# Crop Loss Relationships and Economic Injury Levels for *Ferrisia gilli* (Hemiptera: Pseudococcidae) Infesting Pistachio in California

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**ABSTRACT** *Ferrisia gilli* Gullan (Hemiptera: Pseudococcidae) is a new pest in California pistachios, *Pistacea vera* L. We conducted a 3-yr field study to determine the type and amount of damage caused by *F. gilli*. Using pesticides, we established gradients of *F. gilli* densities in a commercial pistachio orchard near Tipton, CA, from 2005 to 2007. Each year, mealybug densities on pistachio clusters were recorded from May through September and cumulative mealybug-days were determined. At harvest time, nut yield per tree (5% dried weight) was determined, and subsamples of nuts were evaluated for market quality. Linear regression analysis of cumulative mealybug-days against fruit yield and nut quality measurements showed no relationships in 2005 and 2006, when mealybug densities were moderate. However, in 2007, when mealybug densities were very high, there was a negative correlation with yield (for every 1,000 mealybug-days, there was a decrease in total dry weight per tree of 0.105 kg) and percentage of split unstained nuts (for every 1,000 mealybug-days, there was a decrease in the percentage of split unstained of 0.560%), and a positive correlation between the percentage of closed kernel and closed blank nuts (for every 1,000 mealybug-days, there is an increase in the percentage of closed kernel and closed blank of 0.176 and 0.283%, respectively). The data were used to determine economic injury levels, showing that for each mealybug per cluster in May there was a 4.73% reduction in crop value associated with quality and a 0.866 kg reduction in yield per tree (4.75%).

**KEY WORDS** *Ferrisia gilli*, mealybug, pistachio, economic injury level, crop damage

The mealybug *Ferrisia gilli* Gullan (Hemiptera: Pseudococcidae) is an important new pest of pistachios, *Pistacea vera* L., in California. It was discovered in 1997 in commercial pistachio orchards in Tulare County, CA, and was later described as a new species by Gullan et al. based on differences in behavior, morphology, and genetics from existing species (Gullan et al. 2003, 2010). Since that time *F. gilli* has been reported from all major pistachio-producing regions of California (Haviland et al. 2012). *F. gilli* can cause visible damage by residing in and fouling the pistachio cluster; moreover, the excreted honeydew is rich in carbohydrates that promote sooty molds, which can further foul the cluster. Haviland et al. (2012) reported that two of three annual generations occur from June through September when the *F. gilli* population is predominantly found in the pistachio cluster feeding on the hulls or rachis of fruit and that, in untreated pistachio trees, it can reach densities greater than 100 mealybugs per cluster in August and September. It is unknown, however, if large populations of *F. gilli* reduce tree vigor and the resulting crop yield or if mealybug feeding on the cluster damages shell or nut quality underneath the exterior hull. Nevertheless, concerns by growers and researchers over high numbers of *F. gilli* feeding in the clusters have made this an economically important pest of pistachios that needs to be managed (Gullan et al. 2003, Haviland et al. 2006).

Management programs for *F. gilli* in California are based on the application of an insecticide, usually containing the active ingredient buprofezin, during early June when mealybugs are primarily in the cluster and in the first (crawler) or second instar developmental stage, which are easier to kill with insect growth regulators (Bentley et al 2012, Haviland et al. 2006). Application timing is improved by monitoring for mealybugs in May and early June, which is accomplished by identifying trees with *F. gilli* infestations and then evaluating these trees weekly to determine peak crawler emergence in order to properly select and time insecticide treatment. However, applications are based solely on the presence of mealybugs and the farm manager's risk tolerance, and economic injury levels (EILs) have not been established for *F. gilli* in pistachio.

We conducted a 3-yr field study in a commercial pistachio orchard to develop economic injury levels to improve treatment decisions for monitoring programs used in May and June. Insecticides were used to establish pistachio trees with gradients of mealybug densities

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and then the effect of mealybug density on fruit yield and six parameters of fruit quality were evaluated. Regression analyses were used to correlate mealybug density to each type of damage and to determine the percentage of crop loss per mealybug per cluster during monitoring in May. Crop loss estimates were coupled with estimates of crop value and control costs to develop a formula that could be used by pistachio growers to calculate EILs for a projected yield at harvest. This formula, when used by growers, will allow monitoring programs in May and early June to be used to determine the need for a treatment and treatment timing, for *F. gilli* in pistachios.

