Seasonal Abundance of Spider Mites and Their Predators on Red Raspberry in Quebec, Canada

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ABSTRACT   Seasonal abundance of spider mites and their predators on red raspberry was studied in 1993 and 1994 at 2 agricultural locations near Quebec City, Canada. Three raspberry systems, wild raspberry, pesticide-free cultivated raspberry, and commercial raspberry treated with a variety of pesticides, were sampled at frequent intervals. *Tetranychus mcdanieli* McGregor accounted for 87.5, 80.6, and 95.0% of the identified spider mites collected in the commercial, untreated, and wild systems, respectively. *Tetranychus urticae* Koch was observed in low numbers in both years. Spider mites were more abundant in the commercial and untreated systems than in the wild system, and there was generally no difference between commercial and untreated systems in 1993, whereas in 1994 there was more spider mites in the commercial system than in the untreated one. Predatory mites were present in all systems. *Amblyseius fallacis* (Garman) was the most abundant predator in the commercial system, whereas a complex of other predatory mites species dominated the wild system. The coccinellid *Stethorus punctillum* Weise was abundant in the untreated system and rare in the commercial and the wild systems. Variations of predator abundance among treatments did not correlate with variations of spider mite abundance, and could be explained by seasonal predator-prey asynchrony.

KEY WORDS   *Tetranychus mcdanieli*, *Stethorus punctillum*, *Amblyseius fallacis*, raspberry

SPIDER MITES ARE important pests of red raspberry, *Rubus idaeus* L. (Charles et al. 1985, 1990; Raworth 1989; Gordon et al. 1990; Shanks et al. 1992; Mariethoz et al. 1994). Worldwide, *Tetranychus urticae* Koch has generally been recognized as the dominant spider mite species on red raspberry. *Tetranychus mcdanieli* McGregor has also been reported in Michigan (McGregor 1931), Manitoba (Chamberlain and Putnam 1959), and Ontario (Dondale 1968). Spider mite damage may occur at 2 growing stages of the crop. From late spring to midsummer, infestation of fruiting canes disrupts transpiration and photosynthesis (Sances et al. 1979), and prolonged feeding by high densities of spider mites may cause premature defoliation (Mariethoz et al. 1994). During late summer, spider mites may damage primocanes by reducing starch and sugar reserves, and thereby increase susceptibility of dormant buds to cold temperature injuries (Doughty et al. 1972). The effects of primocane defoliation are unpredictable and spider mites should be controlled preemptively (Raworth and Clements 1996).

In Canada, control of spider mites in commercial red raspberry fields relies mainly on clofentezine, the only registered acaricide. Despite clofentezine efficacy, chemicals do not provide season long control of spider mites. A preharvest interval of 15 d must be observed, and this allows spider mite populations to increase. Peak populations coincide with harvest, when no acaricide can be applied. A postharvest treatment, as suggested by Mariethoz et al. (1994), is costly at a time when no immediate benefits are expected. Furthermore, multiple applications of a single pesticide accelerate the development of resistant populations (Croft 1991).

Because of these limitations, biological control is a valuable alternative to chemical control. This option is particularly attractive, as spider mite biological control has been implemented with success on various horticultural crops (Helle and Sabelis 1985). On red raspberry, a number of predators have been identified as potential biological control agents, i.e., the phytoseiids *Amblyseius fallacis* (Garman) (Dondale 1968), *Phytoseiulus persimilis* Athias-Henriot (Charles et al. 1985, 1990; Wood et al. 1994), and *Typhlodromus pyri* Scheuten (Baillod et al. 1996), and the coccinellids *Stethorus bifidus* Kapur (Charles et al. 1985, 1990) and *S. picipes* Casey (Congdon et al. 1993, Raworth 1989).

Our study had 2 objectives. First, to characterize the spider mite complex and their associated predators in raspberry in Quebec. The faunistic survey was conducted in 3 raspberry systems characterized by different cultural and management practices: commercial, pesticide-free and wild. The 2nd objective was to examine the long-term effects these management practices may have on the seasonal abundance and diversity of spider mites and their natural enemies as

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well as the possible role of wild raspberry acting as a refuge for predators.

Materials and Methods

Study Area and Production Systems. The study was carried out in 2 agricultural communities located near Quebec City (46° 59′ N, 71° 29′ W), Quebec, Canada: Ile d'Orléans (IO location) and Bernières (BE location). Commercial sites were 0.5–1 ha fields of Killarney cultivar intensively managed following local pest management guidelines (Thibodeau et al. 1993). Growers applied 2–3 fungicide treatments to control diseases, including anthracnose *Elsinoe veneta* (Burkholder) Jenk. and gray mold *Botrytis cinerea* Pers. exFr., 2–3 insecticide treatments to control the tarnished plant bug *Lygus lineolaris* (Palisot de Beauvois), the strawberry bud weevil *Anthonomus signatus* Say, and the raspberry beetle *Byturus unicolor* Say, and 1 acaricide treatment for spider mites control. Untreated sites were 0.25–0.5 ha of early-season cultivars, mainly Killarney, undergoing local management practices but free of any pesticides for 2 or more years. Wild sites were bushy areas covering a minimum of 100 m² in which wild raspberry, *Rubus idaeus,* grew naturally and abundantly; the wild sites were also pesticide free. Three sampling sites on different farms were selected for each of the 3 raspberry systems at the 2 locations and considered as replicates.

Sampling. Sampling was conducted weekly in 1993. At the IO location, sampling started on 1 June, 8 June, and 15 June for the commercial wild and untreated systems, respectively, and ended on 21 September. At the BE location, sampling started on 8 June in the commercial and wild systems, on 15 June in the untreated system, and ended on 24 August. In all sites there was no sampling on 3 August. In 1994, samples were collected once or twice a week between 3 June and 27 September, but only at the IO location.

On each sampling date, 50 leaves per site were collected at random. From the beginning of the season until harvest, leaves were taken from the median portion of the fruiting cane. After harvest, leaves were collected from primocanes. Leaves were individually placed in plastic bags, kept in an insulated cooler containing ice, and brought to the laboratory where they were stored at 4°C for up to 3 d.

Identification of Spider Mites and Predators. Spider mites and predators present on leaves were sorted and counted under a stereomicroscope using 6.6–40× magnification and the results were recorded per leaf. In early 1993, spider mites were not identified to the species level. However, from 6 July 1993, and throughout the 1994 season, eggs and larvae were classified as *Tetranychus* sp., and protonymphs, deutonymphs and adults were either classified as *T. urticae* or *T. mcdanieli* using Krantz (1978).

