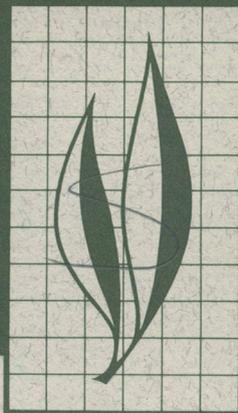


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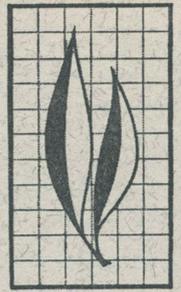


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Systematics and Bionomics of Predaceous and Phytophagous Mites Associated with Pine Foliage in California

- I. Survey of Mites on Native Pines, Including a Description of a New Species of Phytoseiidae
- II. Population Dynamics of Mites on Three Species of Pines in the Forest Falls Area of the San Bernardino Mountains
- III. Laboratory Studies on the Biology of the Phytoseiids *Metaseiulus validus* (Chant) and *Typhloseiopsis pini* (Chant)

Laurence D. Charlet and James A. McMurtry



I. Survey of Mites on Native Pines, Including a Description of a New Species of Phytoseiidae

A survey was made to determine the mite species occurring on the foliage of 17 native species of pines in California. Mites were removed from the needles by an air-agitated water bath; 23 different families were recovered. The Phytoseiidae, Tetranychidae, and Tenuipalpidae were the most frequently recovered families. A new species of phytoseiid, *Amblyseius muricatus*, is described.

II. Population Dynamics of Mites on Three Species of Pines in the Forest Falls Area of the San Bernardino Mountains

Seasonal and annual changes were determined in species composition and population densities of phytophagous and predaceous mites on three species of native pines (*Pinus coulteri*, *P. lambertiana*, and *P. ponderosa*) in the San Bernardino Mountains. Population trends were recorded for the Phytoseiidae, Tetranychidae, and Tenuipalpidae. Four species of tetranychids of the genus *Oligonychus* were present, one species of phytoseiid, *Metaseiulus validus*, and the tenuipalpid, *Brevipalpus* sp. Mite numbers were generally lowest from January to March. Predaceous mites gave a positive numerical response to increases in tetranychid population.

III. Laboratory Studies on the Biology of the Phytoseiids *Metaseiulus validus* (Chant) and *Typhloseiopsis pini* (Chant)

Laboratory studies with the phytoseiid mites, *Metaseiulus validus* and *Typhloseiopsis pini*, were made to assess their potential as natural control agents. The *M. validus* mite developed from egg to adult in about six days at 35 C, and *T. pini* required about eight days at 29 C. With decreasing temperature, the developmental period increased. *Metaseiulus validus* had a maximum fe-

(Continued on inside back cover)

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III. Laboratory Studies on the Biology of the Phytoseiids *Metaseiulus validus* (Chant) and *Typhloseiopsis pini* (Chant)

INTRODUCTION

PHYTOSEIIDS have been the subjects of considerable study for the last 15 years because of the interest in these arthropods as predators of injurious mites. Comprehensive discussions of the research up to 1969 have been presented by McMurtry et al. (1970) and Huffaker et al. (1970). These predators offer the potential of biological control on: grapes in California (Flaherty and Huffaker, 1970); strawberry plantings in California (Oatman and McMurtry, 1966; Oatman et al., 1967; and Oatman et al., 1968); avocado in California (McMurtry and Johnson, 1966); citrus in California and Florida (DeBach et al., 1950; Fleschner, 1958; McMurtry, 1969; and Muma, 1969); and glasshouse plantings of cucumbers in Europe and England (Hussey, 1965; Hussey and Bravenboer, 1971); and to contribute to a total pest management program on apples in Washington (Hoyt, 1969; Hoyt and Caltagirone, 1971). However, before the role that these mites play in the ecosystem can be understood, or the mites can be utilized or manipulated in a pest management program, adequate

biological studies must be made of the characteristics of the predatory species. Such studies should include developmental times, fecundity rates, prey consumption rates, prey preferences, and analyses of the physical parameters which might effect the predator's performance.

Biological information on species of phytoseiids occurring on pines is very limited. Tuttle and Muma (1973) remarked that *Metaseiulus validus* was common on species of pines in Arizona, and could be important as a biological control agent. During the faunal survey portion of this study (Part I), *M. validus* (Chant) and *Typhloseiopsis pini* (Chant) were common on the native species of pines sampled in different parts of California, and *T. pini* was recovered from a wide range of altitudes (0-3400 m). The objectives of this study were 1) to investigate the biology of these two species and 2) to assess their potential in the laboratory as natural control agents of phytophagous mites on the foliage of native California pines.

