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Sampling Mites in Almonds:

I. Within-Tree Distribution and Clumping Pattern of Mites with Comments on Predator-Prey Interactions

L. T. Wilson, M. A. Hoy, F. G. Zalom, and J. M. Smilanick

II. Presence-Absence Sequential Sampling for *Tetranychus* Mite Species

F. G. Zalom, M. A. Hoy, L. T. Wilson, and W. W. Barnett



I. Within-Tree Distribution and Clumping Pattern of Mites with Comments on Predator-Prey Interactions

Tetranychus spp. and peach silver mite, *Aculus cornutus*, are distributed randomly within the foliage of almond trees. Both, however, have extremely clumped patterns of distribution on a per leaf sample unit. The pattern of distribution for *Tetranychus* spp. was additionally affected by the phytoseiid mite, *Metaseiulus occidentalis*, the pattern being less clumped with the predator present. *M. occidentalis* was considerably less clumped than observed for the other mites. Additional analyses indicate that, except at low *Tetranychus* spp. densities, approximately one *M. occidentalis* per ten *Tetranychus* is sufficient to reduce the prey density 2 weeks hence. The distribution relationships in this paper provide a framework for development of a quantitative *Tetranychus* spp. monitoring program, presented in the following paper.

II. Presence-Absence Sequential Sampling for *Tetranychus* Mite Species

A practical monitoring program for spider mites, *Tetranychus* spp., in almond orchards is proposed. It is possible to determine densities of the *Tetranychus* mites after they disperse through each tree by using the proportion of leaves infested with one or more mites rather than counting the actual number of mites per leaf. This presence-absence (binomial) sampling technique may be used in conjunction with sequential sampling to further reduce sampling time. Provisional control action thresholds developed are 0.436 (mean proportion infested leaves) in the presence of the predatory mite *Metaseiulus occidentalis*, and 0.220 in its absence. Optimal numbers of trees to be sampled at various confidence levels are determined for a range of mite densities with leaf samples of 5, 15, and 40 per tree.

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Sampling Mites in Almonds:

I. Within-Tree Distribution and Clumping Pattern of Mites with Comments on Predator-Prey Interactions¹

INTRODUCTION

ALMOND (*Prunus amygdalus* BATSCH) trees are grown on over 418,000 acres in California, representing virtually all of the commercial production in the United States. Their present history in California dates from 1843, when almond trees were brought from the east coast of the U.S. Earlier introductions were made when missions were established by the Spanish (Kester and Asay 1975). Today, most orchards are situated in the San Joaquin and Sacramento valleys of central California.

Barnes and Andrews (1978) and Barnes and Moffitt (1978) demonstrated that phytophagous mites, primarily *Tetranychus* spp. and *Panonychus ulmi* (Koch), are capable of causing substantial yield reductions in California almond and walnut orchards. Although a reduction in yield will usually not occur during the year that an economic infestation develops, reduced vegetative growth and fruit set will result in the subsequent years.

Chemical control of navel orangeworm, *Amyelois transitella* (Walker), at hull split has been shown to trigger secondary outbreaks of spider mites (Hoy et al. 1978, 1979). As a result, many almond growers often incorporate an acaricide with this treatment without concern for mite densities. This "insurance" management tactic is, however, becoming less attractive due to suppressed almond prices, increasing pesticide costs, and the likelihood of pest resurgence and secondary outbreaks caused by predator suppression and increasing pesticide resistance in pest mites. Farmers are finding it increasingly beneficial to spray only when mites are approaching an economic injury level. Unfortunately, this level is difficult to determine due to a general lack of information, including how to quantitatively sample for mites in almonds. Furthermore, although predators are capable of controlling mites in orchard systems (Croft and Nelson 1972, Westigard et al. 1967), the lack of a simple yet quantitative sampling technique has delayed the effective use of predators of phytophagous mites. Estimates of predators' effect in controlling phytophagous mites are time-consuming to obtain and sparse, and for the most part not sufficiently quantitative to be of general use.

This paper examines the within-tree distributions and clumping patterns of *Tetranychus* spp. (Acari:Tetranychidae) (*T. urticae* Koch, *T. turkestanii* Ugarov & Nikolski, and *T. pacificus* McGregor), *Aculus cornutus* (Banks) (Acari:Eriophyidae), and *Metaseiulus* (*Typblodromus*) *occidentalis* (Nesbitt) (Acari:Phytoseiidae) on almonds as a first step in developing a field implementable crop management program. In addition, the quantitative impact of the predaceous mite, *M. occidentalis*, on *Tetranychus* spp. is evaluated.

¹Submitted for publication October 7, 1983.