Predatory mites were mounted in Hoyer's solution on microscopic slides and identified under a microscope. Eggs of predators were reared to the adult stage using a method developed by Brodeur and Cloutier (1992), to facilitate identification whenever they survived up to that stage. Predator identification was carried out to species level whenever possible and to family level otherwise using reference specimens and taxonomic keys (Chant and Hansell 1971, Krantz 1978, McDaniel 1979, Gordon 1985, Chiasson 1986, Borror et al. 1989). Identifications were verified by the diagnostic clinic of the Quebec Ministry of Agriculture, Fisheries and Food, Sainte-Foy, Quebec (MAPAQ), and in some cases by the Agriculture and Agri-Food Canada, Eastern Cereal and Oilseed Research Center (Biological Resources Program), Ottawa. Voucher specimens were placed in the insect collection of the MAPAQ, Sainte-Foy, Quebec.

Seasonal Abundance. At each sampling date, the frequency of infestation was calculated as the number of leaves infested (at least by 1 tetranychid) divided by the total number of leaves sampled. The density was assessed as average number of tetranychid mites per infested leaf. The proportion of each mite species was also recorded for mite feeding stages. Concurrently, predator densities were assessed as total number of predators per 50 leaves. *Amblyseius fallacis* and *S. punctillum* densities were assessed individually and data from other predatory mites and other predatory insects were pooled for analysis.

Data Analysis. The frequency of infested leaves and density of *Tetranychus* sp. and predators were tested for normality and homogeneity of variance using Shapiro–Wilk test and Bartlett test respectively (Snedecor and Cochran 1980, SAS Institute 1989). To meet the assumptions of normality and variance homogeneity, frequency data were arcsine transformed and densities of mites and predators were square root transformed. A split-plot in time analysis of variance (ANOVA) was carried out to test the effects of locations, years, and raspberry systems on the different dependent variables of abundance. Following significant differences, treatment means were compared using the Duncan multiple range test at $\alpha = 0.05$ (Snedecor and Cochran 1980). All statistics were performed using SAS (SAS Institute 1989).

Results

Tetranychid Species Composition. Proportion data showed that *T. mcdanieli* was the dominant species in all systems and sampling sites for both years (Figs. 1–3). This species accounted for 87.5, 80.6, and 95.0% of the identified spider mites collected in the commercial, untreated, and wild systems, respectively. In 1993 and 1994, *T. urticae* was collected in low numbers in all sites. In 1994, *T. mcdanieli* was present throughout the season, whereas *T. urticae* was observed from late June to the last sampling date (Fig. 2).