MATERIALS AND METHODS

Insectary culture

The culture of *Metaseiulus validus* (Chant) originated from material collected in May, 1973, from *Pinus coulteri* in the San Bernardino Mountains near Forest Falls, California, at an elevation of 1800 m. The *Typhloseiopsis*

pini (Chant) were obtained from trees of *P. contorta* growing in South Fork Meadow near Barton Flats, in the same mountain range at approximately 2,500 m elevation. The culture of *M. validus* was started with 24 individuals and that of *T. pini* with 64, but mites from

the same pine species and localities were added occasionally to replenish the cultures.

The phytoseiids were reared in a unit similar to that described by McMurtry and Scriven (1975). The phytoseiids were maintained on a diet of insectary-reared tetranychid mites (Scriven and McMurtry, 1971) and pollen from *P. coulteri* and *P. pinea*.

The cultures were held in wooden boxes with open backs, covered with organdy to permit air exchange (Croft, 1970), in an insectary room maintained at 24 C, 50% RH, and a 14-h photoperiod, hereafter referred to as standard room conditions. Individual mites or eggs were removed from these cultures for use in the biological studies.

For experiments in which mite ♀♀ or eggs were to be isolated, the following procedure was used: An avocado (*Persea indica*) leaf was placed upper surface down on a foam pad saturated with water. The pad was held in a small metal pan, and the leaf was surrounded with strips of Cellucotton® that became wet, thus maintaining a film of water around the leaf (McMurtry and Scriven, 1964a, 1964b). Four small strips of Cellucotton® were placed crosswise on the leaf, dividing it into five separate arenas. Pieces of plastic coverslips were added to the arenas to provide shelters for the phytoseiids. For most of the experiments, various stages of the tetranychid *Oligonychus punicae* (Hirst), the avocado brown mite, were brushed onto the leaves, and pollen was added to serve as food for the phytoseiids. These spider mites were reared on excised *P. indica* leaves in metal pans with saturated foam pads and Cellucotton® borders.

Constant temperature cabinets

Experiments were conducted at different temperatures in modified compact refrigerators, as described by Platner et al. (1973). In this cabinet, both the photoperiod and temperature could

be controlled, and the humidity was regulated by means of sulfuric acid solutions placed at the bottom of the refrigerator.

Development

Mature, gravid ♀♀ of each phytoseiid species were removed from the stock cultures and held on avocado leaves for oviposition. In this way, eggs of a known age could be collected for developmental studies. Eggs were collected every 8 h from the oviposition leaf and were placed singly in the isolation arenas. Because of the poor reproduction of these phytoseiids, there was no standard number of individuals used at each temperature. The number of eggs initially started at the different temperatures varied from 19 to 60. Eggs were checked every 8 h at the 24 C temperature and twice a day at the other temperatures. The stage of each individual was determined on the basis of the number of cast skins present in each arena. In all cases, the time of molt was recorded as occurring midway between the time the cast skin was noted and the time of the previous check. The insectary room (standard room conditions) was used to determine the rate of development at 24 C, and the constant temperature cabinets were used for the other temperatures (7, 13, 18, 29, and 35 C). An RH of 50% and a photoperiod of 14 h were maintained.

Fecundity rates

To determine the number of eggs laid per ♀ per day, gravid ♀♀ (enlarged abdomen with egg usually visible) of both species were placed individually on the divided sections of *P. indica* leaves, with avocado brown mites and pine pollen for food. Eggs laid were recorded and removed every 24 h. Females were replaced if they stopped laying eggs after the first day or did not reproduce after approximately 3 days. The number of ♀♀ used in these tests varied from 15 to 18 at each tempera-

ture (13, 18, 24, 29, and 35 C). Experiments were run for 11 days, with the first day not included in the results.

Food habits

This set of experiments was done in the insectary at standard room conditions. A minimum of 16 ♀♀ or eggs was used in each test. The following prey or foods were tested for both species of phytoseiids: the tetranychids, *Oligonychus punicae* (Hirst), *Panonychus citri* (McGregor), and *Tetranychus pacificus* (McGregor); pine pollen, and crawlers of California red scale, *Aonidiella aurantii*; and the tenuipalpid, *Brevipalpus* sp. To test for feeding and reproduction, individual ♀♀ were isolated on leaves to which the particular food was added every 24 to 48 h as needed. The ♀♀ were examined for evidence of feeding (change in gut coloration), and the arena was searched for eggs. The test was run for 11 days, with the results of the first day not included. Results were considered positive if more than 50% of the ♀♀ showed signs of feeding, or had deposited at least one egg. To test development of the mites on the various foods, eggs were placed singly in leaf arenas and checked periodically to see if development to adult had occurred. Food was added as needed to provide an excess for the predator. If more than 50% developed to the adult stage, the food was considered acceptable.

