Predicting Leaffooted Bug Outbreaks to Improve Control

Project No.: **07-ENTO3-Daane**

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Interpretive Summary:

Work conducted in 2007/08 focused on the leaffooted bug. In spring 2006, many California almond and pistachio orchards had significant crop loss from adult leaffooted bugs (*Leptoglossus* species). The occurrence of leaffooted bug populations covered a wide geographic range, including nut producing regions from the northern, western, and southern Central Valley. However, leaffooted bug densities and damage varied considerably, with some growers reporting significant bug densities and more than 50% crop loss, while nearby growers reported few leaffooted bugs and little crop damage. Regardless, spring 2006 was the worst leaffooted bug year over the past 20 years. Here, we sought to complete studies conducted in 1998-2000, the most recent period of widespread leaffooted population damage. Specifically, we investigated the potential number of leaffooted bug generations per year, adult leaffooted bug overwintering habits, and the development of aggregations.

Results suggest that, under both the 2006 and 2007, there were 3 full leaffooted bug generations annual. There was a partial 4th generation that produced mostly nymphs entering each winter period (e.g., November to December), but with only a few of these surviving to the adult stage and moving to a sheltered area to survive the colder late December through January period. Adults from each generation were long-lived, often depositing eggs over a 3 month period. There was considerable overlap of generations, with adults from one generation still alive when their offspring became reproductive adults. Results are discussed with respect to insecticide use and timing. To improve sampling programs, we also began studies to determine overwintering cues for leaffooted bugs to form aggregations. In field studies, we manipulated leaffooted bug

aggregations to determine if "resident" leaffooted bugs could be drawn into artificial shelters. In both the 2006/2007 winter and the 2007/2008 winter we were unable to attract resident adult leaffooted bugs using different artificial chambers. Another study of aggregation cues utilized large cages, with artificial leaffooted bug aggregations manipulated inside each cage and adult bugs added and allowed to disperse. In this study, we did find aggregations, although there was no clear pattern to the cues that we provided (e.g., virgin females). Instead, aggregations formations seemed to be based on a series of factors – such as temperature, shelter, and possible bug to bug pheromone, sight, and vibrational cues. These results are discussed with respect to possible control solutions. We investigated the survival of nymph and adult leaffooted bugs on almonds when provisioned different types of food and shelter. Under 2007/2008 winter conditions, only the adults survived – and a portion of these were able to produce eggs in spring after a 4 month period with no food.

Objectives:

Objectives in 2006/07 focused on the leaffooted bug, although we have ongoing plans to complete work on the "Gill's" mealybug, which has proved to be, at this time, a minor pest in almonds. Our specific objectives are to:

1. Investigate development of sampling protocols for winter and spring populations of leaffooted bug.
2. Determine overwintering cues that result in leaffooted bug aggregation – and to determine if these aggregations can be manipulated for monitoring or control.
3. Determine the potential number of leaffooted bug generations per year, and when the adult population begins its overwintering period.

Materials and Methods:

<u>Objective 1 – Sampling protocols</u>

a) Emigration from winter aggregations. Previously, we looked at winter mortality of leaffooted bug adults in their aggregations (see Objective 2). This work helps to predict the numbers of bugs in the important spring period. In 2007/2008, we also looked at when these aggregations begin to break up and move into almond. To determine both the mortality and emigration – or when the insect leaves the aggregation – we sampled an olive sites near Porterville, California where leaffooted bug aggregations were numerous. Beginning January 16, 2008 we monitored the number of individual bugs in 20 large aggregations, taking counts about every 2 weeks.

b) Immigration into almond orchards. Previously, we looked at winter mortality of leaffooted bug adults in their aggregations. We also wanted to determine if was more efficient to sample for leaffooted bug adults, or for their damage on nuts in early spring.

