 11.4 | 75 | 22.6 |
| 13 | 0.6 | 34 | 4.4 | 55 | 11.8 | 76 | 23.3 |
| 14 | 0.7 | 35 | 4.6 | 56 | 12.3 | 77 | 23.9 |
| 15 | 0.8 | 36 | 4.9 | 57 | 12.8 | 78 | 24.5 |
| 16 | 0.9 | 37 | 5.2 | 58 | 13.2 | 79 | 25.2 |
| 17 | 1.1 | 38 | 5.5 | 59 | 13.7 | 80 | 25.9 |
| 18 | 1.2 | 39 | 5.8 | 60 | 14.2 | 81 | 26.6 |
| 19 | 1.3 | 40 | 6.1 | 61 | 14.7 | 82 | 27.3 |
| 20 | 1.5 | 41 | 6.4 | 62 | 15.2 | 83 | 28.0 |
| 21 | 1.6 | 42 | 6.8 | 63 | 15.7 | 84 | 28.7 |

59.1% kernel damage. We normally find that kernel damage is about 3–4% 3 weeks after nuts fall, so the data suggest the residue of endosulfan would protect the nuts for about 5 weeks. If all nuts under a tree were harvested and endosulfan was applied to the trees, we expect that the damage level 8 weeks later would be similar to our damage of 5%. However, if thorough coverage is not obtained, the pesticide will have little effect on damage.

Regardless of the efficacy of endosulfan (or any other pesticide), we do not encourage growers to use this option unless damage is extreme and other options have been exhausted. The reasons include worker safety, difficulty in getting good coverage, environmental contamination, costs associated with application, and effect on nontarget insects and mites. The effect of the pesticides on nontarget insects and mites can be extreme. There are numerous other potential pests present in the orchards that are normally kept at low levels by various natural enemies (normally, other insects or mites). Pesticide applications frequently are highly toxic to these natural enemies, and their elimination can cause increased problems with these other pest insects. Thus, pesticide applications should be restricted to only the most serious outbreaks that cannot be reduced using other methods.

## New orchard management

Young orchards that have not yet set their first large crop can become infested with TNB. The nuts on these small trees should be removed to prevent them from becoming the source of TNB in other orchard blocks or for the first large crop. Nuts can be stripped off the trees by hand, or gibberellic acid, which inhibits flower formation, could be used if registration were obtained.

## Economics of pest control

Growers complain that frequent harvests are not a viable option for TNB management. At present, however, it is the only sure method we have of reducing TNB damage to acceptable levels. The predators discussed above may help alleviate some of the problems with TNB, but until this is proven, we have no single method of reducing problems other than frequent harvests.

To show the effect of frequent harvest, we present several different cases where the damage from our field tests is used to estimate the level of damage at different times after the nuts drop (Table 3.4). These were taken in areas with relatively high TNB population levels, so the numbers may be lower at other sites. Using the sampling methods above can help guide you in estimating the damage likely to occur in your area.

**Table 3.5. Economic analysis of harvest frequency and harvest costs.**

*Case 1.* Harvest duration 6 months, price WIS = $0.65, total yield/acre = 6500 lb, cost for 1 harvest = $150, total crop value = $4,225.
*Case 2.* Same parameters as Case 1, except total harvest time is 5 instead of 6 months.
*Case 3.* Same parameters as Case 1, except WIS price = $0.55.
*Case 4.* Same parameters as Case 1, except harvest cost = $250/acre.

| | No. of harvests | Days between harvests | TNB damage (%) | Cost of damage from TNB | Harvest cost | Total cost (harvest + damage) | Total cost WIS/lb (cents) |
|---|---|---|---|---|---|---|---|
| **Case 1** | 2 | 90 | 31.6 | $ 1,335.78 | $ 300 | $1,635.78 | 25.2 |
| | 3 | 60 | 13.9 | $ 588.53 | $ 450 | $1,038.53 | 16.0 |
| | 4 | 45 | 7.8 | $ 329.01 | $ 600 | $ 929.01 | 14.3 |
| | 5 | 36 | 5.0 | $ 209.56 | $ 750 | $ 959.56 | 14.8 |
| | 6 | 30 | 3.4 | $ 144.96 | $ 900 | $1,044.96 | 16.1 |
| **Case 2** | 2 | 75 | 21.9 | $ 924.00 | $ 300 | $1,224.00 | 18.8 |
| | 3 | 50 | 9.6 | $ 407.10 | $ 450 | $ 857.10 | 13.2 |
| | 4 | 37.5 | 5.4 | $ 227.58 | $ 600 | $ 827.58 | 12.7 |
| | 5 | 30 | 3.4 | $ 144.96 | $ 750 | $ 894.96 | 13.8 |
| | 6 | 25 | 2.4 | $ 100.27 | $ 900 | $1,000.27 | 15.4 |
| **Case 3** | 2 | 90 | 31.6 | $ 1,130.28 | $ 300 | $1,430.28 | 22.0 |
| | 3 | 60 | 13.9 | $ 497.99 | $ 450 | $ 947.99 | 14.6 |
| | 4 | 45 | 7.8 | $ 278.39 | $ 600 | $ 878.39 | 13.5 |
| | 5 | 36 | 5.0 | $ 177.32 | $ 750 | $ 927.32 | 14.3 |
| | 6 | 30 | 3.4 | $ 122.65 | $ 900 | $1,022.65 | 15.7 |
| **Case 4** | 2 | 90 | 31.6 | $ 1,335.78 | $ 500 | $1,835.78 | 28.2 |
| | 3 | 60 | 13.9 | $ 588.53 | $ 750 | $1,338.53 | 20.6 |
| | 4 | 45 | 7.8 | $ 329.01 | $ 1,000 | $1,329.01 | 20.4 |
| | 5 | 36 | 5.0 | $ 209.56 | $ 1,250 | $1,459.56 | 22.5 |
| | 6 | 30 | 3.4 | $ 144.96 | $ 1,500 | $1,644.96 | 25.3 |

### Case 1

This analysis assumes that the damage is equal to the average of all the cultivars we tested. The variables used for the various parameters are

Market value (WIS/lb) = $0.65
Yield WIS per tree = 65
Trees per acre = 100
Total yield per acre = 6500 lb WIS
Total value of the crop = 6500 x $0.65 = $4,225
Cost to harvest one time = $150
Total harvest period = 6 months.

Using the gain-threshold calculations discussed on page 8, the $150 management cost per harvest requires that 3.66% of the crop be saved from damage to break even. Using Table 3.4, you can see that 3.6% damage occurs 31 days after the last harvest. This would be the break-even point, and, practically, harvest intervals shorter than this are difficult to achieve. The question is whether harvesting every month would be the best economic solution.

A table can be set up to show the number of harvests, equivalent harvest intervals, cost of damage from TNB, harvest cost, and total cost of harvest and TNB damage. When this is done, it becomes obvious that the fewer the harvests, the lower the harvest cost, but the higher the TNB damage (Table 3.5). The important column is the total cost column, because it shows that in this situation, the optimal number of harvests is four, spaced 45 days apart. With fewer or more harvests, the total cost increases.

### Case 2

The same figures are used for everything except that the harvest period is reduced from 6 months to 5 months. Again, the optimal timing is for four harvests and the total cost is slightly less than when the harvest period is 6 months because less time is available for TNB damage to accumulate.

### Case 3

In this case, the value of the WIS price is decreased to $0.55/lb WIS, but all other parameters are as in Case 1. Notice that the total cost is still lowest when there are 4 harvests. The lower value of the crop results in lower costs associated with TNB damage and thus lower overall cost.

**Case 4**

In this case, all costs are the same as in Case 1, except the harvest cost is $250/acre. In this case, notice that the difference between three and four harvests is smaller than in Case 1, with only $9.52/acre separating the two strategies. This is because the harvest cost assumes a greater proportion of the total damage cost. If the nut value was reduced to $0.55/lb WIS, three rather than four harvests would be the best strategy.

The calculations above rely on the damage being similar between the different harvest times. However, if the damage changes throughout the season (it is generally worse late in the season) and if the percentage of the crop dropping over the harvest season varies dramatically, then the calculations are just rough approximations. However, if you know ahead of time that the majority of the crop for a particular area comes off early, harvest rounds could be concentrated at that time, and when only a small amount of the crop is on the ground later, the harvest frequency could be reduced. For precise calculations, the amount of the crop being harvested at any one time could be used to estimate the value of the crop on the ground, and then the damage levels differences could be used to determine the gain threshold for any point in time.

### General trends

Unfortunately, we cannot completely define a general rule for all operations. However, the general trends are

- The higher the value WIS and yield per tree, the greater the value of the crop (per acre) and hence a higher number of harvests can be justified because the damage from TNB costs more.
- The higher the number of trees per acre, the higher the value of the crop and a greater number of harvests becomes possible economically, provided the harvest cost is constant. This is where the benefit of using sweepers, whose speed is independent of the number of trees per acre, is an advantage over shakers or hand-harvesting, where speed of harvest is dependent on the number of trees per acre.
- The greater the harvest cost, the fewer the harvests that can be afforded for a given amount of TNB damage.
- The more resistant the cultivar to TNB damage, the lower the damage and the less likely it is that the additional harvests will be required.
- The shorter the total harvest period (within reason), the better the economics of frequent harvest.

The methods described above can be adapted to your particular harvest methods, the field, and the TNB damage level to determine the feasibility of more frequent harvest as a management option.

## Southern green stinkbug

***Nezara viridula*** **(Hemiptera: Pentatomidae)**

### History

The southern green stinkbug, *Nezara viridula*, was first found on Oahu in October 1961, and it spread to the other islands by 1963. From the start it was reported as a pest of macadamia. The damage varies dramatically depending on the cultivar and location (drier parts of the islands have the greatest damage). Reasons for this are not clear, but it may be that in the wetter areas of the islands weeds are more attractive to SGSB than the macadamia trees. In the drier areas, when the weeds dry up (or are mowed or treated with herbicide), the macadamia trees and nuts are the only attractive things left in the orchard. In addition, a macadamia cultivar grown in the wetter production areas tends to have a thicker shell than the same cultivar grown in a dry area and thus is more protected against SGSB.

### Life cycle and description

The eggs of SGSB are laid in batches, with 80 or more eggs per batch (these are called "egg masses"). The eggs are cream colored and barrel shaped with a height of 0.05 inch (1.3 mm) and a diameter of 0.03 inch (0.8 mm) (Fig. 3.9). The egg masses are glued to leaves or twigs, and the glue is considered to be important in attracting certain egg parasitoids. The eggs hatch in about 4–5 days at 80°F. The first immature stage tends to stay in the immediate vicinity of the egg mass and does not feed. This trend continues through the second instar, but older instars do not aggregate. There are a total of five immature stages, each distinguished from the others by a gradual shift in color (from black to green with white and red markings) and size (Fig. 3.9). The immature stages last a total of about 33 days at 80°F. The adult stage is solid green and about 0.5 inch (13 mm) long.

In addition to the green coloration of adults, when the insect enters diapause it sometimes takes on a brownish-red tint. Diapause is a hibernating stage to help the insect survive unfavorable conditions. In temperate areas, diapause is a method of surviving winters or a period of drought. In Hawaii, however, diapause in SGSB

**Figure 3.9. Different life stages of SGSB.**
Far left is egg mass, next 5 on left are immature stages (1st through 5th instar), far right is adult stage.

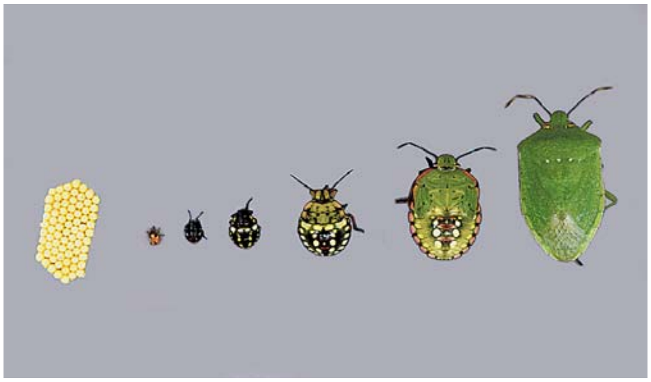


**Figure 3.10. SGSB showing different coloration.**
Center bug is normal color, those on left and right show "diapause" coloration.

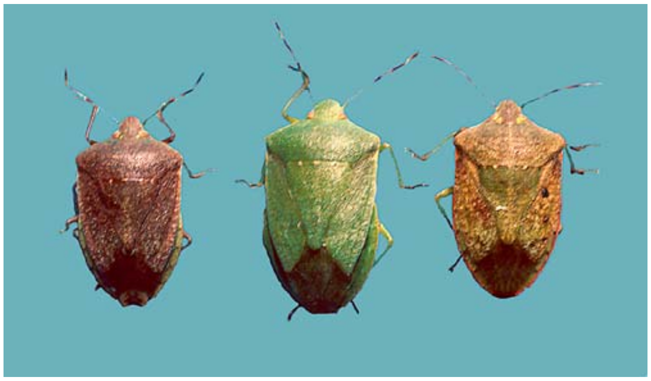


**Figure 3.11. Comparison of the tip of the female (left) and male (right)**

is limited to a reproductive diapause, and the bugs continue to move around and feed at a reduced rate. During this time, the bugs are not able to lay eggs and tend to seek protected spots (e.g., under leaves on the ground). Diapause is initiated by a combination of shorter daylength, lower temperature, and poor food quality. Our studies suggest that SGSB rarely undergoes diapause under the extremes of temperature and daylength naturally found in Hawaii's macadamia growing areas. However, if food quality is low, it is possible that they will enter diapause. Our studies and those in Australia show that the diapause coloration (Fig. 3.10) is not a good predictor of diapause—many of the insects showing this coloration still have completely mature ovaries and are still able to lay eggs.

The bugs require 14–24 days after reaching the adult stage before they mate and begin to lay eggs. The total female egg production averages about three to four egg masses with an average of 71 eggs per mass. Adult longevity can exceed 2 months, but egg production is mostly complete by 30 days.

Adult SGSB can be sexed by examining the lower surface near the tip of the abdomen. The tip of the female's abdomen is relatively flat (Fig. 3.11, left), while the tip of the males have claspers that give it a forked appearance (Fig. 3.11, right).

### Life history in macadamia orchards

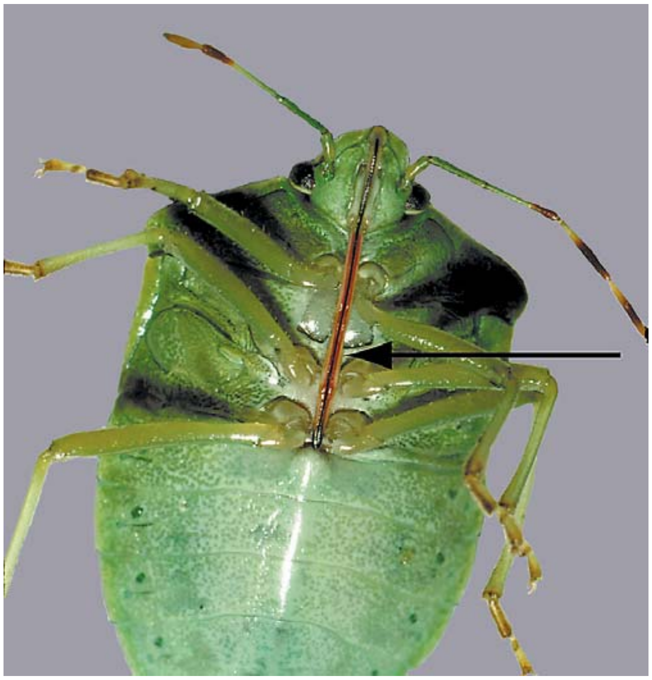
Southern green stinkbug cannot develop on macadamia alone. Our studies clearly show that when given a diet of macadamia alone (whether shelled, in husk, large, or small), SGSB immatures experience 100% mortality in the early stages, and greater than 85% mortality in the last stage before adulthood. In addition, only 42% of females fed the standard lab diet as immatures and macadamia alone after reaching the adult stage produced any eggs, while all the females fed the standard peanut and green bean diet laid eggs. The females reared on macadamia alone that laid eggs also laid an average of 80% fewer eggs than those reared on the standard diet. These data show that SGSB requires alternate host plants to complete development, and several of the weeds in the orchard support survival and reproduction as well as does a standard laboratory diet .

Although adult SGSB can be found in macadamia trees, all stages are more commonly found in weeds within the orchard or at the orchard borders. In the past, recommendations were to plant *Crotolaria* around the border of the orchard so parasitoids of SGSB could control them and to keep the bugs outside the orchard. SGSB marked by Wally Mitchell and his University of Hawaii

## Table 3.6. Host plants for southern green stinkbug found in Hawaii.

| Plant family | Scientific name | Common names |
|---|---|---|
| Acanthaceae | *Asystasia gangetica* | Chinese violet |
| Amaranthaceae | *Amaranthus spinosus* | spiney amaranth |
| Amaranthaceae | *Amaranthus* spp. | amaranth |
| Anacardiaceae | *Mangifera indica* | 'Haden' mango |
| Anacardiaceae | *Schinus terebinthifolius* | christmas berry, pepperberry |
| Asteraceae | *Acanthospermum hispidum* | starbur |
| Asteraceae | *Sonchus oleraceous* | sonchus |
| Brassicaceae | *Brassica nigra* | mustard |
| Brassicaceae | *Brassica oleracea* | collard |
| Brassicaceae | *Brassica oleracea* | cauliflower |
| Brassicaceae | *Brassica oleracea* | cabbage |
| Brassicaceae | *Brassica oleracea* | brussels sprouts |
| Brassicaceae | *Brassica rapa* | turnip |
| Brassicaceae | *Lepidium virginicum* | pepperweed or peppergrass |
| Brassicaceae | *Raphanus sativas* | wild radish |
| Brassicaceae | *Nasturtium officinale* | watercress |
| Capparaceae | *Cleome gynandra* | cat wiskers, wild spider flower |
| Commelinaceae | *Commelina diffusa* | honohono |
| Convolvulaceae | *Ipomoea batatas* | sweetpotato |
| Curcurbitaceae | *Sechium edule* | chayote, vegetable pear, pipinella, |
| Curcurbitaceae | *Cucumis sativas* | cucumber |
| Curcurbitaceae | *Curcurbita* sp. | Japanese pumpkin |
| Cyperaceae | *Cyperus esculentus* | nutgrass |
| Euphorbiaceae | *Ricinus communis* | castor oil, castor bean |
| Fabaceae | *Canavalia cathartica* | maunaloa |
| Fabaceae | *Senna occidentalis* | coffee senna, coffeeweed |
| Fabaceae | *Crotalaria lanceolata* | lanceleaf crotalaria |
| Fabaceae | *Crotalaria pallida* | smooth rattle pod |
| Fabaceae | *Crotalaria spectabilis* | showy crotalaria |
| Fabaceae | *Crotalaria incana* | fuzzy rattle pod |
| Fabaceae | *Desmodium tortuosum* | beggarweed |
| Fabaceae | *Glycine max* | soybean |
| Fabaceae | *Glycine wightii* | wild soybean |
| Fabaceae | *Macroptilium lathyroides* | cow pea, phasey bean |
| Fabaceae | *Medicago sativa* | alfalfa |
| Fabaceae | *Melitotus indica* | green manure, bee plant |
| Fabaceae | *Melitotus indica* | green manure, bee plant |
| Fabaceae | *Phaseolus vulgaris* | green bean |
| Fabaceae | *Pueraria lobata* | kudzu, kudzu vine |
| Fabaceae | *Trifolium repens* | clover |
| Fabaceae | *Phaseolus limensis* | lima bean, butterbean |
| Fabaceae | *Pisum sativum* | garden pea |
| Fabaceae | *Vigna sesquipedalis* | yard-long bean |
| Fabaceae | *Vigna sinensis* ? | cowpea |
| Fabaceae | *Clitoria ternatea* | butterfly pea |
| Lamiaceae | *Leonurus sibiricus* | Siberian motherwort |
| Malvaceae | *Abelmoschus esculentus* | okra, gumbo |
| Malvaceae | *Abutilon grandifolium* | hairy abutilon |
| Malvaceae | *Gossypium barbadense* | cotton |
| Malvaceae | *Malva parviflora* | cheeseweed, marshmallow weed |
| Malvaceae | *Gossypium hirsutum* | cotton |
| Passifloraceae | *Passiflora incarinata* | passion flower, maypops, apricot vine |
| Poaceae | *Saccharum officinarum* | sugarcane |
| Poaceae | *Sorghum bicolor* | sorghum, great millet |
| Poaceae | *Zea mays* | corn |
| Poaceae | *Oryza sativa* | rice |
| Polygonaceae | *Rumex* sp. | sorrel |
| Proteaceae | *Macadamia integrefolia* | macadamia |
| Rosaceae | *Prunus persica* | peach |
| Rosaceae | *Rubus fruticosus* | wild blackberry |
| Rubiaceae | *Richardia brasiliensis* | Mexican clover |
| Rutaceae | *Citrus limon* | lemon |
| Rutaceae | *Citrus sinensis* | orange |
| Rutaceae | *Citrus* x *paradisi* | grapefruit |
| Solanaceae | *Solanum tuberosum* | potato |
| Solanaceae | *Capsicum annuum* | pepper |
| Solanaceae | *Datura stromonium* | thornapple |
| Solanaceae | *Lycopersicon esculentum* | tomato |
| Solanaceae | *Nicotiana tabacum* | tobacco |
| Solanaceae | *Solanum melongena* | eggplant |
| Solanaceae | *Solanum nigrum* | black nightshade, popolo |
| Tiliaceae | *Tilia* sp. | lime |

**Figure 3.12. The mouthparts of SGSB are similar to a hollow needle.**



co-workers tended to be found in the border weeds for several consecutive weeks. Thus they believed that the bugs in the border *Crotolaria* were not moving into the orchard. However, this does not take into account that the bugs may move around at night, and thus they might be moving into the orchard and feeding there. Research has shown that feeding occurs primarily at night, and that as the weeds dry up, SGSB adults migrate into the orchard. This means that leaving the orchard borders untreated or encouraging orchard borders can lead to greater damage.

