STINK BUGS AND LEAFFOOTED BUGS

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Though once considered virtually pest-free, California pistachios are now attacked by a variety of insects within the Hemiptera class, which are called the true bugs (Rice et al. 1985). For convenience, these pests are commonly grouped as "small" and "big" bugs. The small bugs includes several species of Miridae and Rhopalidae that feed upon pistachio, most importantly *Calocoris norvegicus* and *Phytocoris relativus* (see chapter 20, *Phytocoris* and Soft Scale by Beede et al., and chapter 21, *Neurocolpus* and *Calocoris* by Bentley et al.) and lygus (*Lygus hesperus*) (see chapter 22, Lygus bugs by Goodell et al.). The "small bugs" (PLATES 23A,B,C) may be abundant early in the season, but usually cease to cause damage after the shell begins to harden (Bostock et al. 1987, Michailides et al. 1987). This chapter focuses on the big bugs, which is composed of species of Pentatomidae, most notably the redshouldered stink bug (*Thyanta pallidovirens*), Uhler's and Say's stink bugs (*Chlorochroa uhleri* and *C. sayi*), the flat green stink bug (*Acrosternum hilare*), and some species of Coreidae, the leaffooted bugs (*Leptoglossus clypealis and Leptoglossus occidentalis*). Known as "big bugs" by pistachio pest advisers, they cause the same damage as the small bugs before shell hardening is complete in early June. However, during the latter half of the season (from shell-hardening until harvest) the big bugs can continue to puncture the shell and, the adults of some big bug species, can damage the nut-meat even late in the season.

IDENTIFICATION

Adults of the four stinkbug species most common in the pistachio canopy are, at first glance, difficult to separate from each other – because they all share the same basic shape and green body color. Closer examination reveals differences. The two most similar and closely related species are often known together as Say's stink bugs, *Chlorochroa sayi* and *Chlorochroa uhleri*. Both of these are larger than the redshouldered stink bug, always have green and yellow colors on the head and back, and a distinctly rounded appearance when seen from above. Of the two species, *Chlorochroa uhler* is found more often in pistachio orchards. The membranous portion of its wing is transparent and pale in color, while the membranous portion of *C. sayi*'s wing has a purple hue.

The green stink bug, *Acrosternum hilare* (Plates 23D,E,F), is also a large stink bug, but it is always uniformly deep green and has a flat, rather than rounded, back. While, it is very easily confused with the southern green stink bug, *Nezara viridula*, which has almost the same size, shape and color, the latter is rarely found in pistachio orchards. (While most "flat green" stink bugs found in pistachio orchards have proven to be *Acrosternum*, it cannot be assumed that this will always be the case.)

The redshouldered stink bug, *Thyanta pallidovirens* (Plates_23G,H,I), is easily separated from the other "green colored" stink bugs. It is noticeably smaller in size. It is also the only green stink bug adult that commonly has red markings – a stripe across the widest section of its pronotum or "shoulder" – as an adult. However, this marking can be indistinct, and this stink bug has another form that is tan or dull brown, lacking green and red coloration altogether.

The two leaffooted bugs, *Leptoglossus clypealis* and *Leptoglossus occidentalis* are easily separated from the stink bugs. Their bodies are longer, narrower and colored brown with a cream zigzag line across the "shoulder" area. They are named for the leaf-like flattened extensions on their hind legs. *Leptoglossus clypealis* (PLATES 23J,K,L), the species more common in pistachios, has a sharp point on the front of its head, while *L. occidentalis,* the western conifer-seed bug lacks this sharp point.

The descriptions provided apply only to the adult bugs. All species pass through five immature, or nymphal, stages, each of which may be very different from the others; all are distinct from the adult. Although space limitation precludes description here of all of these forms, their recognition may be just as important as that of the adults, because visual monitoring techniques tend to yield more immature than adult individuals. Photographs of these big bug pest as well as the small bug pests can be found at the University of California Statewide Integrated Pest Management Website <www.ipm.ucdavis.edu>. As an example of the importance of proper identification, we highlight two common problems with the misidentification of immature big bugs.

At first glance, immature leaffooted bugs and immature assassin bugs, which are beneficial predatory insects, can be difficult to separate. These two groups can be rather easily distinguished in the field, however, because under a hand lens, assassin bug nymphs will be seen to have a very short, stout beak that often is thrust forward in a stabbing motion (to pierce insect prey), and which, when retracted, does not extend back much beyond the front legs. This contrasts with the long, narrow beak of the leaffooted bugs, which extends all the way under the body, reaching to the hind legs at the rear.

Some immature stages of the pest species of stink bugs may be confused with immature forms of the beneficial grey-brown stink bug, *Brochymena sulcata,* which can be abundant in pistachio orchards, but does not injure the nuts. There are, nevertheless, two distinguishing features of the *Brochymena* nymphs. They have a teardrop-like shape at all ages, and in addition, acquire a pattern of alternate red and black markings as they grow older.

