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Survey of Predators Associated With European Red Mite (*Panonychus Ulmi*; Acari: Tetranychidae) in Ohio Apple Orchards

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SURVEY OF PREDATORS ASSOCIATED WITH EUROPEAN RED MITE (*PANONYCHUS ULMI*; ACARI: TETRANYCHIDAE) IN OHIO APPLE ORCHARDS

Celeste Welty[1]

ABSTRACT

A survey was conducted to identify the types and relative abundance of predatory arthropods associated with *Panonychus ulmi* in 21 Ohio apple orchards. Mite populations were sampled by leaf brushing, and insects and spiders were sampled by limb jarring. A state-wide survey was conducted in early July and in late August 1992, and five blocks were evaluated periodically from May until August 1992 at one farm in central Ohio. Predatory mites were detected in only 27% of the blocks surveyed in early July, but in 74% of the blocks surveyed in late August. The ratio of predatory mites to motile *P. ulmi* was $\geq$0.1 in 20% of blocks in July and in 26% of blocks in August. In commercial orchards, the predominant species was *Neoseiulus (Amblyseius) fallacis* (Acari: Phytoseiidae), but *Agistemus fleschneri* (Acari: Stigmaeidae) and *Zetzellia mali* (Acari: Stigmaeidae) were found in several blocks. In orchards monitored throughout the season, *N. fallacis* was rarely detected until July, and reached the highest density in August when *P. ulmi* was at a seasonal peak. Important predators of *P. ulmi* that were detected in limb-jarring samples were *Stethorus punctum punctum* (Coleoptera: Coccinellidae), green lacewings (Neuroptera: Chrysopidae), the black hunter thrips (*Leptothrips mali*; Thysanoptera: Phlaeothripidae), and the insidious flower bug (*Orius insidiosus*; Heteroptera: Anthocoridae). No regional differences were observed in types of predatory mites or insects; the same types were found in all parts of Ohio.

European red mite, *Panonychus ulmi* (Koch) (Acari: Tetranychidae), is one of the most difficult foliar pests to manage in Ohio apple orchards. Due to a lack of effective registered acaricides and their current high cost, there is great interest among apple growers in using indigenous predators for biological control of this pest. Many growers have observed that mite problems are lessened if they avoid using pesticides known to be highly toxic to natural enemies, although they are not sure which natural enemies are present in their orchard. Knowledge of the specific predators present in individual orchards is important because different species are not equally influenced by pesticides (Thistlewood 1991, Croft 1990, Croft 1975), and species differ in food preferences, prey consumption rates, and seasonal activity patterns (Lienk et al. 1980, Croft 1975, McMurtry et al. 1970).

Mites known to prey on *P. ulmi* in orchards include *Neoseiulus (Ambly-*

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seius) fallacis (Garman) (Acari: Phytoseiidae); *Typhlodromus pyri* (Nesbitt) (Acari: Phytoseiidae); *Zetzellia mali* (Ewing) (Acari: Stigmaeidae); and *Agistemus fleschneri* Summers (Acari: Stigmaeidae). Although Phytoseiids are considered to be the most efficient predators of *P. ulmi*, Stigmaeids can contribute significantly to mite suppression in spring and fall (Laing & Knop 1993). Most of the predatory mite species in orchards do not specialize in one food source; apple rust mite [*Aculus schlectendali* (Nalepa); Acari: Eriophyidae] and pollen are alternate foods for many species (Overmeer 1985).

A predatory insect that specializes on spider mites in orchards is a black lady beetle, *Stethorus punctum punctum* (LeConte) (Coleoptera: Coccinellidae); *S. p. punctum* occurs in eastern North America and is the key mite predator in Pennsylvania orchards (Hull et al. 1977). Generalist predators that feed on spider mites as one of several kinds of prey (Putman & Herne 1966, McMurtry et al. 1970, Parrella et al. 1981) include the black hunter thrips, *Leptothrips mali* (Fitch) (Thysanoptera: Phlaeothripidae); the insidious flower bug, *Orius insidiosus* (Say) (Heteroptera: Anthocoridae); green lacewings (Neuroptera: Chrysopidae); and brown lacewings (Neuroptera: Hemerobiidae). *Panonychus ulmi* is fed upon by other generalist predators but is not a significant part of their diets; these include Coccinellid beetles other than *S. punctum* (Putman 1964); hover flies (Diptera: Syrphidae) (Putman & Herne 1966); and spiders (Arachnida: Araneida) (Putman 1967).