### Alternate hosts

SGSB has a very broad host list, including many common weeds in macadamia orchards (Table 3.6). The most common hosts are *Desmodium* spp. (beggarweed), *Crotolaria* (rattlepod), *Amaranthus* spp. (spiny amaranth), and several other legumes (beans and relatives). The insects develop on these weeds and supplement their diet by casually feeding on macadamia when their host plants are destroyed, such as when mowing occurs in the orchard. Studies performed in other laboratories show that SGSB reproduction increases dramatically when the host plant sets seeds or pods.

**Figure 3.13. Damage to a macadamia nut by SGSB feeding.**

### Damage

The SGSB mouthpart is similar to a hollow needle (Fig. 3.12). The mouthpart is inserted into the nut, and saliva is injected into the kernel. The saliva turns the area around the tip of the mouthpart into a liquid, and the bug sucks this up. This is the cause of the typical pit associated with SGSB feeding (Fig. 3.13). Because the bug's mouthpart is only so long, the thickness of the shell and husk affect its ability to feed on the kernel and inflict damage. A thicker shell and husk mean that the younger stages of the SGSB are not able to reach the kernel and inflict damage. Table 3.7 shows the maximum, minimum, and average mouthpart length of the different stages of SGSB. Preliminary observations indicate that all cultivars tested so far are susceptible to adult SGSB based on their mouthpart length. However, the younger stages are not able to harm full size, mature nuts unless the husk splits.

Damage from SGSB is both direct and indirect. The direct damage is visible as pits on the surface of the nut, and the indirect damage is a result of the insect mechanically introducing mold and fungi into the kernel by the act of feeding. When this occurs, the entire nut may develop mold that completely obscures the pit caused by feeding. This is important because misclassification of damage means that the actual extent of the bug damage is unknown, and management practices to reduce the incidence of mold are doomed to failure if the bug is not controlled. To determine the extent of misidentification

**Table 3.7. Lengths of southern green stinkbug mouthparts.**

| | Length in inches (mm) | | |
|---|---|---|---|
| **Instar** | **Minimum** | **Maximum** | **Average** |
| 1st | 0.030 (0.75) | 0.035 (0.88) | 0.033 (0.83) |
| 2nd | 0.057 (1.45) | 0.069 (1.74) | 0.063 (1.59) |
| 3rd | 0.090 (2.29) | 0.108 (2.75) | 0.098 (2.48) |
| 4th | 0.129 (3.28) | 0.154 (3.92) | 0.142 (3.60) |
| 5th | 0.185 (4.69) | 0.207 (5.25) | 0.197 (5.00) |
| Adult | 0.224 (5.69) | 0.258 (6.56) | 0.241 (6.12) |

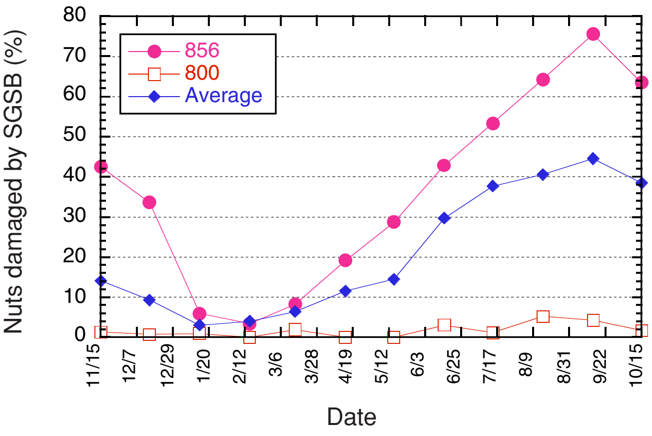
of damage, we collected from processors reject nuts that were classified as moldy nuts, put them into a bleach solution to kill the mold, and then looked for SGSB damage. Over the 4-month period of the study, 25% of the nuts were damaged by SGSB. The 25% damage figure is conservative because the mold eats away at the nut, obscuring smaller feeding punctures.

## Time and location of damage

Studies performed over the last few years have demonstrated that SGSB damage occurs primarily while the nuts are on the ground. Feeding on small nuts (less than 1.1 inches diameter) in the canopy causes abortion, but full size nuts do not drop when they are fed upon. Studies showed that damage occurs on the ground very quickly (within 1 week of nut drop), and green nuts are strongly preferred over those that have dried.

The damage caused by SGSB varies with the time of year as well as the cultivar. For example, at the Kona Research Station we found that cultivar 856 showed the greatest variation over the year, from a low of approximately 6% in February 1990 to a peak of approximately 76% in September 1990 (Fig. 3.14). Cultivar 800 had a rather flat response over the year, with the high and low being separated by less than 4%. The average damage across all cultivars varied considerably, with peak damage occurring in the fall and minimum damage occurring in the winter months (Fig. 3.14).

**Figure 3.14. Seasonal damage trend for southern green stinkbug at the Kona Research Station.** Relative to the average for the seven cultivars observed, cv. 856 had the highest damage and cv. 800 had the lowest damage.



## Monitoring

SGSB is one of the most difficult pests to monitor on a regular basis. Damage cannot be accurately estimated without husking, drying, and cracking the nut. Adults tend to be active a few hours before dusk, during the night, and a few hours after dawn (they often appear to be basking in the sun early in the morning at the top of their host plants). For most of the day, they are down in the deepest part of the vegetation and are difficult to find. The immatures are less mobile than the adults and can sometimes be found on host weeds during the day. Our studies in macadamia found them most often on spiny amaranth (pigweed), Spanish needle, and fuzzy rattlepod. Other host plants on which they were present at different times of the year were castor bean and wild glycine.

Because of the difficulty of directly detecting SGSB, sampling is rarely done except through using processor damage estimates. This is generally unacceptable for dealing with SGSB problems, because by the time the grower receives the estimate it is too late in the season to address the problem. However, this information can be used for small orchards (where the data represents a good cross-section of the orchard) or large orchards if the different sections of the orchard are harvested sepa-

**Table 3.8. Relative susceptibility of macadamia cultivars to SGSB damage in Hawaii.**
Cultivars are in approximately the order from most resistant (top) to the most susceptible (bottom).

| Cultivar | HAES no. | Relative susceptibility | Shell thickness | Husk thickness | Husk split |
|---|---|---|---|---|---|
| Makai | 800 | low | thick | thin | yes |
| Ikaika | 333 | low | thick | thick | no |
| Purvis | 294 | low | thin | thin | yes |
| Pahala | 788 | intermediate | thin | intermediate | yes |
| Mauka | 741 | intermediate | thin | intermediate | yes |
| Kau | 344 | intermediate | intermediate | thin | yes |
| Keauhou | 246 | intermediate | thick | thick | yes |
| Kakea* | 508 | intermediate | intermediate | thick | yes |
| —* | 835 | intermediate | intermediate | ? | yes (low) |
| —* | A16 | intermediate | thick/thin variable | thin | yes |
| — | 856 | high | thick | ? | yes |
| — | 816 | high | thin | ? | ? |
| Keaau* | 660 | high | thin | intermediate | yes |
| —* | A4 | high | thin | intermediate | yes |

*Not tested directly; based on shell thickness, tendency of husk to split.

rately and the data are received separately for the different sections. The data should be used to determine the damage in the different areas, and for heavily damaged areas the weeds present should be checked against the undamaged areas. The weeds mentioned above (spiny amaranth, Spanish needle, fuzzy rattlepod, castor bean and wild glycine) should be checked for SGSB on a regular basis in those areas. Areas that historically have greater damage should receive more attention for management activities.

## Cultivar susceptibility

Cultivar susceptibility to SGSB is a combination of the husk and shell thickness, the tendency of the husk to split, and the stage of the insect feeding on the nut (Table 3.8). Early stages of SGSB have shorter mouthparts and are less likely to be able to completely penetrate through the husk and shell to damage the kernel. When the nuts are small, however, virtually all stages are able to penetrate and feed on the developing kernel. Our studies showed that when the insects were given a choice of size and color, the largest and greenest nuts were preferred. This probably gives some protection to small nuts in the tree when full size nuts are available.

## Management strategies

The most important aspects of SGSB biology from a management perspective are the following:

- Macadamia nuts alone cannot support SGSB development, and weeds are required for SGSB reproduction.
- Sixty-five species of weeds present in Hawaii are recorded hosts (Table 3.6).
- Damage occurs primarily to nuts on the ground within 1 week of nut drop.
- Ants can destroy virtually all the egg masses found, but the species of ant spresent in the orchard is critical—some are good predators, some are not.
- Feeding by SGSB is often misidentified as moldy nuts by the processor.
- Mass destruction of the weed hosts by mowing may cause the bugs to move to adjacent unmowed areas and increase damage there.

For small farms, several management alternatives are possible. First, remove all weed hosts from around the border and within the orchard. This reduces the weedy hosts needed for SGSB reproduction. This should be done in the off-season when no or few full size nuts are present. Planting a ground cover is good, but avoid legumes or any broadleaf plant that harbors either SGSB or koa seedworm. Generally, grasses are not hosts for any of the major pests of macadamia and would be a safe bet. Secondly, if it is not possible to remove weed hosts, prevent them from setting pods by using herbicides or mowing before they set. This is important, because SGSB population levels increase dramatically once the weeds set seed. Third, our studies showed that stinkbugs do not seem to move to adjacent areas when weeds are controlled with herbicide instead of mowing. This is probably because the plants take 3 to 4 weeks to die, and so the movement of pests is more gradual. Finally, do not control ants in the orchard.

Figure 3.15. *Trissolcus basalis* on SGSB eggs.
Photo courtesy of Tracy Johnson.

Figure 3.16. *Trichopoda pennipes* adult.

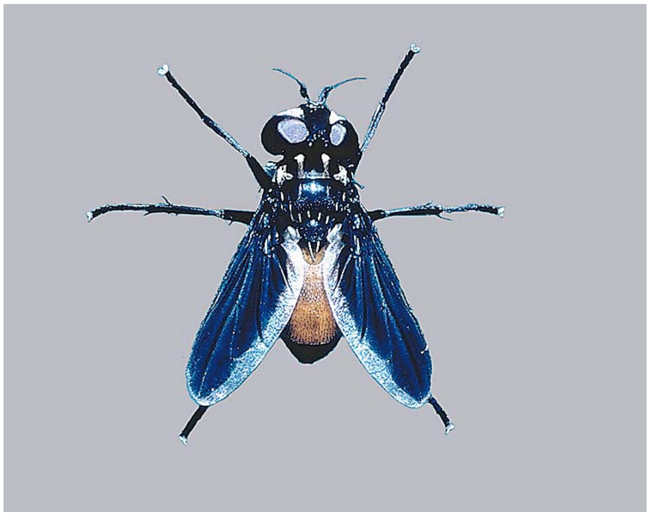


Figure 3.17. SGSB adult with *Trichopoda* eggs.

Figure 3.18. Bigheaded ants feeding on SGSB egg mass.

For large farms, it is critical to know the areas that historically have had the highest stinkbug damage and the cultivar mix in the different blocks within the orchard. Areas with thin shelled cultivars should be considered "high-risk areas" and should be placed into a high-maintenance weed management program that concentrates on prevention of seed set and, if possible, replacement of weed hosts with nonhost plants. If you have a severe problem and want to treat with pesticides, make sure that you treat both the tree and the ground, because most of the bugs are on the ground. Also, the SGSB present in the orchard are probably localized, and you may find that only a small portion of the orchard has SGSB damage and needs to be treated.

### Natural enemies

Biological control of SGSB by an introduced egg parasitoid (*Trissolcus basalis*) (Fig. 3.15) and an adult parasitoid (*Trichopoda pennipes*) (Fig. 3.16, 3.17) has been considered by some to be a landmark success for biological control. However, our studies over a 5-year period suggest that neither of these two species is important in population regulation, at least at the population levels found currently in macadamia orchards. In our studies we found that SGSB egg parasitism was only 2.8% over a 15-month period and less than 8% in two other years. However, it is possible that either or both of these species may act as a stabilizing factor during years of extremely high SGSB population levels.

In our studies, mortality of the egg stages came primarily from ant predation (Fig. 3.18). Bigheaded ant (*Pheidole megacephala*) has been shown to be extremely effective, and mortality rates in one of our plots averaged over 87% for a 15-month period. Other species of ants are also important and affect SGSB population levels in the orchard. We have found 15 ant species on the trunks of macadamia, but only a few species were common in any one orchard. The other species that we have seen affect SGSB include the longlegged ant (*Anoplolepis longipes*), *Monomorium floricola*, *Cardiocondyla wroughtoni*, and *Plagiolepis alluaudi*.

Recent studies have shown that the longlegged ant rarely feeds on SGSB eggs or young SGSB nymphs. When longlegged ants come in contact with young nymphs, the ants move quickly away and do not re-enter the area. Older SGSB nymphs and the adults are occasionally attacked but rarely subdued. Our studies also showed that SGSB damage is generally lowest in areas dominated by longlegged ant. This is probably because other species of ants (such as *M. floricola* and *P. alluaudi*) can co-exist with the longlegged ant.

In contrast to the longlegged ant, the bigheaded ants attack and kill all stages of SGSB. Young nymphs are generally picked up by a single ant and carried into the nest, while older stages are either torn apart or carried to the nest by large numbers of workers. Unfortunately, our studies also showed that areas dominated by bigheaded ants often have more SGSB-damaged nuts. We are currently investigating whether this is caused by exclusion of other ants and natural enemies or because the density of bigheaded ants in an area is generally low enough that discovery of SGSB before feeding is less likely.

*Trichopoda* was considered to be effective, but its tendency to lay large numbers of eggs on a single SGSB adult (Fig. 3.17) when only one can complete development make it a very inefficient parasitoid. In addition, the parasitized SGSB females are still able to reproduce. Although there are reductions in numbers of eggs produced, this is caused by the earlier mortality of parasitized females. Therefore, it is the late reproduction that is eliminated. Unfortunately, reproduction late in the female's life has the least effect on population growth, suggesting that *Trichopoda* is less effective than previously believed.

### Chemical control

Malathion is the only pesticide currently available for control of SGSB. However, while we know the time of year when the greatest kernel damage on nuts collected from the ground is found, we do not know when the damage occurs (i.e., damaged nuts may just stay on the trees). We know that significant damage occurs on the ground after the nuts fall (approximately a three-fold increase over damage found on nuts in the canopy). If pesticides are used, they should target both the trees and the vegetation on the ground. When using both thiodan and malathion, we have noted that ant predation on egg masses is reduced significantly.

## Koa seedworm

***Cryptophlebia illepida*** **(Lepidoptera: Tortricidae)**

## Litchi fruit moth

***Cryptophlebia ombrodelta***

The koa seedworm (KSW), *C. illepida* (Butler), and the litchi fruit moth (LFM), *C. ombrodelta* (Lower), have similar life history traits, cause the same sort of damage, share many of the same host plants, and occur together in all the macadamia growing areas in Hawaii. In studies over the past 10 years on macadamia, KSW typically is about 4–5 fold more common than LFM. Because of this, and the fact that it is difficult to tell the immature stages apart, this text generally will refer to the two of them as if they were one species by referring to them collectively as KSW. Where there are differences, the two pests will be discussed separately.

### History

Koa seedworm is a native Hawaiian insect. It was recorded feeding on macadamia nuts as early as 1919. The litchi fruit moth is a native Australian insect that probably was introduced into Hawaii from Guam in the 1950s. The first specimens were collected in 1958 on Oahu, and LFM is presently found in all macadamia production areas. In Australia, LFM is also known as the macadamia nut borer and is one of the most serious pests of Australian macadamia production.

**Figure 3.19. Life stages of the koa seedworm.** Top photo, two KSW eggs side by side. Middle photo, KSW larva in macnut husk. Bottom photo, KSW adult female.

**Table 3.9. Maximum number of generations per year at various sites in Hawaii based on temperature accumulations.**

| Location | Average number of generations per year* | Variation in number/yr of generations over 5-yr period |
|---|---|---|
| **HAWAII** | | |
| Hilo | 10.0 | 0.6 |
| Kainaliu | 8.4 | 0.2 |
| Ookala | 9.6 | 0.4 |
| Opihihale | 8.5 | 0.2 |
| HI Volcanoes Nat. Park | 4.8 | 0.5 |
| **MAUI** | | |
| Kahalui | 10.4 | 0.8 |
| Kula Res. Sta. | 5.8 | 0.4 |
| Hana | 9.9 | 0.5 |
| **KAUAI** | | |
| Kilauea | 9.4 | 0.5 |
| **OAHU** | | |
| Waimanalo | 10.5 | 0.6 |

*Calculated using a 50.4°F (10.2°C) lower threshold for development, a 78.6°F (25.9°C) horizontal upper threshold, and a total of 865 DD°F (481 DD°C) for egg–egg developmental time.

## Life history

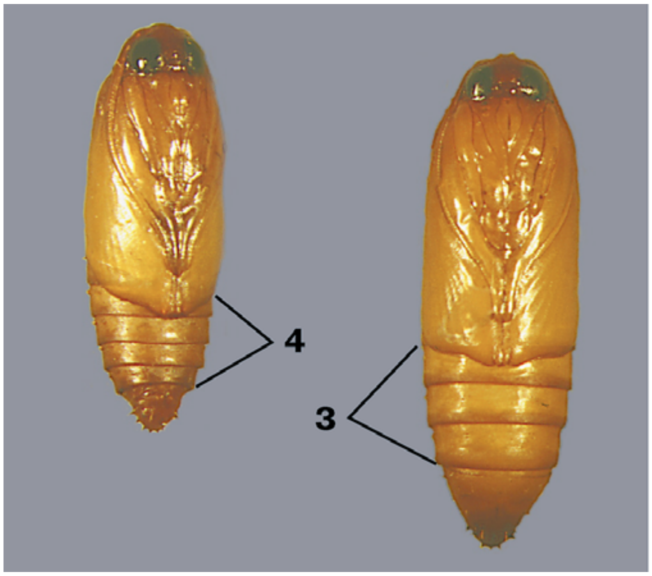
The koa seedworm has four distinct life stages: the egg, five larval (caterpillar) stages, a pupal (resting) stage, and the free-living adult moth (Fig. 3.19, 3.20). Eggs are flattened and 0.03 inch (0.8 mm) in diameter. They are finely reticulate and glued to the surface of the nut. Green fruit in the tree is the primary site of oviposition; eggs are not laid on nuts already on the ground and are only rarely laid on leaves. Studies have shown that adult females rarely laid eggs on nuts smaller than 0.8 inch (20 mm) in diameter. In addition, the larger the nut, the greater the likelihood that a female will choose it for egg laying. Once the egg hatches, the first instar larva chews into the husk. The larva continues to feed in the husk throughout the remaining stages. When fully grown, KSW larvae are about 0.5 inch (13 mm) long. The last instar larva spins a cocoon (of silk with fecal pellets and partially chewed macadamia nut husk) and pupates within the husk. The pupa is about 0.38–0.5 inch (9.5–12.5 mm) long, torpedo shaped, and dark brown. The adult moth emerges, mates, and begins the cycle again.

The entire life cycle of KSW takes about 33 days under a constant 77°F (25°C) temperature, with the egg, larval, and pupal stages lasting an average of 4, 19.4, and 10 days, respectively. Using heat unit accumulations from various sites around the state and laboratory developmental data, we find that on average there are enough heat units accumulated for 8–11 generations per year (Table 3.9). The developmental rate of LFM is about 18% slower than KSW, taking 38 days at 77°F.

The number of KSW and LFM males caught in monitoring traps is related to female egg deposition, except during the fall. In several orchards over a 2-year period, high numbers of KSW and LFM males were found but almost no egg deposition. This suggests that KSW and LFM females are migrating between differ-

**Figure 3.20. Difference between male (left) and female (right) pupae of KSW and LFM.**

Major difference is the number of moveable segments between the wings and the terminal segement of the abdomen.



ent crops. This migration pattern has been reported before in Hawaii and Australia. Both species have 18 or more host plants, some of which are common ornamentals or legume weeds (see *Alternate host plants*, below). In most crops, there probably are not a large number of generations per year, because the fruit are attractive to females for only a short period of time. However, on macadamia, the extended flowering period results in nuts of all sizes being present all year round, and from 8 to 11 generations per year are possible depending on location and temperature.

### Identification

The adult KSW is bronze with light markings on the abdomen and legs (Fig. 3.19). The female KSW is larger than the male and lacks a distinct triangle near the base of the forewing. LFM is larger than KSW and has similar coloration but has a distinct dark triangle near the base of the forewing. Males of the two species can be distinguished by the presence of a large, shiny, dark spot and long blue-purple scales on the inner margin of the hind tibia (Fig. 3.21). LFM have the shiny spot and the colored scales, while KSW males lack the spot and their scales are white. These identifying features work only for the males and are particularly important for separating the two species in pheromone traps because they both respond to the same lure. In addition to the characters mentioned above, the female and male KSW vary dramatically in size. Until you are familiar with the two species, use the hind leg to aid identification.

**Figure 3.21. Hind legs of male LFM (left) and KSW (right).**

Large dark spot (left) is the distinguishing character.

Larvae of the two species are very similar and difficult to separate without a high-power microscope. Size alone cannot be used to differentiate them because even though LFM larvae are generally larger, both species have five larval instars that differ in size. Thus unless you are positive that you have the same age larvae, size alone is not a good indicator.

The pupal stage offers the first chance to separate the two sexes. The major differences are that males have four abdominal segments between the wings and the last (fused) segment while females have three segments (Fig. 3.20), and female pupae are larger. In addition, the males have two pronounced bumps on the bottom (ventral) side on either side of the genital pore, whereas females lack them. The differences between sexes hold true for both KSW and LFM.