DAMAGE

Direct Damage

The stink bugs and leaffooted bugs have needle-like, piercing-sucking mouthparts. They use their mouthparts like minute sharp straws to puncture pistachio leaves, stems and fruit and suck out the plant juice. Rice et al. (1985) demonstrated that hemipteran feeding on developing nuts causes epicarp lesion (the outward symptoms are a darkened area of the hull near the insect puncture). This appears to be simply the result of probing or feeding by any of the bugs in this group, specifically the oxidative effect of their saliva. The lesions often involve mesocarp and endocarp tissues, and can stain shells later in the season. When the bugs' mouthparts probe deeper into the nut and stab the nutmeat, an irregular shaped, sunken, necrotic pocket forms, where a bug has fed directly upon the kernel, and is called kernel necrosis. Often along with feeding a mold infests and stains or blackens the nut, a condition referred to as stigmatomycosis (Michailides and Morgan 1990). This occurs if the bug's mouthparts are contaminated with fungi. In nuts affected by stigmatomycosis, the entire kernel may become dark, wet and foul-smelling.

All of the small and big bugs mentioned can cause significant physical damage (Michailides et al. 1987; Purcell and Welter 1990, 1991; Daane et al. 2005) although there are seasonal differences in the importance of these two groups. Shortly after bloom, when the nuts are "bb-sized," epicarp lesion caused by both groups appears shortly after their feeding and the injured nuts drop from the tree. At this time, some nut drop can be tolerated because the plant "compensates" for this loss by shedding fewer nuts later in the season. Previous work has shown that, early in the season, when the nuts are "bb-sized," feeding punctures can quickly result in epicarp lesions and the damaged fruit often drops from the cluster (Uyemoto et al. 1986; Beede et al. 1995, 1996; Daane et al. 2005). Prior to shell hardening in early June, during nut enlargement, both small and big bugs are still capable of causing epicarp lesion and kernel necrosis. The appearance of external damage is the same. However, developing nuts attacked by the big bugs develop a white netting on the internal shell tissue compared to a dark internal pitting from small bug feeding. After shell hardening, the only the big bugs are able to penetrate the shell and feed upon the developing nutmeat. This damage remains in the cluster, lowering overall fruit quality. The amount of kernel necrosis depends on the species of big bug and when the nut was attacked during kernel filling. Michailides et al. (1988) showed that kernel damage was greatest with adult leaffooted bugs and stink bugs, and that kernel necrosis was most commonly associated with feeding wounds at the base of the petiole where it attaches to the nut. This was referred to as the "Achilles heel" of the pistachio because this tissue remained softer and more easily penetrated during kernel development (July to September).

The seasonal variation in hemipteran species, and its importance to crop yield, can be seen by comparing bug species composition and abundance in the orchard to the number of nuts per cluster. Daane et al. (2005) collected over 20,000 insects in biweekly "sweep net" samples (Figure 23a). Of the total insects collected, about 63% were *Calocoris norvegicus*, 21% were *Lygus* spp., 9% were rhopalids, 2% were redshouldered stink bug, and 5% were various Hemiptera (note that sweep net samples would not detect leaffooted bugs or other species that are found solely in the pistachio canopy).

The collection of small bugs was skewed towards the early part of the season and big bugs were more commonly collected later, although these numbers are subject to a great deal of variation depending on region, orchard location, and season variation in small and big bug densities. In Figure 23a, data from 9 orchard blocks are combined, with information on insect counts superimposed with data on (Fig. 1A) nuts per cluster and (Fig. 1B) lesions per cluster. The results show that while small bugs (such as *Calocoris*, *Phytocoris* and *Lygus*) were most common early in the season, the natural nut drop accounted for the vast majority of early- and mid-season fruit load decrease. This indicates that the small bugs' role, in terms of direct damage, may be minimized because their greatest numbers often occur during the period of natural nut decline.

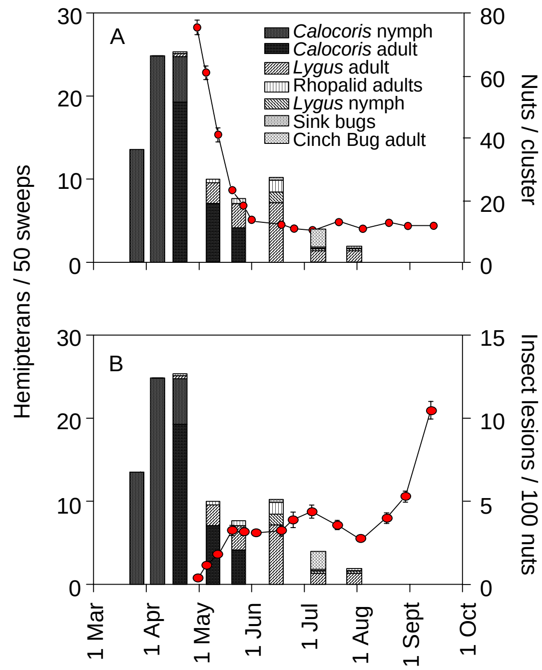

Figure 23a. The average number and species composition of hemipteran pests collected in sweep net samples in 9 orchard blocks along with (A) the average number of nuts per cluster and (B) the average number of insect lesions per 100 nuts (both indicated by closed circles). Fresno and Madera counties, 1999.