Stethorus punctum, *Chrysopa oculata* (Neuroptera: Chrysopidae), an unspecified species of predatory thrips, and three unspecified species of predatory mites were noted by Cutright (1951) to be the major predators of *P. ulmi* in Ohio orchards. Holdsworth (1968, 1972a, 1972b) documented the presence of a similar complex of predatory mite and insect species in a research apple orchard in central Ohio in the 1960s. The project reported here also documented presence of predators but was conducted in commercial apple orchard locations throughout Ohio in 1992. It is possible that the predator complex has changed as pesticide use patterns have changed during the past 25 years. Although some of the standard pesticides used in the 1960s are currently used, such as azinphosmethyl, carbaryl, and endosulfan, others such as lead arsenate and DDT are no longer registered for use on apples, and others such as permethrin and methomyl are used now but were not used in the 1960s.

The major objective of this study was to identify the species of predatory mites and families of predatory insects associated with *P. ulmi* in Ohio, and to evaluate their relative abundance in Ohio orchards. This study was designed as a first step in a long term project on the development of integrated biological and chemical control of *P. ulmi* in Ohio.

MATERIALS AND METHODS

Extensive Survey. A predator survey was conducted in 21 orchard blocks in 16 counties from 2 to 16 July and from 17 to 27 August 1992. Twelve blocks were surveyed in both July and August by two sampling methods; two additional blocks were included in only the July survey, five additional blocks were included in only the August survey, and two additional blocks were included in both months but not with both sampling methods. Blocks were not randomly chosen; an effort was made to identify blocks of mite-susceptible cultivars where mites were not usually an important problem and thus where predator activity was suspected. Block 12 was part of the same orchard where studies were conducted by Holdsworth (1968). Block 16 was one of the blocks included in the intensive survey described below. Blocks were also chosen to expand the geographical coverage of the survey.

Orchard managers provided information on orchard history and management practices, and pesticides used during the previous three years; characteristics of blocks sampled are shown in Table 1. All blocks were typical commercially managed blocks with the exception of Blocks 1, 2, and 11. Block 1 had been previously abandoned but was being brought back into production; it was pruned and mowed but not sprayed with pesticides. Block 2 was a small block of young trees that was just beginning to bear fruit. Block 11 was abandoned after the 1990 harvest and was not sprayed with pesticides in 1991 or 1992. All blocks were Red Delicious apples or a mixture of Delicious and other cultivars, except for Block 1, which was Winesap apples.

Intensive Survey. To document seasonal trends in predator populations, a survey was conducted every one to three weeks from 11 May until 31 August 1992 in five apple blocks at a commercial farm in Licking County, central Ohio. Four blocks of Rome (LR, ND, OP, WW) and one block of Red Delicious (RU) trees were evaluated. The 30-year old Delicious-RU block had a history of large populations of *P. ulmi*, while the 24-year old Rome blocks varied in their history of mite problems: the Rome-LR block had a history of few mite outbreaks, the Rome-ND block had a history of frequent mite outbreaks, and Rome-OP and Rome-WW blocks had variable mite problems.

Pesticides were applied to these five blocks on the farm's normal schedule until a hail storm on 24 June damaged much of the fruit crop; a minimal schedule was used during the rest of the season. Insecticides used in these blocks were endosulfan at the pink bud stage (28 April), azinphosmethyl at petal-fall (14 May in Delicious; 20 May in Rome), and phosmet in cover sprays (27 May and 8 June in Delicious; 2 and 22 June in Rome; 22 and 27 July in all blocks as alternate row applications). Acaricides used were oil at the half-inch green bud stage (17 April) in all blocks, and propargite on 22 June in only the Delicious block. Fungicides used were benomyl at the half-inch green bud stage (17 April), dodine and myclobutanil at pink (28 April), captan and myclobutanil at bloom (11 May), and captan plus metiram or mancozeb at petal-fall, first and second cover sprays, and captan alone in the mid-summer cover spray (22 July). Streptomycin was also used for disease control in the Rome blocks (24 June).