### Alternate host plants

The two species have several host plants in common (Table 3.10). Table 3.10 is a conservatively low estimate of the host list for both species, because it is taken solely from literature sources, and little work on the hosts of either species has been conducted in Hawaii. For example, the different species of *Cassia* may all be hosts for KSW, but they have not been examined. Likewise, some of the *Acacia* spp. are probably hosts of LFM. From

**Table 3.10. Host list of koa seedworm and litchi fruit moth in Hawaii.**

| Host plant | Common name | KSW | LFM |
|---|---|---|---|
| *Acacia arabica* (=*nilotica*) | babul | | X |
| *Acacia confusa* | Formosa koa | X | |
| *Acacia farnesiana* | klu, cassie, kolū, aroma popinac | X | X |
| *Acacia koaia* | koai‘e or koai‘a | X | |
| *Acaia koa* | koa | X | |
| *Adenanthera pavonina* | false wiliwili, hua-‘ula‘ula | | X |
| *Aegle* spp. *(marmelos?)* | bael fruit tree | | X |
| *Alectryon macrococcum* | māhoe | X | |
| *Bauhinia variegata* | orchid tree | | X |
| *Cassia glauca* | kolomona, kalamona | X | |
| *Cassia javanica* x *Cassia fistula* | rainbow shower tree | | X |
| *Cassia occidentalis* | coffee weed, mikipalaoa | | X |
| *Cassia tora* | foetid cassia, habucha | | X |
| *Citrus sinensis* | orange | | X |
| *Coccolobis uvifera* | sea grape | | X |
| *Cocos nucifer* | coconut | | X |
| *Cupaniopsis anacardioides* | tuckeroo | | X |
| *Dodonea viscosa* | ‘a‘ali‘i | X | |
| *Euphoria longan* | longan, dragon’s eye | | X |
| *Filicium decipiens* | fern tree | | X |
| *Indigofera suffruticosa* | indigo, ‘iniko, ‘inikoa, kolu | | X |
| *Inga edulis* | inga | X | |
| *Litchi chinensis* | litchi, lychee | X | X |
| *Macadamia integrifolia*, *M. tetraphylla* | macadamia | X | X |
| *Mangifera indica* | mango | X | |
| *Mezoneuron kavaiense* | uhihui | X | |
| *Parkinsonia* (*aculeata*?) | Jerusalem thorn, Mexican palo verde, ratama | | X |
| *Phaseolus limensis* | lima bean | | X |
| *Phaseolus vulgaris* | garden bean | X | X |
| *Pithecolobium dulce* | Manila tamarind, opiuma | X | X |
| *Poinciana pulcherrima* | pride of Barbados, dwarf poinciana, ‘ōhai-ali‘i | | X |
| *Poinciana regia* | royal poinciana | | X |
| *Prospis pallida* | kiawe, mesquite | | X |
| *Samanea saman* | monkey pod | | X |
| *Sapindus oahuensis* | āulu, kaulu, lonomea | X | |
| *Sapindus saponaria* | soapberry, mānele, a‘e | X | X |
| *Schotia brachypetala* | schotia | | X |
| *Sesbania grandiflora* | sesban, ‘ōhai-ke‘oke‘o | | X |
| *Tamarindus* (*indica*?) | tamarind, wi’awa‘awa | | X |

the economic perspective, the major hosts are macadamia, litchi, longan, mango, beans, and koa. Several of the species on the list, such as coconut, may be casual hosts, or hosts on which eggs can be found, but mortality occurs at a high enough rate to render them important only for quarantine purposes.

## Damage

Koa seedworm is rarely found damaging the macadamia kernel, but it is commonly found in the husk (Fig. 3.19). Kernel damage (Fig. 3.22) is rare because the caterpillar is not able to penetrate a hardened shell. Holes in the shell from KSW occur when the caterpillar penetrates the unhardened shell early in nut development. However, this occurs infrequently because KSW females rarely lay eggs on nuts smaller than 0.8 inch (20 mm) diameter, and nuts larger than 1.1 inch (28 mm) in diameter typically have hardened shells. The length of time it takes a nut to grow from 0.8 to 1.1 inch diameter is about 6 weeks. Because the insect cannot develop

Figure 3.22. KSW damage to kernels.

instantaneously, the period of time that the kernel is susceptible to damage is even shorter than 6 weeks.

Damage by KSW is primarily indirect. Nuts fed upon by KSW fall within a few weeks. If the nuts are fairly small, they are unlikely to be picked up, and thus the damage is not noticed or recorded by the grower or processor. If the nuts are full size but have not reached full oil content (it takes 2 to 3 months from full size to nut maturity), then the nuts are picked up and when processed are counted as "immature" nuts. The damage from KSW is thus important from the time nuts are 0.8 inch diameter until probably about the end of September, when most of the crop is mature.

The correlation of husk damage and kernel immaturity is greatest when the level of *Cryptophlebia* damage exceeds about 20%. Below 20% damage, the rather high natural drop rate "swamps out" the nut drop caused by *Cryptophlebia* feeding.

Although *Cryptophlebia* females do not lay eggs on smaller nuts, it does not mean that smaller nuts may not be attacked. Extremely small nutlets (about 0.2 inch) with *Cryptophlebia* larvae present are occasionally seen, but it is quite rare. Eggs laid in other locations may hatch and the larva may crawl a short distance and so damage small nuts. However, for purposes of protecting the crop, nut damage from *Cryptophlebia* before 0.8 inch diameter is insignificant in Hawaii macadamia orchards.

## Monitoring

Because of the problems with KSW causing premature abscission, sampling plans have been developed for areas where high levels of damage occur. For the sampling to be useful, it should be simple and fast, it should accurately predict damage, and the damage estimates should be reproducible. We have used a number of sampling programs over the years, and the advantages and disadvantages of each are discussed below.

### Adult sampling

The adults of both KSW and LFM are attracted to the commercially available oriental fruit moth sex pheromone. A sex pheromone is a chemical released by females to attract males. The pheromones are a long-range attractant and probably function for up to 200 yards (183 m) or more. The pheromone is fairly specific and generally only affects a few closely related species. This means that when we place the pheromone dispenser in a trap with a sticky bottom, we do not have large numbers of other insects that we must sort through to get an indication of KSW and LFM population levels. This trapping system is useful because it is cheap, specific to KSW and LFM, and easy to use and maintain. However, the drawback is that it only measures the population levels of the males, which do not lay eggs or directly damage the nuts in any way. Instead, these traps rely on an implied relationship between the abundance of males and egg-laying females, which we hope is also related in some way to the crop damage. Several studies indicate that trap catch and the number of eggs per nut showed similar trends early in the year, but not from August to December (Fig. 3.23). In fact, during the fall, male moth catches increased while the number of eggs per nut remained at low levels. This same trend was found at another site during the same year, and at the same two sites in a second year. Clearly, pheromone traps are excellent indicators of whether KSW is present but cannot easily predict damage or egg laying.

### Distribution of eggs and damage in the canopy

Direct samples of nuts can also be taken. However, before a sampling protocol can be developed, the location of damage and egg laying in the tree canopy needs to be determined. We sampled a block of mature macadamia trees (cv. 246) that were approximately 20 feet tall by selecting 25 nuts from between 6–8, 12–14, and 16–18 feet high in the canopy on each of 10 trees (i.e., a total of 250 nuts per height). Both eggs and larval damage were highest in the lower two levels (Fig. 3.24). This

**Figure 3.23. Relationship between male moths per trap-night and mean number of eggs per nut at the Kona Research Station from 11/89 to 12/90.**

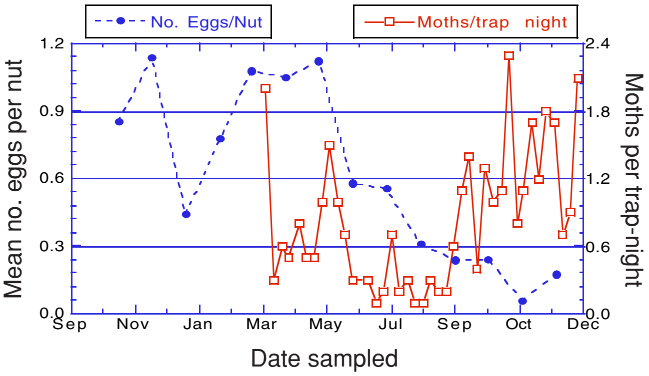
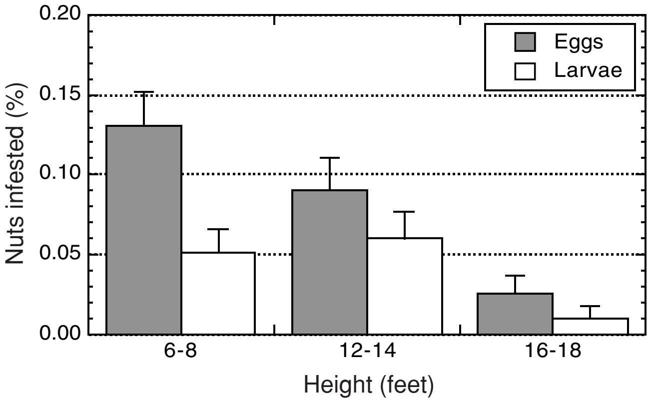


**Figure 3.24. Distribution of eggs and larvae of *Cryptophlebia* spp. in 20-ft tall macadamia trees.** Error bars are 95% confidence intervals.



means that samples taken from the lower level will not underestimate the damage in the rest of the tree. The lower numbers of eggs and levels of damage at the top of the tree are probably not going to bias the estimate of the overall damage because few nuts are found there.

Egg sampling is possible, but a large number of eggs do not hatch, and first instar larvae are often unable to penetrate the husk. In addition, larval damage is much easier to see, which speeds nut evaluation.

### Sampling larvae and damage

Sequential sampling plans for KSW damage use thresholds to determine if the damage is above 20% or below 12% (Table 3.11). If KSW damage is above 20%, then the KSW damage will greatly magnify the percentage of nuts that are immature. If the damage is less than 12%, the damage from KSW will be masked by normal nut drop. Because a single KSW feeding in the nut can cause nut drop, the sequential sample is combined with presence-absence sampling to reduce effort. The sequential sample requires the use of a sampling table. Each nut is inspected, and the total number of nuts infested is compared to the stop-lines column. For example, if you have four nuts infested after examining five nuts, the sequential sample tells you that you are definitely over the 20% threshold, and you need to treat that area. On the other hand, if you have inspected 25 nuts and found no KSW damage, then you are below the 12% damage level and can stop sampling. An example of how to use Table 3.11 is given in Appendix B.

Nuts should be sampled from 10 trees within the sampling area. Sample no more than 10 nuts from each of the 10 trees, evaluating the sample using the sequential sample discussed above. The trees should be located a minimum of 150 yards apart to give a good area-wide estimate of damage.

### Cultivar susceptibility

As mentioned above, KSW kernel damage is rare because larvae can only reach the kernel before shell hardening begins (Table 2.2). Nuts smaller than 0.8 inch (20 mm) in diameter are rarely used by females as egg-laying sites, and shell hardening for most cultivars begins shortly afterward. However, there may be some orchards where greater kernel damage occurs because of differences in rainfall or the presence of older cultivars in which the shell may not harden as rapidly as in newer cultivars.

The relative susceptibility among macadamia cultivars to KSW feeding is known only for eight cultivars. Of these, cultivars 788 and 816 had significantly lower damage than others examined, and 344 had significantly more damage than the other cultivars (Table 3.12).

### Management strategies

Several key points of KSW biology are important for its management:

- KSW females rarely lay eggs on nuts smaller than about 0.8 inch in diameter.
- Feeding by the larval stage within the husk caused increased nut drop for any size nut within 3 to 4 weeks.
- Damage to the kernel can only occur before the shell hardens.
- The time between the nut being acceptable to KSW

**Table 3.11. Sequential sampling chart for KSW damage. The lower threshold is set at 12% husk damage, and the upper threshold is at 20%.**

| No. of nuts inspected | *STOP* if no. of damaged nuts is | | No. of nuts damaged |
|---|---|---|---|
| | Less than: | More than: | |
| 1 | 0 | 4 | |
| 2 | 0 | 4 | |
| 3 | 0 | 4 | |
| 4 | 0 | 4 | |
| 5 | 0 | 4 | |
| 6 | 0 | 5 | |
| 7 | 0 | 5 | |
| 8 | 0 | 5 | |
| 9 | 0 | 5 | |
| 10 | 0 | 5 | |
| 11 | 0 | 5 | |
| 12 | 0 | 6 | |
| 13 | 0 | 6 | |
| 14 | 0 | 6 | |
| 15 | 0 | 6 | |
| 16 | 0 | 6 | |
| 17 | 0 | 6 | |
| 18 | 0 | 6 | |
| 19 | 0 | 7 | |
| 20 | 0 | 7 | |
| 21 | 0 | 7 | |
| 22 | 0 | 7 | |
| 23 | 0 | 7 | |
| 24 | 0 | 7 | |
| 25 | 0 | 8 | |
| 26 | 0 | 8 | |
| 27 | 1 | 8 | |
| 28 | 1 | 8 | |
| 29 | 1 | 8 | |
| 30 | 1 | 8 | |
| 31 | 1 | 8 | |
| 32 | 1 | 9 | |
| 33 | 2 | 9 | |
| 34 | 2 | 9 | |
| 35 | 2 | 9 | |
| 36 | 2 | 9 | |
| 37 | 2 | 9 | |
| 38 | 2 | 10 | |
| 39 | 3 | 10 | |
| 40 | 3 | 10 | |
| 41 | 3 | 10 | |
| 42 | 3 | 10 | |
| 43 | 3 | 10 | |
| 44 | 3 | 11 | |
| 45 | 3 | 11 | |
| 46 | 4 | 11 | |
| 47 | 4 | 11 | |
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| 90 | 11 | 18 | |
| 91 | 11 | 18 | |
| 92 | 11 | 18 | |
| 93 | 11 | 18 | |
| 94 | 11 | 18 | |
| 95 | 11 | 19 | |
| 96 | 11 | 19 | |
| 97 | 12 | 19 | |
| 98 | 12 | 19 | |
| 99 | 12 | 19 | |
| 100 | 12 | 19 | |

**Table 3.12. Relative susceptibility of macadamia cultivars to KSW husk damage.**

| Cultivar | HAES No. | Relative susceptibility |
|---|---|---|
| Pahala | 788 | low |
| — | 816 | low |
| Makai | 800 | medium-high |
| Purvis | 294 | medium-high |
| Mauka | 741 | medium-high |
| — | 856 | medium-high |
| Kau | 344 | high |

females for egg laying and shell hardening is about 6 weeks.

- They are highly mobile and will move between areas and different host plants.
- About 20 plants commonly found in Hawaii are alternate hosts for KSW and LFM (Table 3.10).

For small farms, remove or treat any alternate host plant adjacent to the orchard. The host list includes some legumes, so manage legumes to prevent their population from increasing in those areas. Because legumes are also hosts for SGSB, long-term plans should aim at their removal from your orchard.

On farms of all sizes, growers often see early-season nut drop and are concerned that damage will be excessive throughout the season. However, early-season nut drop is often misleading because early in the season only a few nuts are of sufficient size for female egg laying. This results in these relatively rare larger nuts having most of the eggs laid on them. These nuts then drop after larvae begin feeding in the husk. Later in the season, the number of nuts acceptable to KSW females is much greater and their eggs are spread over the whole crop, resulting in a much lower percentage of nuts with damage. Its important to remember that nut drop 6 to 8 weeks after the majority of the crop is full size will not increase nut immaturity recorded by the processor because most of the oil accumulation has already occurred and the dropping nuts are already mature. This period typically happens around late September to early October, but it may vary with cultivar and orchard location.

### Behavior-modifying chemicals

KSW and LFM females both use the same pheromone chemical to attract males for mating. This chemical has been synthesized and is available both for monitoring

**Figure 3.25. The three most common parasitoids of KSW.**
From left to right, *Calliephialtes grapholithae, Trathalia flavo-orbitalis,* and *Pristomerus hawaiiensis*.

the flights of the males and for use as a control measure through the mating-disruption process. Fortunately for the industry, the chemical is the same as that used by the oriental fruit moth (OFM), which is a major pest of peaches. Because this chemical is already being used for OFM, we have been able to use commercially available lures and dispensers of the chemical for monitoring and mating disruption. When used for monitoring, the lures are placed in a trap that has a layer of sticky material on the bottom that captures the males as they are attracted by the lure. Each lure is supposed to put out the equivalent amount of chemical of one to two female moths. When used for mating disruption, we put out a dispenser that is a thin, hollow, flexible plastic tube (about the size of a pipe cleaner) that is filled with the chemical, dispensing about 500 times the normal rate a female puts out. These dispensers are placed in every tree. The idea is that the orchard is so saturated with the pheromone that the males cannot easily locate the females. If mating does not occur, viable eggs will not be laid. Because of the differences in sensitivity to the pheromone (OFM is more sensitive than KSW or LFM), our best results have come from using the maximum label number of dispensers per acre allowed by the product label.

### Natural enemies

Ten parasitoids have been recorded for KSW and LFM on Oahu, but a survey of KSW infesting macadamia on the island of Hawaii in 1998–1999 recorded only five species, two of which were only rarely found. The three most common species belong to the wasp family Ichneumonidae and attack the larval stage (Fig. 3.25). The most common species varied with location, but over all sites and collections *Calliephialtes grapholithae* was most common, followed by *Trathalia flavo-orbitalis* and *Pristomerus hawaiiensis*. Overall, parasitism was about 6.4%, with the peak being less than 11.4% for all the collections made at any particular site. Levels of parasitism this low cannot regulate KSW population levels, but parasitism may be higher during the winter. Although eggs were not held for parasitoid emergence, we have never found any egg parasitoids in any of our studies. However, significant levels of egg parasitism have been recorded along the coast of Queensland and northern New South Wales in Australia since 1997. The species of wasp belongs to the family Trichogrammatidae but has not yet been identified. A study has commenced to investigate the possibility of mass-rearing the parasitoid so that parasitism levels can be increased early in the season, but results have not yet been evaluated.

In addition to parasitoids, generalist predators can reduce KSW population levels. Ants that nest in the tree or on the ground may contribute to KSW mortality by attacking the larvae in the nuts, but the nuts will probably still drop. The generalist predators may also contribute to egg mortality, but at present we do not have any evidence of which predators are important. In Australia, green lacewing larvae are known to cause significant egg mortality.

### Chemical control

Chemical control of KSW is not a viable option at this time. The only pesticides registered are malathion and various formulations of *Bacillus thuringensis*. Both of these materials have only a short residual activity, which means that a large number of applications would be required to provide protection during the susceptible period from May to October. If a more efficient chemical were available, the sprays should be timed to catch the first instar larvae as they emerge from the egg but before they enter the nut. Because of their location, larvae and pupae are well protected from pesticide sprays.

Even if an efficient pesticide were available, pesticides can destroy or upset natural enemies of both major and minor pests. For example, in trees treated every 2 weeks with Thiodan and malathion, there was a marked decrease in ant foraging compared to untreated controls. This is of concern because of the importance of ants in SGSB population regulation.

# Part 4

# Secondary Pests

In addition to the four major pests, numerous other insects are associated with macadamia nut production. Mitchell and Ironside (1982) listed over 320 species of insects recorded world-wide, but in that survey only 28 were listed as being present in Hawaii. Several new species have been accidentally introduced into Hawaii during the past several years, and previous surveys may not have been extensive. The author's studies over the past decade have added at least 13 ant species, 7–10 beetles, 1 aphid, 5–7 flies, 5–7 parasitic hymenoptera (wasps), and 5–7 miscellaneous minor order insects. Of all the insects and mites on macadamia in Hawaii, only a few reach damaging levels, and these only rarely. The most common secondary pests include broad mite, Hawaiian flower thrips, redbanded thrips, black citrus aphid, katydids, various scales and whiteflies, and flat mite. Several other species are found, but only in very specific situations, and only once or twice have they caused problems in the past decade.

Unfortunately, unless there is information about these pests on other crops or in other areas, the information we have is relatively limited.

The seriousness of these secondary pests varies dramatically among orchards. Much of this variation is related to either cultural practices within the orchard, weather conditions, alternate host plants surrounding the orchard, or pesticide use.

Cultural practices such as fertilizer application and pruning can increase growth flushes, which make the plant more susceptible to redbanded thrips, black citrus aphid, and broad mite.

Weather conditions can affect plant growth, but both temperature and humidty directly affect insect development rate and survival. Temperature has been discussed in other areas (see page 5 and Appendix A), but humidity at the right times can significantly change insect survival. Insects are particularly susceptible to low humidity immediately following a molt. In addition, high humidty may favor the development of *entomophagous fungi* (those that develop on insects). In Hawaii, the best known example of this is the white halo fungus, *Beauveria bassiana*, which causes massive population crashes of the green scale, *Coccus viridus,* on coffee.

Alternate host plants can cause a serious problem by providing a refuge for pests where they can multiply and move into the orchard. In other cases, these alternate host plants may serve as a reservoir for natural enemies to move into the orchard and help control the pests. This means that monitoring these alternate host plants is required to determine if they are more important acting as a source for the pest or for their natural enemies.

Pesticide applications can also affect nontarget insects in the orchard in several ways. First, the pesticide may affect plant growth and attractiveness. Second, natural enemies of these secondary pests may be killed by the pesticide application, and finally, some pesticides at sub-lethal doses have been shown to increase the reproduction of several mite and aphid species.

An updated list of all insects that have been identified on macadamia in Hawaii appears in Appendix E. This will help determine if the next "new" pest is an accidental introduction or an existing secondary pest whose natural enemies have been affected by weather, pesticides, or new cultural practices.