Seasonal Abundance of Spider Mites. The abundance of spider mites in 1993 at the IO location was low at the beginning of the season, as expressed both by frequency and density values (Fig. 1). When the overwintering females migrated to leaves and started to lay their eggs, we could visibly observe small, light colored punctures, which developed into bigger spots as the 1st summer generation developed. Spider mites in-
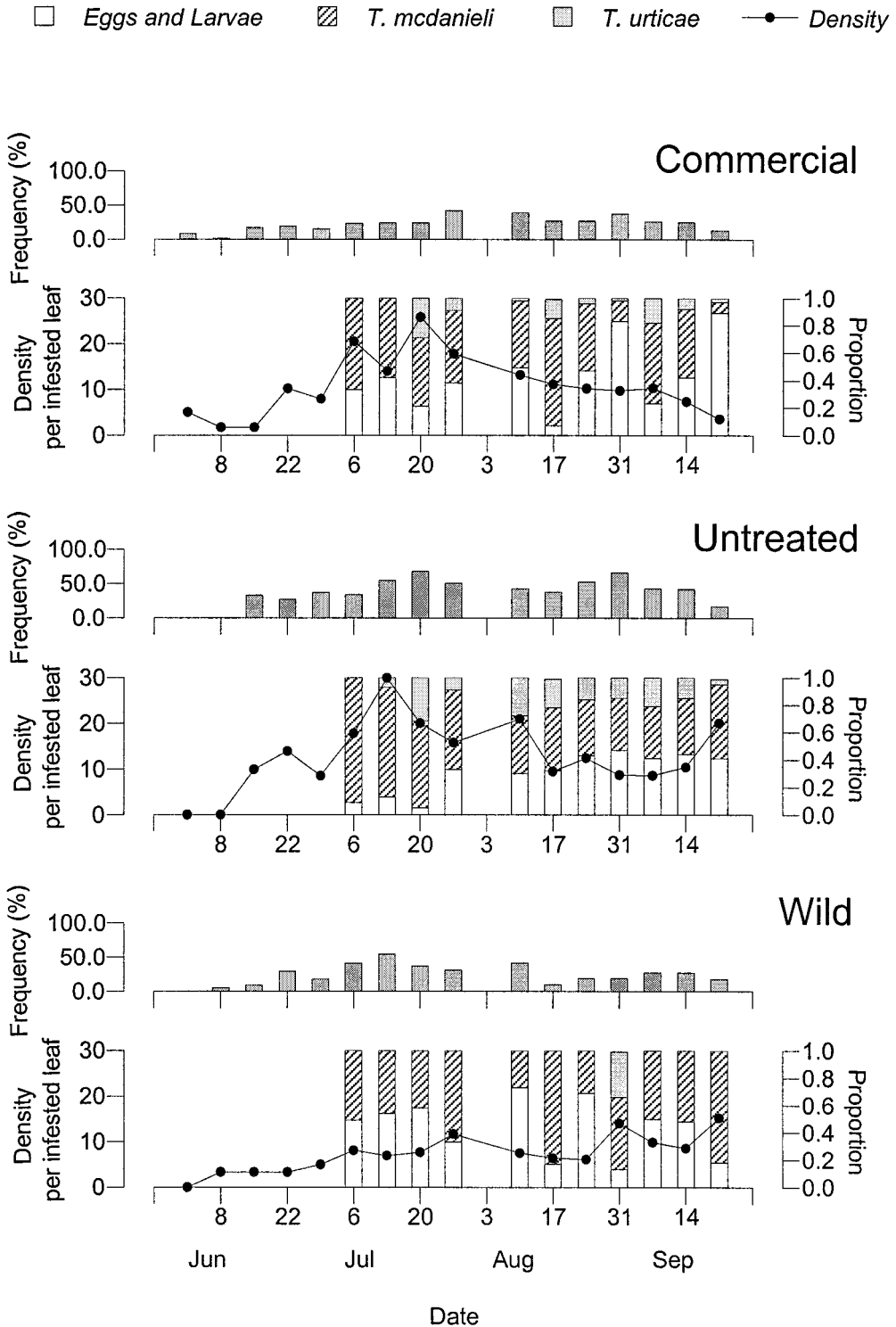
Fig. 1. Seasonal fluctuations of *Tetranychus* sp. on raspberry leaves showing frequency of infestation, density per leaf, and species composition (eggs and larvae not classified to species), in 1993 at the IO location for commercial, untreated and wild systems.
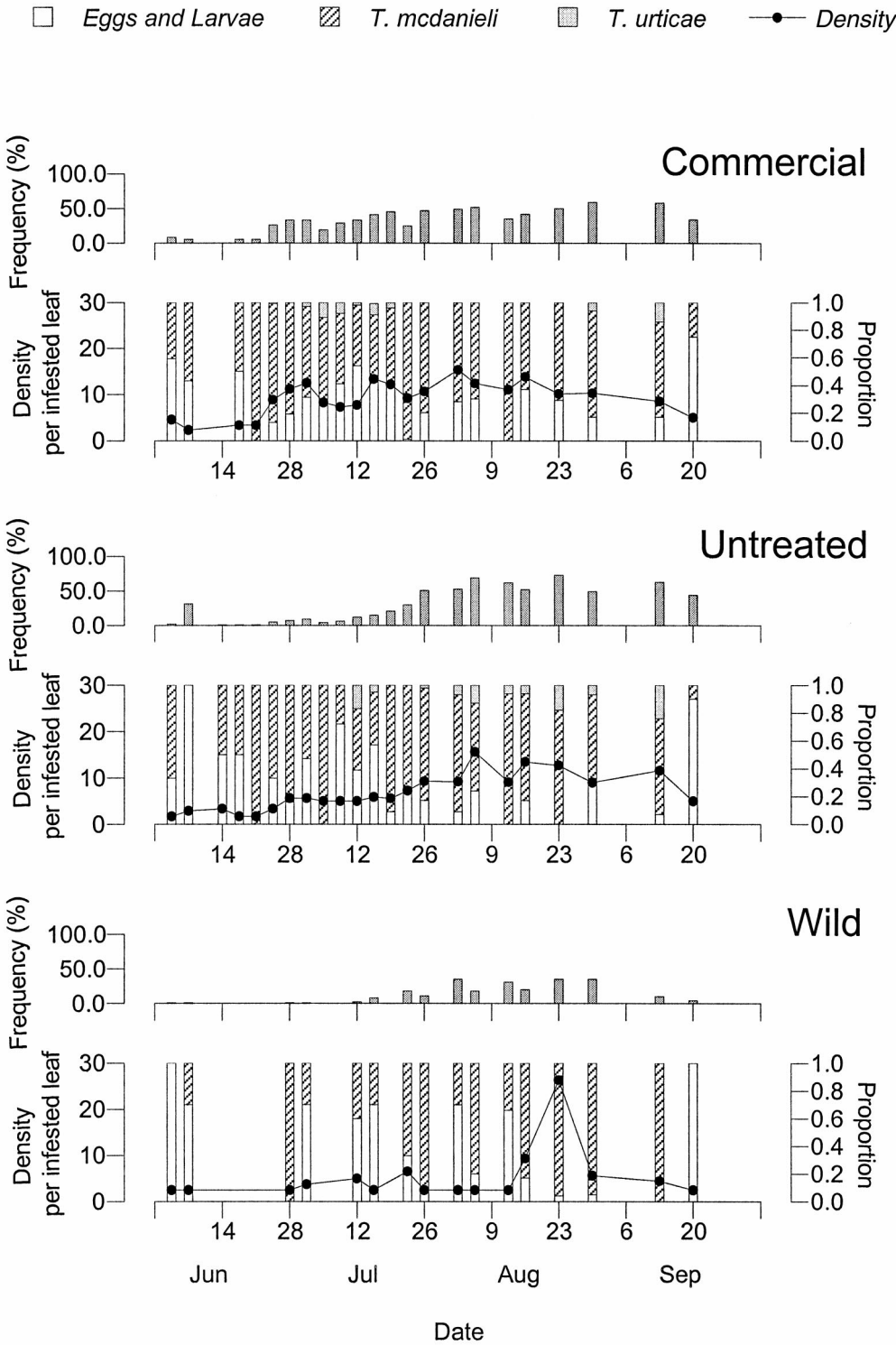
Fig. 2. Seasonal fluctuations of *Tetranychus* sp. on raspberry leaves showing frequency of infestation, density per leaf, and species composition (eggs and larvae not classified to species), in 1994 at the IO location for commercial, untreated and wild systems.

creased consistently over June and by the beginning of July, the density reached a value of ≈10 per infested leaf in commercial and untreated systems. In the commercial system, spider mite frequencies and densities remained relatively high until early September after which populations decreased steadily over the last 3 sampling dates. In the untreated system, frequencies showed a similar trend but densities did not decrease toward the end of the season. In the wild system, variations of the density were lower in amplitude than in the untreated system. In 1994, a similar pattern of spider mite abundance was observed at the IO location (Fig. 2). The longer sampling period in 1994 allowed us to observe population declines in all 3 systems at the end of the season. The overall pattern of spider mite abundance observed at the BE location in 1993 (Fig. 3) was similar to those observed at the IO location in 1993 and 1994.

There was no interaction between locations and raspberry systems for *Tetranychus* sp. frequency and density (Table 1). The frequency of leaf infestation by tetranychids was significantly higher at the IO location than at the BE location (Table 2). When averaged over all sampling systems and dates, the density at the IO location was >3 times higher than at the BE location. Because of a significant interaction between years and raspberry systems (Table 1), the effect of raspberry systems was assessed individually for both years (Table 2). In 1993, the frequency of infested leaves was lower in the commercial and wild systems than in the untreated system, and the density of tetranychids was significantly lower in the wild system than in the commercial and untreated systems. In 1994, there was a significantly decreasing trend in both frequency of infested leaves and mite density from the commercial, to untreated and to the wild systems.

Predator Species Composition. Several insect and mite species were observed on raspberry leaves preying upon tetranychid mites. Insects identified at the species level were *Orius tristicolor* (White) (Hemiptera: Anthocoridae) and *Stethorus punctillum* Weise (Coleoptera: Coccinellidae). Other insects belonged to the families of Aeolothripidae (Thysanoptera), Phlaeothripidae (Thysanoptera), Chrysopidae (Neuroptera), Hemerobiidae (Neuroptera), Coniopterygidae (Neuroptera), and Cecidomyiidae (Diptera). Species of predatory mites other than *A. fallacis* belonged, in order of frequency to the families Phytoseiidae, Stigmaeidae, and Erythraeidae.