Sampling Methods. Populations of *P. ulmi* and predatory mites were sampled by leaf brushing. A sample of 25 randomly selected leaves, from spurs in May and June and from terminals in July and August, was removed from each of ten randomly selected trees per block, held in a paper bag, and chilled until processed in the laboratory. Mites and mite eggs were brushed from each sample onto a glass plate by a mite-brushing machine (Leedom Engineering, San Jose, CA); a thin layer of dish-washing detergent (Joy, Proctor & Gamble, Cincinnati, OH) was spread on plates as an adhesive. Plates were examined under a microscope to determine the mean density of spider mites and predatory mites per 25-leaf sample. For predatory mite counts, the entire plate was always examined. For *P. ulmi* counts, the entire plate was examined for low density samples (<50 mites per plate = <2 mites per leaf) while portions ranging from 1/16 to 1/2 of the plate were examined in higher density samples (>50 mites per 1/16 plate = >32 mites per leaf). The mean number of mites per leaf in ten samples and standard deviations were calculated for each block using the JMP microcomputer program (SAS Institute 1989). The ratio of mean predatory mites per leaf to mean motile *P. ulmi* per leaf was calculated for each block. Presence or absence of apple rust mite (*Aculus schlectendali*) was noted for trees sampled in August. Predatory mites were preserved in alcohol and later mounted in Hoyers solution on glass slides. Species identifications were determined at Ohio State University's Acarology Laboratory.

Populations of predatory insects and spiders were sampled by limb jarring

Table 1. Characteristics of orchard blocks surveyed for predators, 1992.

Block	Location (County)	Status[1]	Cultivar[2]	Size (A)	Age (yr)	Ground mgmt.[3]	Volume[4] (gal)	Technique[5]	No. cover[6]
Southern Ohio									
1 OF	Brown	pab	Wns	1.5	20	mow	-	-	-
2 PK	Highland	com	Del	1	4	bare	40	all	-
3 AM	Clinton	com	Del	10	22	bare	20	all	8
4 HD	Jackson	com	Del	1	27	bare	20	all	6
5 WG	Washington	com	Del	1	22	mow	113	all	-
6 SW	Morgan	com	Del	0.2	27	mow	400	all	4
Central Ohio:									
7 OL	Greene	com	Del	3.5	39	bare	45	all	6
8 WN	Preble	com	Del	7.2	24	mow	28	ARM	6-7
9 WE	Preble	com	Del	5.4	8	bare	31	ARM	6-7
10 DW	Darke	com	Del	0.1	22	mulch	200	all	5
11 SH	Fairfield	aba	Del	10	35	mow	100	all	6–8
12 OT	Fairfield	res	Del	1	9	bare	50	all	6
13 LA	Franklin	res	Del	1.6	8	bare	90	all	6
14 GB	Licking	com	Del	15	12	bare	57	ARM	5
15 HW	Licking	com	Del	7	29	bare	20	all	4
16 RU	Licking	com	Del	14	30	bare	50	all	5
17 CM	Union	com	Del	3	20	bare	50	all	3–4
Northern Ohio:									
18 PV	Columbiana	com	Del	15	24	mow	66	all	5
19 MR	Columbiana	com	Del	2.5	19	bare	40	all	5–6
20 AC	Medina	com	Del	4	9	bare	30	ARM	7
21 ES	Sandusky	com	Del	1	28	bare	30	all	7–8

[1] Status: com = commercial , res = research (managed as commercial), aba = abandoned, pab = partially abandoned (pruned and mowed but not sprayed).
[2] Cultivar: Del = Delicious, WNS = Winesap
[3] Ground management: bare = herbicide strip; mow = mowed grass; mulch = corn cob mulch.
[4] Volume: volume of spray per acre, in gallons.
[5] Spray technique: all = full spray every row; ARM = alternate row middle.
[6] No. cover: typical number of cover sprays.

in each of ten randomly selected trees per block. Each of five branches per tree was hit twice with a rubber mallet over a taut 1 m^2 white nylon beating sheet (BioQuip Products, Gardena, CA), and the resulting five-branch sample of dislodged arthropods was stored until it could be sorted and classified. For most of the season, the sample was collected by sweeping dislodged material from the beating sheet into a dry plastic cup that was covered with a tight-fitting lid and chilled until the contents were sorted and preserved in alcohol. Starting in mid-August, arthropods were removed from the beating sheet with an aspirator and the contents immediately put in alcohol; this allowed for undamaged capture of delicate soft-bodied larvae and reduced the chance of possible predation within the chilled cups. Lacewing larvae were categorized as Chrysopids or Hemerobiids according to characteristics in Tauber (1991). Identifications of the dominant lady beetle and thrips species were verified at USDA's Systematic Entomology Laboratory in Beltsville, MD.