## Materials and Methods

The effect of varying *F. gilli* infestation levels on pistachio crop quality was measured in a commercial pistachio orchard, located near Tipton (Tulare County), CA. In February of 2005, 2006, and 2007, we selected 30, 32, and 35 pistachio trees, respectively, at random from trees that had evidence of mealybug populations during the previous season. The trees were mature 'Kerman' cv. pistachios that were farmed according to standard production practices for irrigation, pruning, disease control, and harvest. Non-mealybug insect pests were managed each year with an application of a permethrin-based insecticide for control of mirid plant bugs in April or May and an application of methoxyfenazide (Intrepid 2F, Dow AgroSciences, Indianapolis, IN) for navel orangeworm, *Amyelois transitella* Walker, approximately 1 mo before harvest. Both insecticides were sprayed to the entire orchard containing the trial and neither insecticide is known to have any effects on *F. gilli*.

Insecticides were used to create different mealybug densities among the sampled trees; the insecticides used varied among years as we gained experience with different products. In 2005, five trees were randomly assigned to each of four insecticide materials and 10 trees were left untreated. Insecticides were buprofezin (Centaur 70WP, Nichino America, Inc., Wilmington, DE) at 2,399 g/ha (2.14 lb/acre), phosmet (Imidan 70W, Gowan Company, Yuma, AZ) at 5,604 g/ha (5 lb/acre), carbaryl (Sevin XLR Plus, Bayer CropScience, Research Triangle Park, NC) at 11,692 ml/ha (5 qt/acre), and imidacloprid (Provado 70WG, Bayer CropScience, Research Triangle Park, NC) at 158 g/ha (2.25 oz/acre). In 2006, five trees were randomly assigned to each of four insecticide materials and 12 trees were left untreated. Insecticides were buprofezin (Centaur 70WP, Nichino America, Inc., Wilmington, DE) at 2,399 g/ha, spirotetramat (Movento 240SC, Bayer CropScience, Research Triangle Park, NC) at 585 ml/ha (8 fl oz/acre), spirotetramat (Movento 240SC, Bayer CropScience, Research Triangle Park, NC) at 877 ml/ha (12 oz/acre), and imidacloprid (Provado 70WG, Bayer CropScience, Research Park Triangle, NC) at 158 g/ha (2.25 oz/acre). In 2007, eight trees were randomly selected and treated with buprofezin (Centaur 70WP, Nichino America, Inc., Wilmington, DE) at 2,399 g/ha (2.14 lb/acre) and 27 sampled trees remained untreated. In all years, foliar applications of insecticides were made in late May or early June in a water volume of 1,871 l/ha (200 gal/acre) using a gas-powered sprayer equipped with a single-nozzle hand gun. None of the insecticides used to establish a gradient of mealybug densities in trees are known to have any effects on other insect pests of pistachios when sprayed in late May or early June.

Mealybug density was recorded every 2–5 wk from late May through September (harvest time) of each year. On each sample date, we recorded the total number of mealybugs present within or immediately adjacent to each of 10 randomly selected clusters per tree. This included those mealybugs on the hull or rachis of the cluster as well as those on wood within 1 cm of the attachment site of the rachis. A hand lens was used to count mealybugs when needed, particularly on sampling dates when small nymphs were present.

Fruit quality was evaluated on 21 September 2005, 21 September 2006, and 10 September 2007. Each tree was harvested individually with commercial harvest equipment contracted by the orchard owner. This equipment consisted of two separate units that worked in tandem to straddle the tree; the first unit contained a shaker arm, a catch frame, a conveyor belt, and a blower to remove leaves whereas the second unit contained a catch frame that was located on the opposite side of the tree. When in operation the equipment mechanically shook nuts from the tree, used the catch frames to direct nuts to the conveyor belt, passed them through a blower to remove leaves, and then deposited the nuts in a 114-liter galvanized steel trash container. Total harvest weight (wet weight) was determined for each tree and a subsample of approximately 10 kg was collected for analysis of nut quality.

Subsamples for analysis of nut quality were submitted within 6 h after harvest to the quality assessment laboratory of a commercial pistachio huller and processor. Within 12 h of arrival at the laboratory nuts from each sample were peeled (to remove the hull) and dried to 5% moisture. Samples were weighed after drying to determine the ratio of wet weight to dry weight. Quality was assessed using a 500 g dry weight subsample of the nuts from each tree. Nuts were initially divided into two groups: nuts with split shells (marketable) and nuts with closed shells (culled from the fresh nut market). Nuts with split shells were divided into five subcategories according to the condition of the shell: shells with no staining (split unstained), with light staining (split light stained), with dark staining (split dark stained), with adhered hulls (split adhered), or with other damage such as deformations to the shell (split damaged). Nuts with closed shells were subdivided into two groups: those with a kernel (closed kernel) and those without a kernel (closed blank). We measured the weight of nuts in each category and determined the percentage of each weight that corresponded to shells and to kernels. All weights associated with pistachio quality were converted into percentages of total dry weight for analyses of crop loss assessments.

**Statistical Analysis.** Mealybug density on each tree was determined by calculating the average number of mealybugs per cluster on each evaluation date.