In contrast, in our surveys the big bugs, especially the leaffooted bug, were common throughout the season and were often found in greater numbers in the pistachio canopy in July and August, after the nut cluster load has dropped to near 20 nuts. During this later part of the season, insect feeding damage may have a greater economic effect because there is little plant compensation, as indicated by the "Insect Lesions per 100 nuts" in Figure 23a. However, it is unclear how much damage an individual bug can cause and whether or not late season bug feeding will result in crop loss, kernel damage or, if there is kernel damage, economic loss.

These questions were investigated at Kearney Agricultural Center. To manipulate seasonal occurrence of bugs, pistachio clusters were isolated with organdy cages (before bud break), into which a single insect was placed at different periods throughout the growing season (see Daane et al. 2005 for details). The resultant numbers of epicarp lesions and kernel necrosis were compared.

As expected, results showed damage levels varied depending on the nut phenology (e.g. season) and insect species. Most nymph and adult species tested could puncture the nut's epicarp, or outer skin layer, throughout the season. However, the darkened epicarp lesions that result from puncture wounds early in the season were not always evident later in the season. Therefore, late season bug feeding might not show any visible external marks for weeks or months after the nut was punctured, if at all.

Of importance for this discussion is the damage caused to the nut meat after shell hardening. The relationship in the insect's ability to damage the late-season nuts may be related to the general size of the insect – leaffooted bugs and flat green stink bugs are large and may be more capable of getting through the shell and reaching the nutmeat. In contrast, *Calocoris* adults and small nymphs of the redshouldered or flat green stink bugs, were unlikely to damage the kernel after shell hardening. Damage to the kernel was greatest with adult leaffooted bugs and stink bugs, with kernel necrosis most commonly associated with feeding wounds located near the "Achilles heel" of the pistachio – that region near the petiole and the shell division, as noted earlier by Michailides et al. (1993, 1996) and Daane et al. 2005).

Results from monitoring damaged nuts in commercial fields during the critical mid- and late-season periods showed that those epicarp lesions formed from June through September directly reduce crop. In other words, the natural nut drop of damaged nuts early in the season (e.g., plant compensation for *Phytocoris* feeding) does not work in mid- and late-season periods. We also found that it can be quite difficult to determine damage levels in August and September because the big bug feeding wounds (epicarp lesions) may not be apparent for many weeks or months after the feeding incident. This means that increases in the number of epicarp lesions observed in August may be the result of a big bug population in July.

In the cage studies we more closely followed this mid- and late-season big bug feeding and consequent damage. Late-season feeding by leaffooted bugs and stink bugs produced the most interesting results, suggesting that feeding after mid-August may not cause epicarp lesions for many weeks (if at all). In Figure 23b, we provide an example of feeding injuries from leaffooted bug caged for seven days in late May (Figure 23b-A) that show feeding wounds quickly turn into new and then old epicarp lesions, which stay with the cluster until harvest. In contrast, when feeding occurred in late June (Figure 23b-C)

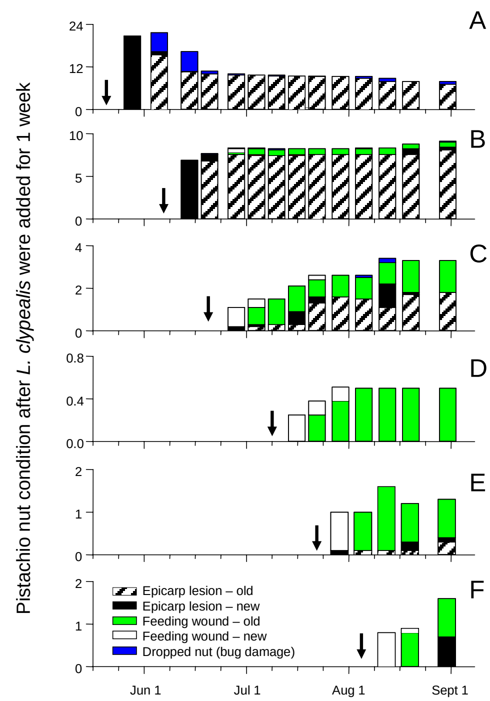

Figure 23b (A-F). Leaffooted bug damage to nuts. The arrows indicate the date when the cages were inoculated with leaffooted bugs (*Leptoglossus clypealis*). Each stacked bar represents averages for the number of nuts that showed the following damage signs: epicarp lesion – old, epicarp lesion – new, feeding wound – old, feeding wound – new, dropped nut with bug damage (key is in the bottom left corner).

the puncture wounds did not readily result in epicarp lesions, and by late July and August, leaffooted bug feeding was rarely evident as an "old" epicarp lesion (Figures 23b-D, 23b-E, 23-F). Overall, it is important to stress that the level of kernel damage dropped as the season progressed and the shell became harder. While some of the adult big bugs could puncture through to the nut meat, the amount of damage after shell hardening was far lower than before.

Indirect Damage

As mentioned earlier, Hemiptera feeding wounds are also associated with the fungal infections and result in a condition called stigmatomycosis (Michailides and Morgan 1990). Another fungus, *Botryosphaeria dothidea* (hereafter referred to as Bd), is a panicle blight of pistachios, which can result in epidemic-like loss to pistachio crops (Michailides et al. 1991). The association between insects and Bd presents could present a threat to pistachio IPM because these pests feed on and move between many different plant species (da Silva et al., 1995), some of which are sources of Bd inoculum (Michailides et al. 1991).