Prey consumption rates

The rate of consumption of two different stages of the prey, *Oligonychus punicae*, by the two species of phytoseiids was determined by isolating individual ♀♀ on leaves as previously described. Either 20 eggs or ♀ spider mites were added to each arena daily for 10 days, and the number consumed by the predator was recorded. The adult ♀ prey consumed (shriveled bodies) were removed daily, and new ♀♀ were added to return the host number to 20

per arena; any eggs laid were removed. A different procedure was required to ensure a constant number of eggs at the beginning of each day. Adult ♀ spider mites were placed on the leaf arenas about 2 days before the eggs were needed, and allowed to oviposit. On the day they were to be used, the ♀♀ were removed, and all but 20 eggs were destroyed. This method was followed for each of the 10 days the experiment was run. Tests were also conducted in the insectary at standard room conditions. Fifteen or 16 ♀♀ were used in each of those experiments.

Effects of photoperiod on oviposition

To test for a reproductive diapause in the phytoseiids, 8-h and 16-h photoperiods were used. The tests were run in the compact temperature cabinets at 21 C and 50% RH in the following manner: Female *M. validus* and *T. pini* were set up on leaves (30 to 40 per leaf) in the insectary room for a period of 48 h, and all the eggs were collected. The eggs were placed on excised leaves in the cabinets at the two photoperiods, and *O. punicae* and pollen were added as food for the developing predators. The leaves were checked daily for mites having molted to the adult stage, and for the presence of eggs. A record was kept of the number of ♀♀ laying eggs at the two photoperiods. The tests were conducted for at least 18 days after the mites had become adults. By this time, all ♀♀ in the 16-h photoperiod had laid eggs.

Sex ratio

To determine the ratio of ♀♀ to ♂♂ in these two species of phytoseiids, 100 to 150 eggs of each species were isolated on avocado leaves at standard room conditions. The mites were fed and allowed to develop to the adult stage, and were then collected and mounted in Hoyer's medium for microscopic examination as to sex.

Preovipositional period, reproductive longevity, and total egg production of *Typhloseiopsis pini*

Individual eggs were isolated on avocado leaf arenas provided with mites and pollen for food. After hatching, the mites were checked daily to determine when the final molt to the adult stage occurred. When a ♀ matured, a newly emerged ♂ was added, and the arena was observed daily to determine when the first egg was laid. In all instances, the event was recorded as oc-

curing midway between the time the event was noted and the time of the previous check. The time from the last molt to the time the first egg was laid constituted the preovipositional period. Daily observations were continued, and the eggs present were recorded and removed. Since the period during which a female is capable of reproducing is an important element in its success as a predator, for the purposes of this experiment, the time from first egg until death was recorded as the reproductive longevity of the ♀.

RESULTS AND DISCUSSION

Development

In almost all instances, the developmental period increased with decreasing temperature (Table 1). There were significant differences between the developmental periods at the lower temperatures, both between predators and among temperatures, of the same phytoseiid species.

Observations during the laboratory studies on development indicated a short quiescent period between the various stages of these predators, since ecdysis was only observed about 12 times. A quiescent period of brief duration was also noted in other phytoseiids

(McMurtry et al., 1970). However, Lee and Davis (1968) stated that with *Typhlodromus occidentalis* Nesbitt, periods of inactivity prior to molting lasted many hours. With *Typhloseiopsis pini* and *Metaseiulus validus*, the time required for ecdysis alone was comparable to that reported for *T. occidentalis*.

Apparently neither species in our study fed in the larval stage, as no gut coloration was observed. However, in some instances, larvae appeared to attempt to capture spider mites of various stages. *Typhlodromus mcgregori* Chant¹, a species closely related to *M.*

TABLE 1
MEAN NUMBER OF DAYS FOR IMMATURE STAGES OF *METASEIULUS VALIDUS* AND *TYPHLOSEIOPSIS PINI* AT DIFFERENT TEMPERATURES**

Temperature (°C)	Egg	Larva	Protonymph	Deutonymph	All stages
<i>M. validus</i>					
13	11.50a	6.13a	All died	—	—
18	5.39b	1.76b	6.10a	5.39a	18.79a
24	3.50c	1.12cf	3.52b	3.18b	11.32b
29	2.08c	0.73c	2.32c	2.06c	7.09c
35	2.02c	0.64c	1.79c	1.89c	6.33c
<i>T. pini</i>					
7	21.50d	7.00c	All died	—	—
13	8.50e	3.33e	8.71d	7.93d	28.09d
18	3.53c	1.52f	4.02e	3.61e	12.56e
24	2.43c	1.07cf	2.49c	2.46c	8.52f
29	2.12c	0.98cf	2.79bc	3.17bc	8.34cf

** Means in a column followed by the same letter are not significantly different at the 1% level (SNK test).

¹ Included in the genus *Metaseiulus* by the senior author.

validus, is also reported to have a non-feeding larval stage (Croft and Jorgensen, 1969). In contrast, *Amblyseius findlandicus* (Ouds.) (Chant, 1959), *T. longipilus* Nesbitt (Bravenboer, 1959), *A. hibisci* (Chant) (McMurtry and Scriven, 1964b), *T. occidentalis* Nesbitt (Lee and Davis, 1968; Croft and McMurtry, 1972), and *A. limonicus* Gaman and McGregor (McMurtry and Scriven, 1965) are reported to feed during this stage.