Methods and Materials

Sampling information and the mite species found in each of the four orchards examined as part of this study are presented in Table I.1. In 1977 one orchard (Yuba City) in Sutter County and one (Highway 132) in San Joaquin County were sampled, whereas in 1978 two orchards were sampled in Kern County. Spider mites, *Tetranychus* spp., were found in all orchards, whereas the predator, *Metaseiulus occidentalis* (Nesbitt), was limited to the Kern County orchards (Bidart and Blackwell). The three *Tetranychus* species were not distinguished due to the impracticability of a sampling method in almonds requiring field species identification. Peach silver mite, *Aculus cornutus* (Banks), was found in the Yuba City orchard in Sutter County. For the 1977 experiments, 25 leaves were sampled from each of the four compass directions (collectively referred to as quadrants in a subsequent analysis) and from the center of the tree for the lower and upper foliage (referred to as locations) of each tree, for a total of 10 areas in each tree. Thirty leaves were sampled at random from the outer area of each tree during 1978. The number of trees sampled in each orchard ranged from 4 to 18 with the number of dates samples were taken ranging from 7 to 11. Over 32,000 almond leaves were examined during the 2-year experiment (see table I.1). For both years the leaves were returned to the laboratory and the number of mites (all stages) were recorded for each leaf using a binocular microscope.

Analysis of Data

The data were analyzed in three parts as described in the following sections.

Within-tree distribution

Factorial analyses of variance were used on the 1977 data to determine whether the *Tetranychus* spp. and *A. cornutus* were randomly distributed between trees, in the different areas of the trees, or clumped in specific areas of each tree for the period May 10 until August 16. The data were originally log transformed to correct for anticipated heterogeneity due to large fluctuations in population density through time. Because a comparison of

TABLE I.1. SAMPLING INFORMATION AND MITE ABUNDANCE
IN 1977-1978 ALMOND EXPERIMENTS

Sampling information	1977		1978	
	Yuba City*	Highway 132†	Bidart‡	Blackwell‡
Number of dates sampled	7	7	10	11
Number of leaves sampled per tree	250	250	30	30
Number of trees sampled	8	4	18	18
Total leaves sampled	14000	7000	5400	5940
Mites recorded	Presence			
<i>Tetranychus</i> spp.	+	+	+	+
<i>Metaseiulus occidentalis</i>	-	-	+	+
<i>Aculus cornutus</i>	+	-	-	-

*Sutter County.

†San Joaquin County.

‡Kern County.

analysis for both transformed and normal data showed little difference in significance, these results are presented for the untransformed data.

Clumping pattern per leaf

The second set of analyses was aimed at determining the clumping pattern of the mites on a per leaf basis as affected by mite density, orchard, and for spider mites by the abundance of *M. occidentalis*. For this analysis both 1977 and 1978 data were used. Clumping was expressed for each species group as the relationship between the proportion of leaves infested with mites (P(I)), the corresponding density of mites per leaf (\bar{x}), and the variance (S^2) of mites per leaf. Wilson and Room (1983) show that this relationship is species or age-class specific for *Heliothis* spp. on cotton. Salt and Hollick (1946) and Guppy and Harcourt (1970) showed that as populations age they become progressively less clumped. The relationship between \bar{x} , S^2 and P(I) for a given species (or age class) can be represented by the following equation:

$$P(I) = 1 - e^{-\bar{x}} \cdot \log_e (a \cdot \bar{x}^{b-1}) \cdot (a \cdot \bar{x}^{b-1} - 1)^{-1} \quad (1)$$

'a' and 'b' describe the relationship between the variance and the mean ($S^2 = a \cdot \bar{x}^b$) and are called *Taylor's coefficients*. Estimates of Taylor's coefficients (Taylor 1961, 1971) were obtained for each species using an iterative regression procedure (Wilson et al. 1983b) and comparisons were made for each species group.

Predator impact on clumping

The effect of predators on spider mites' clumping pattern was determined by separating the data according to whether *M. occidentalis* were present in all samples from each tree. Taylor's coefficients were then estimated as above for *Tetranychus* spp. (with and without *M. occidentalis*), for *A. cornutus* (without *M. occidentalis*), and for *M. occidentalis*. The respective Taylor's coefficients were then compared.

Feeding rates and predation efficacy of *M. occidentalis* were estimated using ratio analyses (see Predator Efficacy section), and by comparing the co-varying densities through time of *M. occidentalis* and *Tetranychus* spp. This second analysis implicitly assumes that the observed decrease in *Tetranychus* spp. density was largely due to predation by *M. occidentalis* (except when the decrease was acaricide induced). This assumption appears to be valid for our study because all of the *Tetranychus* spp. population crashes in our study preceded crop maturation and because other mortality factors were not noted. The period of crop maturation is significant in that it is characterized by a rapid decrease in leaf nitrogen levels, which has been shown in cotton to negatively affect the density and reduce the clumping pattern of spider mites (Wilson et al. 1983a, Tijerina-Chavez 1982) and could be expected to have a similar effect on almonds.