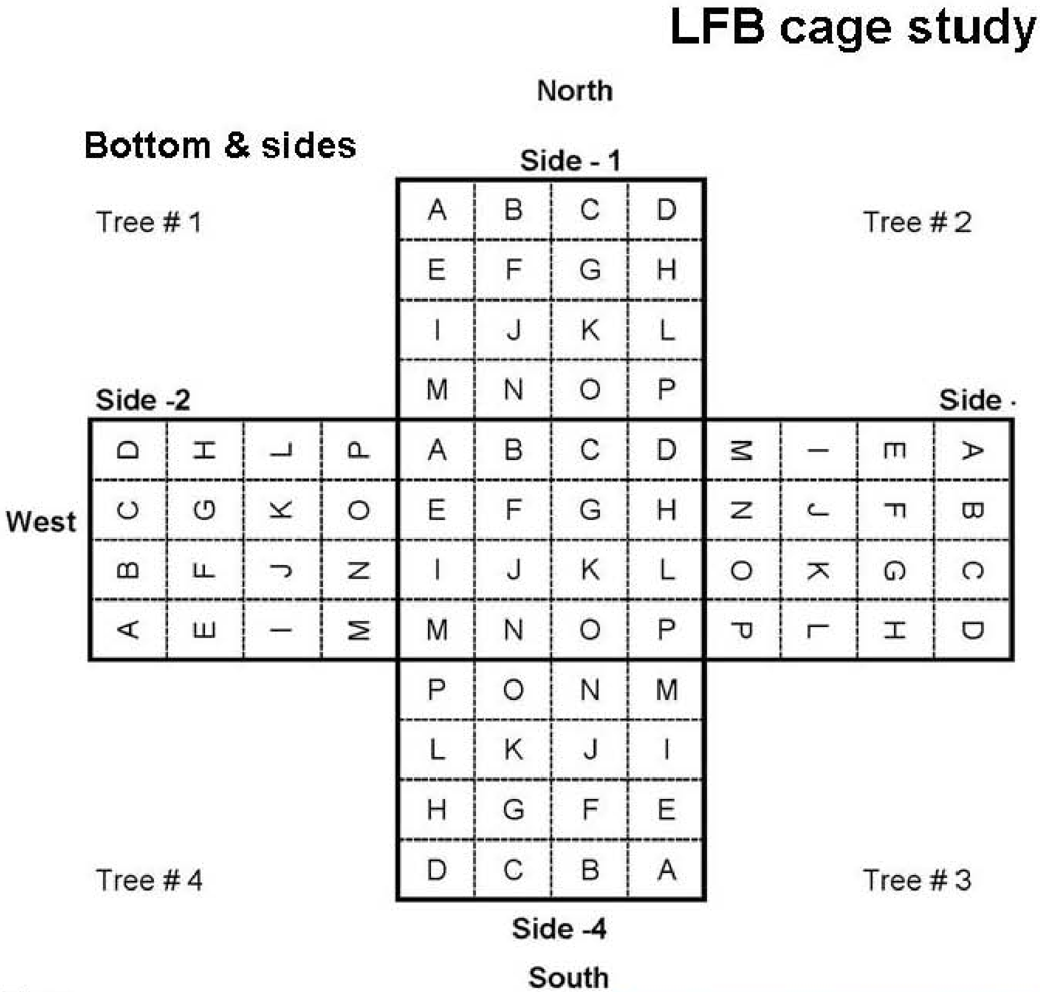
1. To study leaffooted bug immigration – or when the bugs move into the almond from their overwintering sites - we monitored three almond orchards near Orosi, California; these fields have historically had leaf footed bugs each year. Each site was next to the foothills and surrounded by citrus fields and/or eucalyptus trees – all good overwintering locations for leaffooted bugs.
2. At each site, 100 almond trees were observed for one minute on each sample date. Observations were made by circling the tree and looking for leaf footed bug adults and randomly checking 10 nuts for damage. Damaged nuts had sap coming out of the nut from the feeding wound. Most of the leaffooted bugs and damage recorded was at eye level, to search higher in the tree, a 4 ft long pole was used to beat the higher branches to make the adult leaffooted bug take flight. This was only effective when the temperature was at least 70°F. The leaf footed bug's flight is distinctive in that it makes a buzzing sound and is not a fast flier.

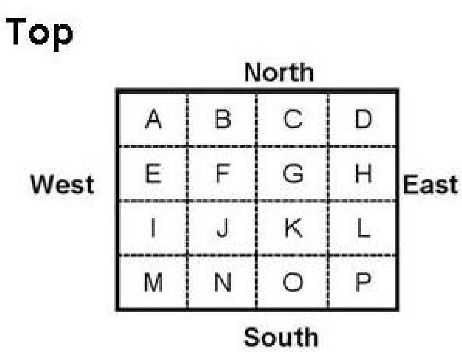
Objective 2 – Overwintering aggregations.

a) Field populations. We studied cues that might lead to the formation of winter aggregations. In November 2006 and 2007, leaffooted bug were observed leaving a pomegranate field and aggregating on citrus (2006/2007), or olive (2007/2008), trees in adjacent fields. They were several aggregates of 15-200 adults tightly clustered on the terminals of both the citrus and olive branches. The aggregations were usually on the sunny side of the tree and towards the outside of the tree. Leaf footed bugs were also observe under the bark of the trunk of palm and eucalyptus trees nearby. We have previously observed leaf footed bugs under loose bark of eucalyptus trees the winter and under the tarps of a covered tractor. Every 1-2 weeks, we monitored the number of bugs in the aggregations, and also recorded their mortality by looking for dead bugs on the ground. This work began after the migrations were formed in December (2006/2007), and January (2007/2008).