The threshold for development varied among species. *Metaseiulus validus* did not complete development at 13 C (Table 1), whereas *Typhloseiopsis pini* reached maturity at this temperature, but not at 7 C (Table 1). Development for *M. validus* was completed at 35 C, whereas few individuals of *T. pini* completed development at even 29 C. These results are consistent with collection data, as *T. pini* is found at high elevations (over 3000 m in some pines), but not at the lower elevations which have higher extreme temperatures. However, *M. validus* was only recovered from pines at lower elevations, which included those on desert slopes (see Part I).

Data indicated that *M. validus* had a longer developmental period than did *T. pini*, except at 29 C (Table 1). This was the case for each developmental stage, as well as for the total time required. *Metaseiulus validus* required about 6 more days at 18 C and about 3 more days at 24 C. In both species, developmental time at the lowest temperature tested was about twice as long as that at the next highest temperature (Table 1). At the higher temperatures tested, the developmental periods were not shortened proportionately. This fact was also shown with the phytoseiids *Typhlodromus caudiglans* (Putman, 1962) and *A. fallacis* (Smith and Newson, 1970).

Although it is difficult to compare the developmental periods for these predators with those of other phytoseiids, *T.*

occidentalis apparently develops faster than *M. validus* at comparable temperatures. At 24 C (Table 1), *M. validus* required about 11 days to develop from egg to adult, but Lee and Davis (1968) found *T. occidentalis* matured in only 6.3 days at the same temperature. Croft and McMurtry (1972) recorded similar times for the same species at 22.5 C, and Laing (1969) reported 8.5 days at a lower temperature (20 C average for fluctuating temperature). *Typhlodromus mcgregori* (in the same genus as *M. validus*) at a temperature of 22 C was reported to develop in only 8.2 days (Croft and Jorgensen, 1969). This was about 3 days faster than *M. validus* at approximately the same temperature.

Figure 1 compares the survivorship of the two species at the different temperatures. *Typhloseiopsis pini* had a higher percentage survival at lower temperatures (13, 18, and 24 C), and *M. validus* had higher survival values than *T. pini* at 29 and 35 C. However, *M. validus* had the greatest number of temperatures (4) with more than 25 percent of the individuals surviving. These survival curves are also consistent with the habitat records (Part I). *Typhloseiopsis pini*, which was collected in abundance at high altitudes where extremes of low temperatures are common, had low mortality at the low temperatures in these tests (Fig. 1). However, *M. validus*, which was more common in the intermediate altitudes (1200–2400 m) where high temperatures occur, had a higher survival rate than did *T. pini* at the higher temperatures (Fig. 1).

In comparing mortality of the different stages, there did not appear to be any stage that had a consistently higher mortality than other stages. It was noticed at the higher temperatures (29 and 35 C) that some mites had difficulty emerging from the molted skin of the previous stage. The high temperature appeared to make the skin extremely adhesive. The mites took much

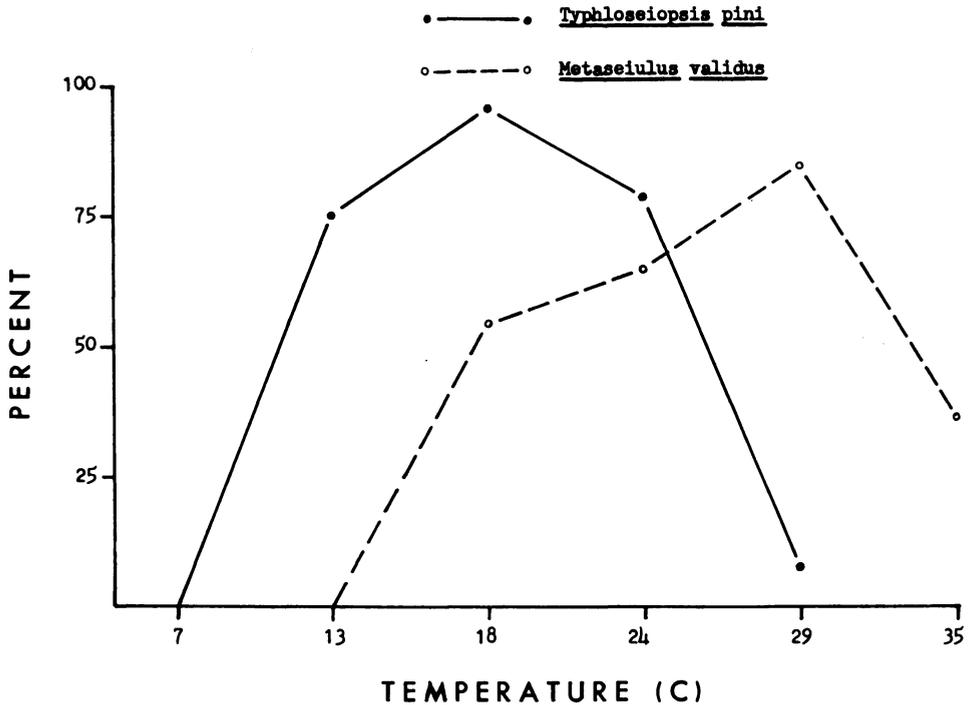


Fig. 1. Percent survival from egg to adult of the phytoseids, *Metaseiulus validus* and *Typhloseiopsis pini* at different temperatures.

longer to extricate themselves, and frequently were never able to detach completely, resulting in their eventual death.