Results and Discussion

The *Tetranychus* spp., which will usually be referred to as spider mites in the remaining text, are considered the primary mite pests in almonds, while *M. occidentalis* is thought to be an important predator. *Aculus cornutus*, although capable of causing damage, is

considered to be more important in its role as an alternative prey for *M. occidentalis* early in the season when *Tetranychus* spp. are scarce, thereby adding stability to a predator/prey system (Flaherty 1981).

General phenology

Table I.2 gives the mean number of mites (all stages) per leaf for the three mite species groups for each of the four orchards for the duration of the study. In 1977 a maximum of ca. 10 and 55 spider mites per leaf in the Yuba City (Sutter County) and Highway 132 (San Joaquin County) orchards, respectively, were recorded. The actual peak in population numbers may have been higher for the Highway 132 orchard because the highest mean occurred on the last sampling date. Sampling was discontinued in the Highway 132 orchard on August 16 when an acaricide treatment was applied after the spider mites reached a density of 50 mites per leaf.

TABLE I.2. MEAN NUMBER OF MITES PER LEAF

Date*	Yuba City		Highway 132
	<i>Tetranychus</i> spp.	<i>A. cornutus</i>	<i>Tetranychus</i> spp.
5/10	0	0	0.02
5/17	0.03	1.37	0
5/31	0.03	0.80	0
6/7	0	0	0.30
6/13	0.01	1.99	0
6/28	0.04	2.06	0
7/11-12	1.33	1.40	6.74
7/19	0	0	45.65
7/26	9.43	0.37	0
8/2	0	0	30.11
8/16	0	0	54.67

TABLE I.2. CONT.

Date†	Bidart		Blackwell	
	<i>Tetranychus</i> spp.	<i>M. occidentalis</i>	<i>Tetranychus</i> spp.	<i>M. occidentalis</i>
4/28	0.02	0	0.24	0
5/8-9	0	0.01	0.11	0
5/22-23	0.02	0	0.16	0
6/8	0.05	0.01	0.39	0
6/22	0	0	12.12	0.38
7/5-6	0.97	0.03	12.75	1.71
7/17-18	1.37	0.23	1.87‡	0.33‡
8/1-3	1.45	0.35	43.01	3.84
8/9	0.91	0.28	23.43	2.65
8/23	0	0	0.13	0.16
8/28	0.07	0.04	0	0
9/8	0	0	0.11	0.04
9/19	0.12	0.03	0	0

*1977.

†1978.

‡Pesticide applied prior to this sample.

Only the Yuba City orchard was found to have *A. cornutus* (table I.1) with peak densities reaching only ca. 2.0 per leaf. Because of the limited amount of *A. cornutus*, data results for this species should be considered tentative.

In 1978, spider mites and the predaceous mite *M. occidentalis* were observed in both Kern County orchards. The densities of both species groups were considerably higher in the Blackwell orchard, peaking in early August following the application of an insecticide during the second week of July. For both orchards the peak numbers of *M. occidentalis* coincided with those observed for spider mites. The higher numbers of spider mites in the Blackwell orchard may be due to the relatively late appearance of *M. occidentalis*.

Within-tree distribution

The 1977 data enable factorial analysis of variance of the within-tree distribution of spider mites in two orchards, and *A. cornutus* in one orchard (table I.3). With the exception of quadrant, all main effects were significant ($p < 0.05$), as were the location by tree interaction ($L \times T$) for Highway 132; only sample date was significant for Yuba City. The lack of significance at the Yuba City orchard may be due to the relatively low densities. The difference in significance levels comparing the two orchards could also be explained by the use of fixed point pivotal sprinkler irrigation at Highway 132 and flood irrigation at Yuba City. The sprinklers are likely responsible for suppressing spider mites on the lower half of all trees and in the western quadrant (although not significantly) because the water washes the mites from that part of the trees. This resulted in both the location (upper vs. lower part of trees) and $L \times T$ interaction being significant for Highway 132 (table I.4). The significant difference between trees at Highway 132 may be partially due to sprinklers, but is probably due in larger part to normal variation in spider mite density from tree to tree (Zalom, Hoy, Wilson, and Barnett, following paper). A significant difference for *A. cornutus* (Yuba City orchard) between trees was also found, further indicating the magnitude of this type of variation. The lack of a significant difference between quadrants within the tree is encouraging and indicates that sampling by random selection of leaves from around the tree is unlikely to result in a biased estimate of spider mite density, at least during the period of May to September. Herbert and Butler (1973) likewise reported significant between-tree differences and did not find quadrant differences when examining the distribution of the European red mite, *Panonychus ulmi* (Koch), the apple rust mite, *A. schlechtendali* (Nal.), and the predaceous mite, *Zetzellia mali* (Ewing), on apple trees.

