Correct Project Number: 97-FZ-o0

Annual Report to
Almond Board of California
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Project No.: 97-FZ-00 Insect and Mite Research

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Objectives:

1. Purchase pheromone traps and lures, and other monitoring supplies for UC Cooperative Extension Farm Advisors as part of their ongoing monitoring efforts.

2. Conduct field and laboratory trials in the San Joaquin Valley to test the effect of several registered materials and new candidate materials as dormant sprays for control of San Jose scale, and to determine the effect of normal and low rates of oil on diazinon efficacy.

3. Conduct field and laboratory trials in both the San Joaquin Valley and the Sacramento Valley to test the effect of registered materials and new candidate materials on peach twig borer, and to test for differences in susceptibility of peach twig borer populations.

4. Support the ongoing Kern County BIOS efforts being conducted by Walt Bentley and Mario Viveros.

Summary of Results:
Objective 1. This objective has been a cooperative effort with many UC Cooperative Extension Farm Advisors over the years. Trapping supplies are purchased each year for use by participating Farm Advisors to help confirm the accuracy of the techniques, and to help them to monitor the activity of specific insects in their counties. The trapping records are assembled at UC Davis at the end of each season. This year over 850 traps and 1350 pheromone lures (plus almond press cake bait) were purchased and distributed to 12 Farm Advisors to monitor navel orangeworm, peach twig borer, San Jose scale, and oriental fruit moth in almond orchards (Table 1).

Table 1. Trapping supplies purchased for monitoring insect pests in almonds, 1997.

Name	Location	Wing Traps	Trap Liners	NOW Traps	SJS Traps	PTB Lures	OFM Lures	SJS Lures	NOW Bait (lbs)
J. Connell	Butte Co.	4	12	4	0	16	0	0	1
R. Duncan	Stanislaus	8	32	4	8	24	24	16	1
R. Coviello	Fresno Co.	8	32	8	0	48	0	0	1
L. Hendricks	Merced Co.	50	100	50	100	100	0	100	5
J. Edstrom	Colusa Co.	6	24	4	8	24	12	16	1
R. Buchner	Tehama Co.	8	32	8	4	24	24	16	1
J. Brazzle	Kern Co.	0	0	0	250	0	0	100	0
W. Krueger	Glenn Co.	4	16	0	0	16	0	0	0
W. Reil	Yolo Co.	15	100	0	0	100	0	0	2
W. Bentley	UC KAC	12	36	50	75	225	100	125	5
P. Verdegaal	San Joaquin	12	36	6	0	36	36	0	1
M. Freeman	Fresno Co.	8	32	8	16	48	0	32	1
F. Zalom	UC Davis	12	36	0	0	90	2	0	1
TOTAL	ALL SITES	147	256	142	461	751	198	405	20

During this year, historic data from this project was used to complete a comparison of several proposed phenology models for the navel orangeworm. In the study, 5 approaches for predicting first egg laying by first and second generation navel orangeworm adults were compared. Two linear deterministic models, one incorporating a horizontal upper developmental cutoff and one incorporating a vertical upper developmental cutoff, were evaluated as were 2 linear models incorporating a stochastic element and a nonlinear approximation which used developmental rate data directly. All of the models provided significant ($P < 0.001$) correlation of predicted egg laying with observed dates, but varied somewhat from 1.00 in their regression coefficients. The nonlinear approximation gave the closest average prediction, however there is difficulty in implementing this approach because it requires integration of weather data with the developmental rate data, and the need for a specific computer program to do this. If there is interest in developing a user version of this program now that the use of microcomputers is becoming more widespread, we could do this as an objective in a future year.

Attached to the end of this report is a manuscript submitted for publication in *Acta Horticulturae* based on a paper delivered at the Second International Symposium on Almond Production held at UC Davis last August.

Objectives 2: Field trials were conducted in Kern County by UC Farm Advisor James Brazzle to determine efficacy of several control approaches against San Jose scale. Treatments for San Jose scale included different rates of the organophosphates diazinon (full, half and quarter rate) and phosmet (Imidan), the pyrethroids permethrin (Pounce or Ambush) and esfenvalerate (Asana), the carbamate carbaryl (Sevin), oil alone, and promising (but as yet unregistered) insecticides including an insect growth regulator from Ciba Geigy and pyriproxifen, a juvenile hormone analog. The scale crawlers from these 19 treatments (including an unregistered control) were monitored using double sided sticky tape applied with and without duck tape placed around the branches. The tapes have all been counted at this time, but data have not been analyzed. This trial is being repeated for the 1998 dormant season, with first results for 1998 expected in May.

Seven Kern County orchards were monitored weekly from late February through the end of September with San Jose scale pheromone traps by James Brazzle. Total numbers of male scales, and the parasites *Prospaltella* sp. and *Aphytis* sp. were counted on the traps. Pesticide use records from 1993 - 97 were also collected for each of the orchards.

Graphs of the weekly trap counts from the 7 orchards are attached to the end of this report, and are labeled as to location. While it would take several years of such observation or controlled field studies to determine cause and effect relationships between location, pesticide use history, and results of current season pesticide use, it was interesting to note some specific observations. At the Wasco Ranch, good levels of parasitism were observed in the early season with the levels of *Prospaltella* sp. peaking at over 400 per trap in mid-March. Scale counts remained low through July as no additional insecticides were applied until hull split. Following a hull split Guthion application, scale populations increased to over 2000 per trap possibly due to disruption of the parasitism. Four orchards with high scale populations early in the season had applied diazinon for 4 years prior to this season. One of these orchards had missed the dormant organophosphate and oil spray in 1995, and one had used concentrate applications instead of dilute applications since 1995. We chose not to put the historic pesticide use records into this report as they could be identified as to grower.

Objective 3: A field trial was conducted on Nonpareil almonds in Kern County by James Brazzle to determine the efficacy of permethrin (Pounce or Ambush), Supracide and spinosad against the peach twig borer, and to determine the impact of these dormant sprays on subsequent spider mite and beneficial populations. This work complemented the 1996 study of these materials which also included the biological product *Bacillus thuringiensis* applied at bloom. All treatments (except for 1 spinsosad treatment) were applied with Volck supreme oil at 4 gallons per acre with an airblast sprayer at 220 gallons per acre, 90 psi and 1.8 mph. Plot size was 2.1 acres, and treatments were replicated 4 times. Unfortunately there was no untreated control. PTB were monitored by counting the total number of twig strikes per tree on April 3, sampling 6 trees per replicate. Spider mite populations were monitored at 2 week intervals beginning in May by sampling 15 leaves per tree from 3 trees in each treatment replicate and mite brushing the leaves.

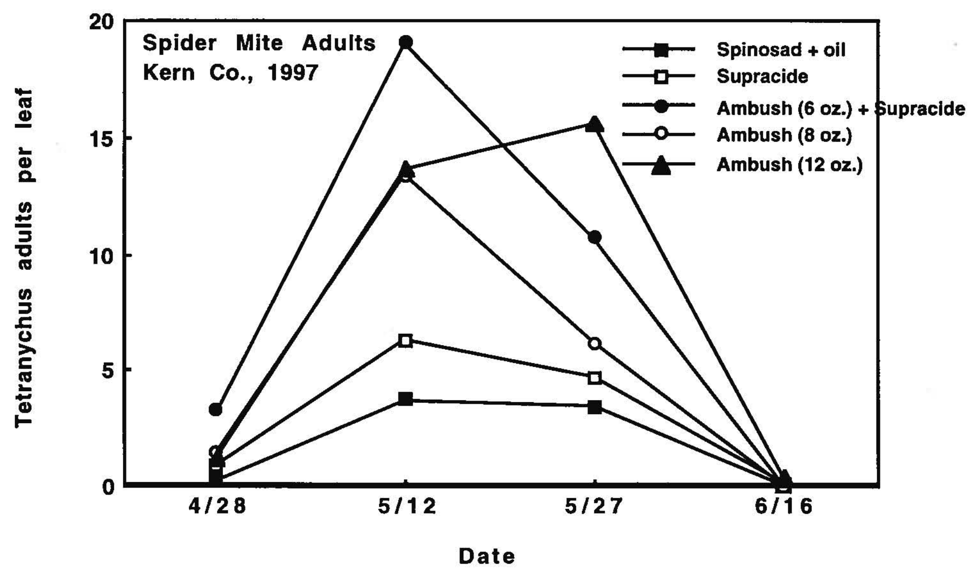
Two way ANOVA with LSD post-hoc testing indicated significant treatment effects ($F = 4.33$; $df = 5, 18$; $P = 0.009$) with permethrin treatments generally providing the greatest level of control (Table 2). Spider mite populations peaked at 19, 7 and 4 mites per leaf in the pyrethroid, organophosphate and spinosad treatment, respectively, with a statistically significant difference being observed for both adults (Figure 1) ($F = 13.64$; $df = 4, 220$; $P<0.001$) and eggs ($F = 12.17$; $df = 4, 220$; $P < 0.001$). Populations of European read mite adults (Figure 2) ($F = 4.09$; $df = 4, 220$; $P = 0.003$)

and eggs (F = 17.85; df = 4, 220; P < 0.001) were also higher on the pyrethroid treated trees. The greatest impact was seen on the number off ERM eggs per leaf which peaked at 118.3, 103.0, 72.4, 46.1 and 27.6 for the high rate of permethrin, permethrin plus methidathion, low rate of permethrin, methidathion and spinosad treatments, respectively.

Table 2. Efficacy of selected insecticides applied in the dormant season for control of peach twig borer in Kern Co., 1997.