Fecundity rates

Table 2 shows oviposition rates at the temperatures at which development oc-

curred in the previous tests. The maximum rate for both species was only about 1 egg per ♀ per day, a rather low value compared with those obtained by other workers with different phytoseids (McMurtry et al., 1970, Table 3). The majority of phytoseids listed had a rate of at least 2 eggs laid per day.

TABLE 2
FECUNDITY RATES FOR *METASEIULUS VALIDUS* AND *TYPHLOSEIOPSIS PINI*
AT DIFFERENT TEMPERATURES ON *OLIGONYCHUS PUNICAE*

Temperature (°C)	No. observations	Number of eggs per ♀ per day		
		Mean**	Range	SD
<i>M. validus</i>				
18	18	0.35ag	0.20-0.70	0.13
24	15	0.78b	0.44-1.00	0.18
29	15	1.08c	0.50-1.62	0.27
35	17	0.88d	0.36-1.40	0.29
<i>T. pini</i>				
13	15	0.16a	0.09-0.27	0.06
18	16	0.52e	0.27-0.72	0.13
24	15	0.95f	0.80-1.25	0.12
29	17	0.40g	0.18-0.66	0.12

** Means in a column followed by the same letter are not significantly different at the 1% level (SNK test).

TABLE 3
 ABILITY OF *METASEIULUS VALIDUS* AND *TYPHLOSEIOPSIS PINI* TO FEED,
 DEVELOP, AND REPRODUCE AT ROOM TEMPERATURE (24C)
 ON VARIOUS FOOD SUBSTANCES*

Host	Feeding	Oviposition	Development completed
<i>M. validus</i>			
<i>Oligonychus punicae</i>	+	+	+
<i>Tetranychus pacificus</i>	+	+	+
<i>Panonychus citri</i>	+	+	+
<i>Aonidiella aurantii</i>	-	-	0
<i>Brevipalpus</i> sp.	-	-	0
Pollen	+	-	-
<i>T. pini</i>			
<i>Oligonychus punicae</i>	+	+	+
<i>Tetranychus pacificus</i>	+	+	+
<i>Panonychus citri</i>	+	+	+
<i>Aonidiella aurantii</i>	-	-	0
<i>Brevipalpus</i> sp.	-	-	0
Pollen	+	+	+

* + occurred or observed; - absent or not observed; 0 not tested.

In both species, there were significant differences in fecundity rates at all temperatures tested. There were also significant differences in fecundity rates between species at most of the temperatures (Table 2). As with developmental rates, the fecundity rates obtained indicate that optimum temperatures for *T. pini* are considerably lower than for *M. validus*. The maximum rate for *T. pini* was 0.95 egg per day at 24 C and that for *M. validus* 1.08 eggs per day at 29 C.

At the temperatures where rates of oviposition of the predators were low, the ♀♀ oviposited consistently, but less frequently (e.g. 1 egg every 2 to 3 days) (Table 2). In the case of *A. limonicus* Garman and McGregor, the low ovipositional rate at 32 C was due to the ♀ reproductivity declining rapidly after 2 days, and ceasing completely after 5 days (McMurtry and Scriven, 1965).

Various workers have shown that the rate of oviposition of phytoseiids can

vary according to the kind of food available (McMurtry and Scriven, 1964b; Elbadry and Elbenhawry, 1968; Elbadry et al., 1968; and Swirski et al., 1970). Therefore, it is possible that tests with different combinations of prey or other foods would result in a higher rate of oviposition for these predators.

Food habits

Results of feeding tests (Table 3) indicated that both species were able to feed, develop, and oviposit on the 3 species of spider mite prey, but not on the scale crawlers or tenuipalpids. *Typhloseiopsis pini* reproduced and developed on pine pollen, and completed at least three generations without having any other food. *Metaseiulus validus* fed only to a limited extent on this type of food, and in only two instances were eggs laid. None of the more than 40 individuals in the test developed beyond the protonymphal stage. Since neither species fed or laid eggs on a diet of red

scale crawlers or tenuipalpids, development on this host material was not tested.

Records were not kept on actual fecundity rates of the predators in these feeding tests, but a qualitative judgment of the different food sources can be made. With *T. pini*, of the four types of food with which oviposition occurred, *Panonychus citri* was the poorest and pollen next. The other two spider mites were most favorable, both resulting in similar rates of egg production. In the case of *M. validus*, oviposition only occurred with the three spider mites as sources of food; and of these, *P. citri* resulted in the fewest number of eggs per ♀.