Cumulative mealybug pressure during each season was then determined for each tree using mealybug-days (Ruppel 1983). To accomplish this, beginning with the second evaluation date of each year we calculated the average number of mealybugs per cluster from the current and previous evaluation dates and multiplied that by the number of days between evaluations. These values were added to determine the cumulative mealybug-days for clusters in each tree from May through harvest.

The effects of *F. gilli* density on pistachio yield and quality were evaluated using regression analysis. For each year of the study we performed linear regression analyses using cumulative mealybug-days as the independent factor and seven different dependent factors: yield, percentages of split unstained, split light stained, split dark stained, split adhered, closed kernel, and closed blank.

EILs were calculated to determine the number of *F. gilli* per cluster in May that justify chemical control according to the formula EIL = CN/YPL where C = the cost per unit or control (US$/ha), N = pest density (*F. gilli* per cluster in May), Y = yield (anticipated yield in kg/ha), P = price per unit of yield (US$/kg), and L = the percentage reduction in crop value for every unit of pest density (% reduction in crop value for every unit of *F. gilli* per cluster in May; Pedigo et al. 1986). Prior to calculating EILs we used linear regression analysis to validate the assumption that *F. gilli* density in May (when treatment decisions need to be made as the independent factor) is correlated to cumulative mealybug-days from May through harvest. This regression was completed across all three years of the study using the 49 trees that were not treated with insecticides. In order to determine the crop loss component of L associated with pistachio quality we regressed *F. gilli* density in May against the percentage of total dry weight that qualified as grower paid weight, which is the unit of quality used within the pistachio industry for determining crop value. Grower paid weight is defined as the sum of the weights of split unstained and split light stained nuts (for which the grower is paid for the weight of the shell and the kernel) and the weights of kernels from split dark stained, split adhered, split damaged, and closed kernel nuts (for which the grower is only paid for the weight of the kernel and not for the shell).

## Results and Discussion

**Effects of *F. gilli* on Pistachio Yield and Quality.** Varying *F. gilli* densities were established among trees within each year and across all three years of the study (Table 1). The mean (±SE) number of mealybugs per cluster in May of 2005, 2006, and 2007 were 0.9 ± 0.2 (range 0.0–3.2), 0.4 ± 0.1 (range 0.0–2.1), and 4.0 ± 0.5 (range 0.0–8.3), respectively. Cumulative mealybug-days per cluster from May through harvest in 2005, 2006, and 2007 were 5,212 ± 961 (range 2.4–12,653), 9,713 ± 1,331 (range 231–28,296), and 34,895 ± 3,757 (range 151–71,790), respectively. In 2005 and 2006 maximum densities of *F. gilli* in May and throughout the season were considered moderately high by the grower cooperator and authors of this study, and densities in May of 2007 were approximately 4-fold and 10-fold higher, respectively. Cumulative mealybug-days in 2007 were approximately 3-fold to 4-fold higher than in 2005 and 2006, respectively, making it an optimal year to determine the effects of mealybug density on crop loss.

**Table 1. Mean (± SE) and range of *F. gilli* per cluster for individual sampling dates used to calculate mealybug-days in pistachio, 2005–2007**

| Year | No. trees | Date | Mealybug density | |
|---|---|---|---|---|
| | | | Mean ( ± SE) | Range |
| 2005 | 30 | 24 May | 0.9 ± 0.2 | 0–3.2 |
| | | 15 June | 3.9 ± 1.5 | 0–38.9 |
| | | 28 June | 6.2 ± 2.0 | 0–51.6 |
| | | 27 July | 125.1 ± 28.7 | 0–428.1 |
| | | 16 Aug. | 50.6 ± 10.6 | 0–186.4 |
| | | 9 Sept. | 22.9 ± 6.2 | 0.1–118.5 |
| | | Cumulative mealybug-days | 5,212 ± 961 | 2.4–12,653 |
| 2006 | 32 | 31 May | 0.4 ± 0.1 | 0–2.1 |
| | | 29 June | 8.8 ± 1.7 | 0.1–39.9 |
| | | 11 July | 12.5 ± 2.4 | 0.4–47.0 |
| | | 25 July | 61.8 ± 13.8 | 0–326.4 |
| | | 9 Aug. | 207.5 ± 33.5 | 1.2–733.8 |
| | | 8 Sept. | 123.0 ± 17.9 | 5.8–368.8 |
| | | 21 Sept. | 121.6 ± 17.7 | 0.9–443.3 |
| | | Cumulative mealybug-days | 9,713 ± 1,331 | 231–28,296 |
| 2007 | 35 | 10 May | 4.0 ± 0.5 | 0–8.3 |
| | | 2 July | 24.7 ± 3.2 | 0.1–70.2 |
| | | 31 July | 766.4 ± 86.8 | 1.9–1,743 |
| | | 4 Sept. | 426.1 ± 48.6 | 0.7–1,144 |
| | | Cumulative mealybug-days | 34,895 ± 3,757 | 151.0–71,790 |

Field notes taken throughout the study were used to document that crop loss estimates could be directly attributable to *F. gilli*. Field sampling documented the near absence of mirid or pentatomid plant bug pests in all three years of the study and nut samples at harvest documented minimal (<0.2%) damage by navel orangeworm in all research plots. Regarding biological control, no parasitized *F. gilli* were found during the entirety of the study. In 2006 and 2007 lacewing larvae (Chrysopidae) and the leafhopper assassin bug, *Zelus renardii* Kolenati, were periodically seen associated with *F. gilli*, though not in sufficient density to have a major impact on mealybug density or crop loss estimates.