# Broad mite

***Polyphagotarsonemus latus***
**(Acari: Tarsonemidae)**

The broad mite, *Polyphagotarsoneumus latus*, is a minor pest of macadamia in most areas. It has a fairly broad host range, attacking a number of weeds and cultivated host plants. It is most severe in the wetter macadamia production areas.

## Life history

The eggs of the broad mite are clear with prominent white tubercles (Fig. 4.1). The eggs are flattened, oval, and about 0.003 inch (0.07 mm) in diameter and are generally glued to a depression or irregularity on the plant surface. If the eggs are laid on the leaves, they are generally laid on the lower leaf surface where the populations develop. The larval stage has six legs and is about 0.004 inch (0.1 mm) long, white, and very slow moving. The larva molts into a clear torpedo-shaped nymphal stage that is unmoving. The adult female has eight legs, with the hind legs reduced to thread-like appendages. Females are oval and initially clear, but with time the female becomes yellowish with a prominent white strip running down the center of the back. Females are typically 0.006 inch (0.15 mm) long. Males are much smaller and are truncated near the rear end. The males are often seen carrying female nymphs at right angles to their body. When the female emerges from the nymphal stage, the male quickly mates with the female. The entire life cycle can be completed in less than 7 days, and within a single generation the population can increase 18-fold.

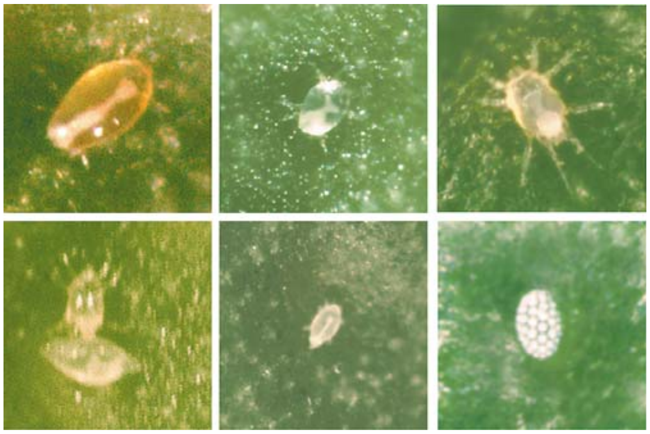
## Alternate hosts

Broad mite is a common pest on a number of subtropical and tropical crops and weeds. A partial host list includes tea, coffee, jute, chilies, tomato, avocado, macadamia nuts, pigweed (*Amarathus* sp.), Chinese aster, chrysanthemum, lemon, orange, strawberry, hibiscus, sweetpotato, morning-glory, lantana, beans, marigold, verbena, and cowpea.

## Damage

The broad mite is exceptional in that it feeds on flowers, young leaves, and the fruit. The most severe problems occur when it feeds on the young, developing flowers. Symptoms include a silver-bronze coloring and deformation. These flowers typically do not set nuts.

**Figure 4.1. Stages of broad mite.**
Upper right, older adult female; upper middle, young adult female; upper right, adult male. Lower left, adult male carrying a female pupa; lower middle, larval stage; lower right, egg stage.



Broad mite will also attack the young leaves in growth flushes. The eggs are laid on the underside of the leaves, and the mites' feeding causes the leaves to become cupped and distorted. This damage is generally most severe in the nursery or on leaves of young transplants.

Damage on the fruit is a silvering on the husk (Fig. 4.2). At this point, there is no evidence that this damage either reduces the quality of the kernel or causes early nut drop. Broad mite silvering of the husk can be distinguished from other similar damage by scratching a fingernail across the fruit. If the damage is from broad mite, the scratch easily reveals the normal green surface. Other damage, such as from flat mite or redbanded thrips, will not scratch off.

## Cultivar susceptibility

There have been no studies on the susceptibility of different cultivars. However, trees planted in areas with high humidity, that have thick canopies in irrigated areas, or that are overfertilized may experience more problems with broad mite. Broad mite does well in most areas in Hawaii, but areas with low rainfall and lower humidity should have the least problems.

## Monitoring

Monitoring should be most intensive in areas where fruit damage was visible the previous years. Examine 10 racemes randomly scattered throughout a tree for damage, and record the number that are damaged. Repeat

**Figure 4.2. Broad mite damage.**
Upper photo shows full-size nuts with nut in center showing test for broad mite damage. Bottom photo shows damage to young nuts.

this sample on 10 other trees that are widely scattered throughout the block. If more than 15–20 racemes are damaged, randomly select five racemes per tree from 10 other trees and use a 10x hand lens to check for broad mite. If the population level is high on more than 20% of the racemes, the block should be treated.

Monitoring for leaf damage should only be done on younger trees (recently transplanted) or seedlings in the nursery. Examine the young leaves that have not yet hardened off for mites, and if more than 20% of the leaves show damage, treat them as described below.

*Once the trees have been treated, further treatments should be triggered by the presence of high numbers of mites and not by the number of damaged leaves or damaged racemes.* Often, by the time broad mite damage is noticed, the infestation had disappeared.

## Control

### Chemical control

Chemical control to prevent damage to the nut should never be carried out unless further research shows a decrease in nut quality associated with mite damage. However, damage to the flowers can reduce nut set. For the racemes, monitoring should begin in blocks where broad mite has been a problem in the past. Wettable or micronized sulfur is highly effective against broad mite and should provide sufficient control that only one application is needed. Insecticidal soap, such as Mpede®, is also highly effective but requires good coverage. With soap, two applications spaced 6 days apart may be necessary to catch the newly emerged larvae, because eggs are not affected. Pesticides should be applied when the thresholds above have been exceeded.

Young transplants and seedlings should also be treated to prevent leaf damage that might lead to stunting and delay of seedling growth. In the nursery, use a backpack mist blower to get good coverage. Sulfur should probably not be used because of possible plant burn if temperatures are high. Mpede® has good contact activity but no residual activity at all. Thus applications require through coverage and should be repeated at 6-day intervals. Mavrik® (fluvalinate) is registered for nonbearing macadamia nut trees and should provide good control with a single application if good coverage is achieved.

Leaf damage on full-size trees should rarely, if ever, require treatment. Exceptions would be if virtually all the new leaf clusters show damage or if damage to the same block of trees occurs over several consecutive years.

### Natural enemies

Natural enemies of broad mite in macadamia nuts are not presently known. In California, phytoseiid mites are known to prey on broad mite in citrus, but those species are not present in Hawaii. However, Hawaii does have a number of phytoseiid mites, and several are closely related to those in California. If phytoseiids are important in Hawaii, pesticide sprays such as sulfur and malathion should be used only rarely, because they are highly toxic to these beneficial mites. In these situations, insecticidal soap should provide good control with minimal impact on the natural enemies.

## Red and black flat mite

***Brevipalpus phoenicis* (Acari: Tenupalpidae)**

Flat mites should never require treatment. Their feeding causes highly visible symptoms, and may be confused with damage caused by broad mite or redbanded thrips. At present, however, there is no known effect on nut development or quality.

### Life history

Flat mites lay their eggs on the nuts, and all subsequent stages can be found there. The eggs are small and light orange when first laid, but after a few minutes they darken to a bright reddish orange. There are five different life stages that include an egg stage, a six-legged larval stage, a protonymph (eight-legged), a deutonymph (eight-legged) and an adult stage (also eight-legged; Fig. 4.3). Each of the larval, protonymph, and deutonymph stages have a resting stage associated with them that precedes the molt to the next stage. The life cycle can be completed in about 3 weeks under typical spring and summer conditions. When the nut is heavily damaged, mites either will be found on undamaged portions or they will have moved to adjacent undamaged nuts.

### Alternate hosts

There are several different alternate hosts of flat mite, many of which occur in Hawaii. Worldwide, it has been reported on citrus, tea, coffee, peach, papaya, loquat, coconut, apple, pear, guava, olive, fig, grape, walnut, and more than 50 species of ornamental plants, including orchids.

### Identification

Adult female flat mites are 0.01 inch long (0.31 mm) by 0.006 inch wide (0.16 mm) and a hand lens of 10x power is required to see them. Immature stages can be less than half this size. Under a hand lens or microscope, they appear to be flattened, and the front legs appear to be wrinkled. They are very slow moving, and the different life stages are often found together.

**Figure 4.3. Flat mite adult female.**

**Figure 4.4. Flat mite feeding damage on husk.**

### Damage

The mites feed through needle-like mouthparts that pierce the upper layer of the husk. They suck up the cell contents, and the feeding results in a bronzing or browning of the husk. In extreme cases, virtually all the nuts on a tree may be affected (Fig. 4.4). Unlike broad mite damage, scratching a fingernail over the surface will not remove the damage.

### Management

At present there is no known effect on nut development or quality. However, if in the future some effects are found, wettable sulfur is highly effective in suppressing flat mite populations.

# Katydids

***Conocephalus saltator***
***Elimaea punctifera***
**(Orthoptera: Tettigoniidae)**

Katydids are a problem when weed growth is excessive and populations build in the weeds. From there, they may fly or walk to the upper portion of the macadamia canopy and feed there.

## Life history

Female katydids have a long sword-shaped ovipositor that is used to insert eggs into plant tissue. Once the eggs hatch, the insect passes through several nymphal stages before the adult stage (Fig. 4.5, 4.6). All stages feed mostly on plant tissue, but they may occasionally feed on insect eggs or very small insects. They are typically seen among weeds within the orchard, but relatively high populations may be found in the upper half of the macadamia canopy.

## Damage

Damage from katydids may be underestimated by most growers because much of it occurs high in the canopy where it is not visible. Katydids feed on young stems, leaves, and racemes (Fig. 4.17). In extreme cases, all the racemes may be destroyed and no nuts will be produced. In addition, feeding on young stems prevents new growth and can result in a triangular tree shape.

Because much of the damage occurs high in the canopy and is difficult to see, growers may notice that tree productivity is lower but think it is due to other orchard management practices, such as inadequate fertilizer applications.

**Figure 4.5. *Conocephalus saltator* adult.**

**Figure 4.6. *Elimaea punctifera* adult female.**

## Host plants

*Conocephalus saltator* has been reported from morning glory blossoms, lantana, sugarcane, honohono grass, coffee, ripe guava fruit, corn, rice, potato, and bean blossoms. *Elimaea punctifera* has been reported from honohono grass, hibiscus, young avocado leaves, garden beans, coffee, cotton, azalea, and *Canna indica*.

## Management

Katydids move into the crop primarily when the weeds grow so high that they contact the lower canopy of the tree. Damage is prevented by managing the weeds to keep them away from the trees during the winter and spring when racemes are just forming or have just set nuts. The trees should also be pruned so that the tree skirts are high enough to prevent contact with weeds. Pesticide applications should not be required.

**Figure 4.7. Leaves fed upon by katydids.**

### Monitoring

Katydids may be active both during the day and at night. They are relatively easy to spot, and are easily taken using a sweep net. Monitoring is probably easiest using a sweep net in the orchard weeds, but damage to the tree can be assessed by looking for damaged leaves on the vertical shoots of the tree, generally higher in the canopy.

## Redbanded thrips

***Selenothrips rubrocinctus***

**(Thysanoptera: Thripidae)**

### Damage

The redbanded thrips (RBT) is an occasional pest of macadamia. Most of the time, thrips are present in the orchard, but damage is typically restricted to the outer surface of the husk. Damaged nuts are covered with a sticky excrement that hardens and gives the fruit an uneven, reddish appearance that resembles melted candle wax (Fig.4.8) or, after sufficient aging, becomes a uniform brownish-rust color. These damage symptoms are not known to cause problems with nut drop, immaturity, or nut quality, and it is not considered worth treating.

In unusual circumstances, redbanded thrips populations can increase to high levels, resulting in bronzing and damage to the leaves (Fig. 4.9 and 4.10; compare the undamaged leaves [arrows] with the adjacent, damaged leaves). Most damage appears to be restricted to recently hardened leaves; young leaves and older, senescent leaves generally are not attacked. If severe enough, this damage probably reduces tree growth and vigor by destroying the productivity of the growth flush for that season. In these cases, and when no natural enemies are present in the orchard, pesticide treatment may be required to at least slow the population growth rate.

### Life history

Most information on redbanded thrips comes from studies conducted in Trinidad, where it is a major pest of cashew. Field observations suggest that the cultivars 246 (Keauhou), 508 (Kakea), 800 (Makai), Honokaa Special, and the two Australian cultivars A4 and A16 are especially attractive to RBT compared to other cultivars.

Thrips have a somewhat unusual life history. The eggs are commonly inserted into plant tissue and may be covered by a small drop of excrement. When they hatch, the first two stages feed and are normally called larvae. The next two stages are nonfeeding and are called the pre-pupa and pupal stages. During these two stages, wings begin to grow but are not functional until the adult stage is reached. After the adult emerges, feeding resumes.

**Figure 4.8. Nuts damaged by redbanded thrips.**

Studies on cashew indicate the entire life cycle lasts from 28 to 43 days at an average temperature of about 70°F (21°C). The egg, larval, pre-pupal, and pupal stages last 8–16, 8–16, 1–4, and 4–7 days, respectively.

### Host plants

RBT has several alternate host plants including azalea, cashew, cacao (the other common name for RBT is cacao thrips), croton, Java plum, guava, litchi, rambutan, mango, passion fruit (*Passiflora* sp.), and Christmas berry (*Schinus terebinthifolius*). Most of these (except cacao) can commonly be found adjacent to macadamia orchards. Christmas berry is particularly common near orchards in the Kona area.

### Identification

The common name, redbanded thrips, describes the appearance of the larval stage (Fig. 4.11). The larvae are small and yellowish to cream colored with a bright red band running from side to side on the first two segments of the abdomen. Late in the pupal stage, the body takes on a blackish cast, which becomes completely black in the adult stage.

The immature stages are typically found held with a small drop of excrement on hairs at the tip of the ab-

**Figure 4.9. Leaves damaged by thrips (foreground) compared to an undamaged leaf (arrow).**

**Figure 4.10. Young leaves damaged by redbanded thrips; arrow indicates an undamaged leaf.**

**Figure 4.11. Leaf infested with redbanded thrips.** Immature thrips are yellowish with a bright red band. Black thrips (bottom left) is an adult. Photo by Marshall Johnson.

domen. The abdomen is normally held erect, and if approached by a predator or parasitoid, the thrips will bend the abdomen over their head to touch the droplet to the predator to discourage attack. The droplets are also responsible for the sticky material on damaged nuts or on the underside of infested leaves.

## Monitoring

Redbanded thrips adults can be monitored using yellow sticky panels. These can be obtained from commercial companies listed in Appendix C.

Place one trap per acre in an area to be monitored. Traps should be examined every week and replaced if necessary. If traps are taken to the office for counting, place clear plastic over the trap and use a felt pen marker to aid in counting the adult stages.

## Control

### Natural enemies

Several predators are probably important in reducing RBT population levels or maintaining them at lower levels. These include lacewings, the minute pirate bugs (*Orius* sp.), phytoseiid mites, and possibly some other predaceous bugs. Parasitoids also have been introduced into Hawaii and at least one has recently been recovered attacking redbanded thrips on rambutan on Kauai. It is probably a *Baryconus* species (Hymenoptera: Scelionidae), which has been reported only from Kauai and Oahu.

### Pesticides

RBT may build up to high levels on alternate host plants and move into the orchard. Inspect orchard borders for any of the alternate host plants listed, and treat them if possible, or remove them.

Pesticides should rarely be applied for redbanded thrips because at present the only known damage is cosmetic and no differences in nut quality or quantity have been demonstrated. However, if populations reach extremely high levels on leaves, control may be justified to prevent damage to the current season's growth. Malathion at low rates provides good control and should reduce the populations enough to prevent damage. However, malathion can reduce the levels of natural enemies, particularly phytoseiid mites. Mpede® may also be effective, but it kills by direct contact only, so it requires good coverage, especially to the lower surface of the leaf. Both malathion and Mpede® will probably require two applications spaced 16 days apart to catch larvae emerging from the eggs, which are inserted into the plant tissue.

# Hawaiian flower thrips

***Thrips hawaiiensis* (Thysanoptera: Thripidae)**

The Hawaiian flower thrips (HFT) is rarely a problem in macadamia in Hawaii. However, when conditions are favorable, the populations build to high levels, and feeding results in flower damage, considerably reducing nut set.

## Life history

The life cycle of the thrips is slightly different from the complete metamorphosis and incomplete metamorphosis discussed in Section 1. Technically, it is a form of incomplete metamorphosis, where the wing buds develop externally as the insect molts. However, the immature stages are called larvae, and there is a pupal stage. The pupal stage is just a resting stage, and unlike insects with complete metamorphosis, the immature stages look just like the adults without completely developed wings.

Eggs of HFT are inserted into the tissue of the raceme or flowers. The egg hatches and the thrips pass through two larval stages and a nonfeeding pupal stage before emerging as an adult (Fig. 4.12). Development takes about 3 weeks during the summer and probably 4 weeks during the flowering period.

HFT populations are a problem primarily when they become well synchronized with the multiple flowerings of macadamia that can occur in Hawaii, or if they are able to build up on their alternate hosts and migrate to macadamia. If flowering becomes either spaced at about 1-month intervals (about the generation time of the thrips) or flowers are produced consistently throughout the spring, then HTF are able to constantly move to the new racemes. Fortunately, this synchronization of flowering and thrips populations is uncommon. It is possible that macadamia is not a preferred host and is infested only when the alternate hosts have finished flowering.

**Figure 4.12. Hawaiian flower thrips.**

## Damage

Thrips have mouthparts unlike any other insect. One of the mandibles is modified into a sharp spine that pierces plant cells and releases the liquid within. The thrips then places its cone-shaped beak to the surface and sucks up the fluid.

On macadamia, HFT damage is primarily to unopened and opened flowers. Feeding on the unopened flowers causes the them to be distorted or prevents them from opening. Feeding on the open flowers can cause the flower to fall off. In heavily infested areas, HTF feeding can dramatically reduce nut set.

## Identification

Adult female HTF have a pale brown head and thorax (the area to which the legs and wings attach) and a black abdomen (Fig. 4.12). Adult females are about 0.04 inch (1 mm) long. The male HFT are uniformly light colored and slightly smaller than the females (about 0.03 inch or 0.75 mm). The immatures are also light colored and smaller than either the male or female adults. The light color of the male and immature thrips can cause some problems in identification of the HFT, because another thrips, *Franklinella incisor* (Fig. 4.13) has a similar appearance and also occurs on the racemes. *F. incisor* has been found on racemes in south Kona, but its distribution throughout the macadamia production area is currently unknown.

Figure 4.13. *Franklinella incisor.*

### Alternate host plants

HTF has a broad range of host plants in Hawaii, including several common orchard weeds. Common host plants in or around macadamia orchards include Formosan koa, klu (*Acacia farnesiana*), kukui (*Aleurites moluccana*), aster, avocado, crown flower (*Calotropis gigantea*), *Cassia*, honohono grass (*Commelina diffusa*), cotton, rattlepod (*Crotolaria juncea* and *C. mucronata*), royal poinciana (*Delonix regi*a), guava, hydrangia, morning glory (*Ipomea cairica, I. congesta, I. pentaphylla*), lantana, haole koa (*Leucaena leucocephala*), paper bark tree (*Melaleuca leucadendron*), monkeypod (*Samanea saman*), hibiscus, pandanus, kiawe or mesquite (*Prosopis pallida*), blackberry (*Rubus lucidus*), African tulip tree (*Spathodea campanulata*), pukiawe (*Styphelia tameiameiae*), *Vanda* orchid, and blue vitex (*Vitex trifolia*).

### Management

#### Monitoring

HFT should be monitored several times during the development of the raceme. If thrips are found in low numbers, return 2 weeks later and sample again. Adult thrips can be easily monitored using yellow sticky cards, but immatures need to be monitored by inspecting racemes. As with most of the secondary pests, sampling plans have not been developed to any extent.

Racemes can be sampled by placing a stiff piece of paper (like a file folder) under the raceme and gently tapping the raceme on the paper. This will dislodge all stages of the thrips onto the paper. Examine 10 racemes per tree from 10 trees spaced 100 feet or more apart that represent the area of concern. Determine the percentage of racemes infested, and also record whether more than 10 HTF were dislodged from each. If more than 30% of the racemes are infested with 10 or more HTF, then treatment may be required.

#### Natural enemies

No studies of HTF natural enemies on macadamia in Hawaii have been conducted. However, thrips in general are attacked by generalist predators such as brown and green lacewings, phytoseiid mites, and minute pirate bugs (*Orius* sp.). Pesticides that affect these generalist predators should be used with care to prevent disruption of biological control of HFT.

#### Pesticides

Thiodan® and Mpede® both are registered and should provide quick knockdown of HFT populations. Mpede has no residual activity and kills by contact alone, so coverage must be complete. Mpede may require a second application about 1 week after the first to catch larvae emerging from the eggs. Thiodan's residual activity means that a second application should not be required. If coverage is complete, more applications of either Thiodan or Mpede should not be required within a season. To prevent high natural enemy mortality, Thiodan should not be used except in the most extreme cases.

## Black citrus aphid

***Toxoptera aurantii*** **(Homoptera: Aphidae)**

The black citrus aphid is rarely a pest of macadamia in Hawaii. Worldwide, it has a host list of over 120 plant species and is noted as being a particularly serious pest of young citrus, cacao, coffee, mango, anona, camellia, gardenia, and ficus. In Hawaii, the only heavy infestations have been in the Kona area, but it may be a minor pest in other areas as well.

### Life history

Aphid life cycles are different from the generalized life cycles mentioned in Part 1. Black citrus aphid does not lay eggs but instead deposits living nymphs. These develop to either winged (alate) or wingless (apterate) forms. Both the winged and wingless forms can lay more living young. The winged form is thought to be a dispersal stage that colonizes an area, then produces the wingless adult forms. The first winged individual on a terminal or raceme is often called a "stem mother" because she is responsible for initiating all the reproduction on that stem. Black citrus aphid males are not found, so all of the individuals on a stem are generally clones of the mother. When the tree is no longer able to support the aphids, nymphs are produced that become winged forms when they become adults.