When feeding on *Oligonychus punicae*, which were a dark green-brown from feeding on avocado leaves, the predators took on a brown cast; those feeding on *Tetranychus pacificus* had an orange coloration of the gut; and the gut became red to reddish brown in predators feeding on *P. citri*. Thus, it is possible, to a certain extent, to deduce what a predator has been feeding on by the coloration of the gut, if some prior laboratory comparisons have been made.

Considering the results of these tests in relation to the fluctuations of *M. validus* populations in the field (see Part II), increases cannot be attributed to use of the kinds of pollen or tenuipalpids that were tested. Thus, the observed increases in numbers of *M. validus* before a buildup of spider mite populations must have been induced by some other food source or a combination of different foods or prey. The laboratory results with *Typhloseiopsis pini* indicate that this predator could utilize pollen as an alternate food early in the season, when mite numbers are low, to ensure its survival and maintain better dispersion patterns in the tree. Individuals of *T. pini* confined with pine pollen alone soon obtained a pale yellow coloration similar to that of individuals recovered from different pine

species during sampling (Part I). This indicates that pollen may serve as an alternate food source in the field. Although ♀♀ on this diet laid some eggs, production did not appear to be as high as that with spider mites. The use of alternate foods in this manner has been discussed by Flaherty and Huffaker (1970) and Huffaker et al. (1970).

McMurtry and Scriven (1966), in a greenhouse study, showed that pollen feeding could increase the effectiveness of *A. hibisci* as a mite predator. The superiority of pollen as a food source was also reported by Knisley and Swift (1971) and by Swirski et al. (1967a, 1967b), who found it increased both the rate of development and egg production.

McMurtry and Scriven (1964b) reported that the rate of oviposition of *A. hibisci* was low and mortality was high on *Tetranychus cinnabarinus* (Bois.), due to the copious webbing produced by this mite which trapped and hindered the movement of the phytoseiid. Both species in this study apparently were not adversely affected by webbing. *Oligonychus punicae* produces large quantities of webbing on the leaves, but the mites had no difficulty maneuvering in the webs. They were observed even walking upside down inside the webbing, and experienced no apparent difficulty in killing the prey inhabiting the masses of webbing.

Prey consumption rates

The numbers of *O. punicae* consumed by *M. validus* and *Typhloseiopsis pini* are shown in Table 4. *Typhloseiopsis pini* consumed the greater number of adult prey and *M. validus* the most eggs (the latter difference was significant at the 1 percent level). Both species consumed significantly more eggs than they did adult prey.

Comparing these rates of consumption with those cited by McMurtry et al. (1970), p. 343, the numbers consumed were considerably less than for most of

TABLE 4
 RATES OF CONSUMPTION AT ROOM TEMPERATURE (24C) OF TWO STAGES
 OF *OLIGONYCHUS PUNICAE* BY *METASEIULUS VALIDUS*
 AND *TYPHLOSEIOPSIS PINI*

Host stage	No. observations	Number prey consumed per ♀ per day		
		Mean**	Range	SD
		<i>M. validus</i>		
Egg	15	2.77a	1.62-4.55	0.82
Adult	15	0.81b	0.40-1.30	0.25
		<i>T. pini</i>		
Egg	15	1.89c	1.10-2.80	0.48
Adult	16	1.11b	0.70-2.20	0.39

** Means in a column followed by the same letter are not significantly different at the 1% level (SNK test).

the other phytoseiids given the same prey stages. The recorded rate closest to that obtained in this study was for *Typhlodromus occidentalis* (Lee and Davis, 1968) at 1.97 per day for the adult ♀ predator (the stage of the prey is unspecified). Most of the other species had a prey consumption rate almost 2× that found for *M. validus* and *Typhloseiopsis pini*. However, a low prey consumption rate may be a desirable, rather than an undesirable, characteristic. A predator that requires less food should be able to survive and reproduce at lower prey populations, and thus maintain the pest at lower densities, compared to a predator having a high rate of prey consumption (Huffaker et al., 1970).

Feeding by the predators is difficult to evaluate quantitatively, since a prey that is attacked and fed on is not always completely devoured. Whether a predator completely consumes a given prey or merely attacks and kills it is significant in a population sense. In this way,

the predator is able to destroy more individuals, and thus increase its efficiency. In studies of the functional response of three species of phytoseiids, Sandness and McMurtry (1970) found that, at high host densities, a hungry predator was stimulated to capture and kill interfering prey that bumped into it while the phytoseiid was feeding.