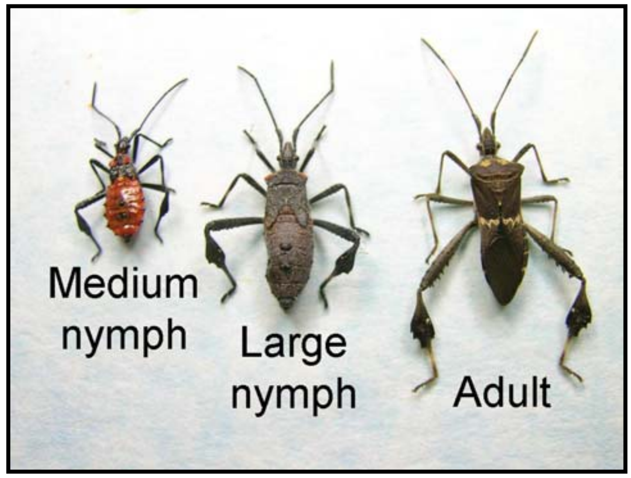
b) Aggregation formation. We used large (10 × 12 foot), cages to manipulate leaffooted bug aggregations. In each of the four corners of the cage a potted tree was placed as a "substrate" for the leaffooted bugs to form an aggregation upon. In each cage either Italian cypress or citrus (each known to be an overwintering tree) (photos 3 and 4). All four trees were provided with food (peanuts and beans), and water, and one of the trees was provided with an artificial aggregation of 20 leaffooted bugs, isolated in the screened cages described previously. The artificial aggregations were tested with three treatments: females only, males only, and both females and males. Only one treatment was used in each cage for each trial.

Once the plot was established, three leaffooted bug adults were released in the center of each cage and their movement was observed periodical over a 48 hour period by mapping their location on all six sides of the cage (see LFB cage study). For each trial, the position of the trees and location of the artificial aggregation was reassigned. There were five trials.





c) Aggregation formation. In the third trial, we used field aggregations found in the olive trees near Porterville. Once aggregations form, the bugs tend to stay together until there is emigration in the spring. To determine if there is a cue for these aggregations, which we have been unable to duplicate under laboratory conditions, we took bugs from 8 large aggregations (28 – 205 adults per aggregation; average 84.1 ± 20.3 bugs per aggregation), to the laboratory for a 24 hr warming period (70°F). We recorded the number and sex of all bugs in each aggregation. After this period, we returned each aggregation to the same tree the bugs were collected from, but scattered the adult leaffooted bugs at the base of the olive tree. For the next two weeks we checked each site to determine if the aggregations reformed.



d) Overwintering adult survival. Do the overwintering leaffooted bugs need to feed? When do they mate? Can both adults and nymphs survive the winter? These questions were answered by collected adult leaffooted bugs, from newly formed winter aggregations in November, and providing them with different food sources. Three stages were tested: adults, large nymphs and medium sized nymphs. There were two treatments: no food and food (peanuts and water). The study was conducted at ambient temperatures at the Kearney Agricultural Center, from December through April. There were 10 individuals per replicate (individual cages), and 5 replicates for each treatment. The leaffooted bugs were checked ever 2 weeks.