Yields per tree across all three years of the study ranged from 3.0 to 26.5 kg dry weight per tree (Table 2); during individual years there were trees with more than 10 kg and less than 20 kg dry weight per tree. Average yields varied among years due to the alternate bearing cycle of pistachios. Mean (± SE) yields in total dry weight per tree in 2005 and 2007 were 19.8 ± 0.8 and 14.6 ± 0.7 kg, respectively, whereas yields in 2006 were only 10.1 ± 1.1 kg.

Linear regression analysis of yield against cumulative mealybug days resulted in nonsignificant relationships in 2005 ($P = 0.15$) and 2006 ($P = 0.49$) and a negative correlation in 2007 ($F = 17.48$; df = 1, 33; $P = 0.0002$) that was expressed by the equation $y = -0.000105 \times + 18.25$.

**Table 2. Mean (±SE), minimum, and maximum values for yield per tree and six parameters of nut quality and regressions of those parameters against cumulative mealybug-days per cluster through harvest, 2005–2007**

| Year (no. trees) | Harvest parameter | Mean ± SE | Range | Linear regression analysis[a] (harvest parameter against mealybug-days) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | $F$ | $P$ | Slope (×1000) | Y-intercept | $R^2$ |
| 2005 | Yield[b] | 19.8 ± 0.8 | 9.3–26.5 | 2.17 | 0.15 | −0.253 | 21.1 | 0.07 |
| (30) | Split Unstained[c] | 53.9 ± 1.5 | 35.1–69.2 | 0.03 | 0.86 | 0.006 | 55.17 | 0.00 |
| | Split Light Stained[c] | 15.1 ± 0.9 | 5.6–27.7 | 0.35 | 0.56 | 0.119 | 14.6 | 0.01 |
| | Split Dark Stained[c] | 9.3 ± 0.8 | 3.2–20.2 | 0.18 | 0.68 | −0.072 | 9.6 | 0.01 |
| | Split Adhering[c] | 0.8 ± 0.1 | 0–2.5 | 0.02 | 0.90 | 0.003 | 0.8 | 0.00 |
| | Closed Kernel[c] | 7.2 ± 0.4 | 3.1–12.3 | 0.09 | 0.77 | −0.027 | 7.1 | 0.00 |
| | Closed Blank[c] | 3.2 ± 0.2 | 1.1–5.5 | 0.03 | 0.87 | −0.006 | 3.2 | 0.00 |
| 2006 | Yield | 10.1 ± 1.1 | 3.0–24.0 | 0.49 | 0.49 | 0.106 | 9.1 | 0.02 |
| (32) | Split Unstained | 61.5 ± 0.9 | 50.4–72.6 | 0.67 | 0.42 | −0.099 | 62.5 | 0.02 |
| | Split Light Stained | 9.4 ± 0.7 | 2.3–16.4 | 0.15 | 0.70 | 0.034 | 9.08 | 0.00 |
| | Split Dark Stained | 3.0 ± 0.3 | 0.8–6.1 | 0.53 | 0.47 | 0.025 | 2.8 | 0.02 |
| | Split Adhering | 1.1 ± 0.1 | 0–2.7 | 2.68 | 0.11 | −0.024 | 1.4 | 0.08 |
| | Closed Kernel | 5.5 ± 0.3 | 2.5–12.6 | 0.01 | 0.94 | −0.006 | 8.0 | 0.00 |
| | Closed Blank | 7.9 ± 0.5 | 3.2–14.7 | 2.96 | 0.10 | 0.075 | 4.7 | 0.09 |
| 2007 | Yield | 14.6 ± 0.7 | 8.1–23.3 | 17.48 | 0.0002 | −0.105 | 18.25 | 0.34 |
| (35) | Split Unstained | 39.7 ± 2.4 | 18.8–69.4 | 126.18 | <0.0001 | −0.560 | 59.2 | 0.79 |
| | Split Light Stained | 3.5 ± 0.3 | 1.0–7.6 | 0.47 | 0.50 | 0.009 | 3.2 | 0.01 |
| | Split Dark Stained | 2.3 ± 0.2 | 0.7–6.6 | 1.92 | 0.18 | −0.013 | 1.8 | 0.06 |
| | Split Adhering | 1.7 ± 0.2 | 0.4–4.5 | 1.26 | 0.27 | 0.009 | 1.4 | 0.04 |
| | Closed Kernel | 18.4 ± 1.4 | 3.3–34.3 | 25.58 | <0.0001 | 0.176 | 4.3 | 0.44 |
| | Closed Blank | 10.5 ± 5.9 | 2.0–26.3 | 47.63 | <0.0001 | 0.283 | 8.5 | 0.59 |

[a] Linear regression analysis was completed independently for each year of the study using all trees as data points. For regressions, df = 1, 28 (2005), 1, 30 (2006), and 1, 33 (2007).