RESULTS

Extensive Survey. *Panonychus ulmi* density in most orchards surveyed throughout Ohio was low (<5 mites per leaf) in early July, but reached damaging levels in many blocks by late August (Table 2). Predatory mites were detected in only 4 of 15 blocks (27%) surveyed in July, but in 14 of 19 blocks (74%) surveyed in August. A ratio of at least one predatory mite to ten *P. ulmi* was detected in three blocks in July and five blocks in August. Predatory mite density was highest (0.6 per leaf in August) in Block 4, in which *P. ulmi* was scarce but *A. schlectendali* was abundant. High predator density (0.4 per leaf in August) was also found in Blocks 16 and 20, but predator to prey ratios were low in these two blocks (Table 2).

The predominant species of predatory mite was *Neoseiulus fallacis*, which was found in two blocks in July and in fourteen blocks in August. Stigmaeid mites were less common: *Agistemus fleschneri* was found in one block in July and in one additional block in August; *Zetzellia mali* was the only predatory mite species in one block (Block 19) in August. In Block 4, where density of predatory mites was highest, a mixed population of *N. fallacis* and *A. fleschneri* was present on both sampling dates; *N. fallacis* was more abundant in early July while *A. fleschneri* was more abundant in late August. The only other predatory species found was *Typhlodromus pomi* (Parrott) (Acari: Phytoseiidae) in Block 11 which was one of the two abandoned blocks included in the survey; a single specimen of *T. pomi* was found in a managed commercial block (Block 12) that was just 100 m away from the abandoned block (Block 11). A few Cunaxid, Tydaeid, and other mites were occasionally found but not determined to species.

In limb-jarring samples, the presence of specific predator types varied among orchards, but no trends of regional differences within Ohio were detected. The most frequently occurring predator category and the most abundant predator was Araneids, although their impact on *P. ulmi* populations is assumed to be negligible (Putman 1967). The most frequently occurring predatory insects were Chrysopid lacewings, black hunter thrips (*Leptothrips mali*), a black lady beetle (*Stethorus punctum punctum*), and insidious flower bug (*Orius insidiosus*) (Table 3). The most abundant predators were *S. punctum* and *L. mali*. *Leptothrips mali* was most numerous in Block 15 and *S. punctum* was most numerous in Block 19; both of these blocks are managed on a lower than typical spray schedule, where at least one mid-summer insecticide cover spray is omitted if key pests such as codling moth are not present at above threshold levels. Other predators found only occasionally were

Table 2. Mean density of *P. ulmi* and predatory mites, and presence (+) or absence (–) of *A. schlectendali* (A.s.), in leaf-brush samples (N = 10 trees) from Ohio orchards, 1992.

	2–16 July					17–27 August					
	Mean (± SD) number per leaf					Mean (± SD) number per leaf					
Block	*P. ulmi* motile	*P. ulmi* eggs	Predators[1]	Ratio[2]	Pred. species[3]	*P. ulmi* motile	*P. ulmi* eggs	Predators[1]	Ratio[2]	Pred. species[3]	A.s.
1 OF	0.1±0.1	0.1±0.1	0	0	•	•	•	•	•	•	•
2 PK	0.1±0.2	0.1±0.1	0.02±0.04	0.19	(undet)	•	•	•	•	•	•
3 AM	1.1±2.1	1.4±2.5	0	0	•	122±38	163±27	0	0	•	–
4 HD	1.1±0.6	0.9±0.6	0.54±0.31	0.49	Nf, Af	0.1±0.1	0.1±0.1	0.65±0.31	6.48	Af, Nf	+
5 WG	10.5±6.2	50.4±31.6	0	0	•	49.9±22.3	90.7±49.0	0	0	Nf	–
6 SW	0.1±0.1	0.1±0.1	0	0	•	<0.1±0.1	0.3±0.3	0.02±0.03	0.57	Nf	–
7 OL	0.2±0.2	0.2±0.2	0	0	•	0.1±0.1	0.4±0.4	0.05±0.05	0.20	Nf	+
8 WN	0.7±0.9	1.1±2.0	0	0	•	44.5±34.2	52.9±38.8	0.04±0.06	<0.01	Nf	–
9 WE	69.2±23.1	92.0±20.4	0	0	•	44.5±14.5	56.9±20.0	0.01±0.03	<0.01	Nf	–
10 DW	10.9±10.0	15.6±13.6	0	0	•	137±50	59.8±35.0	0	0	•	+
11 SH	•	•	•	•	•	0.2±0.2	0.7±1.2	0.11±0.11	0.76	Tp, Af, Nf	–
12 OT	•	•	•	•	•	47.2±26.6	114±62	0.10±0.10	<0.01	Nf, Tp	–
13 LA	•	•	•	•	•	0.2±0.2	0.1±0.1	<0.01±0.01	0.02	Nf	–
14 GB	•	•	•	•	•	3.3±6.0	6.7±11.3	0.16±0.16	0.05	Nf	–
15 HW	•	•	•	•	•	27.2±20.5	26.7±12.4	0.04±0.06	<0.01	Nf	+
16 RU	2.9±3.2	20.6±16.6	<0.01±0.01	<0.01	(undet)	10.1±7.4	13.0±9.1	0.45±0.20	0.04	Nf	+
17 CM	0.2±0.1	0.2±0.2	0	0	•	3.6±5.9	1.4±2.2	0	0	•	+
18 PV	4.4±4.7	5.5±6.4	0	0	•	0.6±0.5	1.1±1.0	0	0	•	+
19 MR	5.7±6.2	4.6±5.5	0	0	•	0.1±0.1	0.1±0.1	0.09±0.20	0.96	Zm	–
20 AC	0.1±0.1	0.1±0.1	0.15±0.12	1.65	Nf	29.4±25.2	27.9±23.0	0.37±0.22	0.01	Nf	+
21 ES	•	•	•	•	•	38.8±38.5	62.2±33.0	0.02±0.03	<0.01	Nf	+