Effects of photoperiod on oviposition

Data in Table 5 show that a short photoperiod induced a reproductive diapause. In both species, 100 percent of the mites reared under a 16-h photoperiod oviposited, whereas under an 8-h photoperiod, oviposition occurred in only about 12 and 28 percent of the individuals of *M. validus* and *T. pini*, respectively. These results are similar to those obtained for *M. occidentalis* by Hoy and Flaherty (1970), who found a high incidence of reproductive diapause at an 8-h photoperiod, and no diapause at 16 h.

TABLE 5
 EFFECT OF TWO DIFFERENT PHOTOPERIODIC REGIMES ON OVIPOSITION
 IN *METASEIULUS VALIDUS* AND *TYPHLOSEIOPSIS PINI* AT 21C

Photoperiod/ phytoseiid	Number ♀♀		% ♀♀ in diapause
	Ovipositing	Nonovipositing	
16 h:			
<i>M. validus</i>	17	0	0
<i>T. pini</i>	20	0	0
8 h:			
<i>M. validus</i>	2	15	88.23
<i>T. pini</i>	4	10	71.43

Various workers have reported a reproductive diapause induced by photoperiod. The first record was probably that of Putman (1962) with *Typhlodromus caudiglans*. Croft (1971) exposed four strains of *T. occidentalis* to a range of photophases from 10 to 17 h. Nearly all mites exposed to the short-day conditions (10–11 h) entered a reproductive diapause (90+%). Knisley and Swift (1971) found that at a 12-h photoperiod, 95 to 98 percent of ♀♀ *A. umbraticus* did not oviposit, whereas a control group reared in constant light began ovipositing several days after reaching maturity. This same result was also reported by Sapozhnikova (1964) for *T. (Amblyseius) similis* Koch in Russia, and by Hoy and Flaherty (1970). The latter authors stated that the ♀♀ were usually dorsoventrally flattened, and generally fed less often than those not in diapause. Sapozhnikova and Hoy and Flaherty emphasized that the most reliable indication of a ♀ being in diapause was the failure to oviposit. This was the case in these studies as well. After molting to the adult stage, the diapausing ♀♀ were somewhat dorsoventrally flattened and less active. But after a few days they began to feed, and thus became more distended and more active, although not as much as the gravid ♀♀ in the control group. Even though feeding was observed, few eggs were laid (Table 5); those mites that did oviposit had a longer preovipositional period than did the mites at the 16-h photoperiod (4–6 days for *Typhloseiopsis pini* and 15–18 days for *M. validus*). Sapozhnikova (1964) found that the photoperiodic response was suppressed under high temperature (25 C with *Typhlodromus* (*Ambly-*

seius) *similis*). At 18 C and an 11-h photoperiod, 100 percent of the mites went into diapause; but at 25 C and a 9-h photoperiod, only 4 percent diapaused.

Sex ratio

The sex ratio in the laboratory cultures of *Typhloseiopsis pini* and *M. validus* was about 1:1 (Table 6). This is a lower proportion of ♀♀ than reported for most species. For example, McMurtry and Scriven (1964a), in three separate trials with *Typhlodromus rickerti* Chant, found a ♀:♂ ratio of 2:1. Croft and McMurtry (1972) observed ratios of 1.7 and 1.8:1 with different strains of *T. occidentalis*, and Croft and Jorgensen (1969) obtained 1.31:1 with *T. mcgregori* in the laboratory. Laing (1969) reported a ratio of 2.5:1 with *M. occidentalis*, and Smith and Newsom (1970) found a 2:1 ratio in studies with *A. fallacis*. However, Lee and Davis (1968) obtained about a 1:1 ratio in their studies with *T. occidentalis* similar to that observed in this study.

Dosse (1957), Chant (1959), and Putman (1962) stated that sex ratios may vary during the season, and Croft and Jorgensen (1969) pointed out that laboratory conditions do not necessarily compare to those in the field. This was also the case with *M. validus*, which was sampled in the field on two species of pines (see Part II). The ratio from these samples (Table 7) was much different than that found in the laboratory, with 2× more ♀♀ than ♂♂. Knisley and Swift (1971) also reported ratios of 5–6:1 in field collections of *A. umbraticus*, whereas in the laboratory, the ratio varied from 1–2 ♀♀ : 1 ♂.

Since the chief function of the ♂ is

TABLE 6
RATIO OF ♀♀ : ♂♂ OF *METASEIULUS VALIDUS*
AND *TYPHLOSEIOPSIS PINI* AT 24C

Phytoseiid	Total no.	No. ♀♀	No. ♂♂	Ratio
<i>M. validus</i>	53	29	24	1.2:1.0
<i>T. pini</i>	61	32	29	1.1:1.0

TABLE 7
 RATIO OF ♀♀ : ♂♂ OF *METASEIULUS VALIDUS* COLLECTED ON
PINUS COULTERI AND *P. PONDEROSA* AT FOREST FALLS
 FROM MARCH, 1972 TO MAY, 1973

Pine species	Total no.	No. ♀♀	No. ♂♂	Ratio
<i>P. coulteri</i>	195	147	48	3.1:1.0
<i>P. ponderosa</i>	94	69	25	2.8:1.0

to fertilize the ♀, it is only necessary that there be enough ♂♂ present in the ecosystem to insure that this function is accomplished. It may be that a smaller ratio than was found in the laboratory is all that is necessary for continuation of the species. However, there is also the possibility that the numbers of ♂♂ fluctuate during the season and, therefore, sampling would be necessary throughout the season to accurately evaluate the sex ratio in the field. In this regard, if ♀♀ were in the overwintering stage, a greater proportion of this sex would be present early in the season, and the numbers of males would be very low. In addition, it may be that there is competition for food in the field between the sexes; therefore, there was greater survival of the ♂♂ in the laboratory where food was in excess.

