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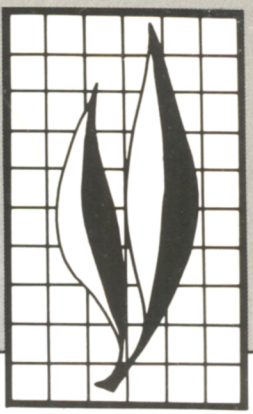

Aphelopus albopictus Ashmead (Hymenoptera: Dryinidae): Abundance, Parasitism, and Distribution in Relation to Leafhopper Hosts in Grapes

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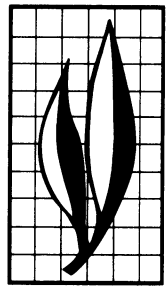

ABSTRACT

Aphelopus albopictus Ashmead (= *A. comesi* Fenton), a dryinid nymphal-adult parasite, has been reported as a major mortality agent for grape leafhopper, *Erythroneura elegantula* Osborn, in the San Joaquin Valley of California. Parasitism levels varied widely among different vineyards. Our studies report up to 33% parasitism of adult grape leafhoppers, with levels considerably less during much of the season.

In comparing the efficiency of the D-Vac and yellow sticky cards for monitoring the abundance of *A. albopictus*, parasitized grape leafhopper adults, parasitized variegated leafhopper adults, and nonparasitized adults of both leafhopper species, it appears that sticky yellow cards are less efficient at capturing *A. albopictus* parasitized grape leafhopper adults than adults of either leafhopper. The two sampling methods did not correlate well for adult *A. albopictus*. The within-vine distribution of *A. albopictus* was consistent with that reported in the literature for the nymphal stages of the variegated leafhopper, with the majority recorded in the more shaded areas within the canopy of the distal third of the canes. However, grape leafhopper and variegated leafhopper adults were not captured in greater frequency on shaded leaves.

The variegated leafhopper, which was abundant at one of the study sites, is rarely parasitized by *A. albopictus*. Chemical intervention for control of this pest will likely increase, resulting in disruption of the normally high level of biological control directed against the grape leafhopper.

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Aphelopus albopictus Ashmead (Hymenoptera: Dryinidae): Abundance, Parasitism, and Distribution in Relation to Leafhopper Hosts in Grapes[1]

INTRODUCTION

TWO IMPORTANT PESTS of grapes in California's San Joaquin Valley are the grape leafhopper, *Erythroneura elegantula* Osborn (Homoptera: Cicadellidae), and the variegated grape leafhopper, *E. variabilis* Beamer. The grape leafhopper is native to wild grapes in the San Joaquin Valley, while the variegated leafhopper has recently moved into the Valley (Kido et al. 1984), likely from either southern California or southwestern Arizona. Damage by both leafhoppers is caused by nymphs and adults feeding on the foliage and by fecal spotting of the grapes. High densities of these insects may also annoy vineyard workers during harvest (Flaherty et al. 1981).

Two parasites are known to attack the grape leafhopper in San Joaquin Valley vineyards. The first is an egg parasite, *Anagrus epos* (Girault) (Hymenoptera: Mymaridae), and the second is a nymphal-adult parasite, *Aphelopus albopictus* Ashmead (= *A. comesi* Fenton) (Hymenoptera: Dryinidae). *Anagrus* normally provides economic control of the grape leafhopper over much of California's grape acreage. Control is particularly evident on grape cultivars grown near streams that contain habitats for overwintering hosts. Although extensive work has been conducted on parasitism by *Anagrus* (Flaherty et al. 1985; Settle et al. 1986; Pickett et al. 1987, 1989), little work has been directed at elucidating the role of *A. albopictus* in controlling the grape leafhopper. However, the potential for *A. albopictus* to exert a considerable degree of control was shown by Cate (1975) who found up to 77% parasitism of adult grape leafhoppers in the San Joaquin Valley.

To better understand the role of *A. albopictus* in regulating grape leafhopper population density, several related studies were conducted in 1984 and in 1985. Specifically, our objectives were to (1) obtain basic information on the seasonality of *A. albopictus* and its two potential leafhopper hosts in different vineyard systems; (2) estimate parasitism rates by *A. albopictus* towards both leafhopper species under a range of environmental conditions; and (3) develop quantitative information on the distribution of *A. albopictus* in grapes.

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METHODS AND MATERIALS

D-Vac sampling

During 1984, weekly D-Vac samples (Dietrick et al. 1959; Dietrick 1961) were taken at two test sites; one at the University of California, Kearney Agricultural Center (KAC), near Parlier, California, the other at a commercial table grape vineyard near Exeter, California. A mature 'Thompson Seedless' vineyard was used at KAC. One-half of the vineyard was managed for raisin production, using flood irrigation and conventional clean cultivation, complete tillage, while the other half was managed for table grape production, using flood irrigation with a mowed weed cover crop.

A mature 'Emperor' table grape vineyard was used at Exeter. This vineyard was furrow irrigated and had a mowed grass cover crop. For both sites, on each sampling date, 60 1-ft^2 (0.093 m^2) suctions of the D-Vac, 30 from each side of the row, were taken from the more shaded areas of the vines.

At the KAC vineyard, 60 D-Vac suctions were taken from the same areas of the vines from each treatment. Samples were returned to the laboratory and frozen for later counting under a low power dissecting microscope. The number of grape leafhopper adults, variegated leafhopper adults, parasitized adults for each species, and male and female *A. albopictus* was recorded.