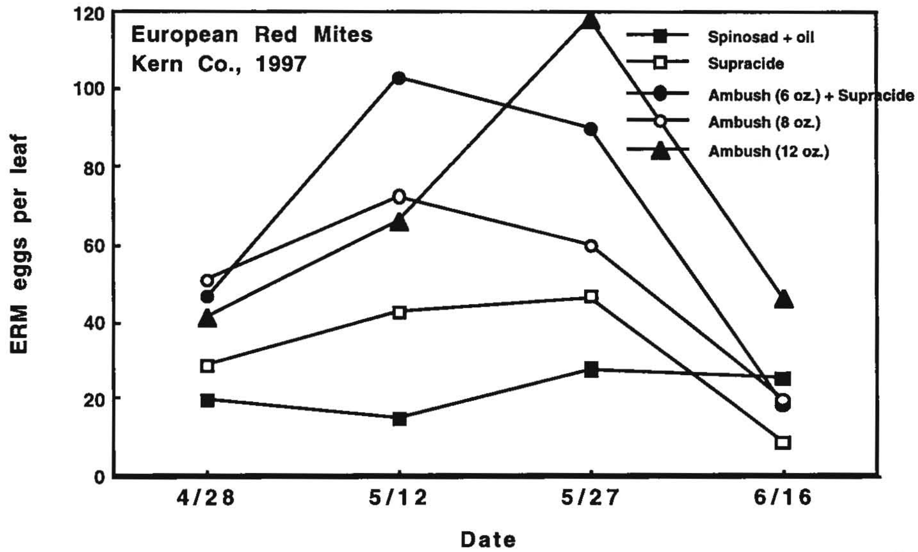
Treatment and rate	Mean no. of PTB strikes per tree ± SE
Spinosad @ 169 ml/ ac.	0.33 ± 0.07 bc
Spinosad @ 169 ml/ ac. + oil	0.46 ± 0.14 c
Supracide @ 8 lbs./ ac.	0.13 ± 0.08 ab
Ambush @ 6 oz./ ac. + Supracide @ 8 lbs./ ac.	0.04 ± 0.04 a
Ambush @ 8 oz./ ac.	0.13 ± 0.04 ab
Ambush @ 12 oz./ ac.	0.08 ± 0.05 ab

Figure 1. Number of adult *Tetranychus* spider mites per leaf.



This study reinforces our belief that a grower needs to evaluate the entire pest management program based upon the risks and benefits associated with each management decision. The added benefit provided with the use of pyrethroids in terms of cost for that treatment and peach twig borer control must be weighed against the cost of potentially managing a higher spider mite population.

Figure 2. Number of adult European red mites per leaf.



Peach twig borer tolerance to pesticides. The susceptibility of peach twig borer to the organophosphate dormant sprays has been questioned by growers in several locations, but no data on possible pest resistance has been developed. In 1997, we sampled peach twig borer populations from Butte, Colusa, Glenn, Kern (2 sites), Merced, Stanislaus and Solano/ Yolo Counties. PTB larvae were removed from the shoot strikes which were gathered from each field site, and placed into individual capped containers containing a standard bean diet. After all of the larvae were placed onto the diet, a drop of one of 5 sequential dosage rates of diazinon, esfenvalerate or spinosad mixed in acetone was applied topically to each larva. The larvae were held at 68°C in an environmental chamber for 48 hours before assessing mortality by prodding the larvae with a needle probe and observing movement. A minimum of 8 larvae (and as many as 15 depending on the number of larvae available from each of the collections) were subjected to each dosage rate. These data will be useful in the future as baselines to determine if any shift in tolerance (indicating the development of resistance) has occurred in case of field failures of these materials.

All of the populations sampled were susceptible to diazinon (Figure 3), but there was considerable diversity in range of susceptibility, with LD 50 values ranging from about 100 ppm (Arbuckle and Dixon) to 700 ppm (Kern Co. 2) and 1000 ppm (Williams). There should be concern about elevated tolerance at the latter two sites.

All of the populations sampled were susceptible to esfenvalerate (Asana), but there was less of a range of susceptibility than occurred for diazinon. This is not unexpected since the pyrethroids have been used in almond orchards for a relatively

Figure 3. Susceptibility of peach twig borer populations to diazinon in 1997.

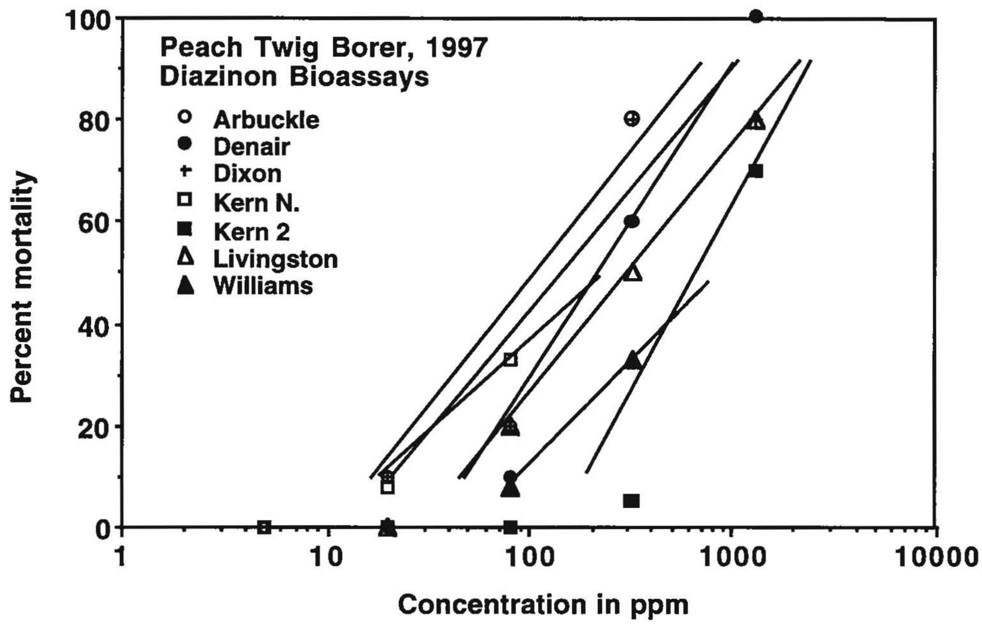
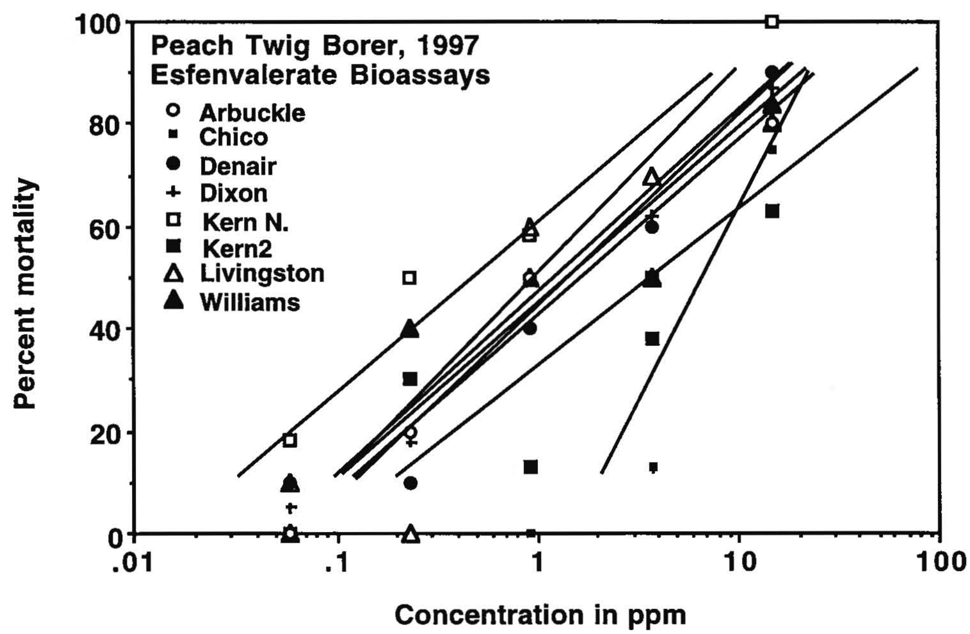


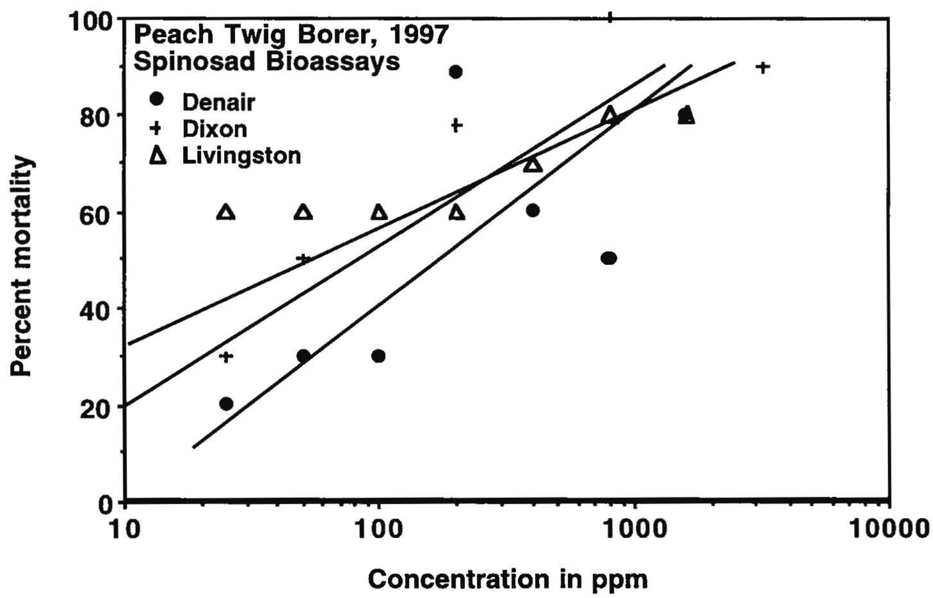
Figure 4. Susceptibility of peach twig borer populations to esfenvalerate in 1997.



short period of time. Virtually all of the orchards had LD 50 values at about 1 ppm. However, one site was somewhat higher at 4 ppm (Williams) and another was much higher at 7 ppm (Chico) than the other sites (Figure 4). The Chico site was sampled based on the observation of Robert Sanders, a crop consultant in the area, that an orchard that had been sprayed with a pyrethroid as a dormant spray for at least 5 years appeared to have more twig strikes the previous year than other orchards he was monitoring that did not display this phenomenon.