Preovipositional period, reproductive longevity, and total egg production of *Typhloseiopsis pini*

Due to the difficulty in rearing and confining *M. validus*, these tests were only run with *T. pini* (Table 8). Total longevity of the ♀, including the preovipositional period and developmental

time (Table 1), averaged about 32 days for this species. The ovipositional rate averaged about 1 egg per day for the total period of egg laying.

In the preovipositional tests with *T. pini*, the mean of 4.33 days at 24 C was somewhat longer than that obtained by the following workers for other species: Smith and Newsom (1970); Lee and Davis (1968); Laing (1969); Knisley and Swift (1971); McMurtry and Scriven (1964a); and McMurtry and Scriven (1965).

The fecundity determined for *T. pini* in this study was considerably lower than that of most species of phytoseiids, as summarized by McMurtry et al. (1970). They stated that the fecundity of *Phytoseiulus* species is generally 50 to 60 eggs, and that the number for other species is commonly around 30 to 40. They also reported that the length of the ovipositional period can be 30 days in moderate or warm temperatures, and much longer in cooler conditions. This is also much longer than found with *T. pini*.

Putman (1962) found that, during the summer, ♀♀ of *Typhlodromus caudiglans* had an average ovipositional period of 36 days. The numbers of eggs

TABLE 8
 PREOVIPOSITIONAL PERIOD, REPRODUCTIVE LONGEVITY, AND TOTAL
 EGG PRODUCTION FOR *TYPHLOSEIOPSIS PINI* AT 24C

Item	No. observations	Mean	Range	SD
Preovipositional period (days)	15	4.33	3.00- 8.00	1.23
Reproductive longevity (days)*	20	18.75	10.00-25.00	4.04
Total egg production (eggs/female)	20	17.70	9.00-27.00	4.41

* Time interval from laying of first egg to death.

laid averaged 2× those obtained with *Typhloseiopsis pini*. McMurtry and Scriven (1964a), working with *Typhlodromus rickeri*, and Lee and Davis (1968) with *T. occidentalis*, obtained values for oviposition and longevity that were about 2× those of *Typhloseiopsis pini*. Both *Typhlodromus rickeri* and *T. occidentalis* ♀♀ averaged one egg per day for the total production period, which was comparable to results obtained with *Typhloseiopsis pini*.

Knisley and Swift (1971) found with *A. umbraticus* that ♀♀ confined with ♂♂ produced more eggs over a longer period of time than ♀♀ confined with ♂♂ for only a short period. Thus, with this species, repeated insemination was required for maximum egg production.

Smith and Newsom (1970) found a highly significant difference in the pe-

riod of oviposition at different temperatures, and twice as many eggs produced at the low temperature. For *Typhlodromus occidentalis*, the data given for total eggs produced and total ovipositional period were: 30.2–42.2 eggs for 30 days (Croft and McMurtry, 1972); 33.7 eggs for 30 days (Lee and Davis, 1968); and 34 eggs for 15.7 days (Laing, 1969).

Thus, in comparison with most other species of phytoseiids studied, *Typhloseiopsis pini* had considerably lower fecundity and a shorter ovipositional period. Although these are indications of the potential a predator has for controlling a particular prey, these characteristics might be offset by another, e.g., by more efficient searching or better distribution in relation to the prey.

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(Continued from inside front cover)

cundity rate of 1.08 eggs/♀ per day at 29 C, and *T. pini* had a maximum of 0.95 at 24 C. Both species could feed, develop, and oviposit on three tetranychid species, but not on scale crawlers or tenuipalpid. Only *T. pini* could feed, develop, and oviposit on pollen. *Metaseiulus validus* consumed 2.77 eggs/♀ per day of *Oligonychus punicae*, and 0.81 adult ♀♀; *T. pini* consumed 1.89 and 1.11, respectively. At an 8-h photoperiod, 88.3 percent of the ♀♀ of *M. validus* and 71.43 percent of the ♀♀ of *T. pini* entered reproductive diapause. At a 16-h photoperiod, neither species entered diapause. The ratio of ♀♀ to ♂♂ of both species was about 1:1. At 24 C, the preovipositional period for *T. pini* was 4.33 days, the reproductive longevity was 18.75 days, and 17.70 eggs were laid per ♀.

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