Fortunately, detailed tests show the big bugs are very poor vectors of Bd. In 1998 and 1999, over 30,000 hemipterans were collected from the ground cover and tree canopy in pistachio orchards in Glenn, Colusa, Contra Costa, Madera, Fresno, and Kern Counties – all of the orchards had some level of Bd infection. A subsample of the collected insects was tested for the presence of Bd. Results showed very few insects tested positive for the Bd inoculum; in fact, Bd inoculum was cultured from less than 0.2% (or 2 out of 1000).

Nevertheless, some Hemiptera carry the Bd inoculum (and the level can be much higher under the right conditions). For this reason, a series of experiments were conducted to determine the bugs' role in the movement of Bd (Steffan et al. 1999). Researchers found between-species differences in the ability of stink bugs and leaffooted bugs to "carry" Bd. For example, after exposure to nut clusters contaminated with Bd, redshouldered and flat green stink bugs "carried" Bd spores for 3 days, while adult leaffooted bugs carried spores for up to 10 days. These differences are most likely related to the ability of the Bd spores to "cling" to the outside of the insect (dissection of the bugs' mouthparts showed that the relatively large Bd spores are carried externally, not internally).

To test their ability to move Bd spores into pistachio, live insects were either placed on clusters heavily contaminated with Bd and then placed on clean clusters or placed on clean clusters that had been recently sprayed with a concentrated Live insects that were contaminated with Bd spores (e.g., walking over infected fruit with conidia) were very poor vectors – probably because the infective Bd spores were stuck to the bug's leg or abdomen hairs and not moved into the fruit.

When the Bd spores are already on the cluster (e.g., the clusters were sprayed with a concentrated liquid spore solution) bug feeding did increase Bd infection. Early season trials with small bugs (*Calocoris* and *Phytocoris*) showed Bd entered early-season fruit via insect damage and mechanical damage (pin pricks). However, most of the damaged fruit dropped from the cluster, thereby lowering early-season cluster inoculation of Bd via insect feeding wounds. When rachises were infected, it may have resulted from *Calocoris* and *Phytocoris* individuals feeding directly on the rachis, thus circumventing the nut-to-rachis infection path. In late-season trials, infection rates resulting from insect feeding were still lower than those resulting from mechanical injury with a pin-prick (Figure 23c).

The accumulated evidence suggests that only a small percentage of hemipterans carry Bd or move the disease between orchards. However, with hundreds to thousands of insects in each orchard, even a small percentage carrying Bd constitutes an important mechanism for disease transmission. If the disease is already present in the orchard, big bugs play a more important role in facilitating disease entry into the pistachio tree (than as a vector of the disease between orchards). The most probable contribution of small and big bugs is providing germination sites for the fungus. By puncturing the epicarp with their mouthparts, the bugs cause fluid to exude out onto the epicarp surface, which allows spores that are already present to germinate and eventually enter the nut.

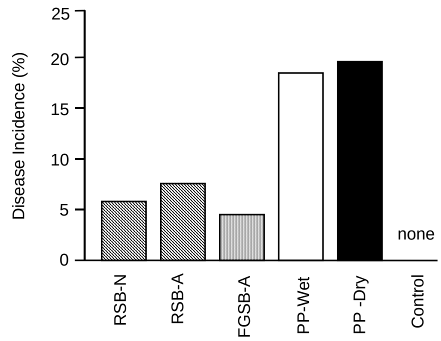

Figure 23c. Diseased clusters at harvest in cages sprayed with a liquid Bd spore suspension and provided with either: redshouldered SB nymph (RSB-N) or adult (RSB-A), a flat green SB adult (FGSB-A), a “pin-prick” immediately after the liquid spray (PP-Wet), a “pin-prick” 24 hrs after the liquid spray (PP-Dry), and a no-spray control (Control).

MONITORING

Many of these hemipteran pests can overwinter both inside and outside the orchard and can immigrate or emigrate in large numbers as adults (nymphs do not fly but adults are often strong flyers), causing severe damage in a short time. This has complicated monitoring decisions and, for many, the goal of monitoring for stink bugs and leaffooted bugs is not well-defined. Some growers are looking for the “first sign” of specific pests in order to time annual treatments, while other attempt to estimate bug densities in order to determine if treatments are needed. Therefore, detection appears important for many growers, as does prediction of damage by the population of bugs present. However, since migration and feeding patterns of the different bugs are not well understood, and economic injury levels for the different types of damage have not been established, it is difficult at this time to evaluate the practical significance of counts of bugs produced by any monitoring method.

We do know that the pests’ migratory behavior, the low economic injury threshold, the relatively poor monitoring systems, and the inefficient biological and insecticidal controls dictate that the primary goal of an IPM program should be to prevent the arrival of hemipteran pests in the pistachio canopy. How does this information relate to monitoring? First, we have to accept that unless we can locate and destroy the pest's overwintering habitat, these bugs will enter the orchard. Second, once they enter the orchard, damage can occur very quickly - in a matter of days - and can be prevented only by (1) frequent and accurate monitoring, followed by an effective insecticide application or (2) keeping the insects out of the orchard canopy. Therefore, a primary goal of any monitoring program is not simply to measure pest abundance, but the ability to use the sampling method frequently, and to accurately detect small numbers of bugs soon after their arrival.

