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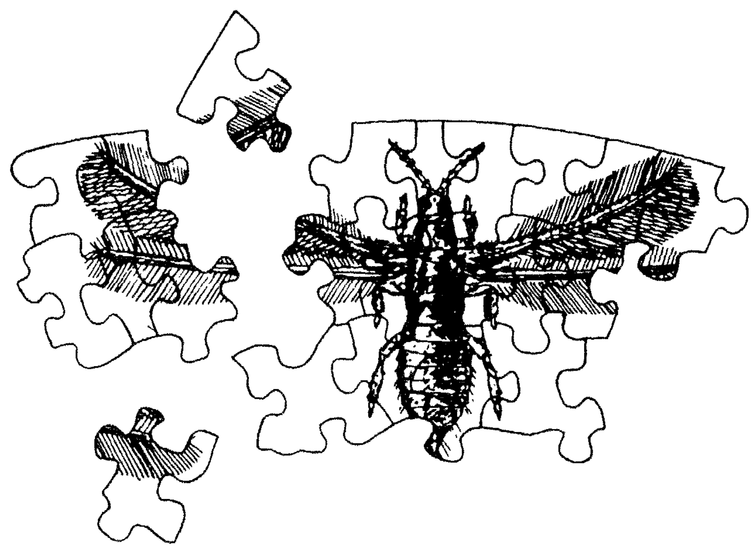
Towards Understanding Thysanoptera



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This conference would not have been possible without the dedicated efforts of many people, only a few of whom can be mentioned here. We thank Steve LaRosa for organization of special events and Eva Noronha-Doane for facilitating registration. Recording of the conference was expertly supervised by Luke Curtis; transcriptions were prepared by Peggy Verville and Nancy Burgess from the University of Vermont, Department of Plant and Soil Science; and layout of the proceedings was prepared by Frances Birdsall. Thanks also to the numerous personnel from the Vermont Department of Forests, Parks and Recreation who helped with transportation and many other technical details.

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TOWARDS UNDERSTANDING THYSANOPTERA

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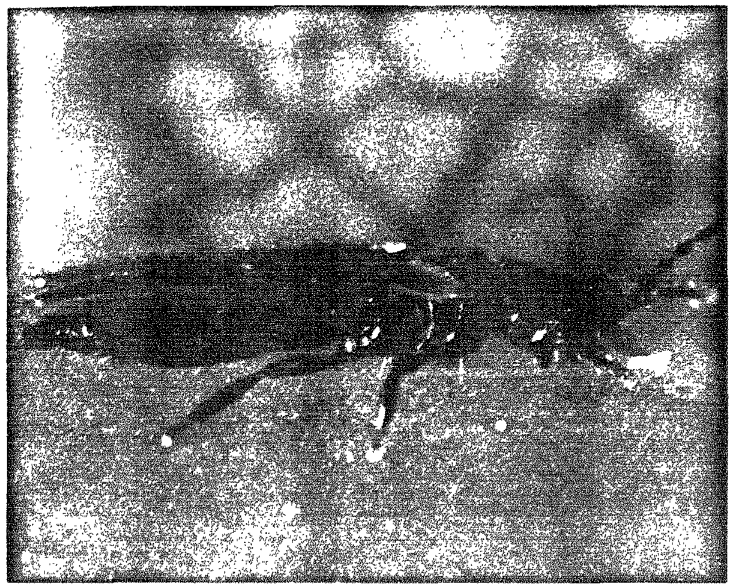
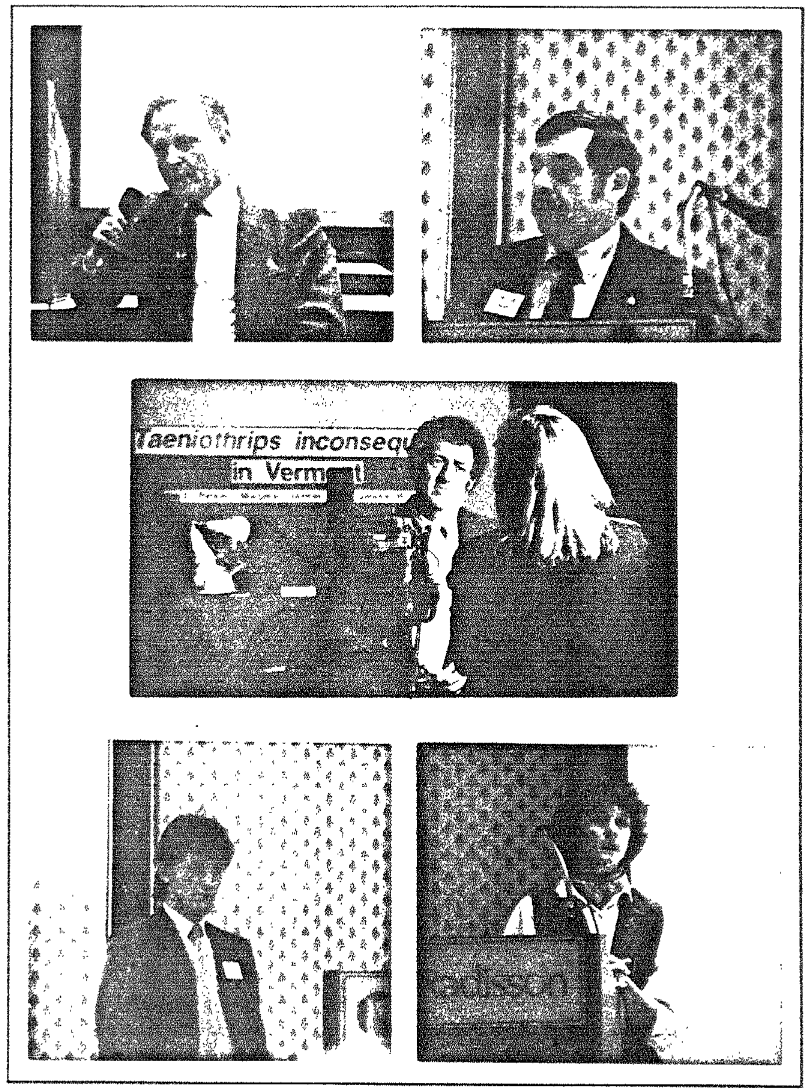