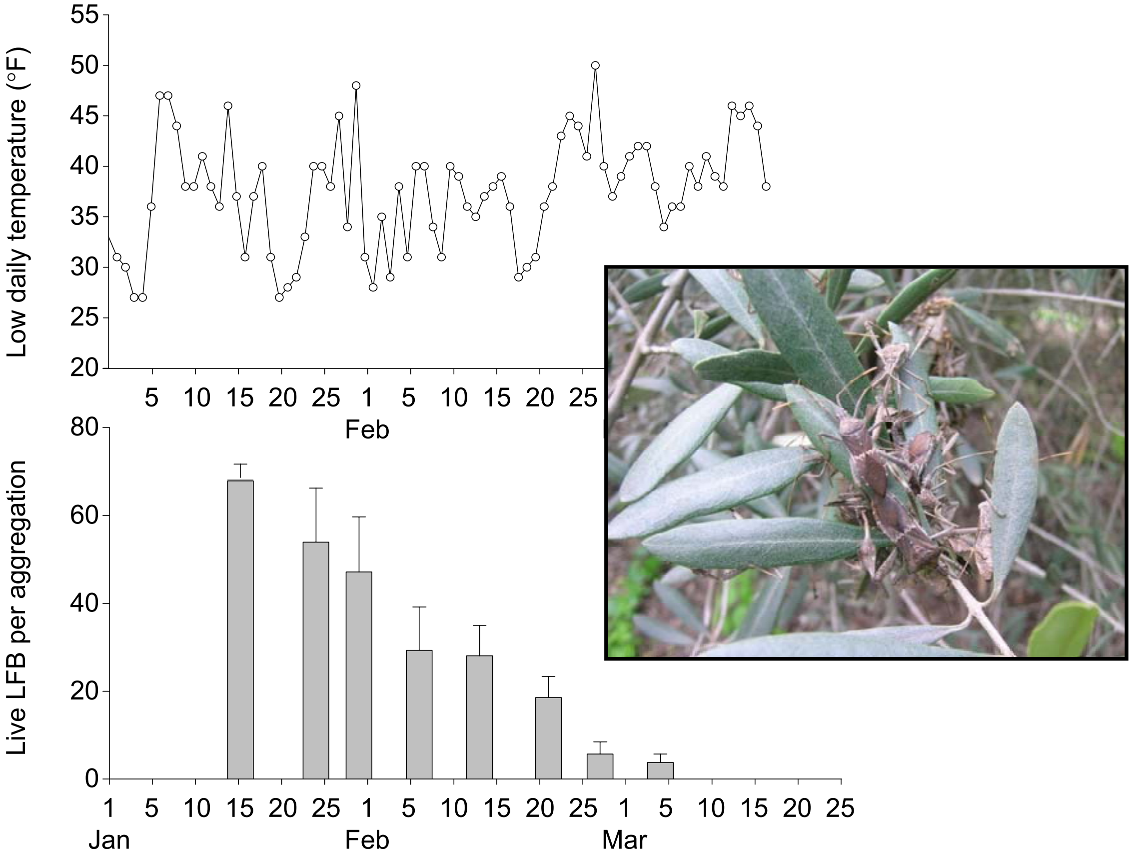
<u>Objective 3 – Number of generations per year</u>

We utilized small cages to collect information on leaffooted bug development. At the Kearney Agricultural Center, adult leaffooted bugs were collected during the winter. This cohort was placed into small tree cages placed outside and held at ambient temperatures. The leaffooted bugs were fed peanuts and provided with an Italian cypress as food and structural support. During each egg-laying period, additional cages were established for each consecutive generation produced. We then determined the longevity of the adults, their egg-laying period, and the number and length of each successive generation. There were three cages per generation. This work is a continuation of studies begun in spring 2006.

Results and Discussion:

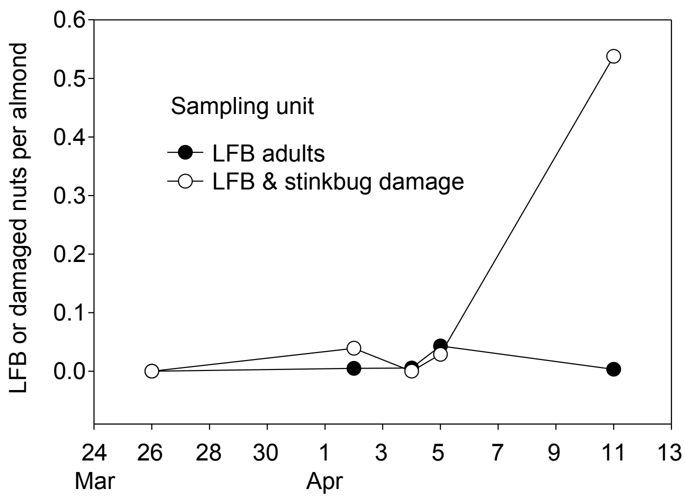
<u>Objective 1 – Sampling protocols.</u>

a) *Emigration from winter aggregations.* The numbers of leaffooted bug adults in the olive aggregations remained relatively constant in December 2007, during which time the temperatures were relatively mild. Beginning in January there were periods of cold weather during which the numbers of bugs dropped, and we often found dead leaffooted bug adults below the aggregation. There was another period of mortality, picked up in the emigration study, when low temperatures dipped between January 25 and February 5.



Emigration was not observed until after February 20, when temperatures increased sharply. Within 15 days (February 25 to March 7), all healthy leaffooted bug adults had left the overwintering aggregations to move to spring feeding sites.

b) Immigration into almond orchards.
By monitoring the aggregations, we found that leaffooted bugs were leaving their overwintering sites (during the 2007 spring period), in late February, early March. Monitoring almonds showed that during this same period, adult bugs were found. Initially, it was easier to see the damage (open circles in the graph), than to find the adults. On the April 5th sampling date, we changed our tactics somewhat. We noted that most of the damage and leaf footed bug were on the south side of the tree which is the sunny side. As a possible faster alternative sampling technique to cover more trees, we made a 15 second search only on the south side for damage and leaffooted bugs. We noted that by looking mainly for damage we were



able to detect more damaged nuts and find more leaffooted bugs per sample period (as compared to the sample dates before April 5th), because the bugs were often still next to damaged nuts . Since it is early in the season with relatively cool temperatures, and these large adult leaffooted bugs seem not to be moving far from their feeding site. Most were observed either feeding or mating near the damaged nuts. Remember that the damage nuts may increase in numbers and stay on the tree even if the leaffooted bug population remains steady or after the leaffooted bugs are gone. As an example, on April 11, in one field we found only 20 adults but over 100 damaged nuts. The other two fields did not increase as much. They both had just two adults and just a few damaged nuts.