Yellow card sampling

Stikem (Seabright Enterprises, Emeryville, California) treated 3-in. × 5-in. (7.6 cm × 12.7 cm) yellow cards were placed within the vineyards during 1984 and 1985. At all vineyards, during both years, yellow cards were changed weekly, with the same information recorded as with the D-Vac sampler. During 1984, sampling was conducted for each treatment within the KAC vineyard. Three yellow cards were placed in each of three randomly chosen vines, within both the clean cultivated and the mowed weed cover crop treatments. One card was placed within the canopy near the trunk, one within the canopy one-half of the way to the end of the cane, and one within the canopy of the most distal part of the cane; nearest where the canes from the adjoining vine meet (cane-pruned vines; see Flaherty et al. 1981).

This method of card placement was also used at the Exeter site, except that four replicates were maintained. A second sampling method was also used at the Exeter site for 1 month, during which peak leafhopper activity had been predicted to occur (Flaherty et al. 1981). Ten yellow cards were placed within a single randomly chosen vine within each replicate. Five cards were placed in the trunk region, and five about two-thirds of the way towards the end of the canes. The five cards in each region were placed individually in each of five locations: (1) above the canopy (this area was usually sunny); (2) below the canopy (always shady); (3) in the center of the canopy (always shady); (4) on the north side of the vine (always shady); and (5) on the south side of the vine (usually sunny).

During 1985, yellow cards were placed within each replicate of the Exeter vineyard. Three additional vineyards were also used: one at the KAC; one at the University of California, Westside Field Station (WSFS), near Five Points, California; and one in the Sierra Nevada foothills (about 2,000-foot elevation) east of Exeter. The Sierra foothill

site consisted of native grapes (*Vitis californica* Bentham) growing alongside a small perennial stream. For each treatment or replicate within each of the four vineyards, a single yellow card was placed in full shade, near the distal third of the canes, on three randomly chosen vines.

Leafhopper and parasite generation development

Estimates of generation time for *A. albopictus* are based upon an accumulation of heat units above a lower developmental threshold of 10.28°C (50.5°F) estimated by Cate (1975) for *E. elegantula*. This threshold is very close to the 10.5°C estimated by Mochizuki (1984) for the variegated leafhopper. Cate (1975) chose to use a 12°C developmental threshold for *A. albopictus*, and for a second grape leafhopper parasite, *Anagrus epos*, based on Campbell et al. (1974), concluding that parasites often have developmental thresholds that are higher than that of their host(s). For the purpose of this study, and in the absence of developmental data for *A. albopictus*, the 10.28°C lower developmental threshold will be used for both *A. albopictus* and for the two leafhopper species, with degree-day (°D) accumulation beginning January 1 of each year.

Data analysis

The Chi-square goodness-of-fit-test statistic was used in analyzing *A. albopictus* sex ratio data. The detailed within-vine data from the yellow sticky cards collected during 1984 from the Exeter site were analyzed using two separate nonreplicated factorial analyses of variance (Zar 1974; Steel and Torrie 1980). For the first analysis, the effects of two main factors were examined: region (trunk vs. the distal third of canes) and location (above, below, center, north, and south as described previously). For the second analysis of variance, two factors were again examined: region and exposure (shade vs. exposed leaves). For this analysis, the center yellow card data were excluded to provide balance with respect to shaded and exposed leaves. Differences between means were tested using Duncan's new multiple range test (Duncan 1955).

The relative efficiency of the D-Vac and yellow sticky card sampling methods at capturing adult grape leafhoppers, adult variegated leafhoppers, *A. albopictus* adults, and parasitized grape leafhopper were compared using the 1984 KAC and Exeter data separately and combined. We used the approach proposed by Kogan and Pitre (1980), treating one data type as the dependent variable (D-Vac) and the other as the independent variable (yellow sticky card) in a simple linear regression analysis. The mean number per card, averaged across vines and region (trunk, midcane, and distal third of the shoots), and the number per 60 suctions of the D-Vac were used as inputs for the regressions. An assumption of this approach is that the slopes of the regressions provide estimates of the relative capture efficiency of one sampling method compared to the other. Because the regression approach is extremely robust, ignoring the assumption of measurement without error for the independent variable appears to cause little problem.

At the WSFS vineyard, rows ran north-south. All other vineyards were oriented east-west All statistical tests, unless otherwise indicated, were conducted at the 5% level.

RESULTS AND DISCUSSION

Parasite, Parasitism, and Leafhopper Seasonal Phenology

Figure 1A-F shows the seasonal pattern of grape leafhopper and variegated leafhopper adults during 1984 and 1985, recorded with the yellow cards. The grape leafhopper was more abundant than the variegated leafhopper at all but the KAC. The near absence of the variegated leafhopper at the Sierra foothill site and at the WSFS site is probably due to this pest's recent introduction to the San Joaquin Valley (Kido et al. 1984), and its fairly limited spread (at the time of these studies) to the remaining regions of the Valley.