PEAR THRIPS, *Taeniothrips inconsequens* (Uzel)
(photo by T. E. Downer)



A few of the conference participants (from top left to bottom right): Trevor Lewis, Institute of Arable Crops Research; Conrad Motyka, VT Department of Forests, Parks and Recreation; Bruce L. Parker, The University of Vermont; Nick J. Mills, Commonwealth Institute of Biological Control; Margaret Skinner, The University of Vermont.

PREFACE

Pear thrips, *Taeniothrips inconsequens (Uzel)*, first surfaced as a pest of sugar maple, *Acer saccharum* Marsh, in Pennsylvania in the late 1970s. Though similar damage was observed in Vermont in the early 1980s, it was probably misdiagnosed as frost damage until 1985, when finally thrips were positively confirmed as the causal agent. Pear thrips damage to sugar maple fluctuated greatly from year to year, raising only slight concern among sugarmakers and forest managers. However, the situation changed dramatically in the spring of 1988, when pear thrips caused widespread, severe foliage damage to sugar maple in southern Vermont (over 200 thousand hectares) and other New England States. Recognized as a potential threat to forest health, pear thrips received tremendous media coverage, including the front page of the New York Times and the CBS Evening News!

The response in Vermont to this crisis was swift. With support from the Vermont legislature and the Department of Agriculture, a major research effort was launched, coordinated jointly by the University of Vermont and the VT Department of Forests, Parks and Recreation. This pest presented unique research and management challenges. Pear thrips on sugar maple represented a known pest on a new host in a new habitat. As of 1988 almost no information existed on this insect in a sugar maple forest. In addition thrips in general were virtually unknown as a northern hardwood forest pest, and forest managers knew little about how to handle such an insect. Finally, because thrips are such small insects, new and specialized methods were needed for survey and study of this pest.

As Vermont's research efforts got underway, it became clear that much could be learned from scientists familiar with other thrips species. The goal of this conference was to gather these specialists together to present their ideas on thrips survey and management methodology, particularly as it related to pear thrips in a forest setting. Participants came from across the United States, Canada and the United Kingdom to share their expertise. Though many didn't know that a "sugarbush" was not a shrub, but a natural stand of mature 30-m-tall sugar maple trees (100 ft), they all knew what maple syrup was! Certainly by the end of the conference all of the participants recognized the unique value of the sugar maple to the heritage and economy of Vermont and the Northeast, and shared our concern for its future in light of the threat of pear thrips.

We thank all of the conference participants who freely and enthusiastically shared their knowledge. Without their expertise and continued technical support, our pear thrips research would not have progressed as far or as fast as it has. We thank all those attending the conference for helping to make it a productive event. Though the pear thrips problem is far from being "solved," this conference started the research process on a solid footing.