We found that the easiest way to determine the presence of leaffooted bugs is to look for their damage. The downside is that in March, the leaffooted bug damage in almonds can be difficult to tell apart from the normal nut drop and blanks that are formed. On the almond tree, the early damage (mid-March), may be a nut that does not form and eventually drops off the tree. Some almond varieties (Butte, Sonora), will show drop while others (non pareils), may have little drop.

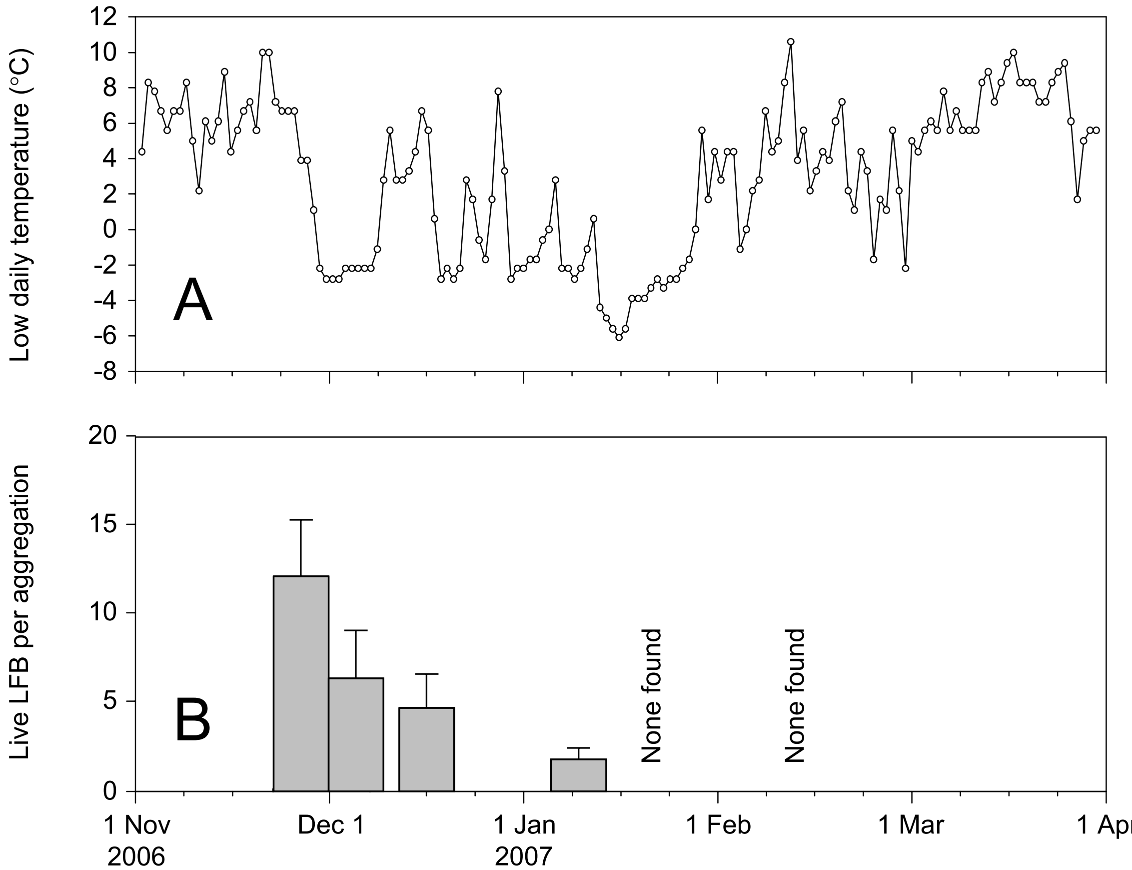
By April, the damage to almond and pistachio nuts is more evident. Both almond and pistachio nuts on the tree and the ground will have evidence of leaffooted bugs. Almond nuts can have “gummosis” exuding from the feeding puncture. A close up of the gumming is seen in an almond on the ground (far left photo). When gumming is found on almonds in the tree, look around that area for evidence of both leaffooted bug and stink bugs – which cause similar damage. Typically, the bugs will get in a group of almonds or a cluster of pistachios and feed on many nuts. For this reason, we move through the orchard rather quickly looking for groupings of damaged nuts, which is often easier to see.