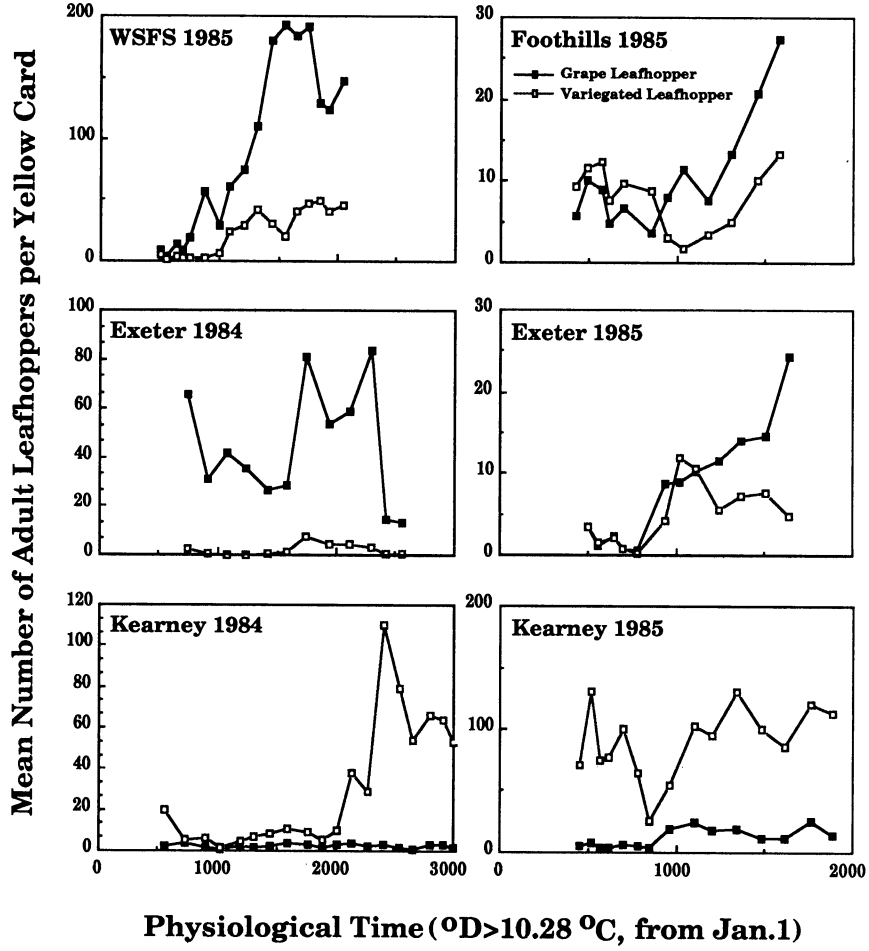

Fig. 1A-F. Seasonal patterns of grape leafhopper and variegated leafhopper abundance during 1984 and 1985.

Grape leafhopper densities at the six sites varied from 2.4 to 90.4 per yellow card, averaged across sampling dates for the season (table 1). Comparing density estimates for the KAC site, leafhoppers were much more abundant during 1985 than in 1984. In contrast, the grape leafhoppers were much more abundant at the Exeter site during 1984 than during 1985, whereas the variegated leafhopper was more abundant at this site during 1985.

In late 1984, the Exeter vineyard was sprayed with methomyl and very few insects remained. The grape leafhopper population apparently had not completely recovered by the end of the following year. The increase in variegated leafhopper abundance may have been due to the high level of resistance to insecticides, which are commonly used in vineyards in this area (Wilson and Flaherty, unpublished data).

Adult—Larval Parasite Population Cycling

Figure 2A-E shows the seasonal pattern of *A. albopictus* adults and parasitized grape leafhopper adults for each site. WSFS is not shown because only five *A. albopictus* were recorded at this site. The yellow card sampling procedure was able to detect the

TABLE 1. THE TOTAL NUMBER, AVERAGE SEASONAL ABUNDANCE OF GRAPE LEAFHOPPER AND VARIEGATED LEAFHOPPER ADULTS, PARASITIZED GRAPE LEAFHOPPER ADULTS, *A. ALBOPICTUS* MALES AND FEMALES, AND THE RELATIVE PARASITE ABUNDANCE FOR EACH SITE DURING 1984 AND 1985, RECORDED WITH THE YELLOW CARD SAMPLER

	Adult		Parasitized	*Aphelopus*			Larval & adult
Locations	GLH*	VLH*	GLH	Female	Male	Σ	*Aphelopus*
Exeter 1984							
Mean/card	40.22	2.24	2.39	1.91	0.84	2.75	5.14
Parasite/GLH			0.059	0.048	0.021	0.128	0.187
Exeter 1985							
Mean/card	14.08	7.53	1.04	0.19	0.16	0.35	1.39
Parasite/GLH			0.074	0.013	0.011	0.025	0.098
Kearney 1984							
Mean/card	2.39	33.79	0.05	0.37	0.04	0.41	0.47
Parasite/GLH			0.022	0.156	0.017	0.173	0.195
Kearney 1985							
Mean/card	11.40	109.46	0.14	0.27	0.09	0.35	0.49
Parasite/GLH			0.012	0.023	0.008	0.031	0.043
Foothills 1985							
Mean/card	12.95	9.05	0.69	1.74	0.74	2.49	3.18
Parasite/GLH			0.053	0.135	0.057	0.192	0.246
WSFS 1985							
Mean/card	90.35	22.90	<0.01	0.01	0	0.01	0.02
Parasite/GLH			<0.001	<0.001	0	<0.001	<0.001
Total Sum†	39,649	49,284	553	586	215	801	1,354

*GLH = grape leafhopper, VLH = variegated leafhopper.