The black citrus aphid lives in dense colonies on the underside of young macadamia leaves or on the racemes. These aphids may be tended by several ant species that can sometimes protect them from parasitism. However, high levels of parasitism have been observed, suggesting that ant tending is not as efficient in protecting the aphids in macadamia as in other crop systems.

Black citrus aphid is one of the few aphids that actually produces an audible scraping sound when disturbed. This sound is caused by the rubbing of one body part over another and is thought to be used for communication.

## Identification

The winged adult is 0.07–0.09 inch (1.75–2.3 mm) long and has a shiny brown to black body with a dark brown-black area on the forewing near the wing margin. The antennae are shorter than the body. The wingless forms are slightly larger than the winged forms and are 0.08–0.09 inch (2–2.3 mm) long. The nymphs are brownish.

## Damage

The black citrus aphid feeds on young leaves during growth flushes and on racemes. Racemes can be attacked before bud break, and aphids can still be found when flowers open. Feeding on racemes may cause flower distortion or death. Feeding on leaves causes curling and distortion (Fig. 4.14).

On citrus and other crops, the black citrus aphid can vector certain diseases. However, it does not vector diseases to macadamia.

## Host plants

Black citrus aphid has a fairly broad host range that includes several agricultural commodities and a range of introduced and native species of trees and shrubs. The agricultural hosts include pomelo (*Citrus maxima*), coffee, lime, and mango. Selected native and introduced species include kamani or Alexandrian laurel (*Calophyllum inophyllum*), ohia ha (*Eugenia sandwicensis*), ficus, hibiscus, kawaʻu (*Ilex anomala*), ixora, *Pittosporum glabrum*, crepe myrtle or kahili flower (*Lagerstroemia indica*), and several fern species. Many of these species may be present in forested areas surrounding the orchard.

**Figure 4.14. Leaves deformed by black citrus aphid feeding on young foliage.**

## Management

### Natural enemies

Observations in areas where black citrus aphid populations were in high numbers indicate a high level of parasitism by a small wasp, *Lysiphlebus testaceipes* Cresson (Hymentoptera: Aphidiidae). The wasp lays its eggs inside the aphid, and when the eggs hatch, the parasitoid larvae feed within the aphid body until the inside is entirely consumed. The wasp larva then pupates within the body, and when it emerges from the pupal case, the adult wasp chews its way out of the hollow body. Parasitized aphids are immobile and typically are a dull brownish color (Fig. 4.15). These parasitized aphids are known as “mummy” aphids and are typically found with a hole in the back part of the abdomen where the parasitoid emerged. Unless the area has been disrupted by pesticide application for other pests, black citrus aphid should not require pesticide applications specifically for its control.

The yellowshouldered lady beetle, *Scymnodes lividigaster*, has also been seen preying on black citrus

**Figure 4.15. Parasitized black citrus aphid, or "mummy" aphid, on a macadamia flower.**

**Figure 4.16. Black citrus aphid and larval stage of the yellowshouldered lady beetle.**
Photo courtesy of Dr. Wallace C. Mitchell

aphids (Fig. 4.16). In addition, a green lacewing, *Chrysopa microphya*, another lady beetle, *Coccinella inaequalis*, and a syrphid fly, *Allograpta obliqua*, have been reported as being natural enemies in Hawaii. However, the effect of these predators on black citrus aphid on macadamia is not known at this time.

As with broad mite and redbanded thrips, fertilizer rates should be carefully monitored to prevent excess new growth that favors black citrus aphid population growth. This is especially important in young trees in the field and in nursery situations.

### Monitoring

Treatments should rarely if ever be required for black citrus aphid. Because it is so rarely a pest, monitoring should be confined to areas with consistent damage or to the nursery, where growth flushes are more common. Adult winged stages can be monitored using yellow sticky cards, but the wingless adults and nymphs need to be monitored by examination of the racemes or leaves. No real information is available on monitoring, but a simple way to monitor would be to look at 10 terminals per tree (or 10 racemes) from 10 trees within the area. Trees sampled should be spaced 100 feet apart in the orchard, or evenly over the nursery area. Record the number of racemes or terminals with damage or aphids present and calculate the percentage of such racemes or terminals. When sampling, make sure that you look for the parasitized aphid "mummies." Record the number of racemes (or leaves) with mummies when sampling for black citrus aphid to get an idea of the level of parasitism occurring in the orchard.

## Part 5

# Pests of Macadamia Not Yet Found in Hawaii

This section is not intended to cover all the pests of macadamia nuts on a worldwide basis. Instead, it will focus on major pests of macadamia in other countries that may be introduced through normal commerce or by persons either accidentally or intentionally circumventing normal quarantine procedures. As discussed in the introductory sections, one of the major ways an insect becomes a pest is through the introduction of the pest into a new area without its natural enemies. Quarantine procedures are intended to prevent such introductions by bringing plant material into an isolated quarantine facility where it can be inspected to be sure it is free of pest insects, diseases, or weeds.

Hawaii is particularly susceptible to accidental introductions. Studies have shown that since the advent of jet airliners in the mid-1950s, an average of 17 new insect species are introduced yearly. While not all of these become pests, it is interesting that virtually all the major insect pests on all crops in Hawaii are accidental introductions. In Hawaii's macadamia nuts, all of our pests except the koa seedworm are introduced species.

This section covers the major pests of Australia, South Africa, Malawi, and South America. Certain pests are common to all areas (such as the southern green stinkbug), but all areas have species that fill ecological niches similar to those in Hawaii. For example, Australia, Malawi, and South Africa all have at least one moth species in the genus *Cryptophlebia* that causes damage similar to koa seedworm.

This section will not cover pests in other areas that are present in Hawaii but are not problems here. For example, latania scale is considered to be a serious problem in certain areas in Australia, but it is present in Hawaii and is not regarded as a pest at all.

## Macadamia felted coccid

***Eriococcus ironsidei*** **(Homoptera: Eriococcidae)**

### Distribution

Queensland, Australia

### Potential method of introduction

For Hawaii, the primary concern is the movement of scion wood or infested seedlings without going through proper quarantine, or importation of in-husk nuts.

### General

The macadamia felted coccid is a native Australian insect, and its host plants are restricted to smooth and rough shelled macadamia nuts. Its name comes from the heavy

**Figure 5.1. Racemes damaged by macadamia felted coccid (undamaged raceme at right).**
Photo by David Ironside, provided courtesy of Geoff Waite.

Figure 5.2. Macadamia felted coccid in high levels on macadamia.
Photo by David Ironside, provided courtesy of Geoff Waite.

resinous covering of the adult female and the second instar male. In Australia, the problems are mostly in areas where the felted coccid is newly introduced. The population generally builds quickly until natural enemies can be introduced.

### Damage
All of the above-ground parts of the plant may be affected. Foliage fed upon is typically distorted, even when only a single individual is present. Feeding on the raceme causes distortion (Fig. 5.1) and nut drop. Heavy infestations (Fig. 5.2) may cause dieback and death of nursery or newly planted grafted trees.

### Host plants
Smooth and rough shell macadamia.

Figure 5.3. Macadamia felted coccid being eaten by immature ladybird beetle larvae (arrow).
Photo by David Ironside, provided courtesy of Geoff Waite.

### Life history
The life cycle of the coccid is a modified type of incomplete metamorphosis. The eggs are laid inside the felted sac of the adult female. They hatch into the first instar, which is known as the crawler stage. The crawler stage is the dispersal stage and is the only mobile stage in females. The crawlers move away from the female and eventually settle down and insert their mouthparts into the plant and begin feeding. Shortly afterward, they molt into the second instar. Typically the female crawlers settle in sheltered areas such as leaf axils, between the flowers on a raceme, near the mid-veins of a leaf, or on cracks in the bark. After settling as a crawler, females never move again but go through two more molts before becoming sexually mature adult females.

Males tend to settle in shaded locations, molt to the second instar, and form the felted sac. At this stage, the males are sessile. After feeding for a period, the males molt to a resting stage known as a pupa. The pupal stage occurs within the skin of the second instar and the winged adult male emerges later. The male then seeks out a female for mating.

The entire life cycle takes about 42–59 days for the female and 33–41 days for the males. In Australia, there are up to six overlapping generations per year.

### Description

The translucent pink-purple eggs are laid within the felted sac of the adult female. Each egg is oval measuring about 0.008 inch x 0.004 inch (0.2 x 0.1 mm). The crawler stage is yellowish but the second instar males are white and about 0.031 inch x 0.016 inch (0.8 x 0.4 mm) in size. Adult females are white to yellow-brown and average 0.028 inch x 0.039 inch (0.7 x 1.0 mm) in size. Adult males are orange, have only 1 pair of wings, and are about 0.031 inch (0.8 mm) long.

### Management

Management of macadamia felted coccid is through a combination of cultural and biological methods. Dispersal is by wind or bird in the crawler stage and is relatively slow without the intervention of man. Dispersal over long distances is typically by movement of infested scion wood or movement of infested trees from nurseries.

### Natural enemies

The most important natural enemies in Australia are three ladybird beetles (Fig. 5.3): *Midus pygmaus*, *Rhizobius ventralis*, and *Serangium maculigerum*. The larva of a predatory moth, *Batrachedra arenosella*, and several parasitic wasps are also important. In addition to the above natural enemies, generalist predators such as lacewings, a larval gall midge, and several predatory mites are also commonly found feeding on macadamia felted coccid.

### Pesticides

Pesticides can be used for control of the felted coccid, and several are registered in Australia. However, if this pest is introduced into Hawaii, the first pesticide to be tried should be a 1% solution of spray oil. This material in other systems is relatively nontoxic to natural enemies compared to synthetic organic insecticides.

## Fruitspotting bug

***Amblypelta nitida* (Hemiptera: Coreidae)**

## Banana-spotting bug

***Amblypelta lutescens lutescens* (Hemiptera: Coreidae)**

### Distribution

Queensland, Northern Territory, and Western Australia

### Potential method of introduction

These bugs should never make it to Hawaii on macadamia because of quarantine regulations on scion wood. In addition, no stage of the bug is found inside the shell, so in-shell nut shipments should not be a hazard. However, because it has many host plants, it is possible that it could make it though on those host plants if quarantine regulations are circumvented.

### General

Fruitspotting bug (FSB) and banana-spotting bug (BSB) are considered to be the most serious pests of macadamia in Australia. Although FSB and BSB share the same sort of mouthparts as the southern green stinkbug (SGSB), the damage caused by FSB and BSB is much worse. If these bugs were to become established, Hawaii growers would have to begin spraying. Biological control agents in the form of egg parasitoids affect a significant proportion of the eggs late in the season in Australia but are not sufficiently effective to reduce crop damage.

### Damage

Both bugs can cause severe damage to nuts of all size and maturity classes (Fig. 5.4, 5.5). In addition, BSB attacks the young, lush shoots, especially after the nuts are mature in the fall. Feeding at this time by a single female is sufficient to kill the shoot. As with SGSB, damage during the early season when the nuts are developing generally results in nut drop, but older nuts rarely drop. Bug feeding is often first noticed by a heavy nut drop under just a portion of the tree.

Figure 5.4. Fruitspotting bug damage to macadamia shells.

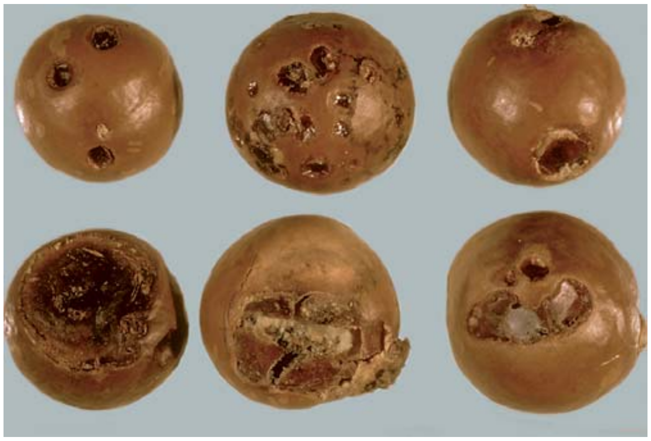


Figure 5.5. Fruitspotting bug damage to kernels.
Undamaged kernel, top right.
Photo by David Ironside, provided courtesy of Geoff Waite.

If the bugs feed through the partially hardened shell, large sunken spots appear in the shell and the kernels are severely deformed (Fig. 5.4). If the damage occurs early enough, the kernel is destroyed and nearly unrecognizable (Fig. 5.5). Feeding often leaves dark spots on the husks that are not present when SGSB feeds.

Figure 5.6. Adult and immature fruitspotting bugs on macadamia.
Photo by David Ironside, provided courtesy of Geoff Waite.

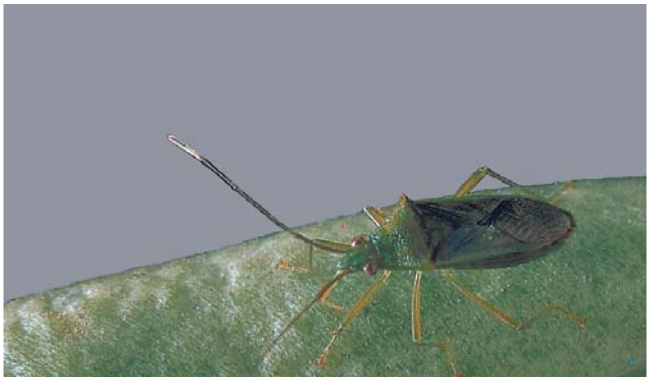
### Host plants

Both species attack macadamia, avocado, custard apple, guava, litchi, passion fruit, pecan, and citrus. The fruitspotting bug also attacks peaches, plums and nectarines. The banana-spotting bug attacks umbrella tree, coffee apple, corky passion vine, white cedar, rough leafed fig, palay rubber vine, and bananas. Attacks on commercial orchards are generally most intense when they are situated close to some of the preferred native hosts that grow in forests.

### Life history

Adult bugs (Fig. 5.6, 5.7) generally lay their eggs singly on nuts, leaves, or terminals. The nymphs of both species hatch from the eggs in about 8 days. The nymphal devel-

**Figure 5.7. Adult fruitspotting bug.**
Photo by David Ironside, provided courtesy of Geoff Waite.



opmental period is about 37 days for the fruitspotting bug and 42 days for the banana-spotting bug. Nymphs typically do not move far, but they often escape notice because they keep fruit or leaves between themselves and the observer. Bugs begin mating within 5 days of emergence, and repeated matings are necessary for constant egg production. Up to 163 eggs have been recorded from a single female, although the normal egg production is probably only a few eggs per day. Adults tend to move about little once a feeding site has been selected. This means that damage within an area can be restricted to only a few trees within an orchard block. Adults can fly but generally do so only for short distances to escape predators or to move to another tree in search of food or a mate.

In Queensland, researchers estimate that 3–4 generations per year occur.

## Description

Both species have the normal incomplete metamorphosis life cycle. The eggs are about 0.067 inch (1.7 mm) long and oval shaped. Initially, they are a translucent pale green, but before hatch, they show brown markings from the developing nymphs, which gives them a dark perlescent look. Eggs are typically laid singly on nuts, leaves, or terminals.

The nymphal stages look similar to one another, with the major differences being size and the elongation of the wing buds. The first instar nymphs of both species look similar, but the later stages can be distinguished by color patterns. The nymphs of the FSB have reddish-black legs and antennae and an orange-brown abdomen. The nymphs of BSB are a pinkish red and white and have a distinctive light red stippling surrounding the pair of large black spots on the abdomen (Fig. 5.8).

**Figure 5.8. Immature banana-spotting bug.**
Photo by David Ironside, provided courtesy of Geoff Waite.

The adult stages of both species are winged and are relatively narrow and parallel sided. Both species are approximately 0.6 inch (15 mm) long and differ primarily in coloration. The FSB (Fig. 5.7) is generally a slightly darker green with a black background sheen, while the BSB is generally slightly more rectangular with a yellowish-brown background color.

## Management

### Natural enemies

Predation and parasitism of the FSB and BSB were considered to be very low in Queensland. However, recent studies have revealed that a complex of three egg parasitoids can attack about 90% of the eggs at certain times of the season. In addition, spiders, especially crab spiders (Thomisidae), account for predation on a small percentage of nymphs. Of interest is that the bigheaded ant, *Pheidole megacephala*, which is common in some Hawaii orchards, has been observed in Queensland to prey on both species.

### Pesticides

The pesticide endosulfan (Thiodan®) is currently recommended in Australia for control of both FSB and BSB.

## Macadamia leafminer

***Acrocercops chinosema***
**(Lepidoptera: Gracillariidae)**

### Distribution

Queensland, Northern New South Wales

### Potential method of introduction:

This insect should not make it to Hawaii unless infested young trees are shipped in without undergoing quarantine inspection. Larvae and eggs could come in on the leaves, and pupae may be found at the base of the tree.

### General

The macadamia leafminer (MLM) is a pest primarily of young trees and is particularly bad in wetter areas at high altitudes. Areas protected from the wind also seem to be particularly hard hit. It is active throughout the year.

**Figure 5.9. Macadamia leaves damaged by macadamia leafminer.**
Photo by David Ironside, provided courtesy of Geoff Waite.

**Figure 5.10. Full-grown macadamia leafminer larvae. The bottom caterpillar is parasitized by a small wasp larva.**
Photo by David Ironside, provided courtesy of Geoff Waite.

### Damage

Damage is caused by the larval stage, which chews through the bottom of the egg and begins feeding between the upper and lower surfaces of the leaf. Feeding by the first two instars is visible as a narrow, white, meandering line on the leaf (Fig. 5.9). Feeding by the third instar larva causes a blister-like blotch mine that can cover the entire leaf surface. If the papery surface of the mine is opened, the larva inside is clearly visible (Fig. 5.10). Mining is generally concentrated on younger leaves and growth flushes.

### Host plants

The only known host plants are smooth and rough shell macadamia, *Polyosma cunninghamii*, and *Stenocarpus salignus*.

### Life history

The adult stage is active primarily at night. The female generally lays the eggs one at a time on the upper surface of the leaf. Up to 96 eggs have been recorded on a single leaf in Queensland. The larva exits the egg by boring through the bottom portion of the egg and begins feeding between the upper and lower surfaces of the leaf. The first two instars are relatively small and the damage is generally minor. The third instar is much larger than the previous two stages and causes much more damage. Feeding by the third instar larva causes a large blotch mine that resembles a blister. The larvae feed within this blister and in extreme cases the blister may cover most

**Figure 5.11. Adult macadamia leafminer.**
Photo by David Ironside, provided courtesy of Geoff Waite.

of the leaf. Upon completing development, the last instar larva leaves the damaged leaf and seeks out pupation sites in debris on the ground. Upon reaching a suitable site, the larva spins a silken cocoon in which it pupates and from which the adult emerges. The entire life cycle takes from 19 to 23 days during the summer in Queensland and from 50 to 53 days in the winter.

### Description

The egg stage is 0.016 inch x 0.02 inch (0.4 x 0.5 mm), flattened, and oval. On the leaf, the egg resembles a small water droplet. Upon hatching, the larvae are pale green, but later become white to yellow with dark undertones (Fig. 5.10). The third stage larvae develop bright red bands. The pupal stage is about 0.16 inch (4 mm) long. The adult is brown with silver bands on the forewings and a wingspan of about 0.31 inch (8 mm) (Fig. 5.11).

### Management

#### Cultural control

Because leafminers prefer younger growth and foliage, heavy pruning or excessive fertilizer should be avoided to reduce growth flushes. In nursery situations, heavy fertilizer could also cause problems with redbanded thrips and broad mite.

#### Natural enemies

In Queensland, a small wasp, *Elachertus* sp. (Hymenoptera: Eulopidae) has been found to be important in regulating MLM population levels. The parasite is an ectoparasitoid (that is, it feeds externally) of the larvae within the mine (Fig. 5.10). Spiders have also been seen preying on the third instar larva as it leaves the leaf to pupate.

#### Pesticides

In Australia, the pesticide Supracide® 400 (methidathion) is used for MLM control.

## Macadamia flower caterpillar

***Cryptoblabes hemigypsa* (Lepidoptera: Pyralidae)**

### Country of origin

Eastern Australia

### Potential method of introduction

The pupal stage is the most likely stage to be accidentally introduced into Hawaii. The mature larva generally leaves the tree to pupate, but some seek cracks or crevices in the bark. Importation of scion wood with pupae if quarantine is bypassed is the most likely method of introduction.

### General

The macadamia flower caterpillar (MFC) is considered one of the more serious macadamia pests in Australia. Feeding by the larval stage can greatly reduce nut set, and with the multiple flowerings common in Hawaii, it could become one of our most serious pests.

**Figure 5.12. Full-grown macadamia flower caterpillar larva (about 0.5 inch) feeding on flowers.**
Photo by David Ironside, provided courtesy of Geoff Waite.

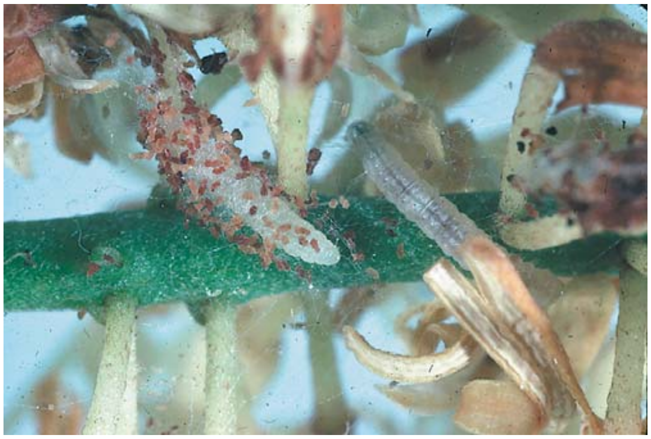


**Figure 5.13. Moth of the macadamia flower caterpillar (wingspan about 0.5 inch).**
Photo by David Ironside, provided courtesy of Geoff Waite.