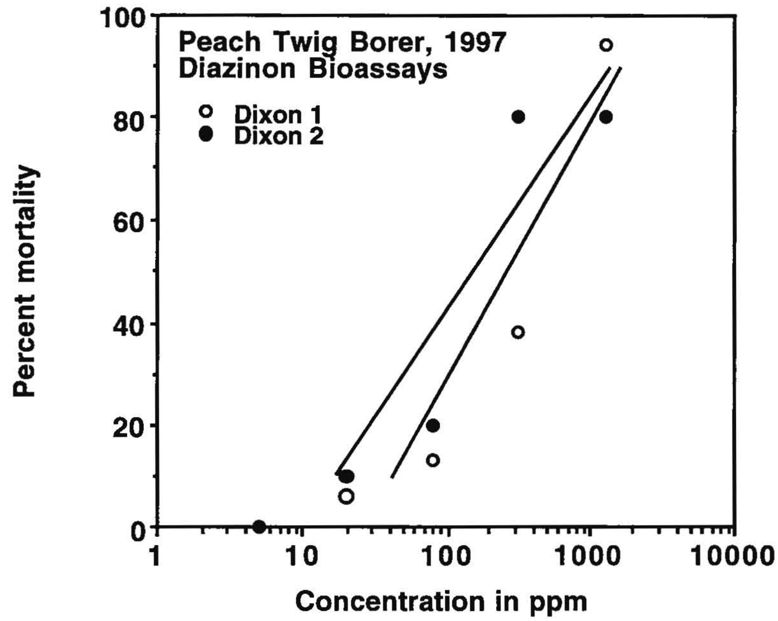
We attempted to use the same bioassay for spinosad (Figure 5), a new biological pesticide from DowElanco, as we did for the other conventional pesticides from sites where we had collected enough larvae to run the bioassay for all 3 materials. In the end, we only had sufficient larvae to run the bioassay at 3 sites. The LD 50 for these sites was about 100 ppm with little variability between sites. We feel that this bioassay is unsatisfactory for spinosad as the rate at which the LD 50 occurs is so much higher than what is observed for mortality at field rates. We are attempting to develop a new bioassay based on a total immersion of the larvae.

Figure 5. Susceptibility of peach twig borer populations to spinosad in 1997.



Because it is very difficult to obtain larvae of the overwintering generation, it would be difficult to use this bioassay under some circumstances. It is often easier to find larvae of the first generation in May, but it cannot be assumed that susceptibility of each generation to the pesticide would be consistent. Therefore, we sampled larvae of both the overwintering generation and the first generation from the Dixon orchard which has remained untreated since planting, and subjected those larvae to the same bioassay as conducted for the various sites. The results of this test indicated that the susceptibility of larvae of both generations were similar (Figure 6) at about 100 ppm.

Figure 6. Comparison of diazinon susceptibility of peach twig borer larvae from overwintering generation (sampled late March) and first generation (sampled in May) from the Dixon site.



Objective 4: In 1994, a project to evaluate the impact of reduced insecticide applications during the growing season to almonds was established in Kern County. The project involves the University of California Cooperative Extension (Mario Viveros, Walt Bentley, and later James Brazzle), the Pond Shafter Water Resource Control District (Brian Hockett), UC Statewide IPM Project (Frank Zalom), Paramount Farms (Doug Blair and Bernard Puget), Amcal Farms (Allan Scroggs), Kern Farms (Ed Kykendal). The project was modeled after the BIOS project in the northern San Joaquin Valley. Cooperators agreed to establish orchards within their ranches ranging in size from 40 to 80 acres which could be managed without insecticides applied during the growing season. In addition, various cover crops were grown in 3 of the 4 test orchards to enhance water infiltration and soil fertility. Navel orangeworm, peach twig borer, oriental fruit moth and San Jose scale were monitored during the growing season using pheromone traps and NOW egg traps. At harvest, nut samples were collected and evaluated for damage resulting from navel orangeworm, peach twig borer, and ants. This information was compared to that of the remainder of each orchard which is managed with conventional insecticide application.

Kernel damage. The results from the first harvest in 1995 varied considerably. For example, total damage in the insecticide free acreage of Ranch 14 was 14.29% (3.89% ant, 4.79% PTB, and 6.29% NOW) after 7 days on the ground. Damage in the conventionally sprayed orchard was 5.64% (0.93% ant, 1.50% PTB, and 3.21% NOW). At Amcal, the sprayed orchard averaged 0.43% and the unsprayed orchard averaged 0.57% damage, essentially no difference between the two. Because of the severe damage observed at Ranch 14, the acreage managed at low intensity was reduced considerably. Acreage at the Amcal location was modified somewhat in 1996 as well, with fewer acres left untreated.

In 1997, the unsprayed blocks were abandoned in all but the Amcal orchard, and therefore the direct comparison of damage could only be done at this location. However, monitoring of San Jose scale and its parasitoids was continued in all orchard blocks to observe the influence, if any, of the reduced insecticide program.

At Amcal in 1997, all but 30 acres were sprayed during the growing season. Both orchard blocks were treated with a dormant spray due to excessive peach twig borer damage in 1996. The dormant treatment was applied on January 20, and consisted of 4.66 lb. of Imidan 70W plus 4 ounces of Pounce plus 6 gallons of Volck oil in 175 gpa. Both blocks were also treated for ants with 6 pints of Lorsban 4E on July 1 in 45 gpa. The 30 acres in the 'unsprayed' block received no other spray while the comparison block was treated on June 20 with 4 lb. of Guthion in 175 gpa. Both orchard blocks received excellent winter sanitation averaging 0.05 nuts per tree in the 'unsprayed' and 0.08 nuts per tree in the 'sprayed' orchard blocks in February mummy counts. Seven 200 nut samples were collected from the 'unsprayed' block and nine 200 nut samples were collected from the 'sprayed' block on August 19 for the Nonpareil variety, and on September 5 for the Sonora variety. Total Nonpareil damage averaged 1.17% in the 'sprayed' orchard block (0% ant, 0.06% NOW, and 1.11% PTB). Total damage for Nonpareil averaged 2.57% from the 'unsprayed' orchard block (0% ant, 0.42% NOW, and 2.15% PTB). The Sonora variety averaged 3.94% damage (0.72% ants, 1.83 % NOW, and 1.39% PTB) in the sprayed orchard block and 3.36% (0.43% ant, 2.07% NOW, and 0.86% PTB) in the unsprayed orchard block.

The Guthion treatment did not significantly reduce damage in the Sonora variety. The reduction in Nonpareil damage is consistent with the estimated 50% control expected from such a treatment. Although a 1.4% reduction in damage appears to be small, this allows for grower bonus payments from processors which can average as much as 10 cents per pound, making the treatment economically sound. Without this bonus, the cost of the treatment might not be justified by reduced damage.

San Jose scale monitoring. San Jose scale is major problem for Almond growers throughout the state. Work done in conjunction with Lonnie Hendricks has shown that orchards in Merced and Stanislaus Counties, particularly those which remain unsprayed, are not as heavily infested as are those in the southern San Joaquin Valley counties. Monitoring of male San Jose scale and crawler activity was carried out both in orchards which had been managed without insecticides and in those where insecticides had been used during the growing season. In the Kern County orchards observed throughout the course of this study, San Jose scale has not proven to be an important problem. However, insights were gained into the relationship between scale and scale parasitoids, particularly where growing season sprays were stopped.

At Amcal in 1997, San Jose scale traps were set out on February 27, and first male scales were recorded on March 14. The layout of the plots in this orchard had been changed in 1996 and 1997 from the original design established in 1995. However, we were able to identify locations which 1) received no growing season spray since 1995, 2) received no sprays in 1995 and 1996, but was sprayed with Guthion in 1997, and 3) was sprayed in 1995, 1996 and 1997. As mentioned earlier, all these locations did receive a dormant spray in the winter of 1996/1997. Trapping data presented on Table 3 is accumulated through July 15, 1997. The greatest number of male scales and crawlers were trapped in the locations sprayed continually during the 3 years of the study (Table 3). The 1997 spray had not yet been applied when the scale counts were totaled, and therefore both the unsprayed comparisons were truly unsprayed. These two locations were found to have the lowest abundance of male scale, lowest abundance of scale crawlers, and highest abundance of the parasitoid *Encarsia perniciosa* . The abundance of scale in all orchard areas is relatively low compared to what is observed in outbreak situations in other orchards. At this site, it appeared that treatment history impacted the number of *Encarsia*. One would expect that the greater abundance of scale in the sprayed orchard block would result in a greater number of parasitoids, however, this was not the case. The orchard block with the greatest number of male scales and crawlers was also the area with the lowest count of parasitoids.