†Based on a total of 1,163 sticky cards.

alternating cycles between *A. albopictus* adult and larval populations. Population peaks, estimated as the highest observed densities, were 824°D apart (804 × 82.4 and 843 × 32.8°D for adults and larvae, respectively). This estimate is about 27% longer than reported by Mochizuki (1984) for the variegated leafhopper, who estimated the generation time at 668°D.

A closer examination of the Mochizuki (1984) data revealed that his unit of generation time was the combined egg, nymph, and preoviposition adult duration, a value that excludes a large percentage of an adult variegated leafhopper's life. Although considerably more variable, estimated population peaks for adult grape leafhopper and variegated leafhopper were 887 ± 197.9 and 813 ± 178.0°D apart. Sampling was initiated too late in 1984 to estimate the timing of the first *A. albopictus* population

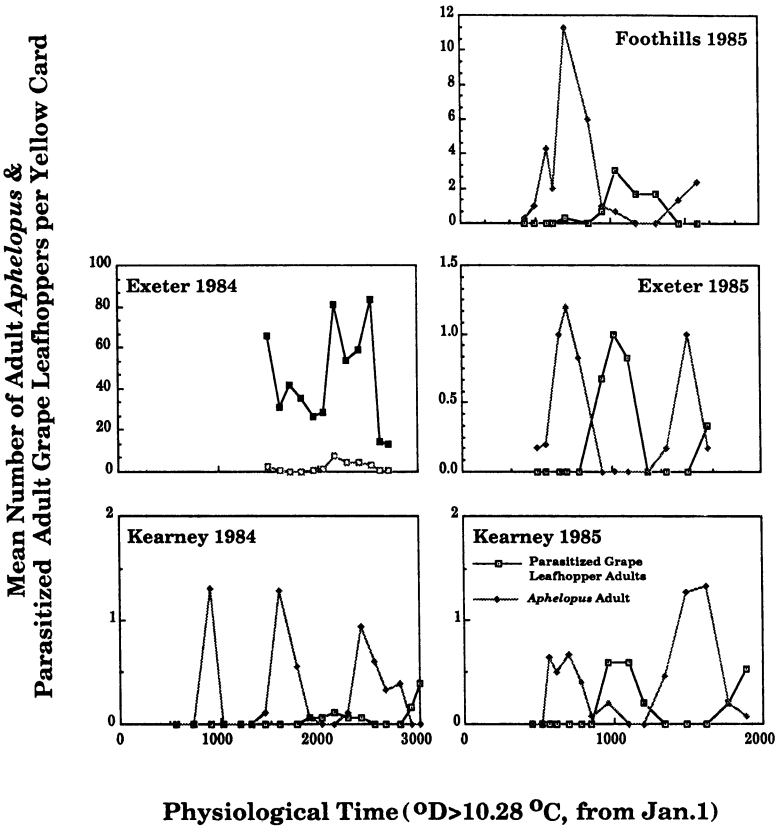

Fig. 2A-E. Seasonal patterns of *A. albopictus* adults and parasitized grape leafhopper adults for each site during 1984 and 1985.

flight. During 1985, the first peak occurred at about 694°D, corresponding to the early part of the first generation leafhopper nymphal emergence.

Parasitism Rates and Parasite/Prey Ratio Analysis

Figure 3 shows the seasonal parasitism rate by *A. albopictus* directed against the grape leafhopper, estimated for the 1984 Exeter site. Both the D-Vac sampler and the yellow card method showed a peak level of parasitism in August. With the exception of one date, the D-Vac consistently indicated a higher level of parasitism than did the yellow cards, peaking at 33% on August 1. Cate (1975), monitoring vineyards in the Napa Valley and San Joaquin Valley with a D-Vac, reported a maximum grape