[b] Reported in kg dry weight per tree.

[c] Reported in percentage of total dry weight.

This means that for every 1,000 mealybug-days there was a decrease in total dry weight per tree of 0.105 kg.

Pistachio quality was measured at harvest using six different parameters (Table 2). The most important parameters are the percentage of split in-shell nuts that are unstained or have light staining, which are the percentage of total dry weight for which a grower is paid (weight of both the kernel and the shell). During all three years, the maximum split unstained nuts were relatively uniform, ranging only from 69.2 to 72.6%, whereas the minimum percentages were 35.1, 50.4, and 18.8 for 2005, 2006, and 2007, respectively. Linear regression of the percentage of split unstained against cumulative mealybug days showed no relationship in 2005 and 2006 ($P > 0.42$) and a highly negative correlation in 2007 ($F = 126.10$; df = 1, 33; $P < 0.0001$), expressed as $y = -0.000560 \times + 59.2$. This means that for every 1,000 mealybug-days there was a decrease in the percentage of split unstained of 0.560%.

During all three years, linear regression showed no relationship between the percentages of split light stained ($P > 0.42$), split dark stained ($P > 0.18$), or split adhered ($P > 0.11$) and cumulative mealybug-days (Table 2). This means that feeding by the mealybug on the hull did not produce any significant reductions in parameters of nut quality that are related to the condition of the shell; in other words, the kernel and shell are protected from direct mealybug damage by the hull that is removed shortly after harvest.

Closed shell nuts with a kernel or that were blank made up the last two parameters of nut quality (Table 2). In 2005 and 2006 the mean percentages of closed kernel and closed blank nuts were < 7.9% of the total dry weight with a range across the two years of 1.1 to 14.7%. Linear regression analyses showed no relationship between mealybug-days and the percentage of closed kernel ($P > 0.77$) or closed blank ($P > 0.10$) nuts in 2005 or 2006. However, the percentages of closed kernel and closed blank nuts were approximately twice as high in 2007 compared with 2005 and 2006. In 2007 the percentage of closed kernel ranged from 3.3 to 34.3% while closed blank ranged from 2.0 to 26.3%. Linear regression analyses found highly positive correlations between the percentage of closed kernel ($F = 25.58$; df = 1, 33; $P < 0.0001$) and closed blank ($F = 47.63$; df = 1, 33; $P < 0.0001$) against mealybug-days. This means that for every 1,000 mealybug-days there was an increase in the percentage of closed kernel and closed blank of 0.176 and 0.283%, respectively.

Conclusions regarding the effects of *F. gilli* on quality components of crop loss were made based on regression analyses from the three years of the study. The results suggest that the most important component of crop loss is a reduction in the percentage of split unstained and an increase in the percentage of closed blank, whereas reductions in the quality of the shell were not significant. In 2007 for every 1,000 mealybug-days there was a 0.560% decrease in the percentage of split unstained that was offset by a 0.459% increase in the percentage of closed kernel (0.176%) and closed blank (0.283%). Losses in crop value occurred under this scenario because growers are paid for the price of the shell and the kernel for split unstained nuts whereas growers are only paid for the weight of the kernel for nuts with closed shells.

The primary mechanism for crop losses associated with both yield and quality is likely a reduction in kernel size and weight. Mealybugs are phloem feeders

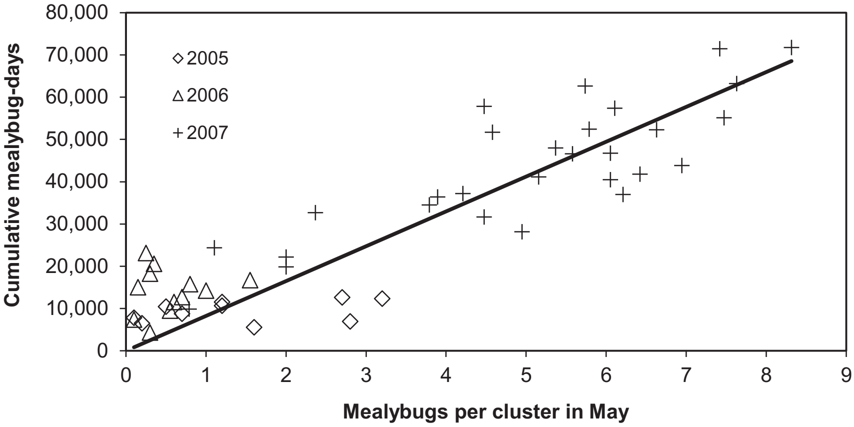

**Fig. 1.** Linear regression [$y = 8247\times$, ($R^2 = 0.76$)] of cumulative mealybug-days per cluster from May through harvest and the number of mealybugs per cluster in May ($y$-intercept forced to zero) for trees that did not receive insecticide treatments in 2005, 2006, and 2007.