Table 3. Summary of San Jose scale monitoring, Amcal, Kern County, 1997.

	Unsprayed 1996 & 1997	**Unsprayed 1996, Sprayed 1997**	**Sprayed 1996 & 1997**
Average male SJS/ trap 2/7-7/15	226.67	248.3	379
Average SJS crawlers/ tape 4/14-5/15	18.67	27.44	146.83
Average *Encarsia*/ trap/ season	183.00	376.33	160

The Lost Hills site had the lowest abundance of males scales and scale crawlers in 1997. Traps were set on February 27 and male scales were first recorded on March 14. Interestingly, *Encarsia perniciosa* was first trapped on March 7, which was prior to the capture of male scales. Table 4 presents results of the scale and parasitoid monitoring. Seasonal counts of male scale averaged 199.75 in the unsprayed orchard block and 49.75 in the sprayed orchard block. The abundance of *Encarsia* was greatest in the unsprayed orchard block, but it is difficult to ascertain whether this was due to the impact of the spray or to the greater scale population.

Table 4. Summary of San Jose scale monitoring, Lost Hills, Kern County, 1997.

	Unsprayed	**Sprayed**
Average male SJS/ trap 2/7-7/15	199.75	49.75
Average SJS crawlers/ tape 4/14-5/15	0.25	1.33
Average *Encarsia*/ trap/ season	105.25	17.25

Two San Jose Scale monitoring traps were placed in each orchard block at Ranch 14 on February 27, and first male scales were trapped on March 14. Table 5 presents the results of the monitoring. The greatest number of male scales were trapped in the unsprayed portion of this orchard (the orchard did have a spray of Imidan in 1996 which could have influenced parasitoid activity). Crawler densities were relatively low in both areas but the highest number were found in the 'unsprayed block. This same area averaged 404 *Encarsia* per trap per season, the highest number trapped in Kern County, but far below the thousands of *Encarsia* which can be found in the Merced and Stanislaus County orchards.

Table 5. Summary of San Jose scale monitoring, Ranch 14, Kern County, 1997.

	Unsprayed 1995 and 1996	**Sprayed**
Average male SJS/trap 2/7-7/15	998.5	111.00
Average SJS crawlers/ tape 4/14-5/15	36.38	0.63
Average *Encarsia*/ trap/ season	404.00	45.00

Ant monitoring. Ant populations in the three orchard comparisons were monitored by placing 1/3 of a hot dog within a plastic vial, and dropping this to the soil surface for 2 hours. After 2 hours the vials were picked up and frozen. Ants feeding on the meat were captured in the vials. The ant counts from these frozen samples have not yet been tabulated. Ten or 20 vials were dropped either on the berms or in the alley middles to determine areas of greatest foraging. This method was followed on separate dates in May and July after soil treatments were applied.

Summary. The unacceptably high amount of insect damage observed during the first 2 years of this study at Ranch 14 has resulted in the loss of 3 cooperators. Although damage in both treatments at Amcal and Kern Farming has remained relatively low, it was still higher than that found in the sprayed blocks of these orchards. Often the level of damage was just high enough to prevent growers from receiving bonuses from the processors. Therefore, elimination of the seasonal insecticide spray use was considered too much of a risk for these cooperators.

San Jose scale monitoring will continue in 1998, with the intent of correlating male counts with sticky trap crawler numbers in an attempt to develop treatment guidelines for this pest. The results from 1997 indicate the possibility of integrating *Encarsia perniciosa* into the decision making process. Also timing of needed sprays could be designed to reduce impact to this important parasitoid.

VALIDATION OF PHENOLOGY MODELS FOR PREDICTING DEVELOPMENT OF THE NAVEL ORANGEWORM *Ameylois transitella* (Walker) IN CALIFORNIA ALMOND ORCHARDS.

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Keywords: almond, navel orangeworm, Ameylois transitella, phenology

Abstract:

Five approaches for phenological prediction of first egg laying by first and second generation *Ameylois transitella* (Walker) adults were validated using egg trapping data from multiple years and production areas in California. Two linear deterministic models, one incorporating a horizontal upper developmental cutoff and one incorporating a vertical upper developmental cutoff were evaluated as were 2 linear models incorporating a stochastic element and a nonlinear approximation which used developmental rate data directly.

All of the models provided significant ($P < 0.001$) correlation of predicted egg laying with observed dates, but varied somewhat from 1.00 in their regression coefficients. The nonlinear approach gave the best prediction, however there is difficulty in implementing this approach. Relative merits of each approach are discussed.

1. Introduction

The navel orangeworm, *Ameylois transitella* (Walker), is a key pest of California almonds. Navel orangeworm larvae and pupae overwinter in mummy nuts remaining in the orchards. The resulting moths begin to emerge in April, and reinfest remaining mummies with the first generation. Moths of this generation begin emerge in late June or early July, usually near the time of Nonpariel hullsplit, and lay eggs on mummies or new crop nuts. Larvae of this second generation cause direct damage to meats following hullsplit, and the resulting moths produce eggs from which larvae emerge that will reinfest the crop or infest later maturing varieties (University of California, 1985).

Oviposition by females of the navel orangeworm, can be monitored using egg traps (Rice, et al., 1976, Van Steenwyk and Barnett, 1985) filled with almond presscake fortified with almond oil as an attractant (Rice, et al., 1984). However, the traps become less efficient after hullsplit when many new crop nuts are present and compete with the traps as an oviposition site (Sanderson and Barnes, 1990).

Wade (1961), Gal (1978), and Engle and Barnes (1983) measured development of *A. transitella* in the laboratory and determined a similar lower developmental threshold of about 13°C. Seaman and Barnes (1984) demonstrated the importance of an upper developmental threshold in reducing variability of generation estimates using regressions of field data, holding the lower developmental threshold constant at 12.8°C. Their estimate of the upper developmental threshold was 34.4°C, which was subsequently confirmed by Sanderson, et al. (1989a) who through laboratory studies determined the actual upper developmental threshold to be in the range of 32.2 to 34.4°C.

Thermal summation (usually measured as degree-days (DD)) is a measure of physiological time, and this provides a common reference for the development of organisms. Several techniques are available for calculating DD, but perhaps the most common method which incorporates an upper developmental threshold is the single sine curve method (Baskerville and Emin 1969) using a horizontal upper developmental cutoff. The horizontal cutoff assumes that development occurs at a constant rate once the upper threshold is reached. It is also possible to utilize a vertical developmental threshold which assumes that development stops when temperatures reach or exceed the upper threshold. All methods of thermal summation and both types of cutoffs are considered "linear" approximations because the rate of development is presumed to be a straight line directly related to temperature.

Seaman and Barnes (1984) and Sanderson, et al. (1989a) proposed thermal summations for *A. transitella* egg and egg to adult development of 623 and 607 DD, respectively, on mummies, and 425 and 410 DD, respectively, on new crop nuts using a vertical cutoff and lower and upper developmental thresholds of 12.8°C and 34.4°C. The average thermal summation for egg to adult development has been shown to be longer on mummies than on new crop nuts by a factor of 1.48. Thermal summation for *A. transitella* using the developmental rate data presented by Sanderson et al. (1989b), but with a horizontal cutoff have been used by Cooperative Extension in California. These heretofore unpublished thermal summations are 569 DD on mummies and 384 on new crop nuts.

This study presents validation of these two linear approaches for phenological prediction using egg trapping data from multiple years and production areas in California. Models incorporating stochastic elements and a nonlinear approximation are also proposed and validated with field collected egg trapping data.

2. Materials and methods

A. transitella egg traps (e.g. Rice, et al., 1976) baited with almond presscake (Rice, et al., 1984) were deployed in commercial almond orchards by University of California Cooperative Extension Advisors and Specialists in Colusa, Fresno, Kern, Madera, Merced, San Joaquin, Sutter, Tulare and Yolo Counties from 1978 through 1985, and in an orchard in Butte County from 1982 through 1996. The traps were placed in orchards by the first week of April, and monitored weekly or twice weekly. Eggs were removed from the traps after each observation. All orchards had maximum and minimum daily temperatures available either within the orchard or from a nearby station available from the University of California Statewide IPM Project's weather database. Only complete data sets where both the initiation and end of each generation could be determined were used for the validation study. Thirty-four data sets for both the first and second *A. transitella* generations met this criteria from the 9 counties. Fourteen data sets for the first generation and 12 data sets from the second generation met this criteria from the second generation at the Butte Co. orchard.

For each orchard data set from the 9 county study, the initial date of egg-laying resulting from the first generation and second generation adults was compared to predicted dates of first eggs obtained from 5 different approaches to phenological estimation. Developmental thresholds (12.8°C minimum and 34.4°C maximum) and developmental rates used for all estimations were based upon those presented by Sanderson et al. (1989b).