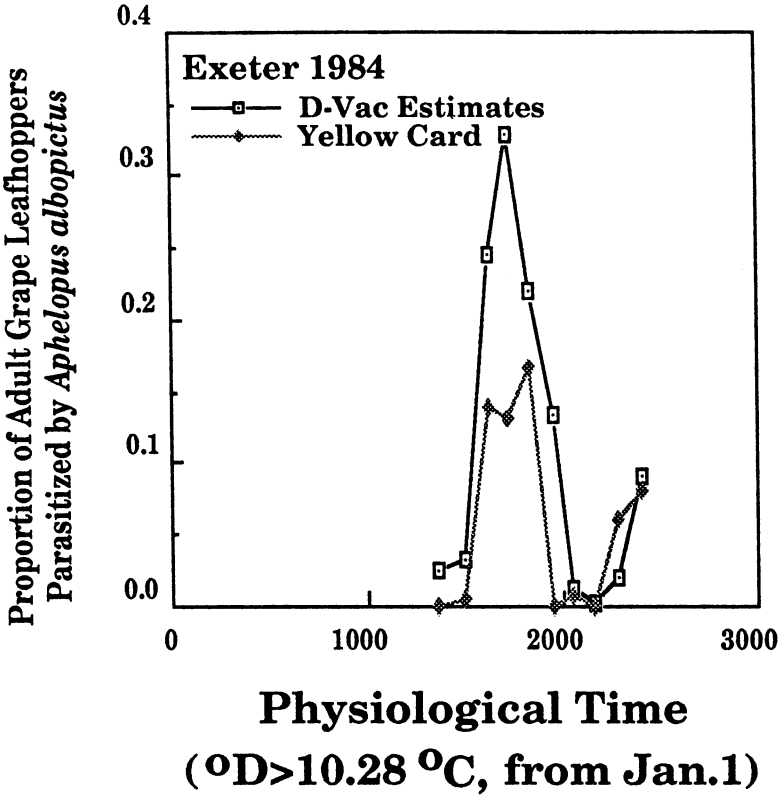

Fig. 3. A comparison of the estimated seasonal parasitism rate by *A. albopictus* directed against the grape leafhopper for the 1984 Exeter site, for both the D-Vac suction sampler, and the yellow card sampler.

leafhopper parasitism ranging from 22% to 77% with the peak occurring from June 28 to August 6, depending on the vineyard. The maximum level of parasitism reported during our studies, although considerably less than that reported by Cate (1975), is sufficient to result in minimal suppression in grape leafhopper density. In our studies, seasonal parasitism ranged from a low of one parasitized grape leafhopper out of 27,556 adult grape leafhoppers at the WSFS location to 75 parasitized leafhoppers out of 1,056 (7.4%) for the 1985 Exeter site.

The ability of a parasite to control a pest population can be assessed using graphical analysis of parasite-prey co-varying patterns. The ratio of parasites to prey at which the prey density begins to decrease can provide an estimate of what can be termed an effective parasite/prey ratio. Such pattern can be derived using a broad range of models and assumptions as summarized by Price (1975).

Based on the data presented in figures 1 and 2, grape leafhopper–*A. albopictus* co-varying patterns were created for three of the study sites. In our analysis, each point represented the parasite density and the associated grape leafhopper density that corresponds to each grape leafhopper population peak. Parasite density was represented by the combined number of adult parasites and parasitized leafhopper adults. The lack of an apparent pattern (results not shown) indicates that parasitism by *A. albopictus* is likely not the major factor responsible for regulating the population dynamics of the grape leafhopper, although *A. albopictus* can have a major impact on grape leafhopper population density (see Cate 1975). With only five parasitized variegated leafhopper adults found during both years of study, *A. albopictus* is certainly not regulating this leafhopper's population density.

A. albopictus Sex Ratio and Parasite Host Gender Preference

A total of 801 *A. albopictus* adults were recorded with the yellow cards, of which 586 or 73.5% were female (table 1). All sites for both years had greater capture of females than males. The average female/male sex ratio, estimated by summing the total number of each sex, was 2.77. A Chi-square goodness of fit test comparing the number of *A. albopictus* females and males across sites was significant ($\chi^2 = 28.10$, $P<0.01$), implying that the variability in sex ratio between sites or years was greater than expected based upon random expectation. Three additional Chi-square goodness of fit tests were also conducted; the first using only the 1984 and 1985 Exeter data, the second using both years' data for KAC (separate but neighboring vineyards for the 2 years), the third test combining the 1984 sites and comparing these results with those from the 1985 sites.

Of these three analyses, the capture of females and males was significantly different for all sites. However, only the KAC analysis ($\chi^2 = 9.26$, $P<0.05$) showed a significant change in the abundance of each sex, with the female proportion being 90.2% in 1984 and 75% in 1985. The high proportion of females recorded with the yellow cards may reflect a difference in searching behavior comparing males and females of this species. Female *A. albopictus*, for example, likely orient toward leaves (or yellow cards) in search of suitable hosts, whereas males may orient toward females. The difference may also be due to an intrinsic sex-ratio bias for this species.

Parasite Behavior and Relative Preference for the Grape Leafhopper and the Variegated Leafhopper

Most dryinids will parasitize all members of the same leafhopper family within a geographical area (Olmi 1979). *A. albopictus* has been reared from at least two other *Erythroneura* species (Fenton 1918a, b, 1924), both of which are not found in San Joaquin Valley vineyards. During our studies, 553 *A. albopictus* parasitized grape leafhopper adults were recorded. In contrast, only five variegated leafhopper adults were recorded parasitized by *A. albopictus*. Although Olmi (1979) indicated that dryinids are relatively catholic in their preference for leafhoppers, these results suggest that the variegated leafhopper is either a poor host for *A. albopictus*, or that this leafhopper is not recognized as a suitable host. To partially elucidate which of these two hypotheses is correct was the objective of preliminary observations where an *A. albopictus* adult female was confined within a 12.7-cm-diameter petri dish with six third to fifth instar variegated leafhopper nymphs and then subsequently removed and confined with an equivalent number of grape leafhopper nymphs.

When confined with variegated leafhopper nymphs, the female oviposited in one-third instar nymph; and then stepped on, appeared to ignore or avoid, or even chased for a short distance the other variegated leafhopper nymphs. She then returned to the same nymph previously attacked and proceeded to oviposit a second time. When placed with the grape leafhopper nymphs, her behavior was markedly different; the parasite in this case proceeded to oviposit into one leafhopper nymph after another, sometimes chasing each of them for a short distance before catching and inserting an egg.