Seasonal Abundance of Predators. At the IO location in 1993 in the commercial system, *A. fallacis* was generally the most common (seasonal proportion 54%), throughout the season (Fig. 4). Other predatory insects and mites accounted for 30 and 15% of the predators, respectively. They were collected from mid-July to the end of the sampling period. *Stethorus punctillum* relative abundance remained low (1%) throughout the season. In contrast, *S. punctillum* was the dominant predator in the untreated system. The coccinellid was collected on the 1st d of sampling and, throughout the season accounted for 10–100% (average 43%) of all predators sampled. As opposed to the

commercial system, *A. fallacis* was less common (15%) and appeared later in the season. Other predatory mites were recorded in the untreated system from 6 July to the end of the season (11%). Other predatory insects were also collected on most sampling dates and accounted for 31%. *Stethorus punctillum* was rarely found in the wild system (2%). In the latter system, most predators belonged to the group of other predatory mites (59%), whereas *A. fallacis* and other predatory insects accounted for 23 and 15%, respectively.

In the commercial system at the IO location in 1993, the density of predators was low in June but reached a 1st peak in mid-July and a 2nd one at the end of the season (Fig. 4). In the untreated system, predator densities were higher than in the commercial system during June and early July on all sampling dates by a magnitude of ≈3-fold. Highest numbers of predators were recorded on 1 July, thus earlier than in the commercial system. In the wild system, predator densities increased throughout the season, reached a peak on 31 August and decreased rapidly afterward.

At the IO location in 1994, in the commercial system, *A. fallacis* was the dominant predator species (64%) (Fig. 5) as in 1993 (Fig. 4). It appeared later in the season but then largely predominated among predators. Frequency of other predatory insects was 27%, whereas other predatory mites and S. *punctillum* accounted for only 8 and 1%, respectively. In the untreated system, predator frequency was 59% for other predatory mites, 18% for *A. fallacis*, 13% for other predators, and 10% for *S. punctillum.* In 1994, the frequency of predators collected in the wild system exhibited the same pattern as in 1993, with predominance of other predatory mites.

At the IO location in 1994, predator densities averaged less (5.3 per 50 leaves) than in 1993 (13.4) in the commercial system (Fig. 5, compare with Fig. 4). Densities had reached up to 11.5 by 26 July, a minor peak representing only 30% of the densities reached the previous year on 27 July. The densities were at their highest with a peak of 37.3 on 13 September. Predator density in the untreated system in 1994 followed a trend similar to 1993. One exception is that lower numbers of predators were collected throughout July (26.1 per 50 leaves in 1993 and 16.5 in 1994) and September (10.9 in 1993 and 2.3 in 1994). In 1994 in the wild system, predator densities differed from those recorded in 1993. Higher densities were recorded in June (2.8 in 1993 and 10.0 in 1994), whereas lower densities were recorded and September (17.7 in 1993 and 6.0 in 1994).

At the BE location in 1993, predator composition differed from that recorded at the IO location (Fig. 6, compare with Fig. 4). In the commercial system, *A. fallacis* was the dominant species (43%) but was collected 1 mo later than at the IO location. Other predatory insects accounted for 28%, whereas other predatory mites and *S. punctillum* accounted for 22 and 6%, respectively. *Stethorus punctillum* was more common than at the IO location. In the untreated system, other predatory mites were the most abundant predators (49%), followed by *S. punctillum* (24%), other pred-
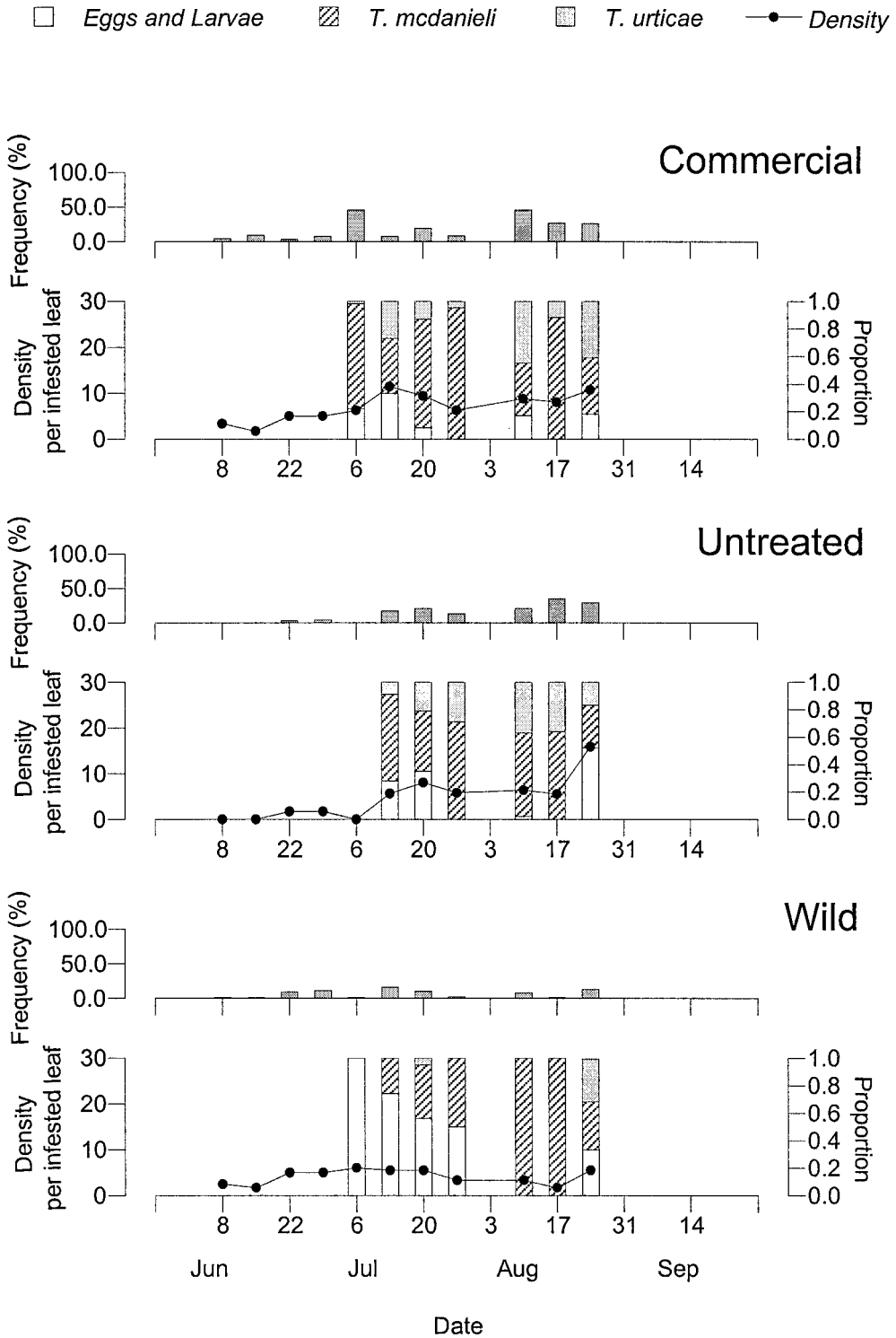
Fig. 3. Seasonal fluctuations of *Tetranychus* sp. on raspberry leaves showing frequency of infestation, density per leaf, and species composition (eggs and larvae not classified to species), in 1993 at the BE location for commercial, untreated and wild systems.