TABLE I.3. SIGNIFICANCE LEVELS FOR FACTORIAL ANALYSES OF VARIANCE ON THE EFFECTS OF SAMPLE DATE (D), QUADRANT (Q), LOCATION (L), AND TREE (T) ON THE DENSITY OF *TETRANYCHUS* SPP. AND *ACULUS CORNUTUS* IN 1977 FOR THE HIGHWAY 132 AND YUBA CITY ORCHARDS

Source of variation*	<i>Tetranychus</i> spp.		<i>Aculus cornutus</i>
	Highway 132	Yuba City	Yuba City
D	0.01	0.01	n.s.
Q	n.s.	n.s.	n.s.
L	0.01	n.s.	n.s.
T	0.05	n.s.	0.01
LT	0.01	n.s.	n.s.

*All remaining 1st, 2nd, and 3rd order interactions were not significant at the 5% level.
n.s. = not significant.

They did, however, find a significantly greater abundance of the phytophagous mites in the lower part of the tree with the reverse observed for *Z. mali*. Westgard and Calvin (1971), working with *T. urticae*, *P. ulmi*, and *M. occidentalis* in pears, reported results similar to ours, but again they found a significant location difference. The lack of an apparent location difference in our study may be due to our trees being relatively young (ca. 8 years old), although mature, and therefore not having a wide within-tree microclimatic range. The apple trees used by Herbert and Butler (1973), on the other hand, were 25 years old and possibly more architecturally complex. The difference may also be due to the architecture of various tree species. The age of the orchard used by Westgard and Calvin (1971) was not reported.

Clumping pattern per leaf

Figure I.1A-C shows the proportion of infested leaves as a function of density for the three mite species groups. *Tetranychus* spp. and *A. cornutus* were similarly clumped in their distribution but were considerably more clumped than *M. occidentalis*. When a leaf is found with mites, that leaf is likely to have more mites of species that are more clumped in their distribution. The high degree of clumping observed for *A. cornutus* and *Tetranychus* spp. likely reflects the relatively low dispersal rate and the colony-forming characteristics of these species. This is not to say that the characteristics of mite colonies on leaf surfaces are the same for *A. cornutus* and *Tetranychus* spp. The distribution of *M. occidentalis*, on the other hand, is much less clumped. This is expected for predatory mites which, in general, have a higher searching and dispersal rate than their prey. The observed differences in clumping pattern on a per-leaf basis between these mite species should not be taken to represent clumping pattern or dispersal differences on a large scale, such as between trees. Large-scale differences are facilitated primarily by aerial dispersal and not by walking.

Predator impact on clumping

Figure I.1A shows that a considerable amount of variability in clumping pattern was observed for the *Tetranychus* spp. As an initial attempt at evaluating the effect of the

TABLE I.4. MEAN NUMBER OF *TETRANYCHUS* SPP. PER 25 LEAVES (AVERAGED BY SAMPLING DATE) FOUND IN EACH QUADRANT IN 1977 FOR THE HIGHWAY 132 AND YUBA CITY ORCHARDS

Orchard	Quadrant				
	North	South	East	West	Center
Highway 132	50.4	35.8	46.6	8.7	32.3
Yuba City	3.7	4.0	6.0	6.4	6.8

Highway 132		Yuba City	
Lower	Upper	Lower	Upper
16.4*	53.1	5.5	5.3

*Differences between means were found by comparing the lower and upper parts of the trees at Highway 132.

predaceous mite, *M. occidentalis*, on the clumping pattern of the spider mites, each 30-leaf sample taken in 1978 (there were no *M. occidentalis* in the 1977 orchard samples) was grouped by predator/prey ratio. Because a consistent change in clumping pattern was not found with predator/prey ratios of 0.25, 0.50, 0.75, 1.00, or 1.25, possibly due to limited data, the non-'0' categories were combined. The two symbols in Figure I.1A show the proportion infested-spider mite density curves for those samples with predators present (●) and those samples without predators (○) (1977 and 1978 data). It is apparent that in the presence of predatory mites, spider mites are less clumped, i.e., when predaceous mites are present, there are fewer spider mites per leaf for a given proportion of leaves infested with spider mites. To insure that the greater degree of clumping for spider mites observed without *M. occidentalis* was not due to some intrinsic difference between the Kern County orchards and the more northern San Joaquin and Sutter county orchards, Taylor's coefficients were estimated for all orchards. In addition, the Kern County orchard samples having spider mites without *M. occidentalis* were analyzed separately from those samples with