Based on the few cases of parasitism reported in the field, and from the petri dish arena observations, *A. albopictus* is apparently able to parasitize and develop in the variegated leafhopper. We do not have an explanation for the low preference shown by this parasite for variegated leafhopper nymphs or the possible inability of this parasite to recognize this leafhopper as a host, although the two leafhopper species do differ in several ways. The variegated leafhopper is much darker than the grape leafhopper. The variegated leafhopper is similar in size, but may oviposit in and feed upon a wider age range of leaves than does the grape leafhopper (Wilson et al. 1987). The variegated leafhopper nymph also differs behaviorally in that it appears to move much more rapidly than the grape leafhopper. It also holds the tip of its abdomen up off the leaf surface, unlike the grape leafhopper whose posterior is more parallel to the leaf surface. Settle et al. (1986) reported that *Anagrus epos* was able to parasitize and develop on the variegated leafhopper, but it had a much lower parasitism rate than observed for the grape leafhopper in the same vineyards. For *Anagrus*, this lowered parasitism appears largely due to the greater depth of variegated leafhopper eggs within the leaf tissues, resulting in their being better concealed.

Relative Efficiencies of D-Vac and Yellow Card Sampling

Table 2 summarizes statistics from the regression of D-Vac estimates, with means from the yellow cards, for adult grape and variegated leafhopper, adult *A. albopictus,* and parasitized grape leafhopper adults recorded for Exeter and Kearney during 1984.

TABLE 2. REGRESSION PARAMETERS DERIVED BY CONTRASTING D-VAC SAMPLER AND YELLOW STICKY CARD ESTIMATES OF SEASONAL ADULT GRAPE LEAFHOPPER, VARIEGATED LEAFHOPPER, AND *A. ALBOPICTUS* ADULT ABUNDANCE FOR THE 1984 EXETER AND KEARNEY SITES

Location	a	b	r^2	n	a	b	r^2	n
	Grape leafhopper				Variegated leafhopper			
KAC	15.302	11.068	0.19	16	88.406	10.434	0.96*	15
Exeter	154.080	11.037	0.27	10	9.565	2.649	0.39	9
Combined	24.334	13.487	0.67*	26	34.694	10.856	0.94*	24
	Aphelopus				Parasitized grape leafhopper			
KAC	0.981	0.632	0.07	16	—	—	—	4†
Exeter	1.715	−1.200‡	0.34	10	31.874	4.137	0.52*	9
Combined	4.057	−0.254	0.02	26	25.350	4.452	0.59*	13

*Regression significant at the 0.05 significance level.

†Yellow cards did not capture any parasitized adult grape leafhoppers at the Kearney plot.

‡Minus sign shows negative slope.

The relative numbers caught with each method do not indicate each method's efficiency at capturing the three species. The D-Vac estimates are based on a sample unit size of 60 suctions of the device, the opening of the suction tube being 1 ft^2 (0.073 m^2), with each suction continuing for about 10 to 15 seconds before the sampler moved to the next location in the canopy. The yellow cards, in contrast, are 3 in. × 5 in. (7.6 cm × 12.7 cm) in size, appear to attract parasites and leafhoppers in their immediate vicinity, and are removed from the field and replaced once a week. Both sampling methods detected the presence of each species at the same time. The variability was considerable, however, and a significant correlation between the sample methods was only found for five of the 11 regressions.

Significant regressions were observed for the Exeter and Kearney sites combined for each leafhopper species and for parasitized grape leafhopper adults (table 2). The slope of the regression line suggests that a single D-Vac sample (60 suctions) captures about 13.5 times the number of adult grape leafhoppers recorded by a yellow card left in the field for a week, and 10.9 times the number of adult variegated leafhoppers. A D-Vac sample unit also captured an estimated 4.5 times the number of parasitized grape leafhopper adults as recorded per yellow card. The lack of correlation for the *A. albopictus* data was possibly due to a lower abundance and fewer samples having this species.

Within-Vine Distribution

The first analysis of variance of the 1984 Exeter data showed a significant difference in the numbers of *A. albopictus* on the trunk region of the canopy versus the canopy region associated with the distal third of the canes (table 3). Significant differences were also found in comparing the numbers in each of the five locations (above, below, center, and so on). The relevance of the significant region by location (R × L) interaction for *A. albopictus* was clarified by the second analysis of variance, where the location factor was replaced with a division of the data into shaded leaves and leaves

TABLE 3. THE WITHIN-VINE DISTRIBUTION OF *A. ALBOPICTUS* ADULTS AND LEAFHOPPER ADULTS BY VINE REGION, CARD LOCATION, AND VINE; NUMBERS REPRESENT MEAN CUMULATIVE YELLOW CARD COUNTS FOR THE 1984 EXETER SITE*

Regions†		Locations					Exposure	
Trunk	Distal ⅓	Up	Down	Center	North	South	Sunny	Shady
			Aphelopus albopictus adults					
11.40a	20.89b	13.50a	16.00ab	14.31a	24.13b	12.80a	26.19a	40.13b
			Grape leafhopper adults					
94.79a	116.93a	130.62a	93.97a	124.07a	84.62a	96.00a	113.31a	89.30a
			Variegated leafhopper adults					
4.10a	4.94a	6.38a	4.62ab	3.73b	3.75b	4.13b	5.25a	4.19a

*Means followed by the same letter within each of the four factors do not differ significantly. Hypothesis testing was based on Duncan's new multiple range test (Duncan 1955).