(Ben-Dov 1995) and their feeding can reduce the amount of nutrients, such as carbohydrates, nitrogen, and phosphorus, in the rachis and hull that are intended for kernel development. Interception of nutrients by mealybugs has the potential, therefore, to reduce kernel size and weight. Reductions in kernel weight provide an explanation for reductions in yield of total dry weight per tree found in this study. Reduction in kernel size also provide an explanation for decreases in the percentage in weight of split unstained nuts and increases in the percentage of the weight of closed shell nuts because splitting in pistachios is the direct result of the mechanical forces caused by the kernel as it expands in size within the shell. Therefore, smaller kernels are less likely to reach a size where mechanical force causes the shell to split, resulting in a greater percentage of closed shell nuts.

**Economic Injury Levels.** EILs were determined for *F. gilli* density in May for which an insecticide treatment is justified. The May timing is a critical monitoring period already used by growers to make decisions regarding treatments during crawler emergence in early June (Haviland et al. 2012). Prior to calculating EILs we performed regression analysis to validate an assumption that *F. gilli* density in May is correlated to mealybug-days from May through harvest. The result was a highly significant correlation ($F = 627.15$; df = 1, 49; $P < 0.0001$; $R^2 = 0.76$; Fig. 1). Due to the highly significant results of this analysis, we determined that mealybug density in May is an excellent predictor of cumulative mealybug-days and could be used as a reliable monitoring component for the determination of economic injury levels.

EILs were calculated according to the formula EIL = CN/YPL (Pedigo et al. 1986). The cost of control (C) was assumed to be $150/ha ($60/acre) based on the standard grower practice of applying buprofezin (Centaur WDG, Nichino America, Inc., Wilmington, DE) at a rate of 2,400 g/ha (2.14 lb/acre) at a cost of $0.0395/g ($1.12/oz) of product with an application cost of $43.24/ha ($17.50/acre). This cost of control was based on the assumption that one application of buprofezin provides 100% control of *F. gilli* based on work by Haviland (2006, 2007) and conversations with growers. Pest density (N) was defined as one *F. gilli* per cluster in May. Yield (Y) was defined as the anticipated yield in kg/ha and was left as a variable in the model so that EILs could be calculated for any anticipated yield. Price (P) was defined at $4.4/kg ($2/lb) based on a 10-yr average return to pistachio growers reported by the USDA National Agricultural Statistics Service (2013).

The percentage reduction in crop value (L) was determined by summing the effects of mealybug density on crop quality and yield. For crop quality there was a highly significant correlation between *F. gilli* per cluster in May and grower paid weight ($F = 112.33$; df 1, 48; $P < 0.0001$; $R^2 = 0.70$; Fig. 2). This means that for every mealybug per cluster in May there is a reduction in the percentage of grower paid weight of 4.05%; dividing this value into the y-intercept of 85.6% resulted in the ratio of crop loss of 4.73% (quality component of L) for every increase of 1 mealybug per cluster in May.

We also calculated the percentage reduction of crop value (L) associated with yield. This was done differently than assessments of reduction in crop quality because regressions between mealybugs per cluster and year could not be done across years because cluster number per tree was not constant. Therefore, we calculated yield loss by combining the relationships between mealybug density in May and cumulative mealybug-days during all three years of the study (Fig. 1) with the relationship between cumulative mealybug-days and yield in 2007 (Table 2). The year 2007 was chosen for the analysis because it had the greatest range of mealybug densities in May, the largest number of trees, and because the relationship between yield and mealybug density was highly significant ($F = 17.48$; df = 1, 35; $P = 0.0002$). This allowed us to substitute mealybug-days from the first equation [mealybug-days = (8247)(mealybugs per cluster in May)] into the second equation [yield = (−0.000105)