GREENHOUSE THRIPS, *Heliothrips haemorrhoidalis*, IN CALIFORNIA AVOCADO ORCHARDS: BIOLOGICAL CONTROL STUDIES

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Greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché), on avocado in California, is another case, like pear thrips, of a species being present for many decades but only recently increasing to major pest status. Damaging infestations, previously occurring only sporadically and mainly in areas within a few kilometers of the coast, now are common in the interior districts of Ventura and San Diego Counties in southern California. Greenhouse thrips causes scarring of fruit, mainly on the Hass variety, reducing its market value. The problem has brought about an increased use of insecticides by avocado growers, who generally avoid spraying thereby encouraging control of most arthropod pests by resident natural enemies. This paper summarizes investigations conducted over the past several years on the most common indigenous natural enemies and on introduced parasitoids of *H. haemorrhoidalis* in California.

Native Natural Enemies

***Franklinothrips vespiformis* (Crawford).** This predaceous thrips has been recorded as an obligate predator, mainly on thrips but also on mites, leafhoppers and whiteflies in tropical America, Florida and Texas (Callan 1943, Entwhistle 1972). Subtropical southern California

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apparently is the northernmost record for the species. *F. vespiformis* sometimes is observed in relatively large numbers on avocado after the decline of a heavy greenhouse thrips infestation. Both adults and larvae are active predators on thrips. Pupation occurs in a cocoon on the foliage or fruit. We have seen no indications that this predator has a significant impact on greenhouse thrips before high population densities have developed.

Chrysopera carnea **(Stephens).** Green lacewing larvae are voracious predators of various small arthropods, especially aphids. *C. carnea* larvae, when released on avocado, showed an ability to suppress thrips numbers. The first experiment, conducted in Irvine, Calif., utilized caged fruit clusters (10 clusters on six trees, and a minimum three fruit per cluster) artificially infested with 100 thrips, about 70% of which were larvae and 30% adults. Four days later five first-instar lacewings were introduced to each of five of the caged clusters on three of the six trees. At this time thrips numbers averaged 21.8 and 16.2 on the release and control clusters, respectively (n = 5 clusters per treatment). After seven days, the number of thrips were 0 and 11.5 in the release and control clusters, respectively ($P \leq 0.01$ level).

In another similar experiment, conducted in orchards at Irvine and Fallbrook, Calif., artificially infested fruit clusters were placed on uncaged branches of six separate trees. A lemon fruit cluster containing ±100 thrips larvae was tied to a branch in contact with each of the other clusters. Four days after the fruit were infested, ten first-instar lacewings were placed on infested clusters on three of the trees. At the Irvine site, thrips numbers at the time of predator introduction averaged 21.8 and 16.2 larvae per cluster on the release and control clusters, respectively. Fourteen days later, the averages were 4.0 and 49.0 thrips per cluster, respectively ($P \leq 0.01$). Results in the Fallbrook orchard were similar. Thrips numbers averaged 74.0 and 62.3 larvae per cluster on release and control clusters, respectively, when the predators were introduced. The final count 14 days later averaged 12.6 and 64.3 larvae per cluster on the release and control clusters, respectively ($P \leq 0.01$).

These preliminary experiments showed that releases of lacewing larvae can suppress thrips populations. However, no research has been conducted to determine the commercial feasibility of using *C. carnea* for greenhouse thrips control.

Phytoseiid mites. Phytoseiids, important biological control agents of spider mites, are known to feed and reproduce on thrips larvae, and some species have been shown to be important biological control agents of thrips, including citrus thrips, *Scirtothrips citri* (Moulton), on California citrus (Tanigoshi et al. 1985; Grout & Morse, unpublished findings), and onion thrips, *Thrips tabaci* Lind., on greenhouse-grown vegetables (Ramakers 1988, Hansen 1989). Preliminary trials in the laboratory were conducted on four species of phytoseiids for potential feeding and reproduction on *H. haemorrhoidalis*: *Euseius hibisci* (Chant) and *Amblyseius* (*Neoselulus*) *barkeri* (Hughes), species used in greenhouses for control of *T. tabaci* on sweet pepper; *Typhlodromus rickeri* Chant, introduced from India and established on avocado in a few areas of southern California; and *Iphiseius degenerans* (Berlese), another introduced species not known to be established in California.