For our research program, the March-April monitoring consists of a sample 200 trees per block, with about 10 groups of almonds (4-5 nuts). Note that the sample is biased because we scan the tree for damage rather than randomly selecting nuts. There is not an economic injury level, because the tree can compensate for some nut drop, but any large nut drop or damage by any bug species may be cause for concern.

<u>Objective 2 – Overwintering aggregation</u>

a) Field studies. Leaffooted bugs overwinter as adults, typically in aggregations located in protected areas, such as in woodpiles, barns, under the bark of eucalyptus trees, in cypress trees or juniper trees. These pests can also overwinter in the orchard in plant debris, pump houses, or cracks along the tree trunk. Our work indicates that in late March and throughout April, the adults disperse from these overwintering aggregations to find food sources.

In both 2007 and 2008, we correctly predicted that densities of leaffooted bug would be lower than the 2006 season. Naturally, this was due in large part to the increased vigilance of growers and to the increased pesticide use, particularly with Lorsban, targeting leaffooted bugs. However, work in both winters 2006/2007 and 2007/2008 showed a great amount of mortality when low temperatures dipped below freezing for extended days. The example provided is from the 2006/2007 season, monitoring aggregations in a citrus orchard. The low temperature periods near December 1st and 25th and January 7th were associated with dramatic reductions in leaffooted bugs. Results in the 2007/2008 winter aggregations in olives were similar – but not as dramatic.



What is needed now to make this information useful? It would be difficult to set up regional monitoring programs throughout California – as we had originally planned. This is because each year volunteers would have to find aggregations to monitor. In most years, this can be very difficult. An alternate, and better plan, would be to determine the low temperature relationship between the leaffooted bug adults and their mortality. Using these data, a predictive model could be developed to predict overwintering mortality in different regions.

b) Large cage studies. There is little known about the overwintering and aggregation cues. Adult leaffooted bugs may aggregate in areas simply because they are shelter. It is also possible that males call females using a sex pheromone or that clustered leaffooted call in others using an aggregation pheromone. We conducted three trials to investigate overwintering biology and aggregation cues. We used large (10 × 12 foot), cages to manipulate leaffooted bug aggregations. In each of the four corners of the cage a potted tree was placed as a "substrate" for the leaffooted bugs to form an aggregation upon. We then added to one of the cages an artificial aggregation of caged leaffooted bug adults.

This was our second attempt at this trial (we conducted the experiment in the 2006/2007 season as well). Results were similar in both years and provided little evidence that we could artificially create aggregations. The freely released leaffooted bugs did not readily or consistently form aggregations in the cages.

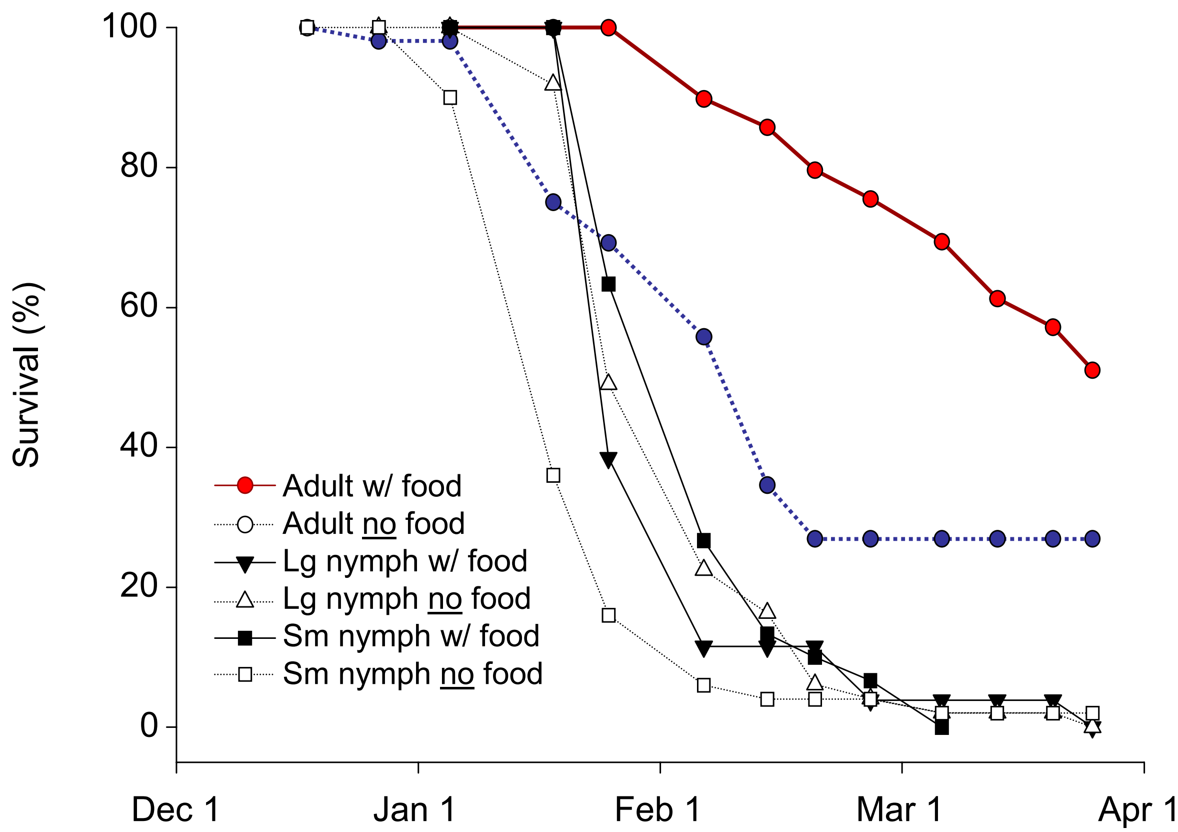
While we made many adjustments to last year's design, we suspect that either the design is flawed, or that the trial was conducted too late in the season. Aggregation cues might be a combination of changing climate, from summer to fall, as well as an insect cue, such as an aggregation pheromone, sound, or vibration cue (or a combination of many cues). Support for this observation is the aggregations that formed in the small cages used to conduct the study of leaffooted bug generations. Through the fall winter and spring, we observed aggregations forming in the early morning hours (photo 5), and, as the temperatures warmed each day, the insects would begin to break from the aggregation and move about the cage.