Table 1. Split-plot ANOVA showing the effects of locations, years, and raspberry systems on frequency of leaves infested by *Tetranychus* sp., *Tetranychus* sp. density, and density of *A. fallacis*, *S. punctillum*, other predatory mites, and other insect predators

Source of variation	df	MS	F	P > F
Tetranychus sp. frequency[a]				
Locations	1	2.12	12.81	0.0038
Raspberry systems	2	1.05	6.34	0.0132
Locations × raspberry systems	2	0.33	2.00	0.1774
Among fields error	12	0.17		
Years	1	1.01	13.44	0.0003
Years × raspberry systems	2	0.78	10.40	0.0001
Among samples error	397	0.08		
Tetranychus sp. density[b]				
Locations	1	61.51	16.36	0.0016
Raspberry systems	2	28.13	7.48	0.0078
Location × raspberry system	2	8.21	2.18	0.1553
Among fields error	12	3.76		
Years	1	92.94	50.73	0.0001
Years × raspberry systems	2	15.30	8.35	0.0003
Among samples error	397	1.83		
A. fallacis density[b]				
Locations	1	20.35	9.62	0.0092
Raspberry systems	2	6.74	3.19	0.0777
Locations × raspberry systems	2	0.06	0.03	0.9739
Among fields error	12	2.12		
Years	1	3.52	2.03	0.1555
Years × raspberry systems	2	0.16	0.09	0.9141
Among samples error	397	1.74		
S. punctillum density[b]				
Locations	1	13.78	8.21	0.0142
Raspberry systems	2	3.29	1.96	0.1833
Locations × raspberry systems	2	17.11	10.19	0.0026
Among fields error	12	1.68		
Years	1	18.32	25.45	0.0001
Years × raspberry systems	2	17.74	24.64	0.0001
Among samples error	397	0.72		
Other predatory mites density[b]				
Locations	1	6.45	0.80	0.3897
Raspberry systems	2	46.19	5.70	0.0182
Locations × raspberry systems	2	14.27	1.76	0.2134
Among fields error	12	8.10		
Years	1	5.11	2.52	0.1131
Years × raspberry systems	2	11.63	5.74	0.0035
Among samples error	397	2.03		
Other predatory insects density[b]				
Locations	1	15.67	17.76	0.0012
Raspberry systems	2	0.59	0.68	0.5261
Locations × raspberry systems	2	3.89	4.41	0.0366
Among fields error	12	0.88		
Years	1	18.87	23.45	0.0001
Years × raspberry systems	2	9.49	11.79	0.0001
Among samples error	397	0.80		

[a] The arcsine transformation was applied.
[b] The square-root transformation was applied.

Table 2. Effect of raspberry systems on frequency and density of *Tetranychus* sp.

Treatment	*Tetranychus*	
	Frequency, %	Density (*n*/infested leaf)
Location		
IO	26.9a	5.744a
BE	7.6b	1.800b
1993 Commercial	21.9b	6.517a
1993 Untreated	30.5a	7.140a
1993 Wild	17.1b	4.439b
1994 Commercial	29.5a	5.221a
1994 Untreated	14.5b	1.749b
1994 Wild	10.4c	0.076c

Means are computed for each location and, because of a significant interaction between years and raspberry systems, for each raspberry system within years. Within column data followed by the same letter do not differ significantly according to the Duncan multiple range test (alpha = 0.05).

the season, reached 20.3 on 10 August, and decreased afterward. In the untreated system densities increased regularly over the season to reach 30.3 on 24 August. In that system, the date of the last sampling did not allow us to observe a decrease in predator densities. In the wild system, densities did not fluctuate much but remained low throughout the sampling period and averaged only 1.8/50 leaves.

Statistical analysis of predator abundance showed a significant effect of locations on densities of *A. fallacis* (0.72/50 leaves at the IO location and 0.06 at the BE location), but no effect of years or raspberry systems (Table 1). The ANOVA revealed significant interactions between locations and raspberry systems and between years and raspberry system for densities of *S. punctillum* and other predatory insects (Table 1). As a consequence, the effect of raspberry systems was assessed individually for each location and year (Table 3). In 1993 at the IO location, *S. punctillum* and other predatory insects were significantly more common in the untreated system than in the commercial and wild systems. In 1993 at the BE location, densities of *S. punctillum* and other predatory insects did not differ among systems. In 1994 at the IO location, densities of *S. punctillum* were significantly greater in the untreated system than in the commercial and wild systems. This is similar to 1993 results but not to the same magnitude. Other predatory insects were significantly more abundant in the wild system than in the other 2 systems.