[1] Phytoseiids and Stigmaeids.
[2] Ratio of predatory mites to *P. ulmi* motiles.
[3] Predator species: Nf = *Neoseiulus fallacis*; Af = *Agistemus fleschneri*; Zm = *Zetzellia mali*; Tp = *Typhlodromus pomi*; undet = undetermined.

Table 3. Mean number of predatory insects in limb-jarring samples (N = 10 trees) from Ohio orchards, 1992.

	Mean (± SD) number per 5-branch sample							
	2–16 July				17–27 August			
Block	Chrysopidae	*L. mali*	*S. punctum*	*O. insidiosus*	Chrysopidae	*L. mali*	*S. punctum*	*O. insidiosus*
1 OF	0.2±0.4	0.4±1.0	0.3±0.5	0	•	•	•	•
2 PK	0	0	0	0.1±0.3	•	•	•	•
3 AM	0	0	0.1±0.3	0	0.2±0.4	0	0	0.4±0.7
4 HD	0	0	0.5±1.0	0	0	0.2±0.4	0.1±0.3	0.1±0.3
5 WG	0	0.4±0.7	0	0	0.4±0.5	3.1±1.9	0	1.1±1.0
6 SW	0.4±0.7	0.5±0.5	0.3±0.7	0	0.3±0.5	5.1±2.6	0	0
7 OL	0.2±0.4	0.2±0.6	0.1±0.3	0	0.2±0.4	0.2±0.6	0	0.2±0.4
8 WN	0	0	0	0	1.6±1.3	0.2±0.4	0.3±0.5	2.1±3.0
9 WE	0	0	0.2±0.4	0	0.6±1.1	0.2±0.4	0	0.2±0.4
10 DW	0.1±0.3	0	0	0	0.6±0.8	0.2±0.4	0	1.3±1.1
11 SH	•	•	•	•	0.1±0.3	0	0	0
12 OT	•	•	•	•	0.3±0.7	0.1±0.3	2.5±2.4	0.3±0.7
13 LA	•	•	•	•	0.5±0.7	0.1±0.3	0	0
14 GB	•	•	•	•	0.2±0.4	5.2±2.5	0.3±0.5	0
15 HW	•	•	•	•	0.8±0.8	12.3±6.4	3.6±2.8	0.6±1.0
16 RU	•	•	•	•	0.4±0.5	1.6±2.0	0.2±0.6	0
17 CM	•	•	•	•	0.4±0.5	3.0±3.1	0.2±0.6	0
18 PV	0	0.1±0.3	3.1±1.8	0.1±0.3	0	0.1±0.3	4.8±4.7	0
19 MR	0.2±0.4	0.1±0.3	1.5±1.8	0	0.8±1.3	3.5±1.6	20.1±18.4	0.4±0.5
20 AC	0	0	0	0	0.5±0.7	1.2±1.6	0.7±1.0	0.1±0.3
21 ES	0	0	0.7±1.1	0	0.2±0.4	0	0	0.1±0.3

Coccinellid beetles other than *S. p. punctum*, brown lacewings (Neuroptera: Hemerobiidae), hover flies (Diptera: Syrphidae), rove beetles (Coleoptera: Staphylinidae), and soldier beetles (Coleoptera: Cantharidae).