## Damage

Feeding by the larval stage causes destruction of the buds and flowers (Fig. 5.12, 5.15). If flowering is protracted, young nuts may be attacked, along with the growing tips of shoots.

## Host plants

The host plants are all native Australian trees in the family Proteacea. The hosts include both rough and smooth shell macadamia, red bottlebrush or kahili flower (*Grevillea banksii*), and silky (or silver) oak (*Grevillea robusta*). In addition, *G. pinnatifida*, *G. glauca*, and woody pear (*Xylomelum pyriforme*), which are not present in Hawaii, are host plants.

## Description

The adult stage has a wingspan of about 0.5 inch (12–13 mm) and the forewings are pale brownish-gray with black and white specks. The hindwings are grayish with a marginal fringe (Fig. 5.13).

**Figure 5.14. Macadamia flower caterpillar egg on unopened flower.**
Photo by David Ironside, provided courtesy of Geoff Waite.

**Figure 5.15. Damage to macadamia racemes from macadamia flower caterpillar.**
Photo by David Ironside, provided courtesy of Geoff Waite.

The eggs are oval and the average size is 0.02 inch x 0.012 inch (0.5 x 0.3 mm). They are white just after being laid, but they turn yellow later on (Fig. 5.14). Just before hatching, the dark head capsule of the larva is visible within the egg.

The first instar larva is yellow with a dark brown head capsule. Larvae are about 0.03 inch (0.75 mm) long when they first hatch from the egg but become darker with each molt. The full-grown larva is about 0.47 inch (12 mm) long and reddish-brown, although some larvae may vary from green to gray (Fig. 5.12).

### Life history

In Queensland, studies have shown that the adult stages can occur throughout the year. However, the greatest numbers are found during the main flowering periods. Everbearing cultivars can allow continuous reproduction and help increase damage to adjacent areas. Typically, early flowering cultivars are not heavily hit, but later flowering ones or cultivars with prolonged flowering periods are most heavily damaged. In Hawaii, with the several flushes of flowering that occur within a season, MFC could be a severe problem.

Adult female moths lay eggs on the racemes during the 4 hours following dusk. The eggs are laid either singly or in groups of two to three anywhere on the buds or the raceme stem. Studies in Queensland have found up to 400 eggs per raceme. Flowers with buds 0.12–0.28 inch (3–7 mm) long appear to be the preferred size, although females will lay eggs on racemes at all stages of flowering.

There are five larval stages, all of which feed on the flowers or buds. Where a larva enters a bud, a drop of sap is often seen on the side of the flower. The edges of the flower become brown, and excrement is often seen near the entry hole. Older instars feed mainly on the outer portion of the buds or on the raceme stem. When fed upon, the stems generally look unthrifty, with webbing containing frass and damaged bud parts being visible.

Late in the larval stage, the caterpillars typically leave the tree and move to a protected location, spin a silken cocoon, and pupate. Occasionally the caterpillars pupate on the tree in cracks or crevices in the bark.

The entire life cycle can be completed, under Hawaii conditions, in probably from 23 to 30 days.

### Management

#### Natural enemies

Studies in Queensland have identified a wide variety of natural enemies. The most important species appear to be the larval parasitoids *Agathis rufithorax*, *Brachymeria* sp., and *Phanerotoma* sp. In addition, *Trichogramma flava* parasitizes the egg stage, and a small mirid bug, *Termatophylum* sp., preys on the larval stages.

#### Pesticides

The pesticide endosulfan (Thiodan®) is currently registered in macadamia in Hawaii and is one of the recommended materials for MFC control in Australia.

**Figure 5.16. Macadamia twig girdler damage to macadamia leaves and twigs.**
Photo by David Ironside, provided courtesy of Geoff Waite.

## Macadamia twig girdler

***Neodrepta luteotactella***
**(Lepidoptera: Xyloryctidae)**

### Country of origin

Australia

### Potential method of introduction

This insect is unlikely to be introduced into Hawaii unless quarantine is bypassed.

### General

Twig girdler is most common on young trees. The insect is active year-round in Australia, but the adult moths

**Figure 5.17. Adult macadamia twig girdler.**
Photo by David Ironside, provided courtesy of Geoff Waite.

are least common in the winter, and the damage is greatest in the summer and fall. Areas with the biggest problems are generally orchards at higher elevations.

### Damage

Twigs of infested trees show signs of girdling at the forks or leaf whorls (Fig. 5.16). The leaves may be skeletonized and incorporated into webbed shelters where the larvae are found. The twigs become weakened and easily snap off, which induces a bunched growth habit. Larvae can also tunnel through the husks and kernels, similar to koa seedworm or litchi fruit moth, but this is rarely a problem on mature trees. Damage from twig girdler is most severe on young trees, where death or stunting can occur.

### Host plants

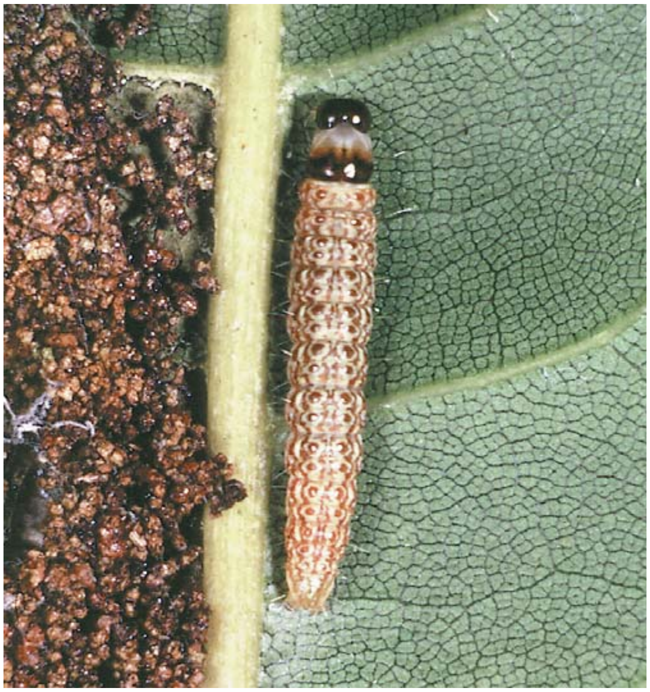
The host plants are all native Australian trees in the family Proteaceae. The hosts include both rough and smooth shell macadamia and proteaceous trees in the following genera: *Banksia*, *Grevillea*, *Hakea*, *Persoonia*, *Buckinghamia*, *Stenocarpus*, and *Xylomelum*.

### Description

The adult moth is silver-white with yellow legs and antennae (Fig. 5.17). The wingspan is about 1 inch (26 mm). Adults are active at night and are attracted to mercury vapor lamps.

The egg is about 0.03 x 0.015 inch (0.76 x 0.38 mm) in size. When initially laid they are yellow, and they later change to a reddish-orange. Eggs are laid singly at leaf axils on the terminal shoots, often near old damage from twig girdler.

**Figure 5.18. Macadamia twig girdler larva on macadamia leaf. Debris at left is fecal pellets.**
Photo by David Ironside, provided courtesy of Geoff Waite.



The larva passes through six to seven instars, although up to nine are possible. When hatched, larvae are about 0.06 inch (1.5 mm) long and yellow-orange with a black head capsule. A full grown caterpillar is about 0.9 inch (23 mm) long, with a dark head capsule, and its body is mottled brown with longitudinal rows of dark brown dots (Fig. 5.18). Immediately before pupating, the larva becomes lighter in color and contracts in size. The caterpillar then constructs a dull brown, silken cocoon about 0.5 inch (12.5 mm) long.

### Life history

The development time in the field in Australia is from 3–5 months. Laboratory studies have shown that at 26°C development requires from 62 to 84 days. This time is broken down as 7 days for the egg stage, 39–69 days for the larval stage, and 12–17 days for the pupal stage.

### Management

#### Natural enemies

Studies in Queensland show that a broad range of natural enemies attack MTG. Most of these natural enemies are wasps that attack the larval stage. The more common parasitoids are *Agathiella* sp. (Hymenoptera: Braconidae), and *Goryphus turneri* and *Stiromesostenus albiorbitalis* (both Hymenoptera: Ichneumonidae).

### Pesticides

Control is rarely necessary with MTG because of natural enemy activity. However, the pesticide endosulfan (Thiodan®) is currently registered in macadamia in Hawaii and is one of the recommended materials for MTG control in Australia.

## Twospotted bug

***Bathycoelia natalicola***

**(Hemiptera: Pentatomidae)**

## Yellowspotted bug

***Bathycoelia rodhaini***

**(Hemiptera: Pentatomidae)**

### Country of origin

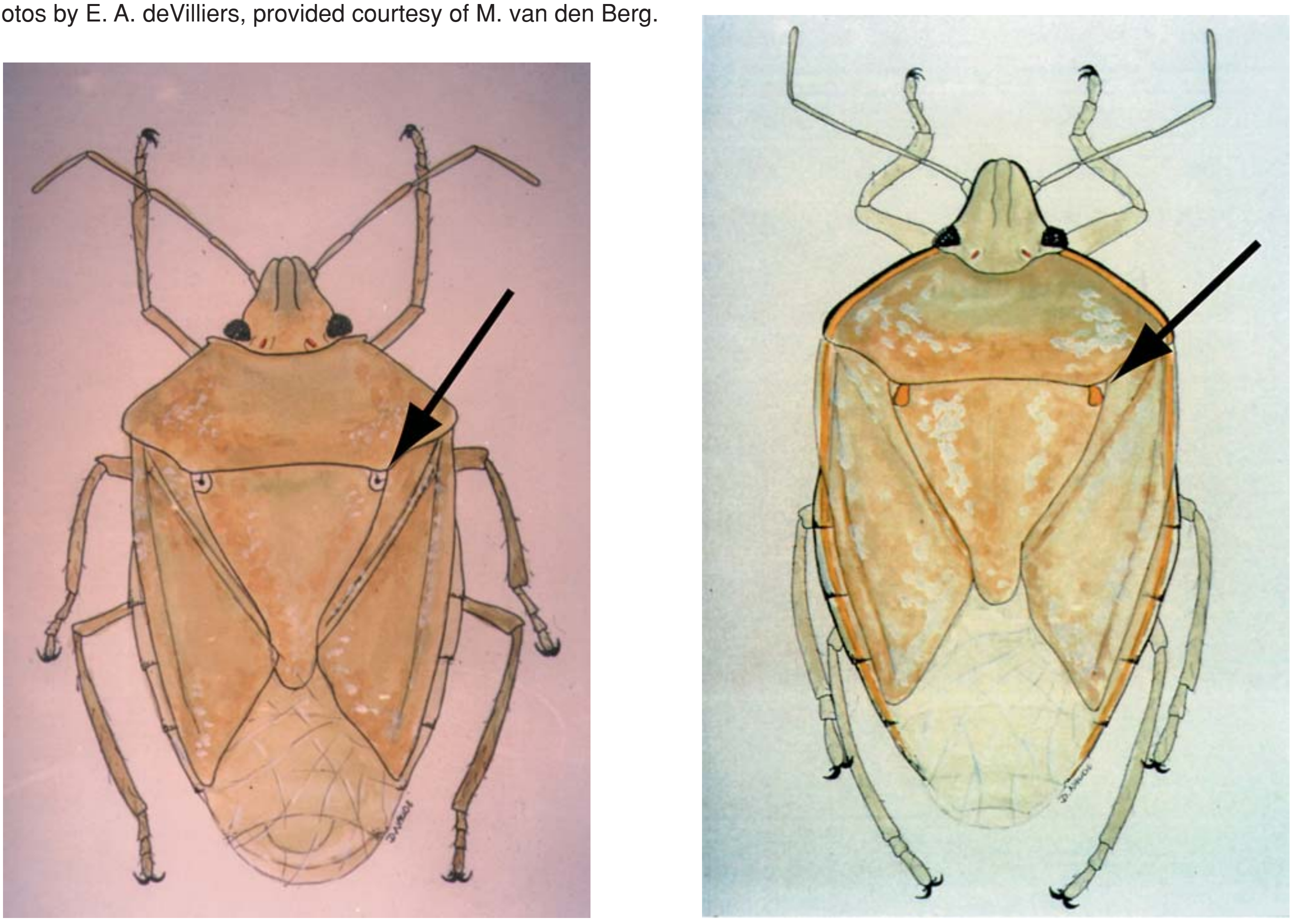
TSB and YSB are indigenous to Africa and are very common in South and Central Africa. In South Africa, virtually all the production areas contain TSB. Both species are common in all Malawi macadamia production areas.

### Potential method of introduction

These bugs should never make it to Hawaii on macadamia, because of quarantine regulations on scion wood. In addition, no stage of the bug is found inside the shell, so in-shell nuts shipments should not be a hazard. However, because it has a number of different host plants, it

**Figure 5.19. Drawings of the twospotted bug (left) and yellowspotted bug (right) with arrows indicating the spots that distinguish them from one another.**

Photos by E. A. deVilliers, provided courtesy of M. van den Berg.



is possible that it may make it though on those host plants if quarantine regulations are circumvented.

### General

These two bugs are probably the most severe pests of macadamia in Africa. Their long mouthparts and severe damage can completely destroy kernels that are fed upon.

### Damage

The mouthparts of both species are similar to SGSB, and their mode of feeding is as described for SGSB. However, both insects' mouthparts are about 14 mm long (about 2.3 fold longer than SGSB). This allows them to penetrate the husk and shell of all macadamia cultivars at any time in their development. In addition, the younger instars may also reach to the kernel, whereas with SGSB, only the last instar (rarely) and adult stage can damage the kernel.

### Host plants

The TSB is found on several species of *Terminalia* in Mauritius, and various stages have been found on coffee, guava, and bluegum (*Eucalyptus* spp.). Macadamia is the favored host in Malawi.

### Description

The eggs are laid in masses of about 14 each, usually on the underside of the leaves. The eggs are larger than those of SGSB. The nymphs are light brown, but as they develop the color changes from green to yellow. YSB adults are fairly large, measuring about 1 inch long x 0.5 inch wide (23 x 13 mm). TSB are slightly smaller and measure 0.83 inch long by 0.43 inch wide (21 x 11 mm). The YSB has two orange-yellow spots on either side of the scutellum (Fig. 5.18, right), while the TSB has two tiny black spots ringed with white in the same location (Fig. 5.19, left).

### Life history

Eggs are laid in groups of about 14 eggs on virtually all above-ground parts of the plant. Egg laying occurs only at dusk, and the eggs hatch in 5–7 days. As with SGSB, the first instar nymph does not feed but remains near the egg mass. After the first molt, the second instar nymphs disperse and are commonly found on nuts or flowers. The nymphal developmental period is 27–47 days, depending on temperatures. The adults become sexually mature about 8 days after the final molt and 2–9 days later begin laying eggs. Lab studies in South Africa showed adult females live an average of 44 days. A total of four generations per year have been recorded in South Africa.

### Management

#### Natural enemies

Most of the natural enemies found in Malawi have been egg parasitoids. A total of five parasitoids have been collected: *Mesocomys* sp. (Hymenoptera: Eupelmidae), *Ooencyrtus* sp. (Hymenoptera: Encyrtidae), and *Telenomus* sp., *Trissolcus seychellensis*, and *Trissolcus maro* (Hymenoptera: Scelionidae). In South Africa, a total of five egg parasitoid species were recovered including two *Trissolcus* spp., one unidentified Scelionid, an *Anastatus* spp. (Hymenoptera: Eulophidae), and a *Pachyneuron* sp. (Hymenoptera: Pteromalidae). Two tachinid flies, *Cylindromyia eronis* and *Bogosia bequaerti*, were found parasitizing adult stinkbugs in South Africa.

#### Pesticides

A number of pesticides are registered and have been tested in South Africa and Malawi. In South Africa, cypermethrin as a foliar spray, aldicarb (Temik®) as a soil treatment, and monocrotophos as a trunk treatment all provided good control. In Malawi, endosulfan (Thiodan®) is considered the material of choice because of low toxicity to natural enemies.

## False codling moth

***Cryptophlebia leucotreta***

**(Lepidoptera: Tortricidae)**

## Macadamia nut borer

***Cryptophlebia batrachopa***

### Country of origin

South Africa, Malawi, Zimbabwe, (sub-Saharan Africa); also recorded from Madagascar, Mauritius, Reunion, and St. Helena.

### Potential method of introduction

These species would likely not be introduced on macadamia, unless unhusked nuts or infested scion wood were air-shipped to Hawaii. It is more likely that they would come in on other commodities.

**Figure 5.20. Larvae of the false codling moth and its damage to macadamia shell and husk.**
Photo by E. A. deVilliers, provided courtesy of M. van den Berg.

**Figure 5.21. Larvae of *Cryptophlebia batrachopa* and its damage to macadamia husk.**
Photo by E. A. deVilliers, provided courtesy of M. van den Berg.

### General

In Malawi, *C. leucotreata* in conjunction with *C. batrachopa* fills the same niche as KSW and LFM in Hawaii's macadamia orchards, and they occur in approximately equal numbers. They are similar in appearance and life history, much like KSW and LFM. *C. leucotreta* is a serious pest of cotton and citrus as well as macadamia, and it has been shown to develop insecticide resistance rapidly.

### Damage

Damage is caused by the caterpillars boring into the husk and causing nuts to fall before full oil content is reached. As with KSW, entry through the shell is rare once the shell begins to harden.

### Host plants

The false codling moth (FCM) has a broad host range and could be a serious problem for Hawaii agriculture. FCM has been reared from banana, litchi, citrus, cotton, corn, sorghum, guava, hibiscus, custard apple (*Annona reticulata*), olive, persimmon, avocado, pomegranate, and mangosteen.

### Life history and description

Females deposit from 100 to 400 eggs that are generally laid singly on nuts and hatch 6–8 days later. Eggs are white, flattened ovals about 0.035 inch (0.9 mm) in diameter with a finely pitted surface. As with KSW and LFM, nuts are most attractive to the ovipositing females when they are larger than 0.8 inch (20 mm) in diameter. The eggs hatch and the larvae either tunnel directly into the fruit or move a short distance from the egg and enter the fruit there. The larvae feed within the husk for 3–4 weeks until they mature. At that time, they are about 0.6–0.7 inch (15–18 mm) long and vary in color from grayish white to pinkish white with discrete, small, dark green spots and a dark brown head capsule (Fig. 5.20, 5.21). The mature larva emerges from the nut and drops to the ground to pupate. Pupation can occur in the soil, in crotches of branches, or occasionally in dropped nuts. The pupal stage lasts about 9–14 days. The adults are gray with a silver spot on the inner wing (*C. batrachopa* lacks this spot), and adults are about 0.25 inch (6–7 mm) long with a wingspan of 0.8 inch (20 mm). There is no diapausing stage of *C. leucotreta* in South Africa, so that reproduction is continuous. In Malawi, however, diapause does occur. The total developmental time is generally 5–6 weeks.

### Management

#### Natural enemies

A wide variety of parasitoids of FCM have been recorded from citrus, cotton, and macadamia nuts. On macadamia nuts in Malawi, a total of seven species of larval parasitoids have been recorded from both FCM and *C. batrachopa*. Most of these have only been identified to the genus level and include a chalcid wasp (*Antrocephalus* sp.), three species of Ichneumonid (*Apophua* sp., *Diadegma* sp., and *Trathala* sp.), and three species of Braconid (*Ascogaster* sp., *Bracon hancocki*, and *Phanerotoma* sp.). All the species except *Diadegma* are endoparasitoids (occur within the larva). *Diadegma* is an ectoparasitoid and may move on to other caterpillars after killing its initial caterpillar. *Antrocephalus* sp. appears to be a larval-pupal parasitoid (the larva is parasitized and emerges from the pupal stage of the host). In the studies conducted in Malawi, *Diadegma*, *Ascogaster*, and *Bracon hancocki* were the most common species.

In addition, an egg parasitoid, *Trichogrammatoidea cryptophlebiae*, has been found to be highly effective at reducing FCM (and *C.batrachopa)* populations.

### Mating disruption

The pheromone for FCM has been synthesized and it has been used for both monitoring and mating disruption studies. The studies showed mixed results and indicated some problems with finding the correct blend and probably with pheromone release rates. But dispenser technology has greatly improved since those studies were performed, and it is likely that mating disruption will be a viable technology soon. However, as in some other cases where mating disruption is used, migration of already mated females between alternate, untreated host plants into the orchard diminishes the efficacy of mating disruption.

### Pesticides

Pesticides have been recommended for FCM control on a number of crops. However, control is often unsatisfactory because the eggs are typically laid in areas that are difficult to contact with the pesticide spray. In addition, there have been problems on both cotton and citrus with insecticide resistance.

In Malawi, the pyrethroids deltamethrin and cypermethrin are recommended for control of FCM and *C. batrachopa*. However, this would be a last-ditch recommendation in Hawaii because of the probability of destroying the natural enemies of our current pests and resulting in pest resurgences. If either of these pests makes it to Hawaii, some of the "softer" pesticides, such as growth regulators, or some of the newer pesticide chemistries should be pursued on a short-term basis until biological control can be established.

**Figure 5.22. Leafcutting ant, *A. cephalotes,* carrying leaf back to nest.**
Photo courtesy of USDA-ARS.

## Leafcutting ants

***Atta cephalotes, A. mexicana, A. sexdens***

### Country of origin

Members of the genus *Atta* are all found in tropical and subtropical portions of North and South America. The group is most common from about 30° south latitude to 30° north latitude. The three species above were reported by Mitchell and Ironside (1982) to be a problem in Costa Rica, but other species in South American macadamia growing areas are probably also involved.

### Potential method of introduction

Ants of any species would probably be most likely to come in on plants introduced with soil.