Four of the approaches were linear in that *A. transitella* development was assumed at occur linearly depending on temperature above a minimum developmental threshold until a maximum developmental threshold was reached. Each of these methods involved thermal summation in degree-days estimated from maximum and minimum daily temperatures associated with each orchard site using a single sine curve method (Baskerville and Emin, 1969). A fundamental difference between the approaches was the manner in which the upper threshold was considered, employing either using a horizontal or a vertical cutoff. The horizontal upper cutoff assumes that development continues at a constant rate at temperatures in excess of the upper threshold. Thermal summations using this approach were 569 DD on mummies and 384 DD on new crop nuts. The vertical upper cutoff assumes that no development occurs at temperatures exceeding the upper developmental threshold. Thermal summations using this approach were 607 DD on mummies and 410 DD on new crop nuts. These thermal summations are actually mean values. Because genetic diversity may be observed in developmental time within a population, a certain amount of overlap typically occurs between generations. Most DD phenology models are strictly deterministic. This means that the beginning of one generation to the beginning of the next generation is assumed to be constant, and the emergence pattern is assumed to follow a normal distribution. Two of the approaches we validate in this study are such models, using either a horizontal or a vertical cutoff at the upper developmental threshold. Degree-days for these approaches were calculated using the Degree-Day Utility (DDU) of the UC Statewide IPM Project's computer system. Adding a stochastic parameter to the linear models to account for variability in population distribution due to genetic diversity in developmental times and other factors is an approach to improving prediction, but this approach is not normally used in application because it complicates calculating the summations. In this study, we added a stochastic parameter to both the horizontal and vertical cutoff approaches which assumes variance of development rate such that 4% of the population will complete development before 85% of the total DD for the average adult of a generation has elapsed. This parameter was derived from development studies conducted by Sanderson (1986). The fifth approach used the developmental rate data directly in a nonlinear manner. A sine wave was drawn between the minimum and maximum temperatures on each day of the study, with each 24 hr period being divided into hourly increments. The temperature during each period was related to the corresponding amount of development that would have occurred according to the developmental rate curve in Sanderson et al. (1989). The proportional development for each hourly period was summed over each day and for subsequent days until a full *A. transitella* generation was indicated.

The deterministic models using the horizontal and vertical cutoffs were validated using the egg trapping data from the Butte Co. orchard.

Predicted date of first egg detection using *A. transitella* egg traps and resulting from oviposition by first generation and second generation moths was determined for each orchard using each of the approaches as indicated previously. The predicted dates were paired with the date eggs were actually observed in egg traps in the same orchard. For each method, linear regression analysis (Abacus Concepts, 1989) was used to compare the predicted and observed dates for the combined orchards from the 9 counties and for the combined years in the Butte Co. orchard.

3. Results

Two statistics are of particular importance in evaluating the efficiency of prediction by any model, the regression coefficient (slope) and the correlation coefficient (r). The assumption is that a regression coefficient of 1.00 would indicate an accurate average prediction of Julian date first eggs laid by first and second generation *A. transitella* adults would be found on egg traps compared to the actual date for this event. The level of significance of the correlation coefficient indicates the reliability of the prediction.

3.1 Multiple locations

Figure 1 presents the predicted and observed Julian dates for first eggs resulting from oviposition by first and second generation *A. transitella* adults in the multi-county study using the 5 approaches. In all cases, predicted date was significantly related to observed date ($P < 0.001$) as indicated by the corresponding correlation coefficients (Table 1). The highest correlation coefficient ($r = 0.958$) was obtained for both the nonlinear model and the linear model with horizontal cutoff and a stochastic parameter, although the deterministic model with horizontal cutoff also indicated a high degree of correlation ($r = 0.936$). The regression coefficient of the nonlinear model was 1.017, indicating effective average prediction of initial egg-laying (Table 1). The regression coefficients for the linear deterministic model with horizontal cutoff (0.957) and the linear model with horizontal cutoff and a stochastic parameter (0.907) indicted a average prediction within 10% of 1.00.

The variability of the predicted versus observed dates about the regression line as illustrated by the spread of the data points around the regression lines for each model (Figure 1) is less for eggs of the second generation than for eggs of the third generation, possibly due to the overlapping of generations. The variability was less for the nonlinear model than for any of the linear models in the first generation. The addition of a stochastic element somewhat improved the correlation coefficients using either a horizontal or vertical cutoff, but it only appeared to increase the efficiency of the prediction incorporating a vertical cutoff (Table 1).

Table 1 - Statistics for validation of thermal summation approaches for 2 *A. transitella* data sets collected from California almond orchards, 1 = data from 9 counties combined, 1978 - 86, and 2 = data from Butte County, 1982 - 96. All r values are significant at $P < 0.001$

Method	Data set	n	Slope	Intercept	r
Horizontal	1	68	0.957	7.617	0.936
Horizontal Stochastic	1	68	0.907	12.742	0.958
Vertical	1	68	0.707	49.087	0.736
Vertical Stochastic	1	68	0.870	20.904	0.832
Nonlinear	1	68	1.017	-4.282	0.958
Horizontal	2	26	0.816	34.262	0.931
Vertical	2	26.	1.017	6.735	0.972

3.2 Multiple years

Figure 2 presents the predicted and observed Julian dates for first eggs resulting from oviposition by first and second generation *A. transitella* adults in the Butte Co. orchard using the two linear deterministic models for the 14 years in which data sets meeting the described criteria were available. For both models with horizontal and vertical cutoffs, highly significant ($r = 0.931$, horizontal and $r = 0.972$, vertical, $P < 0.001$) correlation coefficients resulted from the analysis (Table 1). The regression coefficient for the vertical cutoff model indicated a very close average prediction (1.017) to the observed dates. The regression coefficient for the horizontal cutoff model was somewhat less in this case (0.816).

Thirty year average DD for the National Weather Service Chico Climatic station (in Butte Co. near the orchard), indicates 1 June, 1 July, and 1 August daily summations of 8.05, 11.05 and 12.67, respectively using a horizontal cutoff and 8.05, 11.05 and 9.27, respectively using a vertical cutoff.

4. Discussion

Our validation studies indicated significant ($P < 0.001$) correlation of predicted egg laying with observed dates for all of the phenological approaches tested, but the relative accuracy of the approaches varied somewhat from 1.00 in their regression coefficients. The nonlinear approach gave the closest average prediction, however there is difficulty in implementing this approach because it requires integration of weather data with the developmental rate data presented by Sanderson (1986) and the need for a specific computer program to do this.

Linear approaches which can use a generalized method of thermal summation are more commonly used in practice. Each of the 2 deterministic models provided average estimates of first egg laying within 10% of observed dates with one of the egg trapping data sets analyzed, with the horizontal cutoff method providing the closest estimation for the multiple location data and the vertical cutoff method providing the closest estimation for the multiple year data. Seaman and Barnes (1984) indicated that a vertical cutoff gave the best agreement to their original egg trapping data (which was collected for 2 years in Kern Co., CA almond orchards), but they did not include statistics which would permit the relative comparison of this approach with the horizontal cutoff method. The incorporation of a vertical cutoff should provide average estimations which somewhat underestimate developmental rate as opposed to a horizontal cutoff which should overestimate development, so it might be expected that such a model would be more accurate in warmer areas such as Kern Co. However, the thermal summation proposed for a given phenological event will directly affect the prediction. In the case of *A. transitella*, the thermal summations proposed for the horizontal and vertical cutoff methods reflect such a difference. The addition of a stochastic parameter to account for genetic variation within *A. transitella* populations increased the correlation of predicted to observed dates of first egg laying for both the horizontal and vertical cutoff methods relative to the deterministic models, but it did not improve the regression coefficient for horizontal cutoff method.

The most useful application of a phenology model for *A. transitella* is to predict initial egg laying of first generation moths which typically occurs near hullsplit of the Nonpariel cultivar, and initial egg laying by second generation moths which can further infest the Nonpariel crop as well as pollinators. Predicting egg laying by the first generation of moths relative to when hullsplit is occurring can be useful in timing pesticide sprays for *A. transitella*. It is best to apply the hullsplit treatment at hullsplit after oviposition has begun or to wait to apply the treatment if oviposition begins after hullsplit. Predicting egg laying by the second generation of moths relative to when almonds are can also be useful. Early harvest (Connell, et al., 1989) before egg laying by second generation moths or early in the period of oviposition is an effective means of limiting damage to new crop nuts.

Our results indicate that *A. transitella* phenology could most accurately be predicted using a nonlinear method integrating incremental temperatures with the developmental rate curve. It was also possible to predict *A. transitella* phenology using deterministic models with either a horizontal or a vertical upper development cutoff. Adding a stochastic element these linear models did not appreciably improve the predictions.