The ANOVA revealed a significant interaction between years and raspberry systems for other predatory mites density (Table 1). Therefore, the effect of raspberry systems was tested for each year (Table 4). In 1993, there was a significantly increasing trend in densities of predatory mites from the commercial to the untreated and to the wild system. In 1994, the densities of other predatory mites were significantly lower in the commercial system than in the untreated and wild systems.
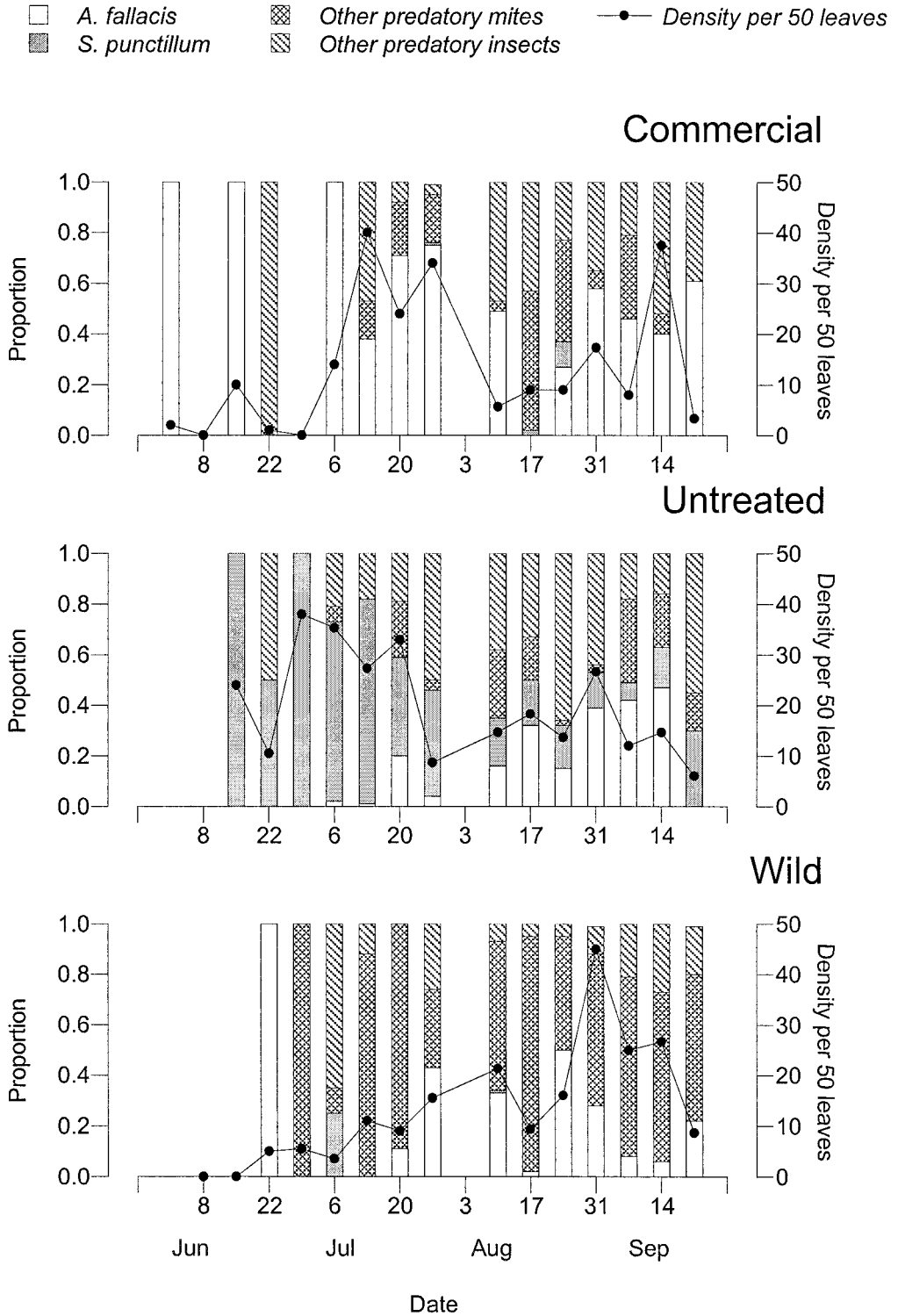
atory insects (18%), and A. *fallacis* (9%). Throughout the season, other predatory mites were largely dominant in the wild system (76%), especially before mid-July. Other predatory insects accounted for 24% of the predators. Notably, *A. fallacis* and *S. punctillum* were not observed at the BE location.

At the BE location in 1993 in the commercial system, predator densities were very low at the beginning of