Excised avocado leaves were placed under-side down on water-saturated foam pads in pans of water, and strips of "cellucotton" were placed around the edges of each leaf to confine thrips and mites. Ten first instar or early second instar thrips and one adult female phytoseiid were placed on each leaf, and observed daily for six days. There were five replicates for each species. During the 6-day period, no dead thrips were observed, and the phytoseiid mites were mostly dead or had escaped from the leaf arenas. Attempts by the phytoseiids to capture and feed on the thrips were observed on several occasions. When contact was made with the thrips larva, the latter would bend the tip of the abdomen upward toward the predator and often discharge a droplet of fecal material on the attacking mite. This not only thwarted the attack but the mite often became stuck to the substrate.

Megaphragma mymaripenne **Timberlake.** This trichogrammatid parasitoid of thrips eggs has been found sometimes to attack a fairly high percentage of *H. haemorrhoidalis* eggs in heavy infestations in California. Extensive studies in two orchards where the parasite was abundant showed that parasitization of thrips eggs sometimes reached 40-50%. However, these studies suggested that *M. mymaripenne*, by itself, was not a regulating factor of greenhouse thrips populations (Hessein & McMurtry 1988).

Introduced Natural Enemies

Goetheana parvipennis **Gahan.** This eulophid parasitizes larvae of greenhouse thrips as well as the red-banded thrips, *Selenothrips rubrocinctus* (Giard) and *Hercothrips insularis* Hood (Callan 1943). Biological studies of this parasitoid are reviewed by Entwhistle (1972) and Hessein & McMurtry (1989). *G. parvipennis* was introduced from West Africa to Trinidad in 1935, and became established there and in other parts of the Caribbean (Callan 1943, Entwhistle 1972, Bennett & Baranowski 1982). It was introduced into California in 1963 (McMurtry & Johnson 1963) and again in 1982. Although a few recoveries of this parasitoid were made at colonization sites in the same season as the releases, there is no evidence of permanent establishment.

Thripobius semiluteus **(Boucek).** This hymenopterous parasitoid, also in the Eulophidae, was introduced to California in 1986 from New South Wales, Australia, where it is common on *H. haemorrhoidalis* infesting *Liquidambar* (sweet gum) trees (G. A. C. Beattie, personal communication). Parasitized greenhouse thrips, collected in 1988 by J. A. McMurtry in the state of Minas Gerais in southern Brazil, also yielded *T. semiluteus*, a new record for the New World (LaSalle & McMurtry 1989). Releases of *T. semiluteus* in California were started in late 1986 and continued through 1989. The parasitoid has been recovered for three to four years at some of the initial release sites, indicating that it has become established in southern California and has survived both cold and hot weather extremes of the region.

In one instance, after an initial release of fewer than 10,000 parasitoids, parasitization of up to 60% was noted throughout the orchard within two years. Detailed studies in two orchards indicated that thrips populations declined when the parasitization rate increased to 50-60% (McMurtry, Johnson & Newberger, unpublished data). It appears that *T. semiluteus* has the potential to become an important control agent of *H. haemorrhoidalis* on avocado in California. Widespread colonization is now possible as the parasitoid is commercially available. Additional studies are needed to better document the potential of *T. semiluteus* to carry over and impact thrips populations from one year to the next.

Acknowledgment

Our thanks to Horace Johnson for his valuable participation on this project since its inception, and to Nawal Hessein and Sheldon Newberger for their efforts during various phases of the program. G. A. C. Beattie, New South Wales Department of Agriculture, Rydalmere, NSW, Australia, provided the Australian stock of *Thripobius semiluteus*. This research was supported in part by funds from the California Avocado Commission and the University of California Statewide IPM Program.

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BIOLOGICAL CONTROL OF CITRUS THRIPS, *Scirtothrips citri*, BY PREDACEOUS PHYTOSEIID MITES

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Introduction

Acari of the family Phytoseiidae are important predators of spider mites. Since the taxonomic treatises of Nesbitt (1951) and later by Chant (1959), over 1000 described taxa have been listed by Moraes et al. (1986). This represents a conservative 10-fold increase for species descriptions over the last thirty years. During this period, research efforts have also been directed toward the study of phytoseiid population ecology and predatory interactions with tetranychid spider mites, especially those on agricultural crops (e.g., tree fruit, avocado, citrus, greenhouse vegetables and cotton). Research on the diets of phytoseiid mites indicate that many species are facultative and general predators that readily feed and reproduce on pollen and nectar; mites in the families Tydeidae, Tenuipalpidae, Tarsonemidae and Eriophyidae; immature instars of whiteflies and thrips; and honeydew secretions of aphids and armored scales (McMurtry & Rodriguez 1987).