c) Manipulating aggregations. Of the 8 aggregations that were removed, warmed, and then returned to the field – there were 5 aggregations reformed (62.5%). The average number of adults per aggregation was 50.3 ± 12.1, which was smaller than the original average (84 bugs per aggregation). Here, we included as a single aggregation when two smaller aggregations were formed near each other. At those trees where no aggregation was formed, there were no dead insects found at the tree base, and there were few individual bugs scattered in the tree (e.g., not forming an aggregation). This suggests that the adults had moved to a different tree to reform the aggregation.

While we were unable to induce aggregations in the artificial orchard (in the large cages), or in the field using artificially constructed cages (please see the 2006/2007 annual report), these data strongly suggest cues are used by leaffooted bug to form aggregations. We suspect that pheromones may be important to get the adults into the vicinity of the aggregation, and that vibration signals may be important to help form the aggregation.

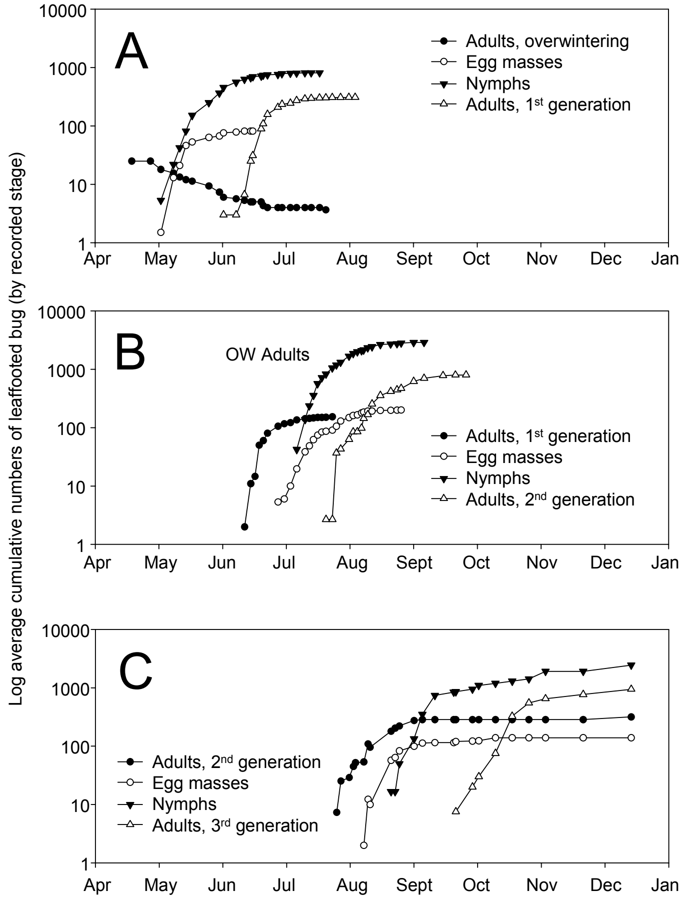
d) Overwintering adult survival. Results show that adults are the leaffooted bug stage that best survive the winter. Adults both with and without food were able to survive until late March, when egg laying began. More adults that had food provisions survived, as was to be expected. Because most overwintering aggregations are not on sites where "nut" crops are available, we suspect that the most important element of the food was moisture – keeping the adults from desiccating. None of the medium sized or large nymphs survived the winter.