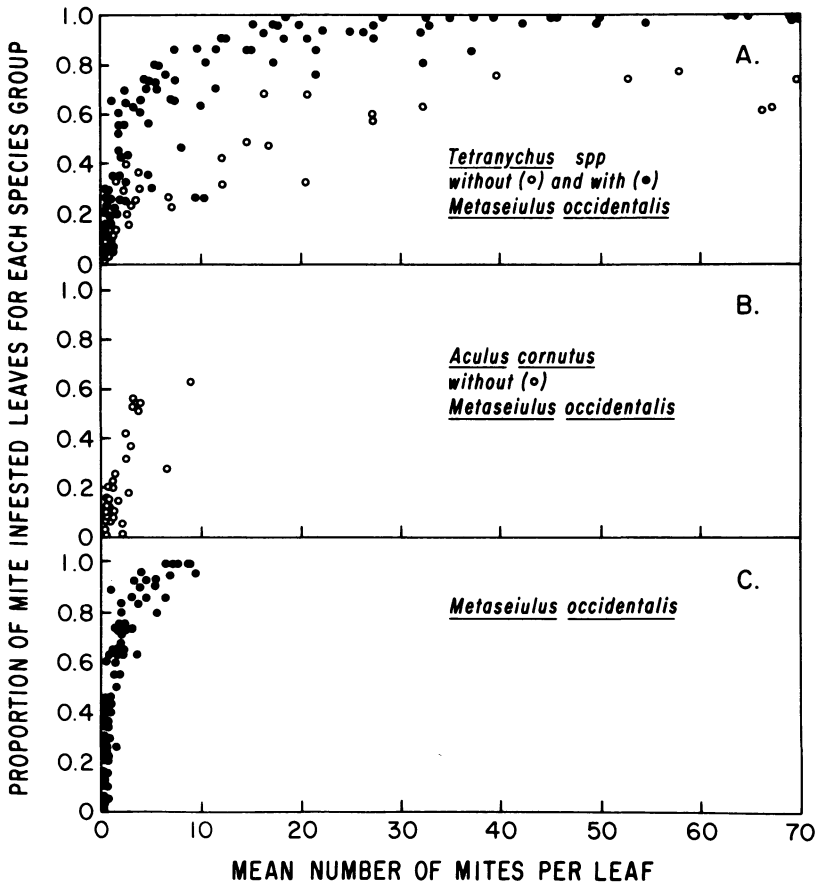


Fig. I.1A-C. Proportion of mite-infested leaves as a function of mite density for each of three mite species groups, and the effect of the predaceous mite, *M. occidentalis*, on the relationship between proportion of spider mite-infested leaves and spider mite density curve.

M. occidentalis (table I.5). The values for the 'a' coefficient for spider mites in the absence of *M. occidentalis* for both areas were ca. 20.0, compared with 6.0 when predators were present. In addition, the 'b' coefficients were higher in the absence of predators. The reduced values for Taylor's coefficients reflect the biological significance of predation decreasing the pattern of spider mite clumping. The similarity between the clumping pattern of spider mites and that of *A. cornutus* is apparent from the coefficients in Table I.5, although the *A. cornutus* data are limited to lower densities. The much lower pattern of clumping for *M. occidentalis* is apparent because of the lower values for both the 'a' and 'b' coefficients (figure I.1C). Although Croft et al. (1976) and Herbert and Butler (1973) present Taylor's coefficients for the mite species examined in their studies, their coefficients were based on what each called a *per tree sample unit* basis and therefore cannot be compared directly with our per leaf sample unit estimates. Wilson et al. (1983a) did, however, report 'a' and 'b' coefficient values of 6.16 and 1.54 for mobile *Tetranychus* spp. on cotton, using a per leaf sample unit. When including eggs as well as mobile stages, the 'a' and 'b' coefficients are ca. 20.00 and 1.57 for *Tetranychus* spp. on cotton (Wilson unpub. data), which compares favorably with their clumping pattern on almond leaves in the absence of *M. occidentalis*.