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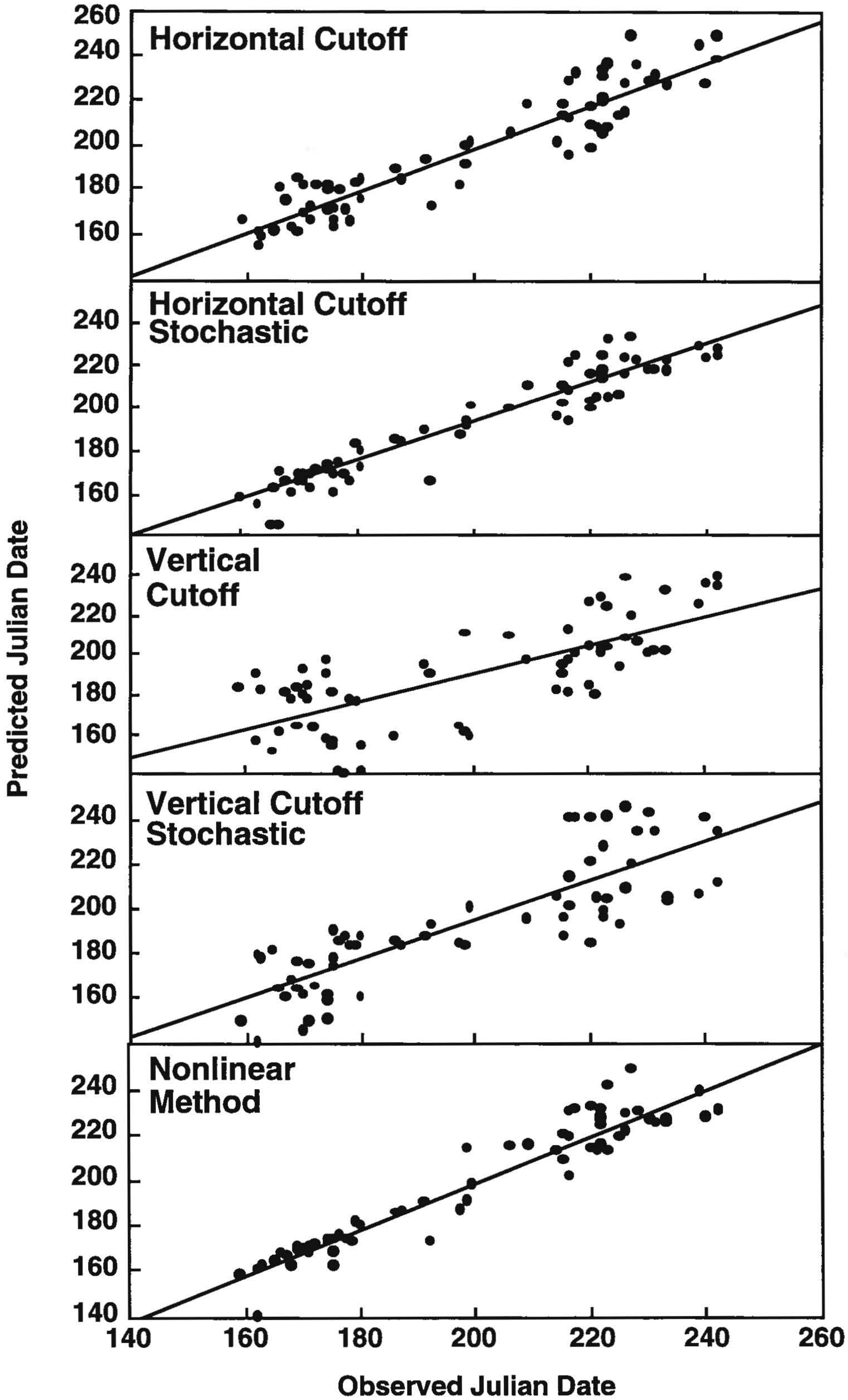


Figure 1. Predicted vs. observed julian dates for beginning of egg laying for 9 CA counties, 1978-86.

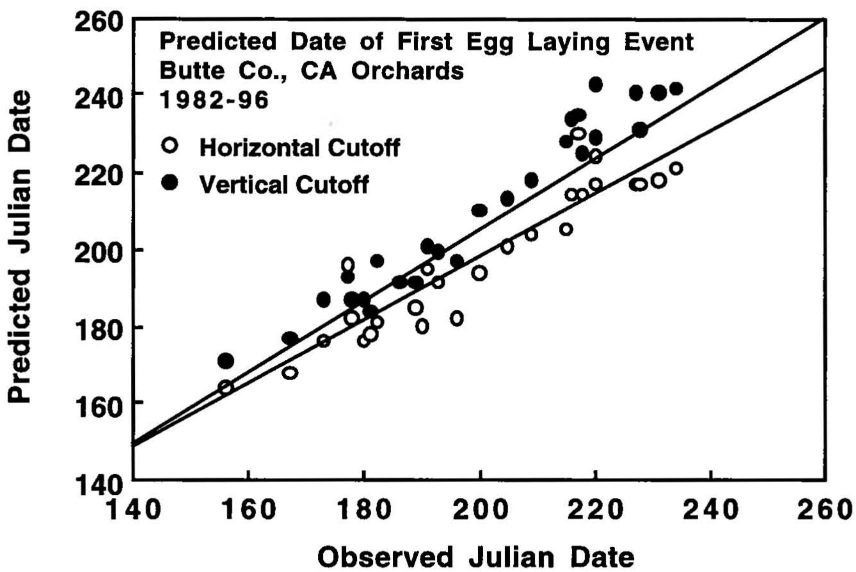
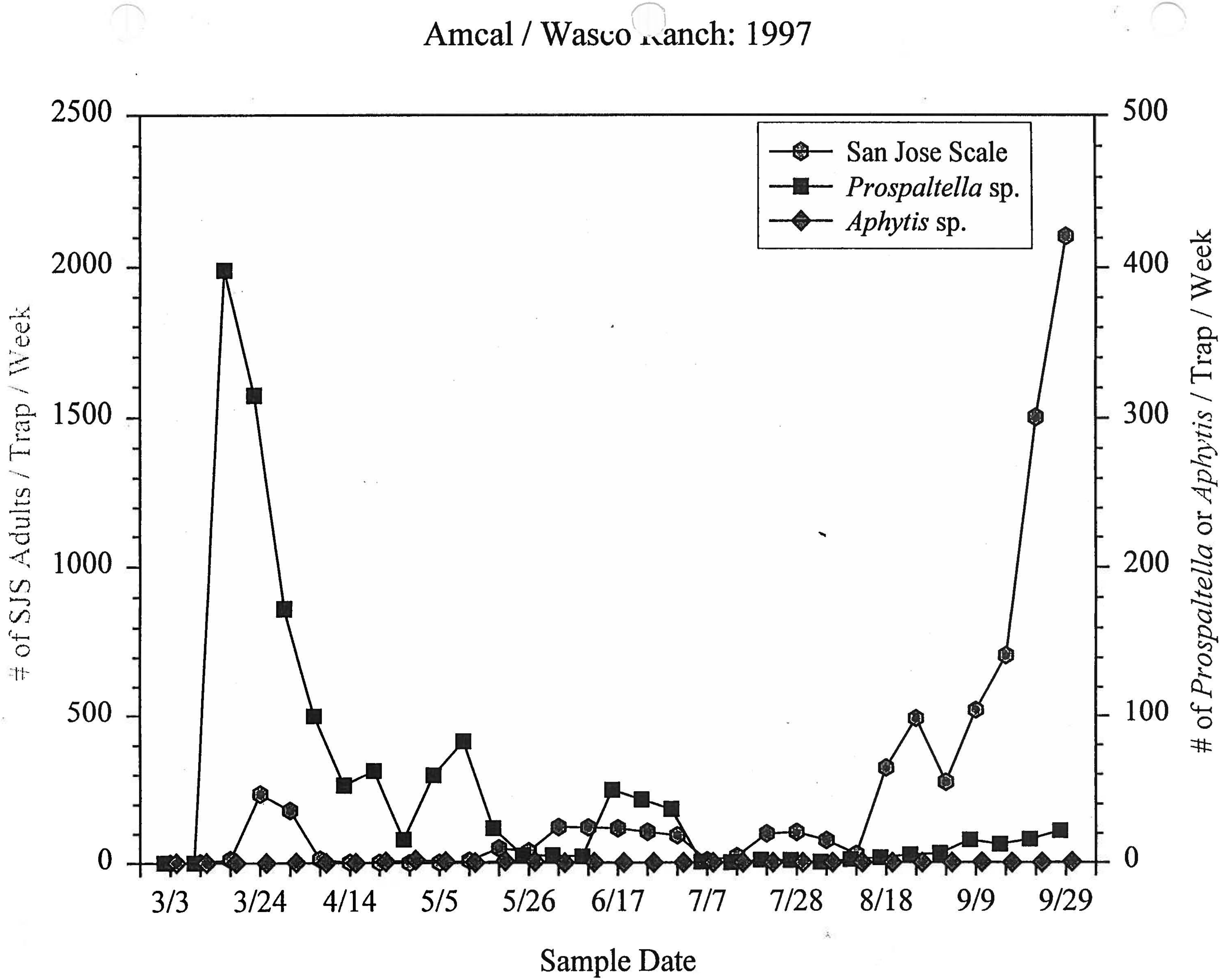
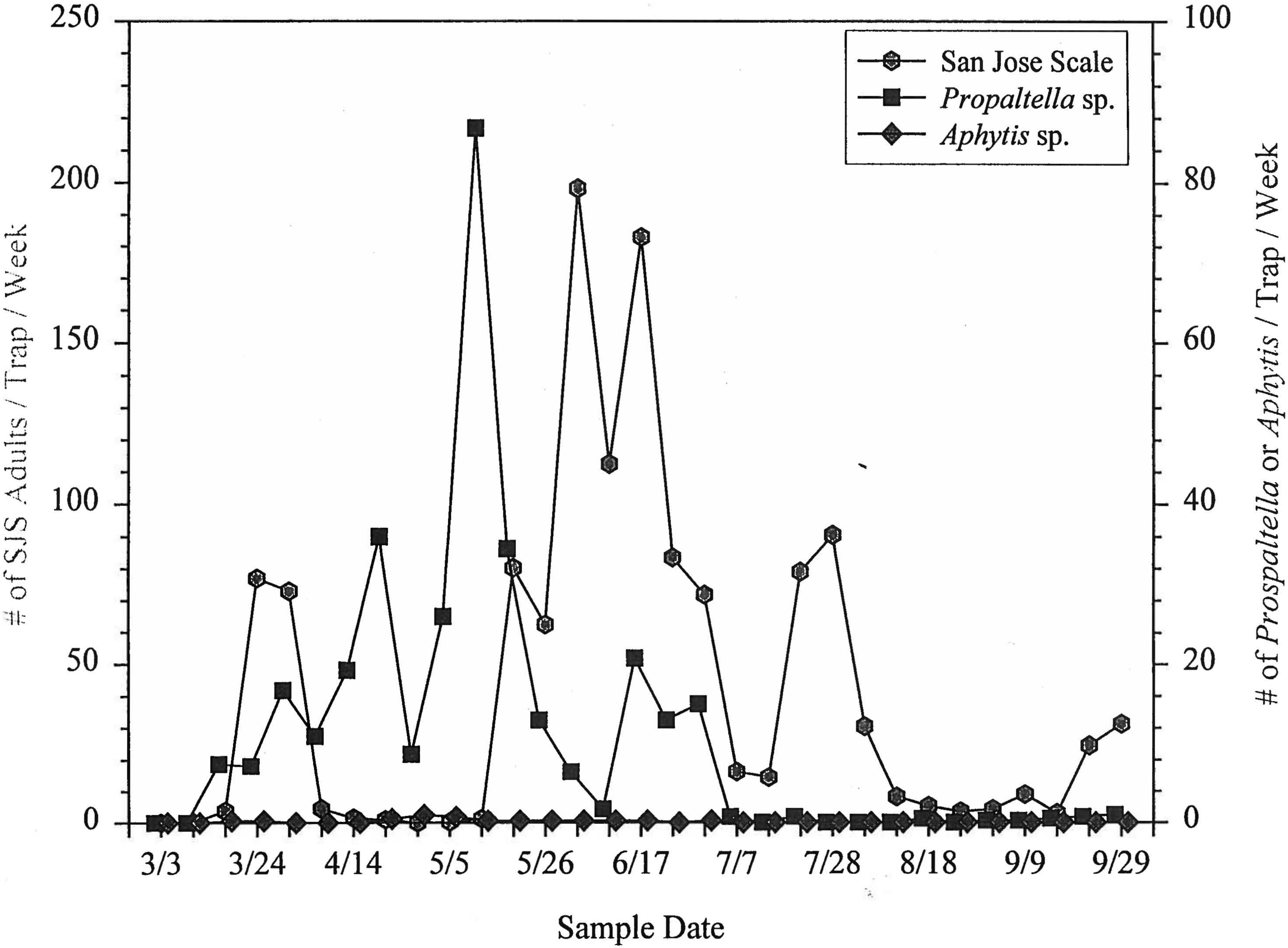