### General

Leafcutting ants are fungus-growing ants that feed on fungi that they culture within their nests. Leaves are cut from the tree and taken to the nest where they are licked and cut into small pieces (Fig. 5.22). Worker ants chew the pieces into a pulpy mash to which they add salivary secretions. This mash is then placed in the fungus garden near fungal mycelia and fertilized with fecal droplets. The ant salivary secretions are thought to contain some essential enzymes for fungal growth, because the fungi appear to lack the full complement of enzymes necessary to metabolize nitrogen from the leaves. The fungus thus cannot exist without the ants, and it will die if the ants are removed.

Adult ants feed on the fungus but also are nectar feeders, predators, and scavengers. The larvae are able to subsist and grow solely on the fungus.

Figure 5.23. Ant barriers on trunk of litchi tree. White material is fiberfill batting wrapped in clear tape covered by adhesive.

*A. cephalotes* in particular appears to become a problem when forest land is cleared for agriculture, and it is considered a pest of agriculture in general from Mexico to Brazil.

### Damage

Damage from leaf cutting ants can be extensive, particularly on young transplanted trees. Typically, the damage starts at the edges of the leaf, which are notched by the ants, but entire trees can be defoliated overnight.

### Host plants

There appears to be some variability in the range of host plants used by leaf cutting ants. In general, however, they have a very broad host range and can forage from their nest to a distance of over 300 feet.

### Life history and description

All the leafcutting ants have a similar life history. Before the nuptial flight, the new queen cuts off a small wad of fungus and stores it in a small cavity in her mouth. The nuptial flights begin in the afternoon, and mating takes place in the air. Following the flight, the males die and the queen casts off her wings and excavates a burrow in the soil. The nest is typically 8–12 inches (20–30 cm) deep and about 2.4 inches (6 cm) long and high. The queen spits the fungal wad on the floor of the chamber, and within 3 days it begins to grow in all directions. The queen begins to lay eggs and tends the fungus by using droplets of fecal liquid. After the first month, the first workers emerge and within a week they dig their way to the surface and begin foraging for leaves. At this point, the queen specializes in egg laying and the workers take over care of the fungal garden. A colony has only a single queen and she can live up to 15 years.

Nest growth is initially slow but increases dramatically with time. For example, a nest of *A. sexdens* that was 77 months old contained 1920 chambers, with 248 of them occupied by fungal gardens or ants. The loose soil excavated by the ants was measured and found to be 1820 $ft^3$ (22.7 $m^3$) and weighed about 88,200 lb (40,000 kg). Estimates of the number of workers in a single *A. sexdens* nest range from 5 to 8 million, and their foraging trails can be longer than 330 ft (100 m).

### Control

Physical barriers used to prevent ants from ascending trees in other crop systems should be effective for macadamia. In Hawaii, barriers for the bigheaded ant, *Pheidole megacephala*, in coffee consist of a fiberfill batting wrapped around the trunk and held in place by tape coated with an adhesive (Fig. 5.23). The fiberfill batting is packed tightly enough to prevent the ants from going under it, and the fiberfill also does not absorb water. The barriers can last up to 2 years but require recoating with the adhesive every 1–2 months depending on the amount of dirt and dust present. The tree must also be trimmed so that no part of it contacts anything the ants can climb up. The cost of maintaining the barriers is excessive for large orchards but would be reasonable for a small farm orchard.

Pesticides can control leafcutting ants, and several studies have been done to determine their efficacy. However, with the rapid changes in laws, application technology, and new chemistry, no recommendation can currently be made for the leaf cutters if they should make it to Hawaii. If the ants do make it to Hawaii, it is likely that they would be subject to an eradication effort, because they would probably cause an ecological disaster for Hawaii's forests and native vegetation.

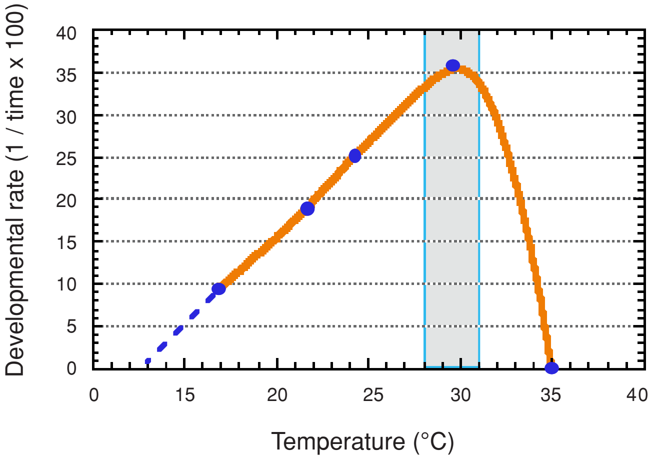
# Appendix A.
# Heat-Driven Phenology Models

Models for insect development can be created that take advantage of the relationship between temperature and developmental rate. Because the insect is cold-blooded, its developmental rate is related to the environment's temperature, not to normal calendar-based time. The unit of time for temperature-based time (also known as *physiological time*) is called the *degree-day* (°D). By definition, a degree-day is the amount of heat accumulated when the temperature is 1° above the lower threshold for development for 1 day. Because different insects have different lower thresholds for development, when using a degree-day developmental scale, the lower threshold must be defined. For example, a time is given as 200 $^{\circ}\mathrm{D}_{50^{\circ}\mathrm{F}}$. Degree-days are normally calculated using tables that list the upper and lower daily thresholds. The heat is then accumulated over time.

The models work because of what is called "*the law of constant thermal summation*." Basically, this means that the amount of heat required for an insect to complete development is constant, regardless of how fast the heat is accumulated (within reason). An analogy is that a 5 gallon bucket holds 5 gallons, regardless of whether you use a quart container or a half-gallon container to fill the bucket.

How is the lower threshold for development and the time in degree-days for the insect to complete a stage determined? This is done by running lab experiments to determine how long (in calendar days) it takes the insect to complete development at four or more different temperatures. The rate of development (1 / developmental time) is then plotted against the temperature (Fig. 6.1). On the graph, note that the temperatures from 15°C to 30°C lie approximately on a straight line. By drawing a line through these four temperatures, the developmental rate can be projected down to the point where the developmental rate is zero. This point is about 13 °C and is known as the *lower threshold for development* or *developmental zero*. The developmental rate is highest in the light grey area. However, if the temperature goes higher, the developmental rate drops rapidly down to zero. The point where the developmental rate starts to drop is where heat starts to disrupt the physiological processes that occur within the insect. If the temperature drops, the insect will go on developing without any ill effects. This point is called the upper threshold for development. If the temperature goes above this point, the developmental rate drops to zero and the animal dies, because the physiological processes are irreversibly disrupted. This is the basis behind the use of high temperatures to disinfest fruit-fly infested fruit; the temperature is raised high enough that the insect dies.

**Figure 6.1. Developmental rate of the egg stage of koa seedworm as a function of temperature.**



To determine the total length of time (in degree-days) for the insect to complete development, simply divide the slope of the line used to project to developmental zero by 1 (i.e., 1 / slope).

### Example calculations

The temperature and developmental rate during the four lower temperatures (linear portion of the curve in Fig. 6.1) are found in Table 6.1.

The data above can be used with a technique called linear regression to determine the slope and the intercept of the line through the four temperatures. When this is done, the slope is equal to 0.021 and the intercept is –0.26. The sample calculations of the developmental zero are given by: [–x intercept / slope] or 12.4. The duration of the stage is 1 / slope or 1 / 0.021 and equals 47.6 degree-days.

**Table 6.1. Developmental time of koa seedworm at different temperatures.**

| Temperature (°F) | Average developmental time (days) | Developmental rate* |
|---|---|---|
| 62.4 | 10.7 | 0.093 |
| 71.1 | 5.3 | 0.188 |
| 75.7 | 4.0 | 0.250 |
| 85.3 | 2.8 | 0.357 |

*Rate = 1 / average developmental time

# Appendix B.
# Sequential Sampling Examples

Two examples of sequential sampling for infested nuts are shown in Table 6.2. The chart is used by recording in the fourth column whether or not a nut is infested (1 if infested, 0 if not). The number of infested nuts is then totaled in the fifth column. In Example 1, sampling stops after the 15th nut is examined (only 15% of the work of sampling all 100 nuts). Sampling does not stop at nut 13 when the total number of nuts damaged is *equal to* the value in Column 3. The total number of infested nuts must be *greater than* the value in Column 3 to stop sampling. In Example 2, sampling stops after examining 33 nuts (33% of the work of a 100-nut sample). As with Example 1, sampling does not stop after nut 27 when the number of nuts damaged is *equal to* the value in Column 2; it must be *lower than* the value in Column 2. The correct way to interpret Example 1 is that the percentage of nuts infested is significantly greater than 20% infested, which is the upper threshold for management action, and some treatment should be applied. The correct interpretation of Example 2 is that the percentage of damaged nuts is significantly lower than 12%, and no treatment need be applied. If 100 nuts are sampled without reaching a decision, return in 10 days and resample the area.

## Table 6.2. Examples of sequential sampling to arrive at a pest management action decision.

| Example 1 | | | | |
|---|---|---|---|---|
| No. of nuts inspected | *STOP* if total no. damaged nuts is | | Nut is infested (yes = 1, no = 0) | Total number damaged |
| | Less than: | More than: | | |
| 1 | 0 | 4 | 0 | 0 |
| 2 | 0 | 4 | 0 | 0 |
| 3 | 0 | 4 | 1 | 1 |
| 4 | 0 | 4 | 0 | 1 |
| 5 | 0 | 4 | 1 | 2 |
| 6 | 0 | 5 | 1 | 3 |
| 7 | 0 | 5 | 0 | 3 |
| 8 | 0 | 5 | 0 | 3 |
| 9 | 0 | 5 | 0 | 3 |
| 10 | 0 | 5 | 1 | 4 |
| 11 | 0 | 5 | 0 | 4 |
| 12 | 0 | 6 | 1 | 5 |
| 13 | 0 | 6 | 1 | 6 |
| 14 | 0 | 6 | 0 | 6 |
| 15 | 0 | 6 | 1 | 7 |
| 16 | 0 | 6 | | |
| 17 | 0 | 6 | | |
| 18 | 0 | 6 | | |
| 19 | 0 | 7 | | |
| 20 | 0 | 7 | | |
| 21 | 0 | 7 | | |
| 22 | 0 | 7 | | |
| 23 | 0 | 7 | | |
| 24 | 0 | 7 | | |
| 25 | 0 | 8 | | |
| 26 | 0 | 8 | | |
| 27 | 1 | 8 | | |
| 28 | 1 | 8 | | |
| 29 | 1 | 8 | | |
| 30 | 1 | 8 | | |
| 31 | 1 | 8 | | |
| 32 | 1 | 9 | | |
| 33 | 2 | 9 | | |
| 34 | 2 | 9 | | |
| 35 | 2 | 9 | | |
| 36 | 2 | 9 | | |
| 37 | 2 | 9 | | |
| 38 | 2 | 10 | | |
| 39 | 3 | 10 | | |
| 40 | 3 | 10 | | |
| 41 | 3 | 10 | | |
| 42 | 3 | 10 | | |
| 43 | 3 | 10 | | |
| 44 | 3 | 11 | | |
| 45 | 3 | 11 | | |

| Example 2 | | | | |
|---|---|---|---|---|
| No. of nuts inspected | *STOP* if total no. damaged nuts is | | Nut is infested (yes = 1, no = 0) | Total number damaged |
| | Less than: | More than: | | |
| 1 | 0 | 4 | 0 | 0 |
| 2 | 0 | 4 | 0 | 0 |
| 3 | 0 | 4 | 0 | 0 |
| 4 | 0 | 4 | 0 | 0 |
| 5 | 0 | 4 | 0 | 0 |
| 6 | 0 | 5 | 0 | 0 |
| 7 | 0 | 5 | 0 | 0 |
| 8 | 0 | 5 | 1 | 1 |
| 9 | 0 | 5 | 0 | 1 |
| 10 | 0 | 5 | 0 | 1 |
| 11 | 0 | 5 | 0 | 1 |
| 12 | 0 | 6 | 0 | 1 |
| 13 | 0 | 6 | 0 | 1 |
| 14 | 0 | 6 | 0 | 1 |
| 15 | 0 | 6 | 0 | 1 |
| 16 | 0 | 6 | 0 | 1 |
| 17 | 0 | 6 | 0 | 1 |
| 18 | 0 | 6 | 0 | 1 |
| 19 | 0 | 7 | 0 | 1 |
| 20 | 0 | 7 | 0 | 1 |
| 21 | 0 | 7 | 0 | 1 |
| 22 | 0 | 7 | 0 | 1 |
| 23 | 0 | 7 | 0 | 1 |
| 24 | 0 | 7 | 0 | 1 |
| 25 | 0 | 8 | 0 | 1 |
| 26 | 0 | 8 | 0 | 1 |
| 27 | 1 | 8 | 0 | 1 |
| 28 | 1 | 8 | 0 | 1 |
| 29 | 1 | 8 | 0 | 1 |
| 30 | 1 | 8 | 0 | 1 |
| 31 | 1 | 8 | 0 | 1 |
| 32 | 1 | 9 | 0 | 1 |
| 33 | 2 | 9 | 0 | 1 |
| 34 | 2 | 9 | | |
| 35 | 2 | 9 | | |
| 36 | 2 | 9 | | |
| 37 | 2 | 9 | | |
| 38 | 2 | 10 | | |
| 39 | 3 | 10 | | |
| 40 | 3 | 10 | | |
| 41 | 3 | 10 | | |
| 42 | 3 | 10 | | |
| 43 | 3 | 10 | | |
| 44 | 3 | 11 | | |
| 45 | 3 | 11 | | |

# Appendix C.
# Monitoring Tools

The purpose of this appendix is to show the various traps and monitoring tools mentioned in other parts of this manual. Use of the traps is mentioned in the various sections on pests.

Pheromone traps (Fig. 6.2) for koa seedworm and litchi fruit moth are very selective and bring in very few other types of insects. An exception is the moth *Stoeberhinus testaceus,* which also is attracted to the same pheromone (the oriental fruit moth pheromone). These moths are smaller and quite different in appearance, with several spots on the wings. Pheromone traps for KSW and LFM only attract males. The trap has a sticky surface that captures the moths. The KSW and LFM adults can be separated using the descriptions given in this book.

Light traps (Fig. 6.3) are very expensive and difficult to maintain. In addition, they bring in a wide range of insects, making them difficult to use when monitoring only a few specific pest insects. They can be used for monitoring KSW and LFM and, if the correct light source is used, may also attract SGSB. The insects are attracted to the light, hit a clear vane on the trap, and fall into a funnel that carries them to a jar that can be filled with alcohol or water with a small amount of soap (to break the surface tension on the water and allow the insect to sink).

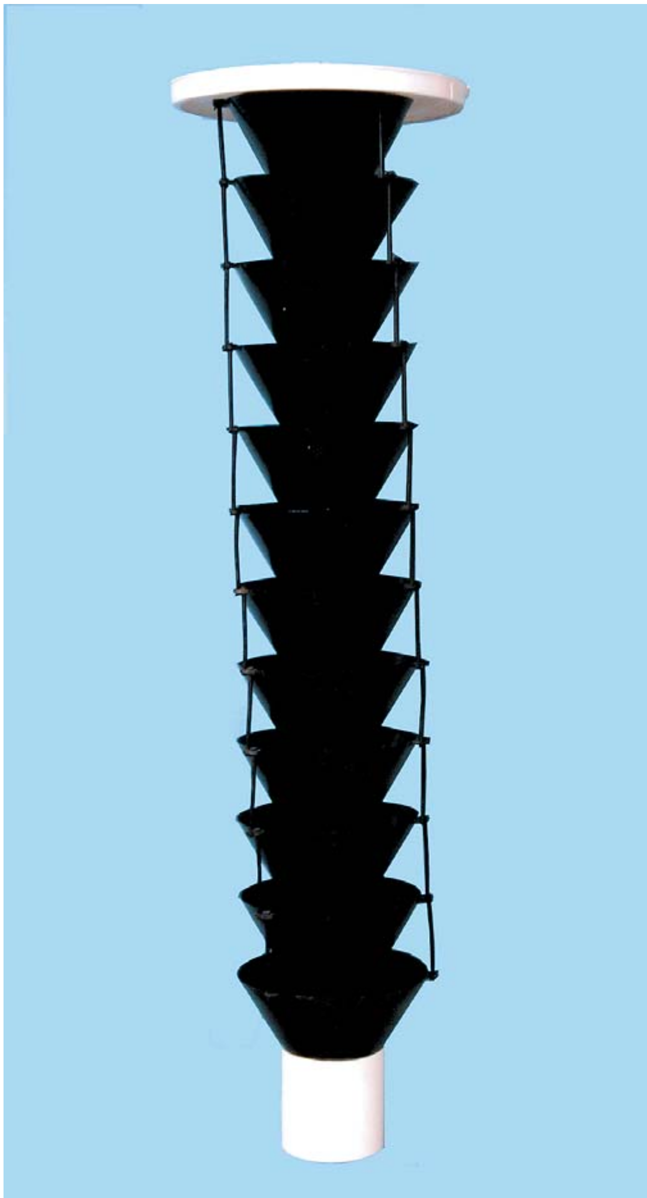
The bag traps (Fig. 6.4) used for TNB are fairly selective and easy to use. Green nuts from the canopy should be placed in a wide mesh bag and marked with flagging tape to help locate the bag later.

**Figure 6.2. A wing-style pheromone trap used to monitor koa seedworm and litchi fruit moth.**

**Figure 6.3. A bucket-style light trap.**
The circular bulb is held up by clear plastic vanes. The insects fly into the vanes, drop into a funnel inside the bucket, and end up in a jar.

**Figure 6.4. Bag trap for estimating tropical nut borer damage.**

**Figure 6.5. Funnel trap, normally baited with ethanol, used to capture tropical nut borer adults.**



Funnel traps used for tropical nut borer monitoring bring in a wide range of insects but not nearly as wide a range as the yellow sticky panels or light traps. They are expensive and cumbersome to use but work well if the faults can be overlooked. The trap is a series of funnels that mimic the trunk of a tree, and ethanol is used as an attractant (Fig. 6.5). The insect flies in, hits a funnel, and drops to a collection jar at the bottom. The ethanol is thought to be attractive because it is one of the first breakdown products of wood decay, and bark beetles tend to attack weak trees.

Yellow sticky panels (Fig. 6.6) are attractive to a wide range of insects. The yellow color is visually attractive and the traps are useful for monitoring redbanded thrips, Hawaiian flower thrips, and certain parasitoids. Because these are visual traps, the trap should be placed near the outer canopy of the tree, and leaves and nuts should be removed from about 1 foot (0.3 m) around the trap.

Adhesives from the traps can be removed from your hands using waterless hand cleaner. Insects can be removed from the adhesives using solvents available from various places where traps are sold.

Commercial sources of insect traps are companies such as Brewer Environmental Industries, Great Lakes IPM, Trece Inc., Gemplers, IPM Technologies, and Centurion. Traps may also be purchased from some pesticide distributors.

In addition to traps, several other sampling devices are available. For example, a beating sheet (Fig. 6.7) is a useful method of sampling insect populations. In other crop systems, a large canvas sheet is placed below a

Figure 6.6. Yellow sticky panel, a visual trap attractive to flying insects such as aphids, flies, and thrips.

Figure 6.7. Beating sheet to dislodge small insects. The raceme is gently tapped on the sheet, and the insects show up against it.

tree branch and the branch is tapped with a padded stick. The insects are dislodged and fall to the sheet where they can be counted or collected. In macadamia, any flat surface such as a manila file folder or a notebook can be used for sampling thrips or aphids on racemes. Place the flat object beneath the raceme and tap the raceme on the surface (Fig. 6.7).

Sweep nets (Fig. 6.8) can be used to sample insects in macadamia orchards, but they are primarily useful for sampling insects in the weeds within or at the orchard border. Pests likely to be collected this way include SGSB and katydids. The sweep net is used by sweeping it back and forth in the top part of the vegetation. For our purposes, a standardized method is not required because the sweep net is used primarily to determine the presence of the insects, not give an absolute number.

Finally, although they are not used to monitor insects, water-sensitive cards are available for checking pesticide coverage. The cards should be placed in various positions in the canopy of the tree before spraying and removed and examined to determine the evenness of coverage.

Figure 6.8. Sweep net used to collect insects from groundcover or other vegetation within the orchard. Net is swept through the top part of the canopy, brushing the vegetation.

# Appendix D. Insect Classification

Classification of insects is difficult because of the extreme diversity of different types. At present, there are about 1.2 million different types of insects described, and it is estimated that the final number will be between 15 and 30 million different types.

Insect classification and identification is important because it gives you access to the scientific literature and because if done correctly it provides information on the evolutionary relationships between the different types of insects. Access to the literature is important because it allows you to see what has been done with the same insect somewhere else and prevents undue duplication of effort. The evolutionary relationships are critical because given information on a closely related insect, they allow a broad predictability about life history of the insect of interest.

Classification of all living things is based on a hierarchical approach. That is, there are a number of levels of identification. A *category* is a level of the hierarchy, such as a phylum, order, family, etc. It does not tell you anything about a specific organism; it provides you with the level at which the identification has been performed. A *taxon* is the name for the animal itself and provides you with a specific identification. The categories used most often (from highest to lowest) are the kingdom, phylum, class, order, family, genus, and species. For example, the koa seedworm would be classed as:

Kingdom–Animalia
  Phylum–Arthropoda
    Class–Insecta
      Order–Lepidoptera
        Family–Tortricidae
          Genus–*Cryptophlebia*
            Species–*illepida*

The kingdom level lumps all animals together and thus gives us little information, other than that it is not a plant, fungus, bacterum, or alga. The phylum level is more useful and separates the different animals, such as the vertebrates (animals with an internal backbone such as mammals) from arthropods that have an exoskelton and from various other invertebrates such as snails (Mollusca), worms (Annelida), nematodes (Nematoda), etc. Classification at the class level gives you even more information. For insects, it means that the body is divided into three major sections (head, thorax, and abdomen), they have a single pair of antennae, a single pair of compound eyes, three pairs of legs, 1–2 pairs of wings, etc. Thus as we go down the levels of the heirarchy, we get more discriminating; that is, fewer organisms meet the criteria to be included in that category and the more similar the animals included in that category are in terms of life history and form. Animals at a lower level of classification (such as the order level) always possess all the characteristics of the levels above (such as phylum or kingdom levels).