Predator efficacy

Figure I.2 shows the estimated proportion infested-density response curves for spider mites with and without *M. occidentalis*, and the direction that the curve would take due to mortality and dispersal. Mortality, as expected, tends to affect density more than it affects the proportion of infested leaves (P(I)), because the proportion of infested leaves is only changed when every spider mite on a leaf with a feeding *M. occidentalis* is either eaten or disperses to another leaf already infested. Mortality thus results in a decrease in the clumping pattern as exemplified by an apparent increase in P(I) for a given spider mite density when *M. occidentalis* is present compared with when *M. occidentalis* is absent. Even if mortality were a random phenomenon, i.e., the probability of one spider mite dying would be independent of any other spider mite dying, then the spider mite P(I)-density curve would rise. However, because predators often concentrate their searching (and feeding) where prey have previously been found, the net effect would be to decrease the density to an

TABLE I.5. COMPARISON OF TAYLOR'S POWER LAW COEFFICIENTS FOR A SINGLE LEAF SAMPLE UNIT FOR 3 MITE SPECIES GROUPS FOR 1977 AND 1978 ALMOND ORCHARDS

Species	Orchards	<i>M. occidentalis</i>		n*	r ²	
		presence	a			b
<i>Tetranychus</i> spp.	Sutter and San					
	Joaquin counties	—	20.793	1.626	57	0.928
	Kern County	—	19.513	1.631	77	0.571
	Kern County	+	6.005	1.566	175	0.908
	All data		8.365	1.577	309	0.862
<i>Metaseiulus</i> <i>occidentalis</i>	Kern County		2.276	1.241	205	0.957
<i>Aculus</i> <i>cornutus</i>	Sutter County		18.028	1.372	44	0.591

*Based on 25 or 30 leaf subsamples.

even greater degree than P(I), resulting in an even less clumped pattern on a per leaf basis. Dispersal of spider mites to other leaves due to attack by *M. occidentalis* would result in an increase in P(I) except, as indicated above, when the dispersing spider mites go to a leaf having other spider mites. Therefore, leaf-to-leaf dispersal also results in a reduction in the per leaf clumping pattern. We are not able to quantitatively evaluate the dispersal component, but by assuming that induced leaf to leaf movement is opposite in effect to mortality (i.e., increases P(I) by the same amount that mortality reduces P(I)), we can obtain estimates of the predators' efficiency, defined as the numerical reduction in prey per predator present. To do this we have to estimate the change in spider mite density due to a given number of predators for the range of observed predator densities. From the two curves (figure I.2) for any equal P(I) values, the difference in densities (the amount that *M. occidentalis* would reduce the spider mite population) is equal to $\bar{x}_{i,w0}$ (mean number of spider mites for a given density without predators) - $\bar{x}_{i,w}$ (mean with predators). In other words, the amount of mortality caused by *M. occidentalis* is equal to the amount that the curve without predators would be shifted to the left so that it became equal to the curve with predators.

The numbers of *M. occidentalis* causing the mortality for the range of spider mite densities was estimated by regressing the number of *M. occidentalis* against the corresponding number of spider mites for all samples for the Kern County orchards (see table I.2). The relationship was extremely tight (Equation 2) and indicates that, on average, for every 11 *Tetranychus* spp. mites, there was approximately one *M. occidentalis*.

$$\# M. occidentalis = 0.094 \cdot \# Tetranychus \text{ spp.}, r^2 = 0.94, n = 21 \tag{2}$$