†Vine and region means are estimated, including data from both regions and all five locations.

primarily exposed to direct sunlight. As with the first analysis of variance, a significant difference was found for the two regions of the vine.

Of further interest, a significant region by exposure (R × E) interaction was present. Although 53% more *A. albopictus* were found on shaded leaves, from figure 4 it is evident that those shaded leaves from the distal third of the canes were significantly more attractive or possibly more suitable for this parasite. The numbers found on the shaded and exposed leaves of the trunk region and on the exposed leaves of the foliage associated with the distal third of the canes had a seasonal average of 12.8, 12.0, and 14.3 *A. albopictus* per card, respectively. In contrast, the shaded leaves from the distal third of the canes had an average of 27.4 parasites per card, or 41% of the total parasite population.

The region by location (R × L) interaction was also significant, apparently due to yellow cards in the below and center locations having a disproportionately large number of *A. albopictus* (fig. 5) when associated with the distal third of the canes. Some of the reasons for differences in the within-vine distribution of *A. albopictus* can be explained by our field observations. The greater number found in the distal third of the canes is likely due to this region having a greater number of leaves; leaves which are on average younger and apparently more attractive to adult grape leafhoppers and to *A. albopictus* at mid-season when this test was conducted. The pattern may be different earlier or later in the season, when the vines possess a different canopy structure.

A significantly greater number of variegated leafhopper adults were recorded on the "above" yellow cards, the area of the vine associated with leaves receiving a greater amount of sunlight and higher temperatures (table 3). Settle et al. (1986) reported a greater number of variegated leafhopper nymphs on the northern side of vines having an east-west orientation, and speculated that the lower leaf temperature and higher humidity associated with these more shaded leaves are more conducive to nymphal leafhopper development.

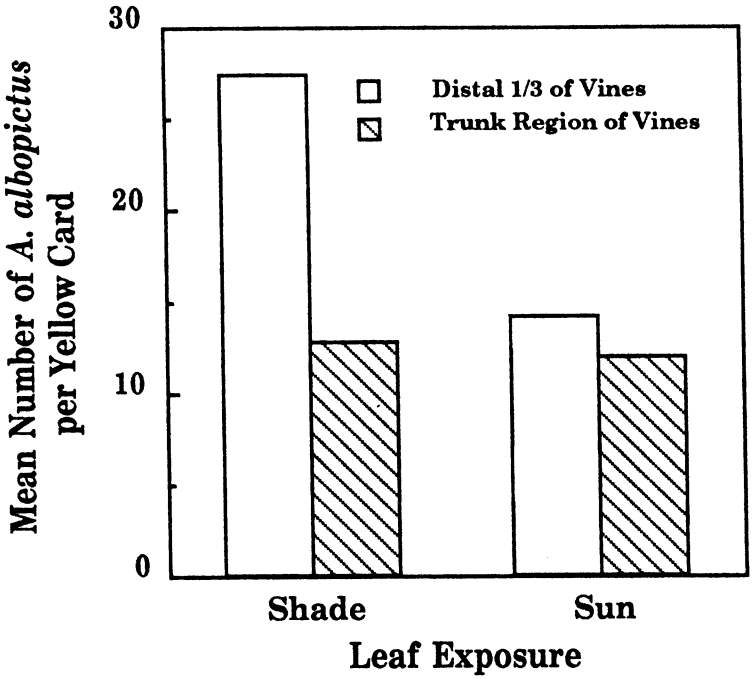

Fig. 4. The effect of vine region and leaf exposure on the abundance of *A. albopictus* adults.

CONCLUSIONS

Parasitism Impact

The co-varying pattern analysis suggests that *A. albopictus* did not regulate the grape leafhopper populations in the study vineyards. The level of parasitism afforded by this parasite was not sufficient to prevent population increase with each successive generation. Cate (1975) reported that an adult female grape leafhopper produces on average 42 eggs during her lifetime, with three generations normally occurring each season.

In our studies the maximum amount of adult parasitism recorded for this parasite was 33%. With 33% mortality occurring at each of the three generations, an average female would be responsible for producing about 2,785 females. Cate (1975), in comparison, reported a maximum of 77% mortality. The number of overwintering adults produced under a 77% mortality regime would correspondingly be 113 times greater than the number emerging from diapause the previous spring. As this level of *A. albopictus* induced mortality would not be reached during all three leafhopper broods, the level of population increase would be even higher. By itself, *A. albopictus* is apparently not capable of regulating grape leafhopper populations.