To sample for these migratory pests, most growers have relied upon "beat-samples" of pistachio foliage. The circular “beating tray” is held under one to several clusters of nuts while that branch is hit sharply with a mallet. Provided that samples are taken frequently and from a large number of trees, the beating tray gives a good indication of changes in the numbers of bugs in the pistachio canopy. However, there are drawbacks to this methodology. First, it takes a good deal of time to sample a large field. Second, samples taken by this method will underestimate the numbers of adult bugs present, especially on warm days when adults will fly away when disturbed (counts of immature bugs, which do not fly, are more accurate, but the mature bugs will appear in the orchards first).

Field Sampling Techniques

Silva et al. (1995) evaluated different sampling programs and showed the beating tray is largely ineffective at determining pest densities and poorly estimates pest presence/detection, especially at low densities. A method that may provide early detection over a greater area is the use of a sweep net in ground vegetation (Figure 23d). Because most of these bugs will feed on the seeds of ground vegetation, sweep samples provide the best indication that hemipteran pests are in the orchard – but little information on their abundance in the canopy (Silva et al. 1996). Sweep nets can quickly sample a large area, they capture both adults and immatures and samples can be stored for a count later in the day.

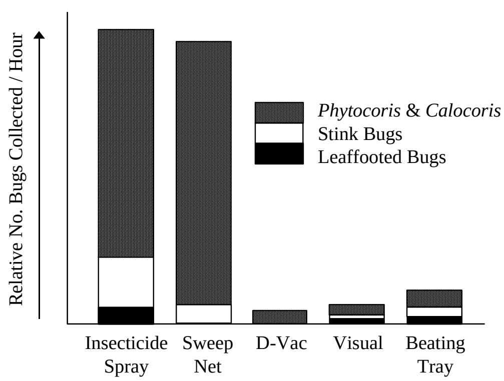

Figure 23d. The relative abundance of bug (per hour sampling) using (A) whole-tree spray and collection, (B) sweep net of ground vegetation, (C) D-Vac suction machine, (D) visual examination of canopy, and (E) a beating tray.

Data also suggest that a ground cover can temporarily "hold" hemipteran pests below the canopy. In collaboration with S&J Ranch, the effectiveness of ground vegetation to monitor hemipteran pests and hold that migratory pest population (until an insecticide could be applied) was tested. The trap crops used were alfalfa (*Medicago* sp.), barley (*Hordeum vulgare*), bell-beans (*Phaseolus* sp.), rose clover (*Trifolium* sp.), Langudoc vetch (*Vicia* sp.), and mustard (*Brassica* sp.). Each orchard was monitored throughout the year for insect populations using a sweep net, and for insect damage using counts of epicarp lesions in the clusters.

There were differences between cover crop species in the numbers of insects collected. Rows seeded with the mustard cover attracted and/or sustained the largest population of bugs, followed by vetch, clover, and alfalfa. From a single season of collections, it appeared that certain hemipteran insects showed preferences for particular cover crop species. Overall, most insects were recovered in mustard. However, this is due to the large number of "less important" hemipterans collected (e.g., rhopalids). For example, there were six different cover crop rows in a given block, yet we found the majority of redshouldered stink bugs in rows seeded with clover, most of the flat green stink bugs in vetch rows, most of the *Lygus* in alfalfa rows, and most of the *Calocoris* in mustard rows. If these insects truly prefer a given plant species, the composition of the cover crop could be tailored to "suit" the insects a grower needs to target in his/her orchard.

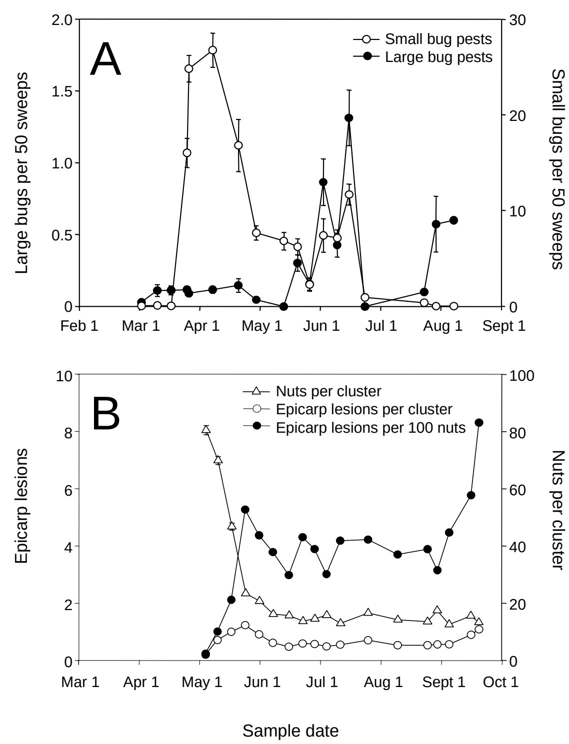

Figure 23e (A-B). A) Average (± SEM) small and big bugs collected from cover crops shows small bugs, primarily *Calocoris norvegicus*, were most common early in the season, while big bugs, most commonly stink bugs, were most common in June samples. B) Average (± SEM) total and damaged nuts per cluster show nuts and damaged (epicarp lesion).