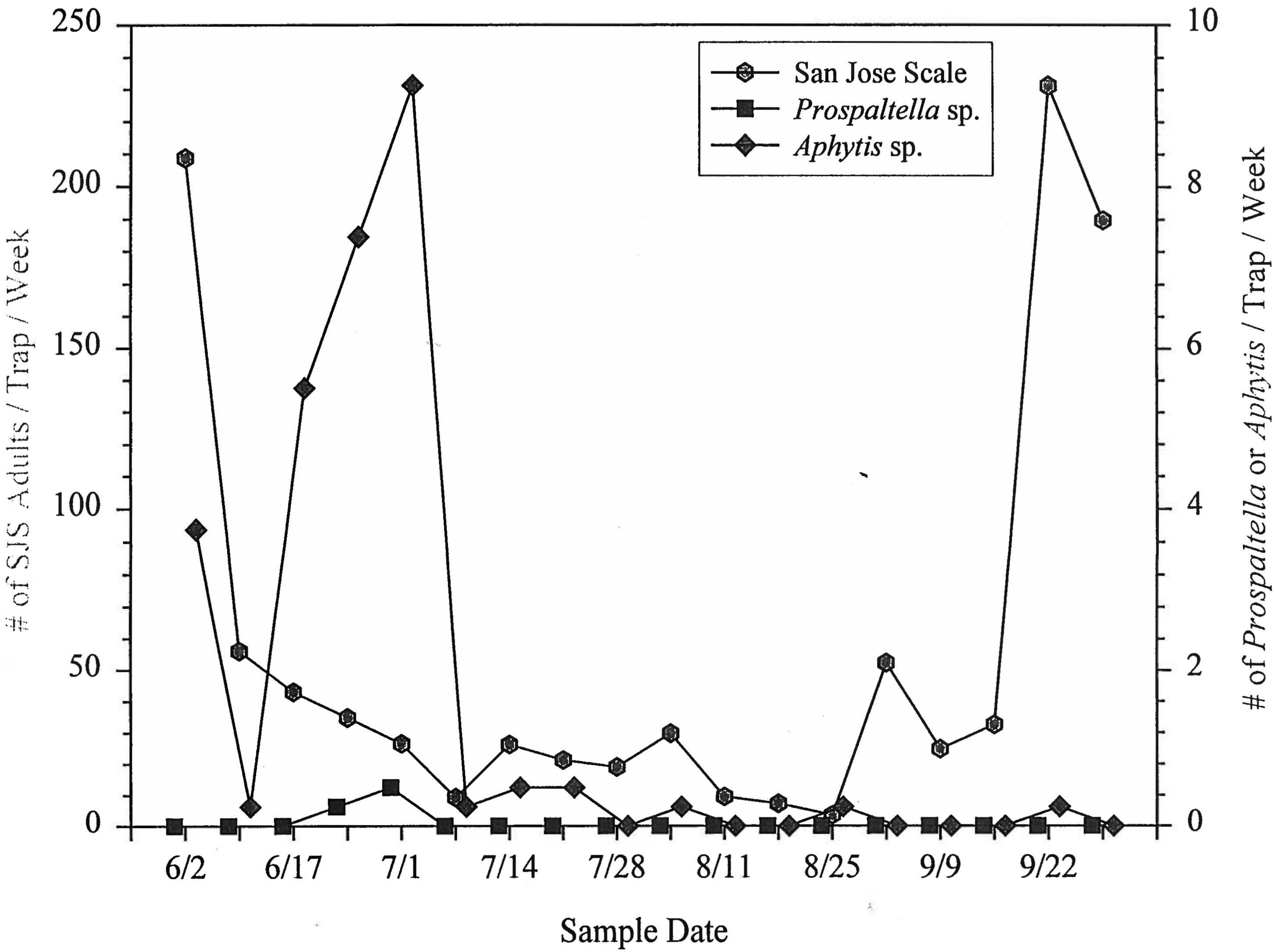
Figure 2. Predicted vs. observed dates for beginning of egg laying for first and second generation moths in Butte Co., 1982-96.


Amcal / Wasco Ranch: 1997
2500
2000
1500
1000
500
0
# of SJS Adults / Trap / Week
500
400
300
200
100
0
# of Prospaltella or Aphytis / Trap / Week
San Jose Scale
Prospaltella sp.
Aphytis sp.
3/3
3/24
4/14
5/5
5/26
6/17
7/7
7/28
8/18
9/9
9/29
Sample Date