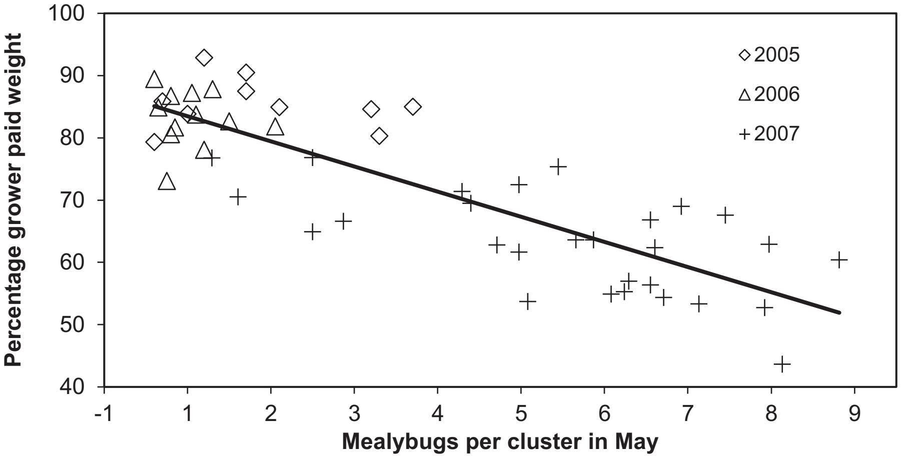

**Fig. 2.** Linear regression [grower paid weight = $-4.052 \times + 85.6$, ($R^2 = 0.70$)] of grower paid weight (percentage of the total dry weight for which a grower is paid) and the number of mealybugs per cluster in May for trees that did not receive insecticide treatments in 2005, 2006, and 2007.

(mealybug-days) + 18.25]. The resulting equation ($y = -0.866 \times + 18.25$) means that for every one mealybug in May there is a 0.866 kg reduction in yield per tree; dividing this value into the y-intercept of 18.25 kg resulted in the ratio of crop loss of 4.75% (yield component of L) for every increase of 1 mealybug per cluster in May.

The variables previously described were used to calculate EILs for any possible yield in total dry weight according to the formula:

$$\begin{aligned}\mathrm{EIL} &= \mathrm{CN/YPL}\\ &= (\$150)(1)/(\mathrm{Y})(\$4.4)(0.0473 + 0.0475)\end{aligned}$$

The equation resolved to the inverse function whereby EIL in mealybugs per cluster in May = $359.61\mathrm{Y}^{-1}$ where Y equals the anticipated yield (dry weight) in kg/ha. For growers in California we suggest the analogous formula (EIL = $316.46\mathrm{Y}^{-1}$) that generates EILs based on anticipated yields that are measured in lbs/acre. These formulas can be used to determine EILs for any value of anticipated yields (Fig. 3). In Table 3 we use the formula to calculate the EILs for typical pistachio yields in California. Yields in pistachio orchards typically range from 2,245 to 4,491 kg/ha (2,000 to 4,000 lb/ac) depending on whether trees are in an "on" or an "off" year in their cycle of alternate bearing. Using the formula this means that EILs for orchards with normal yields (low to high in Table 3) range from 0.16 to 0.08 mealybugs per cluster in May (approximately 1 mealybug per 6 to 12 clusters); EILs for orchards with very low (1,123 kg/ha = 1,000 lbs/acre) to very high (5,614 kg/ha = 5,000 lb/acre) anticipated yields ranged from 0.32 to 0.06 mealybugs per cluster in May (approximately 1 mealybug per every 3 to 16 clusters).

Adjustments in EILs may be necessary due to changes in assumptions that were used in the model. For example, data by Haviland (2005, 2006) suggest that one application of buprofezin provides sufficient control to keep populations of *F. gilli* at a density below the EIL for two seasons; therefore, the costs of application would need to be divided in half to amortize the costs across two seasons and anticipated yields must be estimated for both the current and following seasons. Adjustments to assumptions would also need to be made in cases where modifications occur to the cost of an insecticide for mealybug control or due to changes in the price per pound that a grower receives at harvest.

EILs can also be adjusted in cases when there are ulterior motives for spraying. For example, a grower that is already making an application to the orchard in early June (foliar nutrient or fungicide) might consider removing the cost of application ($43.25/ha = $17.50/acre) from the model. The result is a modified formula of EIL = $255.92\mathrm{Y}^{-1}$ for anticipated yields in kg/ha and $224.14\mathrm{Y}^{-1}$ for anticipated yields in lbs/acre. This results in EILs that are approximately 30% lower than when the full cost of application is included. A second example of ulterior motives is that many growers have orchards that are infested as well as other orchards that do not have mealybugs. Under this scenario growers are likely to treat more aggressively against *F. gilli* in infested orchards as a way to protect uninfested orchards, especially when equipment is shared among orchards and the risk of spread is high.