Another method to monitor both small and big bug densities is to monitor the number of epicarp lesions throughout the season. Figure 23e shows how the number of insects, monitored in the ground cover using a sweep net, can be compared to the number of nuts. We collected >50,000 insects and, of these, we identified 29,873 specimens of bugs that could damage pistachio fruit. Most were collected between 15 March and 1 May (Figure 23e-A) and were composed primarily of small bugs: *C. norvegicus* (63%), *Lygus* (21%), and various rhopalids (9%). Big bugs were far less common, collected most often in June, and composed primarily of stink bugs. We note that our sweep samples underestimate bugs that reside primarily in the pistachio canopy, such as *Phytocoris* and the leaffooted bug.

The number of nuts per cluster dropped sharply from bloom in April to when the fruit load was set in early June (Figure 23e-B). Epicarp lesions increased during this same period and then leveled to <1 per cluster by mid-June. The percentage epicarp lesions climbed sharply just before harvest because of the presence of a large number of leaffooted bugs in 1998 and 1999.

These results suggest that while small bugs were common early in the season (April to May), the natural nut drop may reduce damage levels by dropping damaged nuts during the April to mid-May period. However, epicarp lesions formed after mid-May appear to remain in the cluster. This indicates that the small bugs' role, in terms of direct damage, is minimized because their greatest numbers occur during the period of natural nut decline. Purcell and Welter (1990) report little or no difference in pistachio yield among pistachio orchards with different population densities of *C. norvegicus*. In contrast, big bugs are more common later in the season, after the fruit load has been set. We also note that the increase of big bugs in the cover crop in late-May to early-June (Figure 23e-A) preceded their increase in the pistachio canopy in mid-August. During this later part of the season, insects will be feeding on nuts that will be harvested, and therefore may pose a greater threat to the crop load because there is little or no plant compensation, as indicated by the percentage epicarp lesions (Figure 23e-B). The amount of actual late season damage to the crop is lessened, however, because the harder pistachio shell will prevent most feeding attempts from reaching the kernel. Further, we know that much of the visible epicarp lesions found in September are a result of feeding damage that occurred in July.

Sex Pheromones

Pheromones recently have been identified for most of the important plant-feeding stink bugs, including the redshouldered stink bug *Thyanta pallidovirens* and the closely related *T. custator*, the flat green stink bug *Acrosternum hilare*, the southern green stink *bug Nezara viridula*, Say's stink bug *Chlorochroa sayi*, Uhler's stink bug *C. uhleri*, the conchuella stink bug *C. ligata*, and Consperse stink bug *Euschistus conspersus* (reviewed in McBrien and Millar, 1999). In contrast to many other insects, the pheromones are produced by the male bugs, not the females, and depending on the species, the pheromones attract females only, both males and females, or in the case of Consperse stink bug, males, females, and immatures. Field trials with the pheromones have shown that they are not as powerful attractants as the pheromones for other insects, such as moths. Furthermore, it is likely that stink bugs will only be attracted to pheromone lures when the bugs reach sexual maturity, which in some species can be as long as 10-14 days after the final molt, and bugs are unlikely to be respond to pheromone lures during the fall when they have gone into reproductive diapause in preparation for overwintering.

There are additional possible reasons for the relatively weak attraction of plant-feeding stink bugs to pheromone baited traps that has been seen so far in field trials. First, the adult bugs are long-lived, and they feed, mate, and lay eggs throughout their adult lives. Thus, there is much less pressure on these bugs to attract a mate than, for example, a moth species in which the adults do not feed, and which must find a mate quickly before they run out of energy and die. Second, it has recently become clear that mate-finding in plant-feeding stink bugs is actually a two-step process (is there a citation available here?). In the first, longer-range step, females may be attracted to the vicinity of pheromone-producing males. However, over shorter ranges, i.e., once the male and female are on the same plant, they begin producing vibrational signals, which are transmitted very effectively through the plant stem. The bugs use these vibrational signals as homing beacons, to home in on each other through the complex architecture of the plant. As it walks along the plant stem towards the signal of a potential mate, at each branch point, the bug stops and "listens" with its feet and legs, to determine which side of the junction the signal is coming from. Each sex and species produces a unique repertoire of these vibrational signals, to attract only members of its own species for mating. Thus, this combination of longer-range pheromone use and shorter range vibrational signaling must be taken into account when designing monitoring traps. Work is in progress (Please update the last couple of sentences in this paragraph to reflect the status of this work as of the end of 2005) to determine the feasibility of combining a pheromone lure with a simple battery-operated vibrational device into a trap for stink bugs. However, at the time of writing, pheromone traps for plant-feeding stink bugs are not sensitive or reproducible enough to be used reliably for monitoring stink bug populations in pistachios.