Fig. 4.   Seasonal fluctuations of density (n/50 leaves) and proportions of 4 classes of spider mite predators in 1993 at the IO location for commercial, untreated and wild raspberry systems.
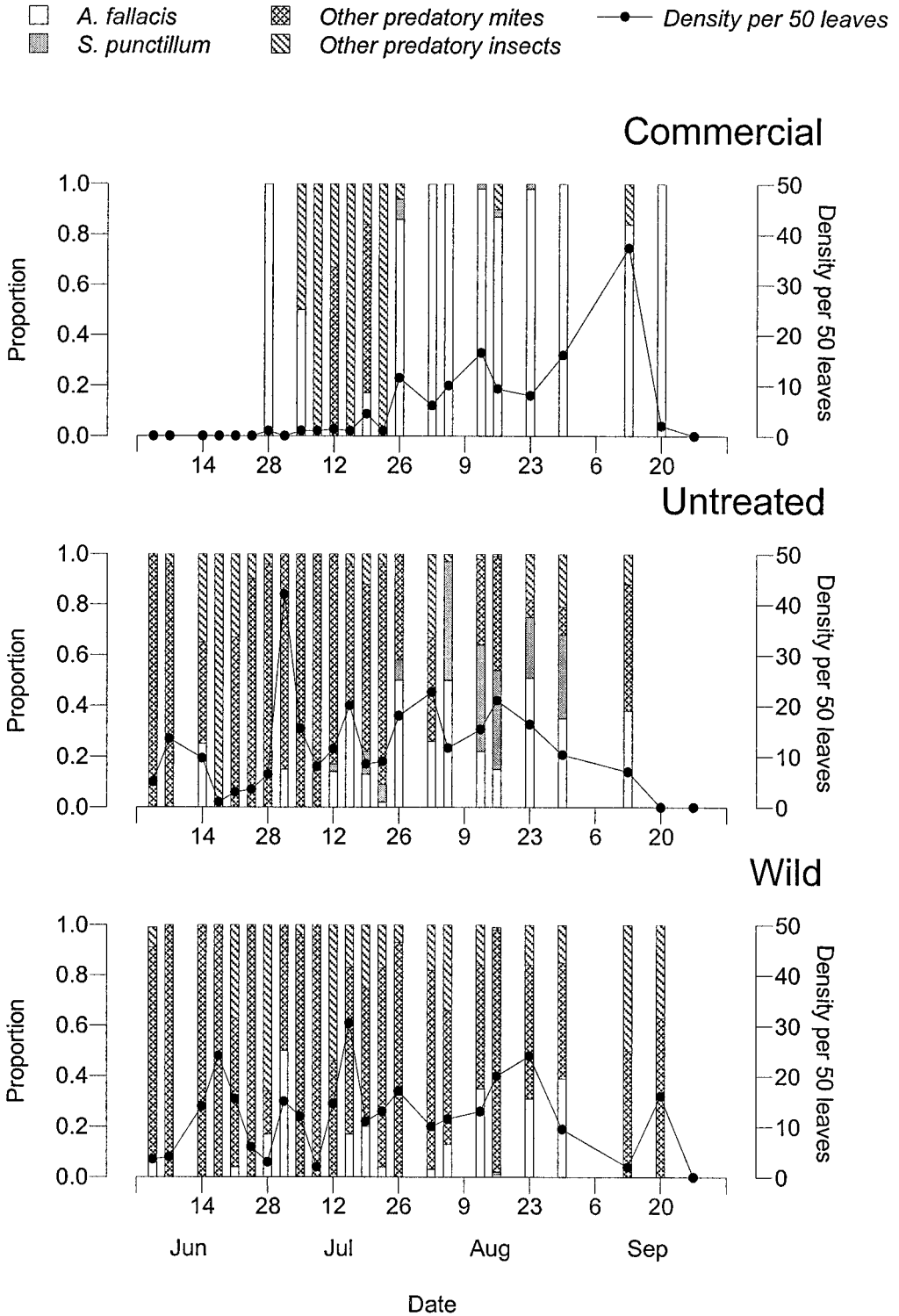
Fig. 5. Seasonal fluctuations of density (*n*/50 leaves) and proportions of 4 classes of spider mite predators in 1994 at the IO location for commercial, untreated and wild raspberry systems.
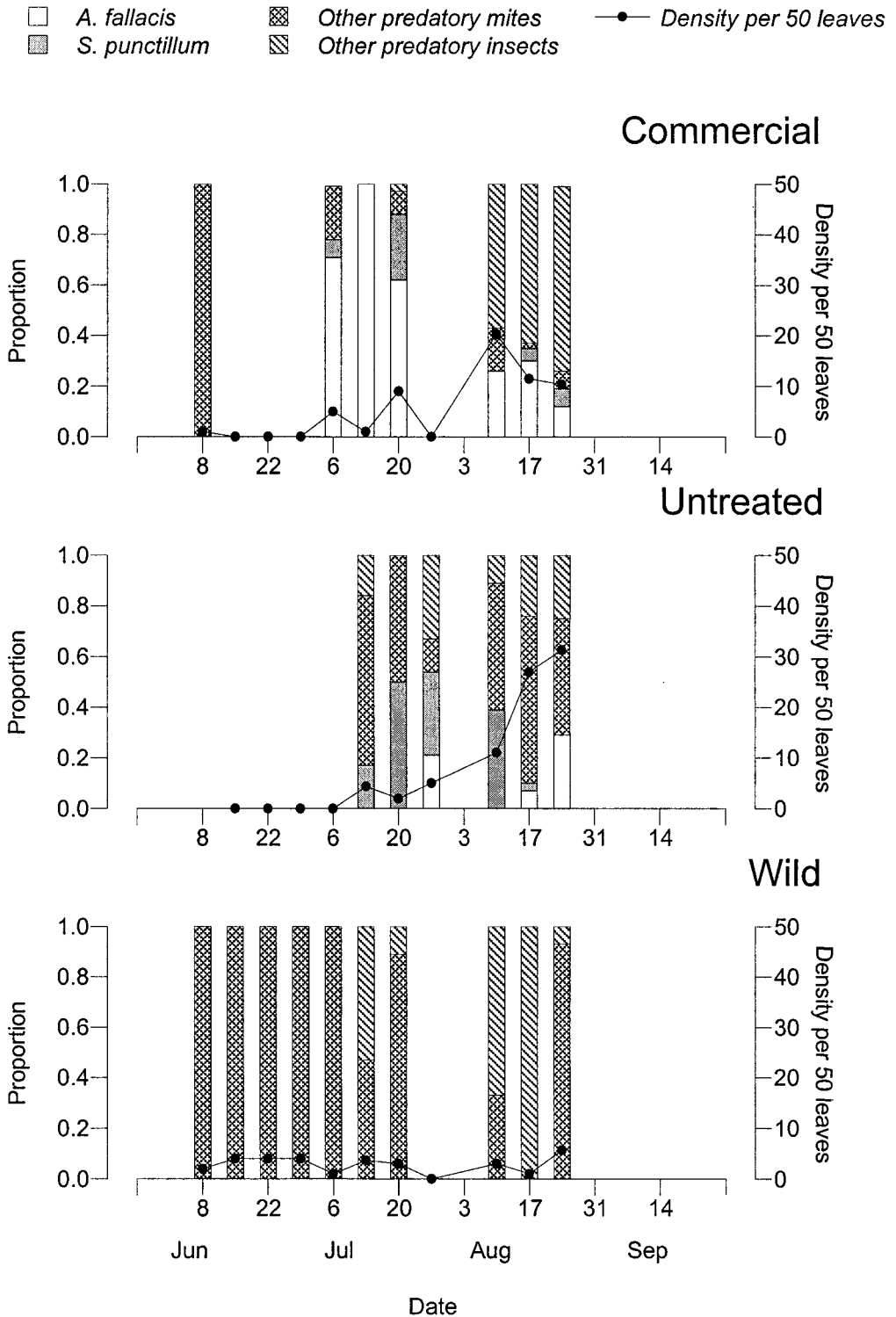
Fig. 6. Seasonal fluctuations of density (*n*/50 leaves) and proportions of 4 classes of spider mite predators in 1993 at the BE location for commercial, untreated and wild raspberry systems.

Table 3.   Effect of raspberry systems on density of S. *punctillum* and other predatory insects

Treatment	Density of *S. punctillum* (*n*/50 leaves)	Density of other predatory insects (*n*/50 leaves)
1993 IO commercial	0.005b	0.437b
1993 IO untreated	3.837a	2.399a
1993 IO wild	0.002b	0.551b
1993 BE commercial	0.056a	0.288A
1993 BE untreated	0.116a	0.264a
1993 BE wild	0.000a	0.093a
1994 IO commercial	0.004b	0.056b
1994 IO untreated	0.234a	0.118b
1994 IO wild	0.000b	0.670a

Because of significant interactions between locations and raspberry systems and between years and raspberry systems, means are computed for each raspberry system within locations and within years. Within column data followed by the same letter do not differ significantly according to the Duncan multiple range test (alpha = 0.05).