*F. gilli* is a new pest of pistachios that can reduce crop value of pistachios. Reductions in crop value were associated with reduced yields in total dry weight and with a reduction in nut quality. Reductions in quality were primarily the result of a reduction in the percentage of dry weight of split in-shell nuts and an increased in nuts with closed shells. This represents a significant shift in crop value due to the pricing structure of pistachios where a grower is paid for the weight of both the shell and the kernel for nuts that can be sold as split in-shell whereas a grower is only paid for the weight of the kernel for nuts with damage to the shell or with closed shells. Other possible effects of *F. gilli* to quality, such

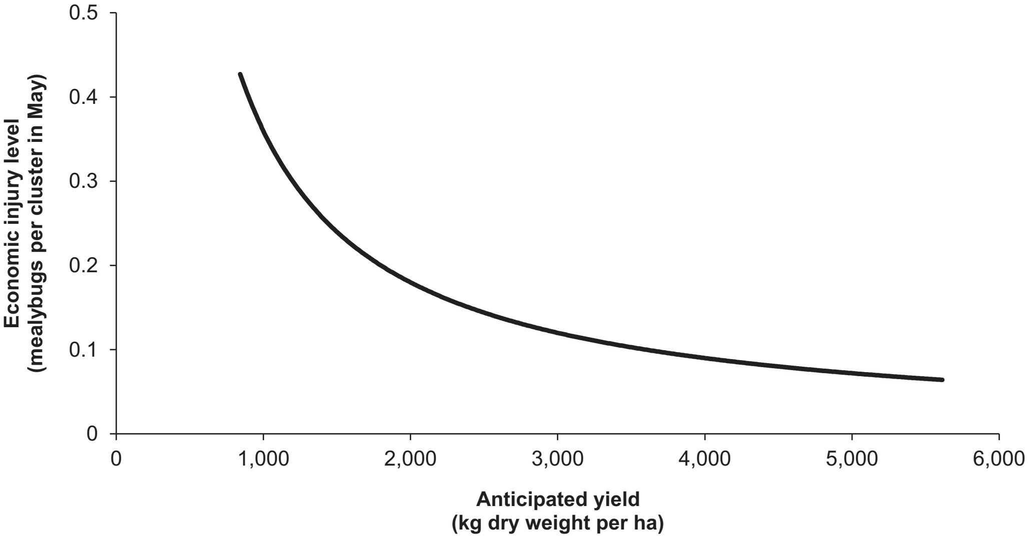

**Fig. 3.** Economic injury levels (EILs) for the number of *F. gilli* per cluster in May for a range of anticipated pistachio yields in kg dry weight per ha ($y = 359.6\times^{-1}$). EILs are based on an assumed crop value of \$4.4/kg per pound, control costs of \$150/ha, and a reduction in grower paid weight of 9.48% (4.73% reduction in yield plus 4.75% reduction in quality) for every 1 mealybug per cluster in May.

**Table 3. Economic injury levels for hypothetical anticipated yields based on the formula EIL = 359.6x$^{-1}$ where x equals the total anticipated pistachio yield in dry weight in kg/ha and EIL = 316.46x$^{-1}$ where x is reported in lb/acre**

| Anticipated yield level | Total anticipated dry weight of pistachios | | EIL (mealybugs per cluster in May) | EIL equivalent reported 1 in mealybug per no. of clusters in May |
|---|---|---|---|---|
| | kg/ha | lb/acre | | |
| Very Low | 1,123 | 1,000 | 0.32 | 3.1 |
| Low | 2,245 | 2,000 | 0.16 | 6.3 |
| Medium | 3,368 | 3,000 | 0.11 | 9.5 |
| High | 4,491 | 4,000 | 0.08 | 12.6 |
| Very High | 5,614 | 5,000 | 0.06 | 15.8 |

The models assume pistachio values of \$4.4/kg (\$2/lb) and control cost of \$150/ha (\$60/acre).

as an increase in staining to the shell or increase in nuts with adhered hulls, were not found during this study.

Current management programs for *F. gilli* are based on monitoring programs in May that are used to determine treatment timing (peak crawler emergence) in early June (Haviland et al. 2012). As a result of the development of EILs in this project, pistachio producers may also use their monitoring programs in May to determine if a treatment is needed. Growers with average anticipated yields of 3,300 kg/ha (~3,000 lb/ac) should treat for *F. gilli* if they find 1 mealybug per every 10 clusters in May. EILs should be adjusted upward or downward due to the fluctuation in yields that are typical due to alternate bearing. In an "off" year with anticipated yields of approximately 2,250 kg/ha (2,000 lb/acre), growers should treat if they find 1 mealybug per 6 clusters in May, whereas in an "on" year, with anticipated yields of approximately 4,500 kg/ha, a grower should treat if there is one mealybug per every 13 clusters. These EILs can be calculated from year to year using the formula EIL = 359.6Y$^{-1}$ (for yields in kg/ha) and EIL = 316.46Y$^{-1}$ (for yields in lbs/acre) where Y equals the anticipated in yield in dry weight. Equations within this manuscript can also be modified as needed in the future to account for other necessary changes in the model, such as those associated with control costs and crop price.

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