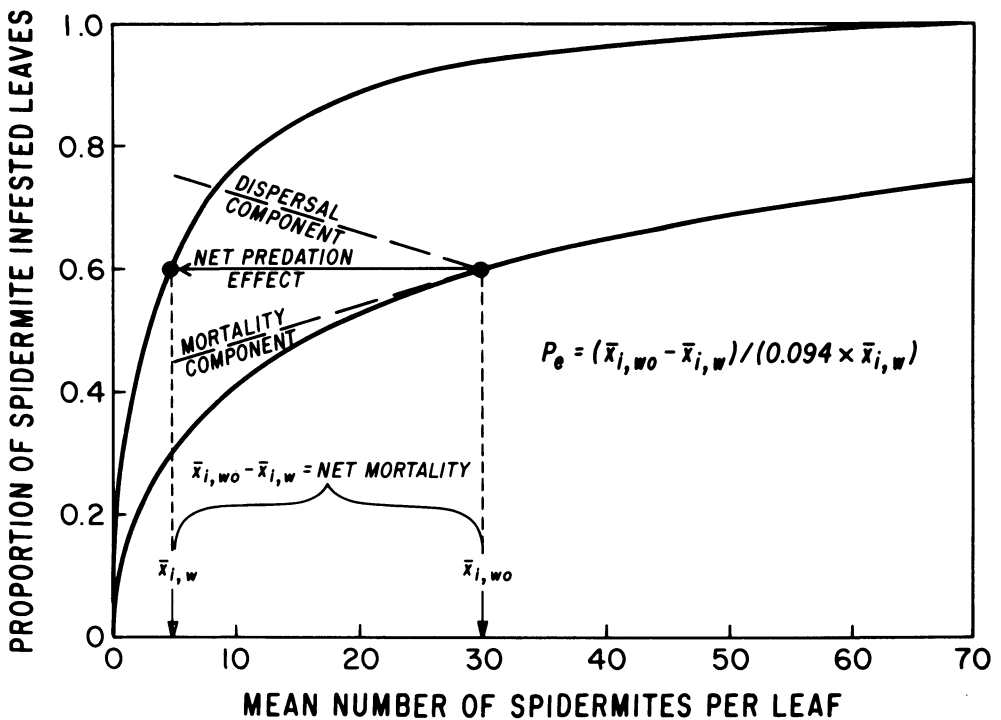


Fig. I.2. Theoretical relationship between predaceous mites and spider mite mortality, dispersal, and density.

Dividing the mortality (change in *Tetranychus* spp. density) necessary to shift the lower curve in Figure I.2 to correspond with the upper curve (P(I) not changing) by the estimated number of *M. occidentalis* causing the mortality results in an estimate of the predators' efficacy (P_e), and is approximated by Equation 3.

$$P_e = (\bar{x}_{i,wo} - \bar{x}_{i,w}) / (0.094 \cdot \bar{x}_{i,w}) \quad (3)$$

Based on estimates of mortality from Figure I.2 and then using Equation 3, predator efficacy values were derived for a range of densities (table I.6). These values indicate that *M. occidentalis* was able to reduce spider mite densities by ca. 25 to 73 times their own density. P_e increases considerably with increasing density, as expected, since each predator would spend less time searching when prey are abundant. The P_e values actually represent net reductions, which means that the actual consumption by the predatory mites would be higher because spider mite reproduction is not separated.

Pest management considerations

Although *M. occidentalis* affects the clumping pattern and density of spider mites, an evaluation of their potential use in pest management requires that we estimate the rapidity with which the spider mite population is brought under control once the predators enter the orchard either naturally or by augmentative release. Eventual reduction of a pest species population is by itself only sufficient if the pest species does not reach an economic injury level. This is equivalent to the population equilibrium position (E.P.), as defined by Stern et al. (1959) and Stern (1973), being sufficiently below the economic injury level so that upward population fluctuations do not result in economic damage.

Without showing early season low density induced variations, Figure I.3A-B shows the spider mite-*M. occidentalis* co-varying pattern for each Kern County orchard. In both orchards the spider mite-*M. occidentalis* pattern cycled with a counterclockwise trajectory.

TABLE I.6. ESTIMATED PREDATION EFFICACY OF *METASEIULUS OCCIDENTALIS* FEEDING ON *TETRANYCHUS* SPP.

<i>Tetranychus</i> spp. density				Predator efficacy
w/o predation (\bar{x}_{wo})	with predation (\bar{x}_w)*	\bar{x}_{wo}	- \bar{x}_w	(P_e)*
0.5	0.15		0.35	25
1	0.25		0.75	32
2	0.5		1.5	32
4	0.8		3.2	43
6	1.1		4.4	43
8	1.4		6.6	50
10	1.8		8.2	48
15	2.5		12.5	53
20	3.2		16.8	56
30	4.5		25.5	60
40	5.6		34.4	65
50	7.0		43.0	65
60	7.6		52.4	73
70	9.0		61.0	72

*Visual estimate.

Such a pattern can be derived using a broad range of predator-prey models and assumptions as summarized by Price (1975). In the Bidart orchard *M. occidentalis* were able to suppress the spider mites before the spider mites reached a density of 1.5 per leaf (figure I.3A). In the Blackwell orchard it appears that the increase in spider mite density had practically been arrested (at ca. 12 spider mites per leaf) the week before an unscheduled acaricide spraying. Once sprayed, however, the spider mites, although temporarily suppressed, rapidly resurged (figure I.3B) with a resulting density far exceeding the level observed just before treatment. Eventually the *M. occidentalis* were able to again suppress the spider mites.

An analysis of these co-varying patterns provides information on the predator/prey ratios at different spider mite densities which result in a reduction in density in the following sample (2 weeks later). Figure I.4 was developed by using only those data points from Figure I.3 that either immediately preceded or corresponded to a decrease in spider mite population, and indicates that at higher densities the effective predator/prey ratio is approximately one *M. occidentalis* per 10 spider mites. This ratio is equal to what was reported for *Amblyseius fallacis* feeding on the European red mite, *Panonychus ulmi*, on apples (Tanigoshi et al. 1983). Again, as is also indicated by the predator efficacy estimates presented in Table I.6, at lower spider mite densities this effective predator/prey ratio increases, probably because *M. occidentalis* spends more time searching than eating.