The results suggest that the adults can survive outside the orchard, without food, and still be a problem. During the winter period, we never observed mating, which was first observed in March.



Objective 3 – Number of generations per year

Results suggest that under the 2006/07 conditions and the 2007/08 conditions, there were three leaffooted bug generations from January to October 2006. As reported previously the overwintered adults began depositing eggs in April, and continued to deposit eggs through May, possibly longer. Nymphs reared from these egg masses passed through five nymphal stages, with the first nymph developing to the adult stage in June. These adults formed the first summer generation. These adults were placed into new cages, provisioned as before, and began depositing egg masses within one week, and from late June through September these adults were producing egg masses. First instar nymphs hatching from these egg masses were collected from July into October. To be clear, adults formed from eggs deposited from the overwintered adult cohort are considered to be adults of the first summer generation. These adults were active from July through October, depositing eggs over a 4 month period. The resulting nymphs formed the second summer generation. Adults from this second summer generation were first observed in August, began depositing eggs soon thereafter, and remained alive to form a portion of the adult population that overwinters. Eggs deposited from the second generation were first observed reaching the adult stage in October; few eggs were found from these adults – which formed the largest portion of the overwintering adult population.



Clearly, adult leaffooted bugs are long-lived and deposit eggs throughout most of their lifetime, often depositing eggs over a 3 months period. This results in considerable overlap of generations, with adults from one generation living beyond the period when their offspring became adults and produced eggs of the next generation. The overlap of leaffooted bug stages makes insecticides applications based on short residual insecticides very difficult because there are always adults that can migrate into the orchard. Typically, control is based on April or May applications of chlorpyrifos (e.g., Lorsban), pyrethroids, or permethrin to kill overwintering adults that have migrated into the orchard. The biggest concern with these products is the potential to flare spider mites later in the season.

There is also some question about the longevity of the different insecticide materials. Because the adult population can migrate into the orchard, materials with longer residual activity might be preferred for the spring application. We are currently testing common materials against adult leaffooted bugs to determine how long after application any residual contact can kill or repel adults...

In general, control in June is not needed because populations of overwintering adults have declined and most nymphs are too small to penetrate into the kernel. By July, however, large nymphs and new adults may be of sufficient size to cause kernel damage, although most of their attempts to reach the kernel fail because of the hardened shell.

Acknowledgements:

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Recent Publications:

Daane, K. M., Haviland, D. R., Viveros, M., and Holtz, B. A. 2006. Leaffooted bug hammers almonds, pistachios. *Pacific Nut Producer* 12(7): 4-7, 26.

Bentley, W. J., Beede, R. H., Daane, K. M., and Haviland, D. R. 2007. University of California IPM Pest Management Guidelines: Pistachio, Insects and Mites. *University of California ANR Publication 3461.*

Three additional peer-reviewed publications are planned.

Recent Presentations:

Insect pests in organic production. *Going Organic – Tree and Vine Production*. Selma, CA. Jan. 2007.

Leaffooted plant bug. *2007 Annual Pistachio Day*. Visalia, CA. Jan. 2007.

Leaffooted plant bug biology and management. *2007 Regional Almond Meeting*. Madera, CA. Jan. 2007.

Leaffooted plant bug: What happened in 2006? *Fresno-Madera CAPCA meeting*. Fresno, CA. Mar. 2007.

Leaffooted plant bug: damage and control. *91st Pacific Branch Entomological Society of America*. Mar. 2007. Portland, OR.

Leaffooted plant bug. *2007 Annual Pistachio Day*. Visalia, CA. Jan. 2007. two - 30 min presentations, ~200 growers and PCAs.

Old pests for a new crop: insects and pomegranates. *Winter Tree Fruit Meeting*. University of California Cooperative Extension. Parlier, CA. Dec. 2007.

Almond leaf scorch, role of insects and weeds. *35th Annual Almond Industry Conference*. Modesto, CA. Dec. 2007.

Predicting leaffooted bug outbreaks. *35th Annual Almond Industry Conference*. Modesto, CA. Dec. 2007.

Leaffooted bug – predictions for 2008. *Madera Regional Winter Almond Day*. Jan. 2008. Madera, CA.