Intensive Survey. *Panonychus ulmi* populations developed slowly in May and June. After they began to build to the threshold level of five mites per leaf in some blocks in mid-July and again in mid-August, they were greatly reduced by heavy rains on 26 July and 27 August. The Delicious block sustained higher densities of *P. ulmi* than the Rome blocks (Fig. 1); the only acaricide application was to the Delicious block on 22 June, although the *P. ulmi* population was below threshold at that time. *P. ulmi* density was lowest in the Rome-OP and Rome-WW blocks, where populations never exceeded one mite per leaf.

The only species of predatory mite found in these five blocks was *N. fallacis*. Predatory mites were rarely detected in these five blocks from May through mid-July, which was the period when *P. ulmi* was present at low density. From late July through late August, predatory mites were more frequently detected (Fig. 1). They reached the highest density, 0.4 mite per leaf, in the Delicious-RU block in late August when *P. ulmi* was at a seasonal peak of 10 mites per leaf. Although the Delicious-RU block had shown no detectable predatory mites in May or June, and only traces of predators in July and early August, its density of predatory mites was one of the highest of blocks included in the extensive survey in August. The Rome-LR block compared with the Rome-ND block did not show lower numbers of *P. ulmi* or higher numbers of predatory mites as would have been expected based on orchard history; these two blocks had similar densities of *P. ulmi* and predators throughout the 1992 season.

Categories of predators detected in the limb-jarring samples in the intensive survey were the same as in the extensive survey. Greater densities and diversity were found in the Delicious block than in the Rome blocks, which may have been due to lower prey density in Rome trees, and to sparser foliage in Rome than in Delicious trees. Predator populations in the Delicious-RU block are used to illustrate seasonal trends (Table 4). The most abundant predator and the only type found throughout the season was Araneids. Predators found predominantly in May and June were Syrphid flies and Coccinellid beetles other than *S. p. punctum*. Coccinellids and Syrphids were more likely associated with prey other than *P. ulmi*; they were found when *Rhopalosiphum fitchii* (Sanderson) and *Aphis pomi* De Geer (Homoptera: Aphididae) were present. Predatory insects that were more likely associated with *P. ulmi* were found predominantly in August: *L. mali*, Chrysopid lacewings, *S. p. punctum*, and *O. insidiosus*. Differences among blocks are summarized by mean numbers of predators per 5-branch sample per week (Table 5); the most predators were found in blocks that had the most *P. ulmi*.

DISCUSSION

The presence of predatory mites in 74% of blocks surveyed in August is encouraging for the development of a biological control component of an integrated mite management program in Ohio. If a ratio of at least one predatory mite to ten *P. ulmi* is needed for biological control, as suggested for the *P. ulmi* and *N. fallacis* system by Croft (1975), then 26% of blocks sampled in August showed promise for biological control. Where predatory mites were detected but at ratios below 0.1, which occurred in 47% of blocks sampled in August, integrated control should be possible but acaricides would be needed to supplement predators for *P. ulmi* suppression.