This analysis, however, partially begs the question in that the effective predator/prey ratio curve illustrated in Figure I.4 enables us to estimate whether the spider mite population density will increase or decrease in the short term (2 weeks), but not the rate of this

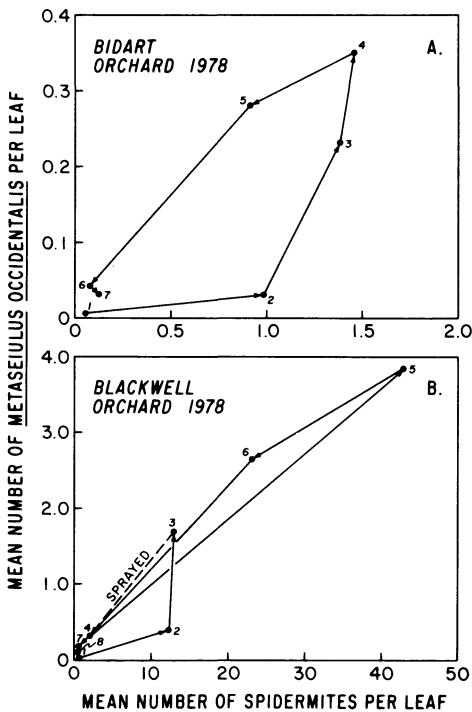


Fig. I.3A-B. Cyclical predator-prey co-varying patterns for *M. occidentalis* and spider mites for the A) Bidart orchard, and B) Blackwell orchard. Numbers represent successive samples.

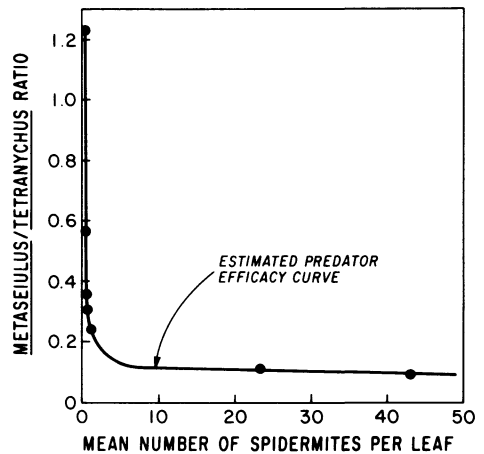


Fig. I.4. Predator/prey ratio curve which results in decreased spider mite density 2 weeks later.

event. Only when the predator/prey ratio falls directly on or above the curve will the spider mite population density be reduced within 2 weeks. Without more detailed spider mite and *M. occidentalis* life table data, we are not able to estimate—for a range of predator/prey ratios at different prey (spider mite) densities—whether an increasing spider mite population will be brought under control before reaching its economic injury level.

Conclusion

An analysis of the within-tree distribution of spider mites, *Tetranychus* spp., and peach silver mite, *Aculus cornutus*, in almond orchards indicates that both are distributed randomly on foliage in the four compass directions and the center of the tree for the upper and lower foliage areas. Both of these species groups have, however, extremely clumped patterns of distribution on a per leaf sample unit. The pattern of distribution for spider mites was additionally affected by the phytoseiid mite, *Metaseiulus occidentalis*, the pattern being less clumped with the predator present. *M. occidentalis* was considerably less clumped in its distribution pattern than was observed for the other mites. Taylor's coefficients for these species correspondingly reflected the per leaf clumping pattern: the more clumped the species group, the larger the coefficients. The distribution and clumping pattern information in this paper provides a framework for development of a quantitative spider mite monitoring program. A quantitative understanding of the clumping pattern of economically important arthropods particularly based on proportion infested-density data as presented here has proven extremely useful for the development of crop monitoring programs for a range of crops (Ingram and Green 1972, Sterling 1975, Wilson and Room 1983, Wilson et al. 1983a,b).

Based on the effect of *M. occidentalis* on the spider mite clumping pattern, estimates of the predators' efficacy were obtained. For the average predator/prey ratio observed in this experiment, it was estimated that *M. occidentalis* were able to reduce the spider mite density by ca. 25 to 73 times their own density. The predatory mite was more effective at high spider mite densities, probably because less time was spent searching for food. Additional analyses indicate that, except at low spider mite densities, approximately one *M. occidentalis* per 10 spider mites is sufficient to reduce spider mite density in 2 weeks. Further research is required to enable prediction of the ability of predatory mites at a range of predator/prey ratios at different prey densities to prevent spider mite populations from reaching an economic injury level.

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