For the other big bugs infesting pistachios, the *Leptoglossus* spp., no long-range attractant pheromones have been identified yet, although there have been hints that these bugs may use attractant pheromones in two contexts. First, there is evidence that adult males produce a group of sex-specific volatiles that may play a role in attracting mates, although none of these chemicals have been completely identified yet. Second, there is evidence from field bioassays that the formation of the well-known overwintering aggregations of adult *Leptoglossus* spp. may be mediated in part by pheromonal signals. However, because these aggregations form only in fall, long after pistachios are harvested, it does not appear likely that the aggregation pheromone could be used for crop protection purposes.

In summary, until the recently developed pheromones (Millar et al. 1999 please add to references) are commercially available, there are no reliable monitoring programs that describe pest abundance, nor are there control action thresholds for individual species. For these reasons, control measures rely upon insecticides (Rice et al. 1986, Bentley et al. 1995).

CONTROL

Control strategies for big bugs are based on three important characteristics of the species involved. The first is that they are *direct* pests, causing damage to the final product as soon as they appear in the canopy. The second is that they can be *migratory* pests, whose arrival in the canopy is merely the last step in a series of events that may have begun as far away as many miles or as close as the ground vegetation below the canopy. The third is that all are *native* pests adapted to host-plants other than pistachios and possessing their own natural enemy complexes of predators and parasites within their current ranges of occurrence.

The fact that they are direct pests has led to common use of insecticidal sprays, primarily pyrethroids, to combat them. These sprays have been effective in killing the bugs. However, the lack of an economic threshold and effective monitoring device forces the crop consultant to rely upon experience and assessment of the hosts proximal to the orchard when contemplating insecticidal treatment. Control of the big bugs by preventing their migration into pistachio canopies remains a matter of controversy. One view is that alternate host plants outside the orchard should be identified and destroyed as soon as possible in order to eliminate the bugs. Others believe that the alternate hosts should be maintained in good condition for as long as possible to keep the bugs in them and to delay migration into the orchard. A third view is that growth of some of the alternate hosts (i.e., natural vegetation or cover crop) should be encouraged on the orchard floor to attract the bugs and prevent their migration from the floor to the canopy. In all cases, it seems prudent to give careful thought to the stage of development of the crop and the level of infestation of alternate host-plants when considering any management practices, such as tilling or mowing, that may affect alternate hosts. The effectiveness of ground vegetation to monitor hemipteran pests and hold that migratory pest population (until an insecticide could be applied) was recently tested in Madera County. The trap crops used were alfalfa (*Medicago* sp.), barley (*Hordeum vulgare*), bell-beans (*Phaseolus* sp.), rose clover (*Trifolium* sp.), Langudoc vetch (*Vicia* sp.), and mustard (*Brassica* sp.). Each orchard was monitored throughout the year for insect populations using a sweep net, and for insect damage using counts of epicarp lesions in the clusters.

There were differences between cover crop species in the numbers of insects collected. Rows seeded with the mustard cover attracted and/or sustained the largest population of bugs, followed by vetch, clover, and alfalfa. From a single season, it appeared that certain hemipteran insects showed preferences for particular cover crop species. Overall, most insects were recovered in mustard. However, this is due to the large number of "less important" hemipterans collected (e.g., rhopalids). For example, there were six different cover crop rows in a given block, yet we found the majority of redshouldered stink bugs in rows seeded with clover, most of the flat green stink bugs in vetch rows, most of the *Lygus* in alfalfa rows, and most of the *Calocoris* in mustard rows. If these insects truly prefer a given plant species, the composition of the cover crop could possibly be tailored to "suit" the insects a grower needs to target in his/her orchard.

The natural enemy complex of the stink bugs and leaffooted bugs includes both predators and parasites. Lacewings *(Chrysopa and Chrysoperla* spp.), assassin bugs *(Zelus* spp. and others), damsel bugs *(Nabis* spp.), ants *(Dorimyrmex and Solenopsis spp.)*, earwigs *(Forficula auricularis)* and spiders are the most abundant predators in pistachio orchards. Important parasites include *Gryon pennsylvanicum* for the eggs of *Leptoglossus, Trissolcus basalis* for those of *Nezara viridula*, *Trissolcus utahensis* and *T. euschisti* for those *of Thyanta pallidovirens and Acrosternum hilare,* and *T. utahensis* for those of *Chlorochroa sayi* and *C. uhleri.* In addition, a fly, *Trichopoda pennipes*, has been reported as a parasite of adult stink bugs. However, the resident natural enemy population has not provided adequate control in years with "heavy" small or big bug densities.

RECOMMENDATIONS

1. All leaffooted bugs and stink bugs found in pistachio orchards should be identified correctly so that records of patterns of attack and successful strategies of control can be kept separately for each species.
2. Monitoring of populations of pest bugs, predators and parasites within orchards should be conducted throughout each season, from budbreak to harvest. (Please refer to Chapter 23: IPM Throughout the Season by Olsen et al.)
3. Surveys of weedy vegetation in and surrounding orchards should be conducted throughout each season to determine the abundances and developmental stages of the different plants and insects present.
4. Careful attention should be paid to the possible impact of any management activities, such as tilling, mowing, or burning, on the bugs within and surrounding the orchard.
5. Decisions to spray should be based on comparison of numbers of insects found, damage observed, developmental stage of the crop and previous yields under similar conditions.
6. Records of pest bugs should be evaluated along with those of numbers of natural enemies, development of the crop, abundance of alternate host plants and yield and damage found at harvest in order to improve recommendations for the future.