Discussion

The spider mite species complex found in Quebec raspberry production systems appears unique. Field surveys over 2 yr and 2 locations showed that *T. mcdanieli* is the most common and abundant species, whereas worldwide *T. urticae* is reported as the major spider mite pest on red raspberry (Charles et al. 1985, Raworth 1989, Gordon et al. 1990, Shanks et al. 1992, Mariethoz et al. 1994). *Tetranychus mcdanieli* was first mentioned as a pest on raspberry in Michigan (McGregor 1931). In North America, this species has been reported mostly as a pest of orchards on the Pacific Coast (Newcomer 1954). Besides the initial reports, only Robinson (1952) in Manitoba and Dondale (1968) in Ontario reported *T. mcdanieli* on raspberry. Robinson (1952) found the species on more than 20 different species of fruit trees, shrubs, and flowering plants. In Quebec, samples sent to the diagnostic laboratory of MAPAQ over the past years, and coming from all raspberry growing areas of Quebec, confirmed *T. mcdanieli* as the dominant spider mite species (M.R., unpublished data). All spider mites collected on other small fruit were identified as *T.*

Table 4.   Effect of raspberry systems on density of other predatory mites

Treatment	Density of other predatory mites (*n*/50 leaves)
1993 commercial	0.174c
1993 untreated	0.850b
1993 wild	1.894a
1994 commercial	0.003b
1994 untreated	2.953a
1994 wild	3.448a

Because of a significant interaction between years and raspberry systems, means are computed for each raspberry system within year. Within column data followed by the same letter do not differ significantly according to the Duncan multiple range test (alpha = 0.05).

urticae, the only exception being 2 samples of *Rubus occidentalis* L. leaves infested by *T. mcdanieli.*

As pointed out in the introduction, spider mites can be detrimental to raspberry production. Raworth (1989) attempted to establish a damage threshold for spider mites under experimental conditions in British Columbia, Canada. Although high numbers of mites were established, he could not demonstrate any yield effect. In Quebec, no economic threshold for spider mite on raspberry has been established. High densities reported in the hot summer of 1993 caused defoliation and early dropping of the fruits in many raspberry fields. Some fields could not be harvested because of the presence of spider mite webs on the fruits.

Amblyseius fallacis, a common phytoseiid mite in Quebec and Ontario apple orchards (Thistlewood 1991, Roy 1993), was the most abundant predator in commercial raspberry plantings. This species was also common in untreated and wild systems. Similarly, *A. fallacis* has been reported as the most specific and abundant predator of *T. mcdanieli* on raspberry in Ontario (Dondale 1968).

When averaged over the entire season, populations of Phytoseiidae, Stigmaeidae, and Erythraeidae were numerically (but not always statistically) greater in the untreated and wild systems than in the commercial system, confirming the negative impact of pesticides on predatory mites (Croft 1991). Additional support comes from a survey conducted by Thistlewood (1991), where phytoseiids and stigmaeids were significantly less abundant in orchards treated with pyrethroids and methomyl, respectively, than in orchards without these 2 pesticides. These pesticides were used in the commercial systems surveyed during the current study.

Stethorus punctillum was common in untreated systems but rare or absent in wild and commercial systems. It seems likely that pesticide treatments, including permethrin, azinphos-methyl, and carbaryl, before fruit harvest (Thibodeau et al. 1993) prevented the establishment of *S. punctillum* in commercial raspberry plantings. A similar pattern has been reported by Shanks et al. (1992) in Washington State. Toxicological studies showed that species of *Stethorus* are susceptible to permethrin (Hull et al. 1985), bifenthrin (Antonelli et al. 1997), organophosphorus insecticides (Bartlett 1963), dicofol, and fenvalerate (Hull et al. 1985). However, a recent field study conducted over a 3-yr period showed that 2 applications of malathion had little effect on *S. punctum picipes* (Antonelli et al. 1997), which appeared to control spider mites.

Our study did not show any evidence that wild raspberry acts as a refuge for *S. punctillum*, whether to support overwintering populations or to escape pesticide contact. Why *S. punctillum* did not colonize wild raspberry? Although we do not have a definite answer to this question, it seems that wild raspberry leaves are not suitable for the development of *S. punctillum*. Attempts made to rear *S. punctillum* in the laboratory on wild raspberry were unsuccessful and no oviposition occurred (M.R., unpublished data). Possible re-

pellency by the trichomes present on leaves, stems, and petioles might be an explanation.

Variations of predator abundance among treatments did not correlate with variations of spider mite abundance. Tetranychids were abundant in the untreated system, suggesting that predators could not regulate spider mite populations at a desirable level of control even in the absence of pesticides. One explanation may relate to the degree of seasonal synchrony between tetranychid pests and natural enemies early in the season (Tauber et al. 1986), as predators or parasitoids must be very active in the early stages of pest population growth to have a significant impact (Van Driesche and Bellows 1996). For example, several coccinellid predators have higher thermal requirements for development than aphids, which allows the prey to become active earlier than its natural enemy (Obrycki and Tauber 1982).

Chant (1963) stated that overwinter mortality dominates the seasonal dynamics of phytoseiid populations. High mortality of diapausing females (up to 80–90%) in temperate zones could limit predatory mite capacity to regulate spider mite populations early in the season (Overmeer 1985). In 1993, extremely cold temperatures had been recorded in Quebec City with average low temperature of −20.9°C in February. This is 5.2°C lower than the 20-yr average. Also, Hu et al. (1996) suspected *A. fallacis* winter mortality from cold temperatures in February and March 1993 to be, in part, responsible for the slow build-up of predatory mite summer populations in apple orchards in Massachusetts.

We know little about the seasonal activity of *S. punctillum* (McMurtry et al. 1970) and the question of its early seasonal synchrony with spider mites remains open. *Stethorus punctillum*, an introduced species from Europe (Putnam 1955), has become established in Quebec, but might not be well adapted to achieve satisfactory spider mite control early in the season. Asynchrony between local pest and prey population build-up could result both from different spring temperature thresholds and from spatial separation, because several species of coccinellids are known to seek overwintering aggregation sites away from cultivated areas (Hodek and Honek 1996). Emphasis should be put on studying its degree of adaptation to climatic conditions prevailing in North America. Furthermore, other biological and ecological attributes may determine the effectiveness of natural enemies: density responsiveness, reproductive potential, searching capacity, dispersal capacity, host specificity and compatibility, and food requirements and habits (Van Driesche and Bellows 1996).

Acknowledgments

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