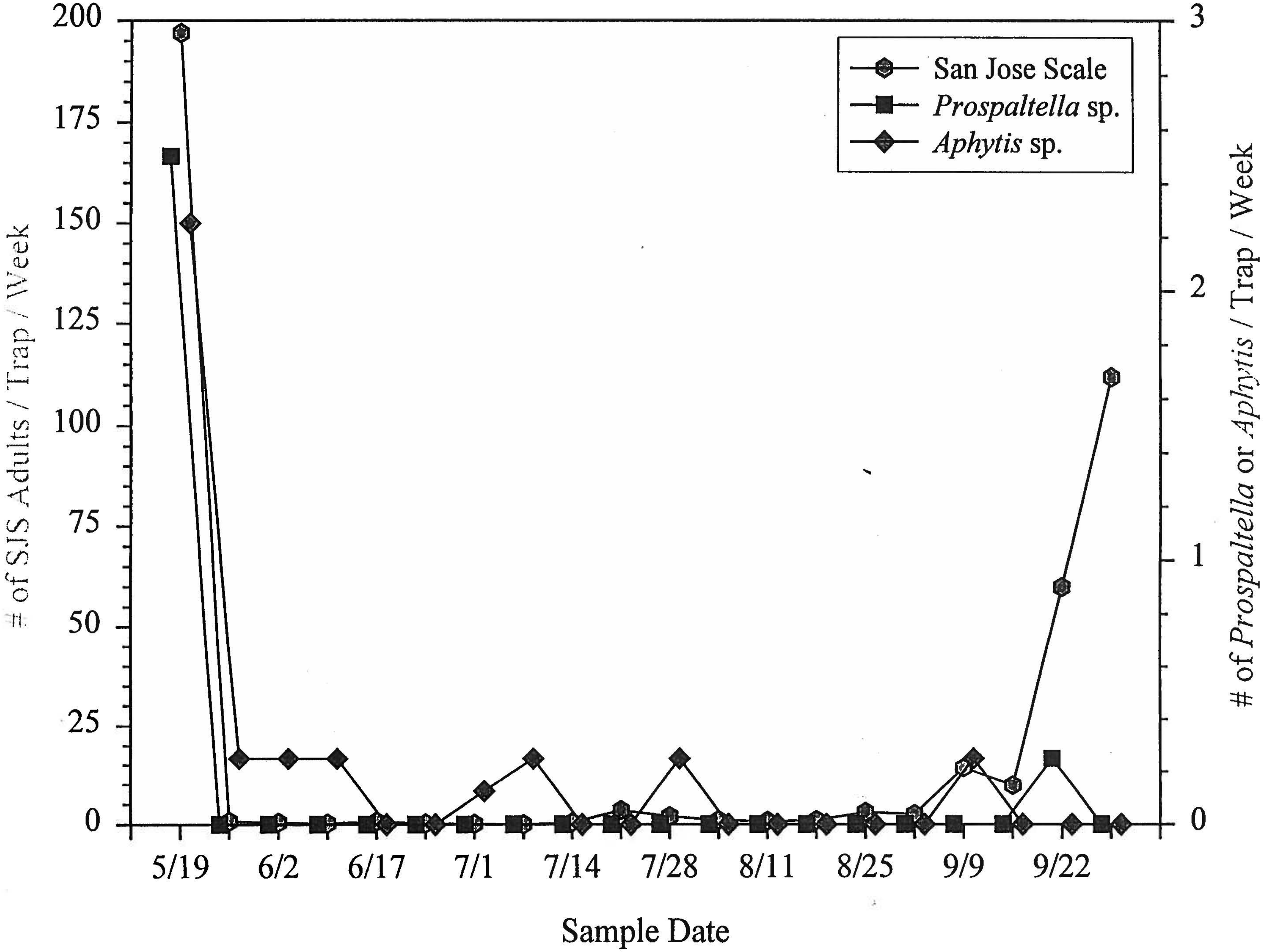
Billings / Delano Ranch: 1997

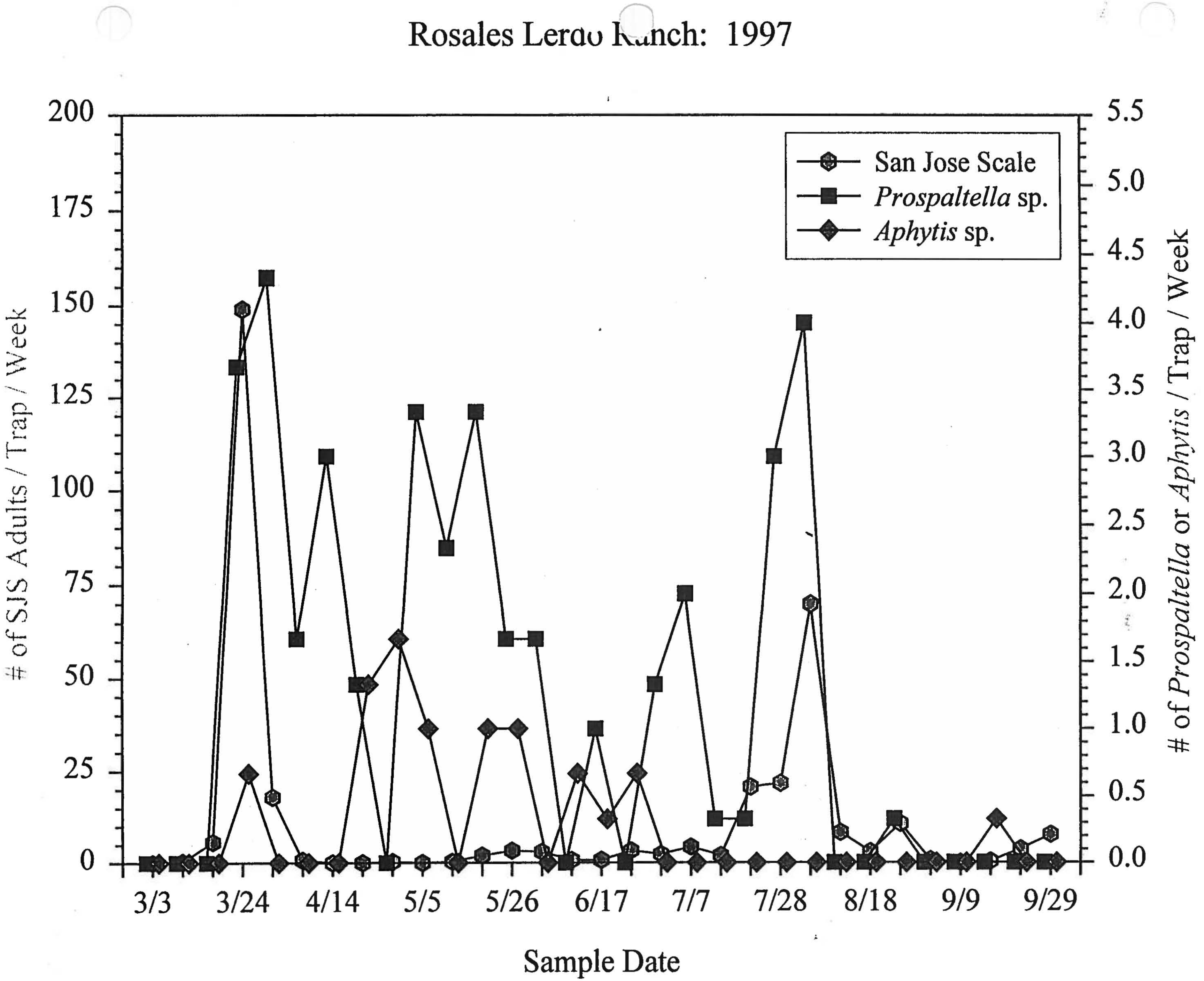


Buttonwillow Ranch: 1997



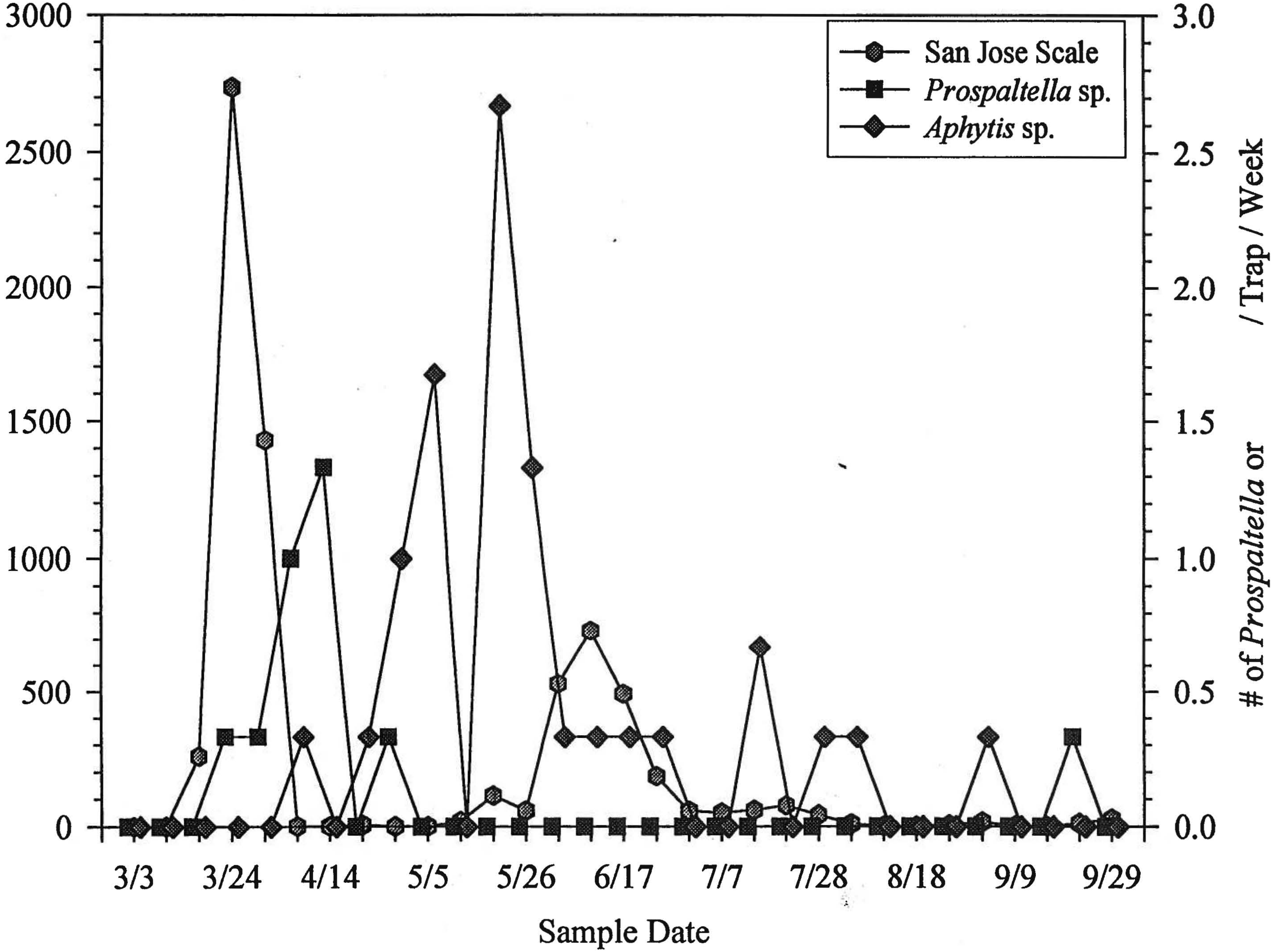
Peterson / McFarland Ranch: 1997





Rosales Lerdo Ranch: 1997
San Jose Scale
Prospaltella sp.
Aphytis sp.
# of SJS Adults / Trap / Week
# of Prospaltella or Aphytis / Trap / Week
200
175
150
125
100
75
50
25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3/3
3/24
4/14
5/5
5/26
6/17
7/7
7/28
8/18
9/9
9/29
Sample Date

Shafter / Riversiue Ranch: 1997



Stockdale Ranch: 1997