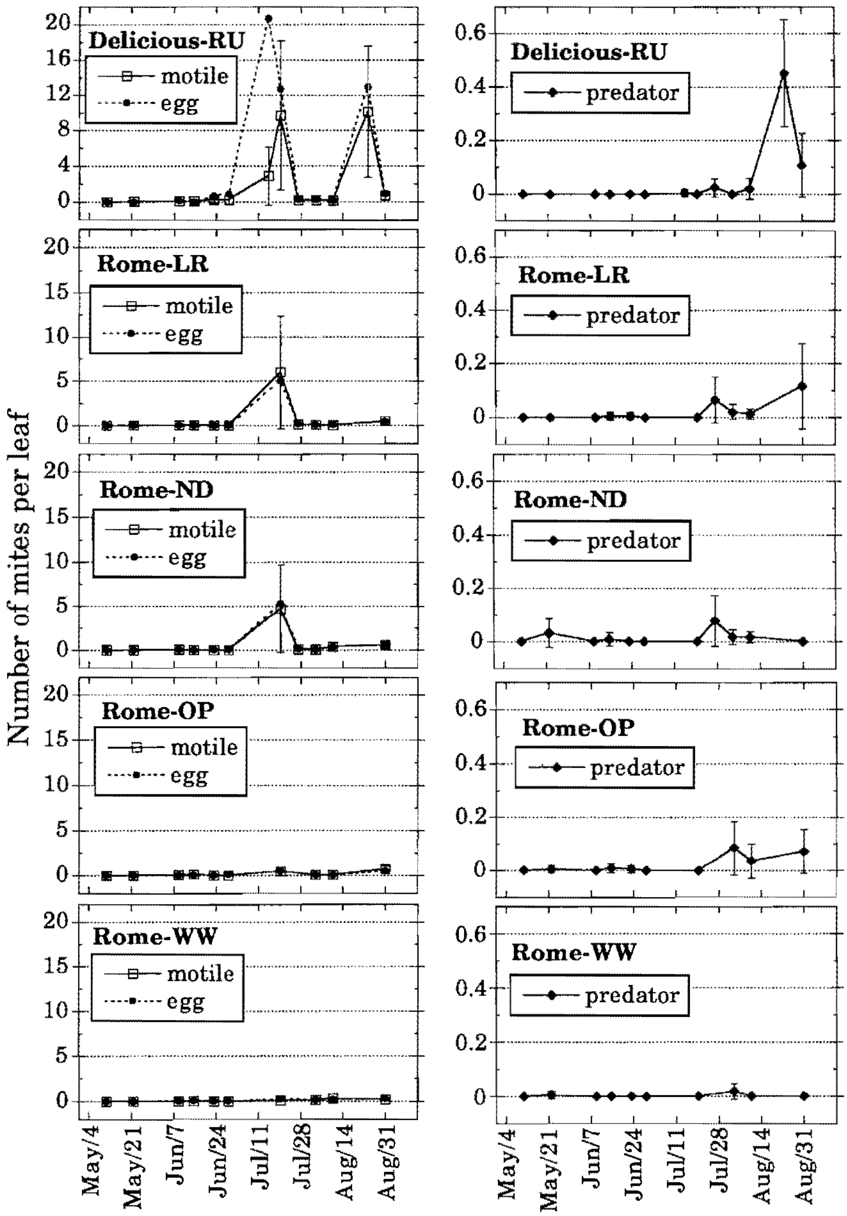

Fig. 1. Number of *P. ulmi* motiles, *P. ulmi* eggs, and predatory mites per leaf in one block of Delicious and four blocks of Rome apples from 11 May to 31 August 1992 in Licking County, Ohio; mean of 10 trees sampled (± standard deviation, for *P. ulmi* motile and predatory mites).

Table 4. Density of predatory arthropods in limb-jarring samples (N = 10) on eleven dates in 1992 in Delicious-RU block; Licking County, Ohio.

	Mean (± SD) number per 5-branch sample							
Date	Araneids	Coccinellids	Hemerobiids	Syrphids	Chrysopids	*L. mali*	*S. punctum*	*O. insidiosus*
11 May	0.5±0.5	0.1±0.3	0	0	0	0	0	0
22 May	0.6±0.7	0.2±0.4	0.1±0.3	0	0	0	0	0
9 June	0.2±0.6	0	0	0	0	0	0	0
15 June	0.1±0.3	0.2±0.6	0	0.1±0.3	0	0	0	0
23 June	0.3±0.5	0	0	0	0	0	0	0
29 June	0.1±0.3	0	0	0	0	0	0	0
20 July	0.1±0.3	0	0	0	0	0	0	0
27 July	0	0	0	0	0.1±0.3	0	0	0
10 August	0	0	0	0	0.1±0.3	0.2±0.4	0	0
24 August	0.5±0.8	0.1±0.3	0	0	0.4±0.5	1.6±2.0	0.2±0.6	0
31 August	0.1±0.3	0	0.2±0.4	0	0.1±0.3	0.8±0.9	0.2±0.6	0.2±0.4

Table 5. Summary of differences among five orchard blocks in density of major predatory insects in limb-jarring samples between 11 May and 31 August 1992, Licking County, Ohio; grand mean of all sampling dates per block (*N* = 9–11 dates), based on means of 10 samples per block per date.

		Mean (± SD) number per five-branch sample per date			
Block	*N*	*L. mali*	Chrysopids	*O. insidiosus*	*S. punctum*
Delicious-RU	11	0.24±0.49	0.06±0.12	0.02±0.06	0.04±0.08
Rome-LR	10	0.08±0.18	0.02±0.06	0.01±0.03	0
Rome-ND	10	0.02±0.06	0.03±0.06	0.02±0.06	0
Rome-OP	9	0.01±0.03	0.01±0.03	0	0
Rome-WW	9	0.02±0.04	0	0	0

There was no unusual orchard characteristic common to the five blocks with predator to prey ratios $\geq$0.1 or to the three blocks with the highest predator density; like most of the blocks surveyed, most of the high-predator blocks had bare ground under the trees, most used the spray technique of covering all rows rather than alternate row middles, and they were variable in presence of *A. schlectendali* as alternate prey. Preliminary analysis of associations between predatory mites and pesticide products used during the previous three years also did not show any trends that explained differences in predator presence, but much more detailed data on pesticide use patterns would need to be collected before conclusions could be made about pesticide influences on predators. It is likely that pesticide use could explain differences in predator occurrence, as has been shown elsewhere (e.g., Thistlewood 1991, Croft 1975).