Classification to the family level is extremely useful because with insects (and mites) the similarities become pronounced enough that identification and life history information become useful in integrated pest management. Classification at lower levels is more difficult and often requires a specialist. The extreme level of classification is, of course, the species level, where only a single type of organism is described. In our example, there is only one type of insect called *Cryptophlebia illepida*, or for the case of humans, only one *Homo sapiens*.

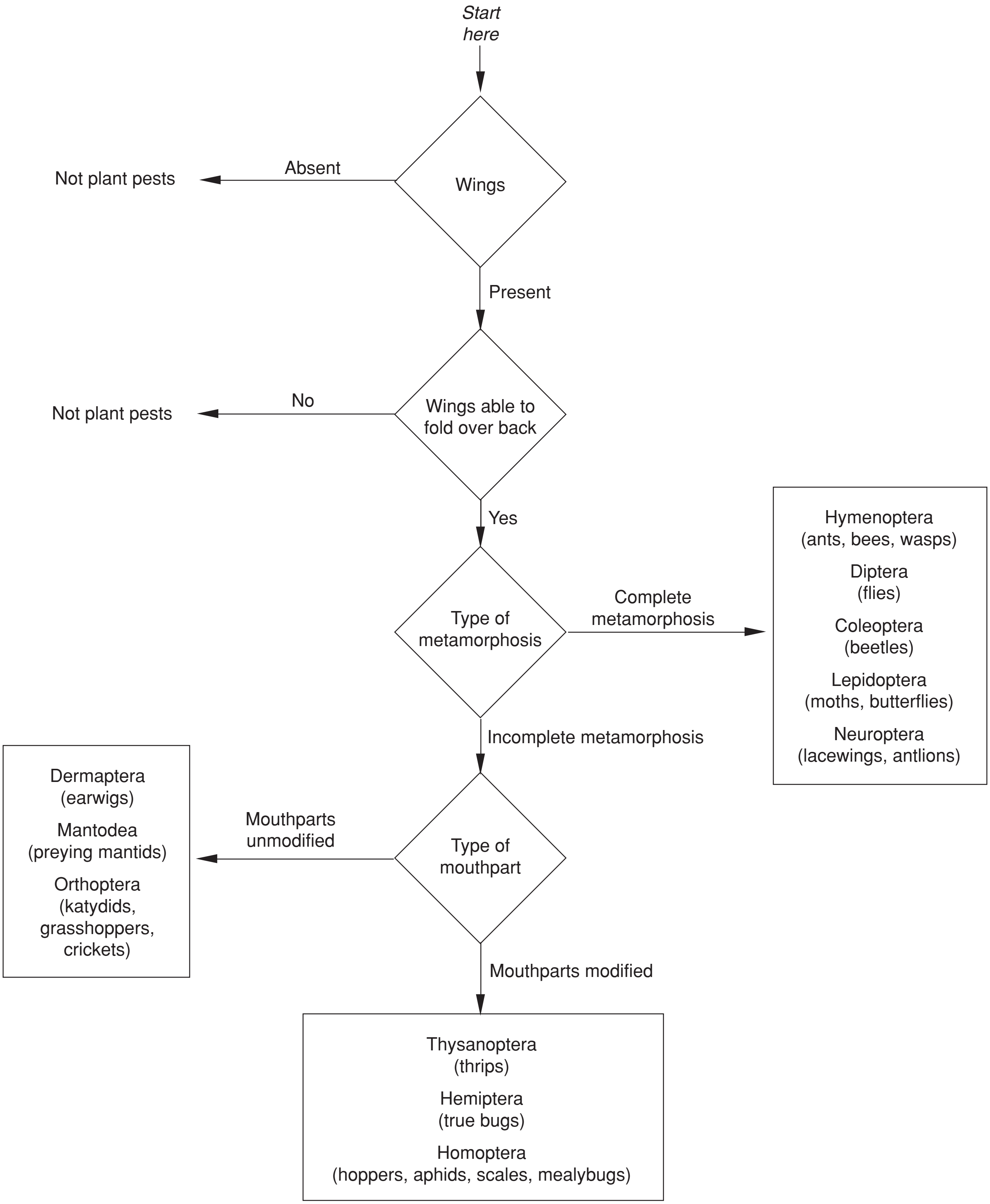
Determining the level of the classification is relatively easy because there are some conventions associated with the naming. For example, the orders of insects all end in either *-ptera* or *-ura,* except for four orders: Phasmida (stick insects), Blattaria (cockroaches), Embiidina (webspinners), and Grylloblattaria (grylloblattids). Of these four orders, only the cockroaches and webspinners are present in Hawaii. All the family names end in *-idae*, and genus names are always capitalized and either italicized or underlined (e.g., *Cryptophlebia* or <u>Cryptophlebia</u>). Specific names are never capitalized, but are also either italicized or underlined (e.g., *illepida* or <u>illepida</u>).

**Table 6.3. Economically important insect orders that occur on macadamia nuts in Hawaii.**

| Order | Common name | Example pest or natural enemy |
|---|---|---|
| Lepidoptera | Moths and butterflies | Koa seedworm |
| Coleoptera | Beetles | Tropical nut borer |
| Hemiptera | True bugs | Southern green stinkbug |
| Homoptera | Hoppers, scales, mealybugs, aphids | Black citrus aphid |
| Orthoptera | Grasshoppers, katydids, crickets | *Conocephalus saltator, Elimaea punctifera* |
| Hymenoptera | Bees, wasps, ants | Bigheaded ant, longlegged ant |
| Thysanoptera | Thrips | Redbanded thrips, Hawaiian flower thrips |
| Diptera | Flies | *Trichopoda pennipes* (SGSB parasitoid) |

The discussion above describes how we name insects (and other organisms) but not how we separate the different types of insects. Insects can be classified based on a number of characters. At the order level, the classification is based on (1) the number and form of wings, (2) types of mouthparts, and (3) life history and type of metamorphosis (Fig. 6.8). About 28 different orders of insects can be rapidly catagorized using these techniques. Not all of these different orders are present in Hawaii, and major pests or natural enemies tend to belong to only a few of the orders. The most common orders important agriculturally are listed in Table 6.3.

**Figure 6.8. Classification of the adults of agriculturally important insect orders based on mouthparts, wings, and life history.**



# Appendix E.
# Insects Identified on Macadamia in Hawaii

Mitchell and Ironside (1982) surveyed the insects found on macadamia worldwide. The following lists (Table 6.4, 6.5) update their lists to include new insect species discovered in Hawaii in the past few years. All new insects are marked with an asterisk after the species name. These lists should not be considered exhaustive, because the author has several drawers full of unidentified specimens, and intensive surveys have not been done just to determine species presence.

**Table 6.4. Plant-feeding insects identified on macadamia.**

| Scientific name | Common name | Order | Family | Plant part attacked |
|---|---|---|---|---|
| *Polyphagotarsonemus latus* | Broad mite | Acari | Tarsonemidae | Flowers, fruit |
| *Brevipalpus phoenicis* | Red and black flat mite | Acari | Tenuipalpidae | Foliage |
| *Araecerus* sp.* | Fungus weevil | Coleoptera | Anthribidae | Feeds on fungus in husk |
| *Carpophilus maculatus* | | Coleoptera | Nitidulidae | On kernels |
| *Hypothenemus obscurus** | Tropical nut borer | Coleoptera | Scolytidae | Nuts |
| *Hypothenemus seriatus** | | Coleoptera | Scolytidae | Twigs, husks |
| *Hamaxas nigrorufus** | | Dermaptera | Chelisochidae | Role unknown, found in husk |
| *Bactrocera dorsalis* | Oriental fruit fly | Diptera | Tephritidaae | Rare; reared from fallen nuts |
| *Nezara viridula* | Southern green stinkbug | Hemiptera | Pentatomidae | Nuts |
| *Aleurodicus disperses** | Spiraling whitefly | Homoptera | Aleyrodidae | Leaves |
| *Orchamoplatus mammaeferus* | | Homoptera | Aleyrodidae | Unspecified |
| *Toxoptera aurantii* | Black citrus aphid | Homoptera | Aphididae | Flowers, terminal growth |
| *Sophonia rufofascia** | Twospotted leafhopper | Homoptera | Cicadellida | Leaves |
| *Abrallaspis cyanophylli* | | Homoptera | Diaspidadae | Branches, nuts, twigs, young foliage |
| *Aspidiotus nerii* | Oleander scale | Homoptera | Diaspididae | On foliage, nuts, branches |
| *Clavaspis herculeana* | Clavate scale | Homoptera | Diaspididae | Twigs, nuts |
| *Duplasidiotus calviger* | Dupla scale | Homoptera | Diaspididae | unspecified |
| *Fiorinia fioriniae* | Avocado scale | Homoptera | Diaspididae | unspecified |
| *Hemiberlesia lataniae* | Lantana scale | Homoptera | Diaspididae | Leaves, branches, nuts |
| *Siphanta acuta** | Torpedo bug | Homoptera | Flatidae | Twigs |
| *Icerya purchasi* | Cottony cushion scale | Homoptera | Margarodidae | Branches, twigs, scions, fruit |
| *Vanduzea segmentata* | Vanduzee treehopper | Homoptera | Membracidae | Young petioles |
| *Pseudococcus longispinus* | Longtailed mealybug | Homoptera | Pseudococcidae | Seedlings, leaves, scions, terminal growth |
| *Anacamptodes fragilaria* | Koa haole looper, citrus looper | Lepidoptera | Geometridae | Unspecified |
| *Achaea janata* | Croton caterpillar | Lepidoptera | Noctuidae | Unspecified |
| *Cryptoblabes aliena* | | Lepidoptera | Pyralidae | Flowers |
| *Ephestria cautella* | Almond moth | Lepidoptera | Pyralidae | Nuts, processed nuts |
| *Amorbia emigratella* | Mexican leafroller | Lepidoptera | Tortricidae | Unspecified |
| *Cryptophlebia illepida* | Koa seedworm | Lepidoptera | Tortricidae | Nuts |
| *Cryptophlebia ombrodelta* | Litchi fruit moth | Lepidoptera | Tortricidae | Nuts |
| *Conocephalus saltator* | Longhorned grasshopper | Orthoptera | Tettigoniidae | Leaves, young shoots, racemes |
| *Elimaea punctifera* | Narrowwinged katydid | Orthoptera | Tettigoniidae | Leaves, young shoots, racemes |
| *Franklinella incisor** | | Thysanoptera | Thripidae | Racemes |
| *Heliothrips haemarrhoidalis** | Greenhouse thrips | Thysanoptera | Thripidae | Racemes, young foliage |
| *Selenothrips rubrocinctus* | Redbanded thrips | Thysanoptera | Thripidae | Nuts, foliage, racemes |
| *Thrips hawaiiensis* | Hawaiian flower thrips | Thysanoptera | Thripidae | Racemes |

*Indicates a new species recorded since the publication of Mitchell and Ironside (1982).

## Table 6.5. Beneficial insects identified on macadamia.

| Scientific name | Common name | Order | Family | Role |
|---|---|---|---|---|
| *Amblyseius largoensis** | | Acari | Phytoseiidae | |
| *Euseius* nr. *haramotoi** | | Acari | Phytoseiidae | |
| *Coelophora inaequalis* | | Coleoptera | Coccinellidae | Predator of black citrus aphid |
| *Cryptolaemus montrouzieri* | Mealybug destroyer | Coleoptera | Coccinellidae | General mealybug predator |
| *Curinus coeruleus** | | Coleoptera | Coccinellidae | |
| *Scymnodes lividigaster* | Yellowshouldered lady beetle | Coleoptera | Coccinellidae | Predator of black citrus aphid |
| *Sticholatis punctata** | | Coleoptera | Coccinellidae | |
| *Leptophloeus* sp.* | | Coleoptera | Laemophloeidae | Predator of TNB |
| *Cathartus quadricollis** | Squarenecked grain beetle | Coleoptera | Silvanidae | Predator of TNB |
| *Allograpta oblique** | | Diptera | Syrphidae | Predator of black citrus aphid |
| *Eristalinus arvorum* | | Diptera | Syrphidae | Pollinator |
| *Ornidia obesa* | | Diptera | Syrphidae | Pollinator |
| *Trichopoda pillipes* | | Diptera | Tachinidae | Parasitoid of SGSB |
| *Porontellus sodalis** | | Hemiptera | Anthocoridae | |
| *Encarsia agilior* | | Hymenoptera | Aphelinidae | Parasitoid of avocado scale |
| *Lysiphlebus testaceipes* | | Hymenoptera | Aphididae | Parasitoid of black citrus aphid |
| *Apis mellifera* | Honey bee | Hymenoptera | Apidae | Pollinator |
| *Plastanoxus westwoodi** | | Hymenoptera | Bethylidae | |
| *Prorops* sp.* | | Hymenoptera | Bethylidae | |
| *Sierola cryptophlebiae* | | Hymenoptera | Bethylidae | Parasitoid of KSW |
| *Sierola emarginata** | | Hymenoptera | Bethylidae | |
| *Sierola koa* | | Hymenoptera | Bethylidae | Parasitoid of KSW |
| *Bracon mellitor* | | Hymenoptera | Braconidae | Parasitoid of KSW |
| *Bracon omiodivorum* | | Hymenoptera | Braconidae | Parasitoid of Mexican leafroller |
| *Macrocentrus calacte* | | Hymenoptera | Braconidae | Parasitoid of LFM |
| *Brachymeria obscurata* | | Hymenoptera | Chalcididae | Parasitoid of KSW, Mexican leafroller |
| *Copidosoma* sp.* | | Hymenoptera | Encyritidae | Parasitoid of KSW |
| *Euderus metallicus* | | Hymenoptera | Eulophidae | Parasitoid of KSW |
| *Anastatus* sp.* | | Hymenoptera | Eupelmidae | Parasitoid of SGSB |
| *Eupelmus* sp. | | Hymenoptera | Eupelmidae | Parasitoid of KSW |
| *Anoplolepis longipes* | Longlegged ant | Hymenoptera | Formicidae | Predator |
| *Cardiocondyla emeryi* * | Ant | Hymenoptera | Formicidae | Predator |
| *Cardiocondyla nuda** | Ant | Hymenoptera | Formicidae | Predator |
| *Cardiocondyla wroughtoni* * | Ant | Hymenoptera | Formicidae | Predator |
| *Iridomyrmex humilis* | Argentine ant | Hymenoptera | Formicidae | Predator |
| *Monomorium floricola** | Ant | Hymenoptera | Formicidae | Predator |
| *Paratrechina vaga** | Ant | Hymenoptera | Formicidae | Predator |
| *Pheidole megacephala* | Bigheaded ant | Hymenoptera | Formicidae | Predator |
| *Plagiolepis alluaudi* * | Ant | Hymenoptera | Formicidae | Predator |
| *Solonopsis papuana** | Ant | Hymenoptera | Formicidae | Predator |
| *Strumigenys godeffroyi* * | Ant | Hymenoptera | Formicidae | Predator |
| *Stumigenys rogeri** | Ant | Hymenoptera | Formicidae | Predator |
| *Technomyrmex albipes** | Ant | Hymenoptera | Formicidae | Predator |
| *Tetramorium bicarnatum** | Ant | Hymenoptera | Formicidae | Predator |
| *Tetramorium similimum** | Ant | Hymenoptera | Formicidae | Predator |
| *Tetramorium tonganum** | Ant | Hymenoptera | Formicidae | Predator |
| *Calliephialtes grapholithae** | | Hymenoptera | Ichneumonidae | Parasitoid of KSW |
| *Echthromorpha agrestoria fuscator* | | Hymenoptera | Ichneumonidae | Parasitoid of Mexican leafroller |
| *Eriborus sinicus* | | Hymenoptera | Ichneumonidae | Parasitoid of KSW |
| *Pimpla punicipes* | | Hymenoptera | Ichneumonidae | Parasitoid of KSW, koa haole looper, Mexican leafroller |

*. . . continued*

### Table 6.5. Beneficial insects identified on macadamia (continued).

| Scientific name | Common name | Order | Family | Role |
|---|---|---|---|---|
| *Pristomerus hawaiiensis* | | Hymenoptera | Ichneumonidae | Parasitoid of KSW |
| *Trathala flavo-orbitalis* | | Hymenoptera | Ichneumonidae | Parasitoid of KSW |
| *Trichogramma* sp. | | Hymenoptera | Ichneumonidae | Reared from eggs of Mexican leafroller |
| *Trissolcus basalis* | | Hymenoptera | Scelionidae | Parasitoid of SGSB |
| *Anarhopus sydneyensis* | | Hymentopera | Encyrtidae | |
| *Chrysopa microphya* | Green lacewing | Neuroptera | Chrysopidae | Predator of black citrus aphid |
| *Sympherobius barberi* | Brown lacewing | Neuroptera | Hemerobiidae | Predator of citrus mealybug |
| *Xiphidiopsis lita* | | Orthoptera | Tettigoniidae | Predator of KSW |
| *Anagris nigricornis* | | Hymenoptera | Encyrtidae | Parasitoid of citrus mealybug |

*Indicates a new species recorded since the publication of Mitchell and Ironside (1982).

# Glossary of Terms

**abiotic factor** – something affecting insect numbers that is not biologically based; for example, rainfall and temperature are abiotic factors that can affect insect population growth.

**biotic factor** – something affecting insect numbers that is biologically based; generally refers to natural enemies such as predators, parasitoids, or pathogens.

**damage** – response of the plant to insect feeding.

**direct** – damage that occurs on the marketable part of the crop. In macadamia, it would be kernel damage or damage that causes the nuts to drop before maturity.

**indirect** – damage that occurs on the unmarketed portion of the crop, such as the leaves.

**economic injury level (EIL)** – the number of insects necessary to cause economic loss to the crop.

**economic threshold (ET)** – the number of insects at which treatment should be applied to prevent economic losses from occurring. The ET is below the EIL to allow the treatment to be applied and reduce the insect population level before it can reach the EIL.

**exoskeleton** – the external skeleton of insects. The exoskeleton is composed of chitin, arthropodin, and other compounds. The exoskeleton protects the insect from the environment and provides attachment points for muscles.

**gain threshold** – the point at which the amount of the crop saved is equal to the cost of the management program.

**hemolymph** – the blood of insects.

**instar** – the name applied to the different immature stages of an insect. They are numbered from youngest (first instar) to last. This name does not apply to the egg stage or the pupal stage.

**larva** – the immature stage of an insect with complete metamorphosis. Various specialized terms, such as maggot, grub, etc., can be used for some groups. The plural is *larvae*.

**law of constant thermal summation** – states that the amount of heat required to complete development of a given stage is independent of the rate the heat accumulates (within reason).

**lower threshold for development** – the temperature below which the development rate drops to zero; also known as developmental zero.

**metamorphosis** – change in body form for an insect as it goes through its life cycle.

**incomplete (simple)** – insects with simple metamorphosis have three stages: an egg, nymphal, and adult stage. The nymphal stages resemble the adult, but lack wings, although wing buds may be present and enlarge as the insect molts.

**complete** – insects with complete metamorphosis have four stages: an egg, larval, pupal, and adult stage. The larval stage generally does not resemble the adult and is primarily a food-gathering stage. The pupal stage is a resting stage that generally occurs in hidden locations, and the adult emerges from the pupal stage. The adult is specialized for reproduction and in some insects may not feed or only feed on nectar or pollen.

**molting** – the process by which an insect sheds its old skin so that it can grow.

**nymph** – the immature stage of insects with incomplete metamorphosis; this term does not apply to the egg stage.

**ovipositor** – the ovipositor is the tube-like egg-laying mechanism at the tip of a female's abdomen. It can be strong enough to pierce plant parts and insert the egg inside the plant. Parasitoids often have long ovipositors that they use to pierce the exoskeleton of their prey and insert the egg inside.

**parasitoid** – an insect that is parasitic in its immature stages, with the adults free-living. Generally a parasitoid kills or consumes only one prey item to complete development, but it may ultimately be responsible for killing many (the adult female typically lays eggs in many host insects, the eggs hatch, and the larva consumes the host). One stage (generally immature) is rigidly associated with the host insect.

**pathogen** – a broad term used to describe any microorganism that may cause disease or death to an insect host; includes bacteria, viruses, fungi, rickettsia, or nematodes.

**pesticide resistance** – when an originally susceptible population of insects increases its ability to resist being killed by a pesticide. The evolution of resistance is a process that increases the proportion of individuals in a population that carry resistance genes. Pesticide resistance is a population-level process.

**pheromone** – a chemical secreted by an animal that affects the behavior of other animals of the same species. Sex pheromones are generally released by the female to attract the male for mating purposes.

**physiological time** – for insects, the development rate is related to the ambient temperature of the environment. Physiological time is measured in degree-days (°D).

**predator** – an organism that kills and consumes many animal food items in its life span.

**pupa** – the resting stage of an insect with complete metamorphosis. In this stage, the genes that control larval form are turned off and those for the adult stage are turned on. The plural is *pupae*.

**raceme** – the flowering structure of macadamia, in which multiple flowers arise from an elongated central structure resembling a stem.

**sample** – a collection of sampling units.

**sampling unit** – The smallest part of the environment collected and examined for insect damage or presence.

**artificial sampling unit** – a convienent but unnatural sampling unit; examples are traps and soil cores.

**natural sampling unit** – some portion of the environment such as a leaf, twig, or fruit that is easy to relate back to the plant.

**upper threshold for development** – the temperature above which development stops because of the disruption of physiological processes.

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