REFERENCES

1. Beede, R. H., Thomas, D., Rice, R. E., Daane, K. M., Padilla, J. and Bentley, W. J. 1995. Relation of *Phytocoris relativus* to lecanium scale infestation on pistachios, pp. 89-99. *In* California Pistachio Industry Annual Report, Crop Year 1994-95.

2. Beede, R. H., Rice, R. E., Daane, K. M., Thomas, D. R., Padilla, J., Soliman, S., Bentley, W. and Weinberger, G. 1996. Relation of *Phytocoris relativus* to lecanium scale infestations on pistachios, pp. 107-118. *In* California Pistachio Industry Annual Report, Crop Year 1995-96.
3. Bentley, W. J., Rice, R. E. and Beede, R. H. 1995. Insect and mite pests. Pistachio Pest Management Guidelines. In M. L. Flint (ed.), UC IPM IMPACT Pest Management Guidelines. UC DANR.
4. Bostock, R. M., Thomas, C. S., Ogawa, J. M., Rice, R. E. and Uyemoto, J. K. 1987. Relationship of wound-induced peroxidase activity to epicarp lesion development in maturing pistachio fruit. Phytopathology 77: 275-282.
5. Daane, K. M., Yokota, G. Y., Krugner, R., Steffan, S. A., Silva, P. G. da, Beede, R. H., Bentley, W. J., and Weinberger, G. B. 2005. Large Bug Damage to San Joaquin Valley Pistachios. California Agriculture Apr-Jun. 2: 95-102
6. McBrien, H. M. and Millar, J. G. 1999. Phytophagous bugs *in* J. Hardie and A. K. Minks (eds.), Pheromones of Non-Lepidopteran Insects Associated with Agricultural Plants. CABI Publishing, Wallingford, UK.
7. Michailides, T. J. 1991. Pathogenicity, distribution, sources of inoculum and infection counts of *Botryosphaeria dothidea* on pistachio. Phytopathology 81:566-573.
8. Michailides, T. J., Rice, R. E. and Ogawa, J. M. 1987. Succession and significance of several hemipterans attacking a pistachio orchard. J. Econ. Entomol. 80: 398-406.
9. Michailides, T. J. and Morgan, D. P. 1990. Etiology and transmission of stigmatomycosis disease of pistachio in California, pp 88-95. *In* California Pistachio Industry Annual Report, Crop Year 1989-90.
10. Michailides, T. J., Morgan, D. P. and Sullivan, A. 1996. Spread of *Botryosphaeria dothidea* in pistachio orchards of the San Joaquin Valley. California Pistachio Industry Annual Report, Crop Year 1995-96.
11. Michailides, T. J., Morgan, D. P., Felts, D. and Necker, E. 1999. Infection of Pistachio Fruit by *Botryosphaeria dothidea* and the Effect of Insect Puncturing. California Pistachio Industry Annual Report, Crop Year 1998-99.
12. Purcell, M. and Welter, S. C. 1990. Seasonal phenology and biology of *Calocoris norvegicus* (Hemiptera: Miridae) in pistachio and associated host plants. J. Econ. Entomol. 83: 1841-1846.
13. Purcell, M. and Welter, S. C. 1991. Effect of *Calocoris norvegicus* (Hemiptera: Miridae) on pistachio yields. J. Econ. Entomol. 84: 114-119.
14. Rice, R. E., Uyemoto, J. K. Ogawa, J. M. and Pemberton, W. M. 1985. New findings on pistachio problems. Calif. Agricul. 39(1):15-18.
15. Rice, R. E., Michailides, T. J., Jones, R. A. and Ogawa, J. M. 1986. Biology and control of insects causing epicarp lesion and kernel necrosis in pistachios, pp 64-68. *In* California Pistachio Industry, Annual Report Crop Year 1985-1986.
16. Silva, P. G. da, Daane, K. M., Beede, R. H., Bentley, W. J., Anderson, C. and Moutou, C. 1995. Biological control of hemipteran pests of pistachio. I. Inventory and sampling, pp 56-61. *In* California Pistachio Industry, Annual Report Crop Year 1994-95.
17. Silva, P. G. da, Daane, K. M. and Korfanta, N. M. 1996. Biological control of hemipteran pests of pistachio: appearance, activity and movement of insects in the orchard, pp. 61-66. *In* California Pistachio Industry, Annual Report Crop Year 1995-96.
18. Steffan, S. A., Daane, K. M. Weir, K. M., Yokota, G. Y., Michailides, T. J., and Holtz, B. A. 1999. The role of hemipterans in the spread of the fungus *Botryosphaeria dothidea*. California Pistachio Industry Annual Reports, Crop Year 1997-98. 15 pp.
19. Uyemoto. J., Ogawa. J. M., Rice R. E., Teranishi, H.R., Bostock, R.M., Pemberton, W.M. 1986. Role of several true bugs (Hemiptera) on incidence and seasonal development of pistachio fruit epicarp lesion disorder. J. Econ. Entomol. 79: 395-399.