The finding that *N. fallacis* is the most common predatory mite species in commercial apple orchards in Ohio shows that Ohio is similar to most other areas in the midwestern and eastern North America where similar surveys have been conducted. *N. fallacis* has been reported as the most common predatory mite in commercially managed orchards in Pennsylvania (Horsburgh & Asquith 1968), Michigan (Strickler et al. 1987), Iowa (Owens & Hart 1978), Ontario (Thistlewood 1991), Wisconsin (Oatman 1973), Missouri (Childers & Enns 1975), North Carolina (Farrier et al. 1980), New Jersey (Knisley & Swift 1972), eastern New York (Weires & Smith 1979), Massachusetts (Hislop & Prokopy 1979), and Maine (Berkett & Forsythe 1980). The occurrence of *T. pomi* as a common predatory mite in an abandoned orchard is consistent with studies in Michigan (Strickler et al. 1987), New Jersey (Knisley & Swift 1972), and Massachusetts (Hislop & Prokopy 1979).

The predominance of a predatory mite other than *N. fallacis* has been reported from commercial apple orchards in several regions. *Typhlodromus pyri* has been reported as the most common predator in western New York (Lienk et al. 1980) and Nova Scotia (Rasmy & MacPhee 1970), but *T. pyri* was not detected in this Ohio survey. Although one or both of the Stigmaeid species *A. fleschneri* and *Z. mali* have been reported as present in most of the predator surveys cited above, they are usually less abundant and found in fewer orchards than the Phytoseiids. These Stigmaeids were reported as the predominant predatory mites in Ohio in the 1960s (Holdsworth 1968, 1972a, 1972b), although these reports were limited to one orchard in central Ohio. The finding that *N. fallacis* was the predominant predatory mite species in Ohio apple orchards in 1992 shows either a difference due to sampling multiple locations, i.e. that Stigmaeids may have been the most common predatory mite in some but not most Ohio orchards in the 1960s, or that a shift in the components of the predator complex has occurred during the past 25 years. Species composition may have shifted due to changes in pesticide use; insecticides that were common in the 1960s but no longer used include lead arsenate, DDT, and phosalone. Methomyl and formetanate hydrochloride were introduced in the 1970s, and permethrin and oxamyl in the early 1980s. Many of the newer broad-spectrum insecticides such as permethrin and methomyl are highly toxic to predatory mites (Thistlewood 1991).

The insect components of the predator complex in Ohio in 1992 were similar to what Holdsworth (1968, 1972b) described; *L. mali*, *O. insidiosus*, Chrysopid and Hemerobiid lacewings, and *S. p. punctum* were present in the 1960s and in 1992, but predatory Mirid bugs were common in the 1960s and uncommon in 1992. As with changes in occurrence of predatory mites, the change in occurrence of Mirids may be due to shifts in pesticide use. The complex of insects that prey on *P. ulmi* in Ohio is similar to that reported from apple orchards in Virginia (Parrella et al. 1981), Pennsylvania (Horsburgh & Asquith 1968), and Missouri (Childers & Enns 1975).

The results of this study will be helpful to fruit specialists who are developing integrated pest management strategies for Ohio apple growers. Growers and scouts will need to be trained to recognize predators. The findings that *N. fallacis* is the predominant predator and that *S. punctum* can reach high densities in Ohio means that growers should be encouraged to adopt practices such as maintaining broadleaf plants under trees as overwintering refuges for predators, using alternate row middle spraying techniques to provide unsprayed refugia for mobile predators, and choosing pesticides that are not toxic to predators. Future work on biological control of *P. ulmi* in Ohio should address the questions of how to establish predators in blocks where natural populations of predators are absent, how to increase the density in blocks where predators are present but at low predator to prey ratios, and whether these ratios are also suitable for Stigmaeid species. The introduction of *T. pyri* should be considered based on its absence in this survey and its recent success in other areas (Hardman et al. 1991, Walde et al. 1992). Information is also needed on how to conserve natural populations of the full complex of predatory insects that inhabit apple orchards, and on what densities of insect predators are needed for biological control of *P. ulmi*. Studies that address these questions would benefit apple growers who want to implement a biologically sound program for mite management.

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