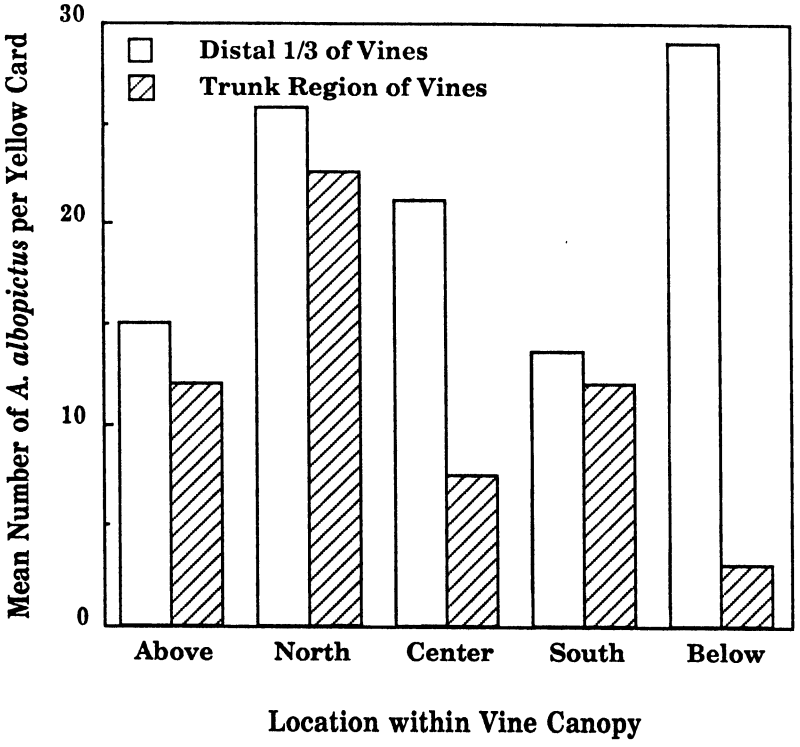

Fig. 5. The effect of vine region and leaf location on the abundance of *A. albopictus* adults.

Monitoring

Settle et al. (1986) reported that a greater proportion of variegated leafhopper nymphs are located on the northern or more shady side of grape vines. Flaherty et al. (1981) recommended monitoring the grape leafhopper by sampling leaves from the more shaded areas of the vine, because of the apparent greater preference for leaves by nymphs in such areas. Our results do not confirm the greater preference by adult grape and variegated leafhoppers for shaded leaves.

The greater mobility of adult leafhoppers may result in a more uniform distribution within the vine and may account for a general lack of significant differences. However, this does not explain why leafhopper nymphs, which are not known to move any great distance from leaf to leaf, are distributed to a much greater degree on shaded leaves (Settle et al. 1986). From an implementation perspective, the only qualification that our data suggests is that a greater number of *A. albopictus* adults would be found were sampling restricted to the shaded areas of the canopy of the distal third of the canes.

Vineyards pruned to have a relatively greater leaf mass in the trunk region, such as many wine grape cultivars (head-pruned vines), would be expected to have a greater number of parasites in this region. Sampling shaded leaves from or nearer to the trunk region of the vines would likely be more appropriate.

The practicality of using a yellow card sampling method is open to some question, since an action threshold based on the adult stage has not been developed. However, the yellow card procedure does have an advantage over the conventional leaf inspection procedure because it enables a fairly quick estimate of adult *A. albopictus* parasitism, which although apparently not effective at our study sites, has been shown by Cate (1975) to exert a considerable impact on grape leafhopper populations. The D-Vac sampler detected a greater number of nonparasitized adult grape leafhoppers than parasitized grape leafhoppers, compared to that estimated with the yellow cards. This implies a behavioral difference between parasitized and nonparasitized leafhopper adults; possibly, the parasitized adults are less prone to fly and are captured less effectively by the D-Vac sampler. This last supposition is partially supported by Cate (1975) who indicated that parasitism by *A. albopictus* interrupts the development of sex organs in the grape leafhopper. Furthermore, once the dryinid parasite reaches the fifth instar, it completely eviscerates the adult grape leafhopper. Both of these factors likely result in leafhoppers that are less vigorous and less likely to fly than those not parasitized. In addition, the earlier instars of the dryinids (the smaller sacs) are much more difficult to see on the yellow cards and are probably not counted as efficiently. Both our results and those by Cate (1975) indicate that this parasite can contribute to the reduction of grape leafhopper population densities, suggesting that monitoring for this parasite may aid in determining appropriate grape leafhopper management decisions.

Implications for Variegated Leafhopper Management

The variegated leafhopper is apparently not parasitized by *A. albopictus* to any great degree. Nor is this pest successfully parasitized by the biotype of *Anagrus* endemic to the San Joaquin Valley; although Gonzalez et al. (1988), Pickett et al. (1989), and the senior author's unpublished data suggest that biotypes (or possibly sympatric species) introduced from other areas of the United States and from Mexico may increase the level of parasite-induced control. The current lack of adequate control of the variegated leafhopper by these biotic mortality agents has led to an increase in insecticide use directed at this pest and against secondary pests, including the grape leafhopper, which is normally controlled by *Anagrus* and other mortality agents (Wilson et al. 1987).

Based on our results, the within-vine distribution of variegated leafhopper adults appears to be sufficiently similar to that observed for the grape leafhopper to warrant the use of a common sampling procedure. In addition, although the variegated leafhopper damages a greater leaf area during its feeding than does the grape leafhopper (Mochizuki 1984), results presented by Wilson et al. (1987) imply that the action thresholds for this pest will be similar to those presented by Flaherty et al. (1981) for the grape leafhopper.

Were action thresholds based on adult yellow card counts developed for both of these leafhopper species, or were nymphal parasitism by *A. albopictus* incorporated into the

management decision process, a considerable difference could be expected when comparing the two leafhopper species. Were *A. albopictus* providing 33% control of the adults grape leafhopper population, but essentially no control of the variegated leafhopper, the adult variegated leafhopper action threshold would be correspondingly less. With a higher level of parasitism, the difference between the two action thresholds would likewise be greater.

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