General field and laboratory observations by Kennett & Flaherty (1974) in the San Joaquin Valley of California and Bravo-Mojica (1975) at the University of California-Riverside during the mid-1970s indicated that the phytoseiid mite, *Euseius tularensis*, preys on larvae of the citrus thrips, *Scirtothrips citri* (Moulton). Earlier, Swirski & Dorzia (1969) in Israel reported that the phytoseiids, *E. hibisci* (Chant), *Amblyseius limonicus* and *Typhlodromus occidentalis* (Nesbitt) readily fed and reproduced on larvae of the castor thrips, *Retithrips syriacus* (Mayet).

Research on biological control has been done by several University of California entomologists to evaluate the predatory potential of native and introduced phytoseiids to regulate the citrus red mite, *Panonychus citri* (McGregor), a key pest of citrus. These researchers have concluded that: 1) *E. hibisci* and *E. tularensis* are facultative predators, 2) population growth and peak densities of *E. tularensis* coincide with or follow those of citrus thrips and not *P. citri* in early spring, 3) *E. tularensis* population growth is correlated with seasonal patterns and abundances of air borne pollen, and 4) both phytoseiid species undergo major numerical increases in April and May and commonly attain two-six active stages per leaf by mid-June (Tanigoshi et al. 1985). This work and my laboratory studies with both predators suggest that these species undergo a dietary switch from pollen in early spring to early generation citrus thrips larvae during early citrus bloom, this at a time when the overwintering eggs of *P. citri* have not yet eclosed (Tanigoshi et al. 1983, 1984).

Rearing Methods

In the late 1970s we at the USDA in Riverside, Calif. initiated field studies to colonize and/or augment *E. tularensis* in commercial orange groves in Riverside and Tulare Counties, Calif.

Deutonymphs and adults of *E. hibisci* and *E. tularensis* will voraciously attack and kill larvae of the citrus thrips. *E. tularensis* is capable of attacking and killing immature citrus thrips from any angle or body segment (Fig. 1). *E. hibisci* can readily capture and consume citrus thrips larvae, and a minimum of ten thrips per day will support a daily fecundity commensurate to that observed on a diet of ice plant pollen (Table 1).

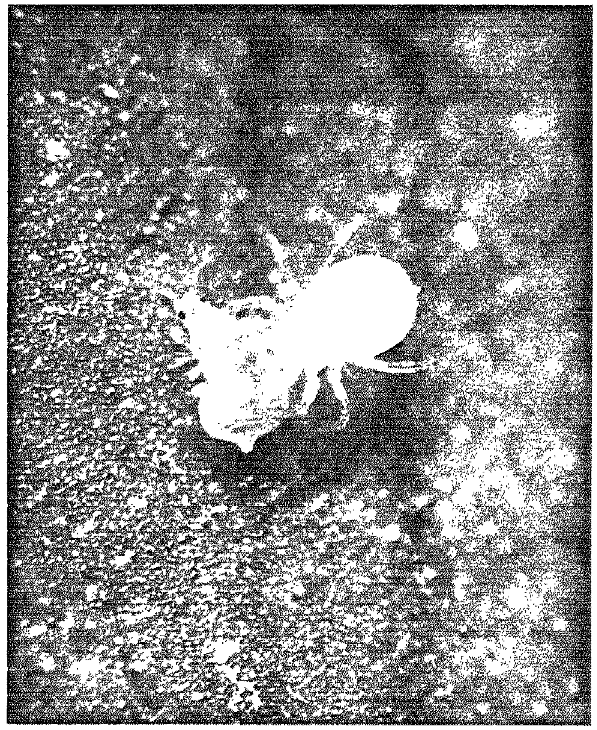

Figure 1. *Euseius tularensis* sucking the body contents of a second instar citrus thrips (photo by J. K. Clark).

Table 1. Oviposition data for *Euseius hibisci* females reared at about 27°C on different foods for 72 hours

Food	No. eggs/female/day		
	1	2	3
Ice plant pollen[a]	0.67	1.47	1.82
10 Citrus thrips larvae/day	0.72	1.10	1.76
20 Citrus thrips larvae/day	0.53	1.43	1.77

[a] *Malephora crocea*.

Both phytoseiid predators were mass reared on about 40 lima bean plants, *Phaseolus limensis* (Per.) grown in two-gallon polyethylene bags, filled with about 3.78 liters (1 gallon) of coarse vermiculite per

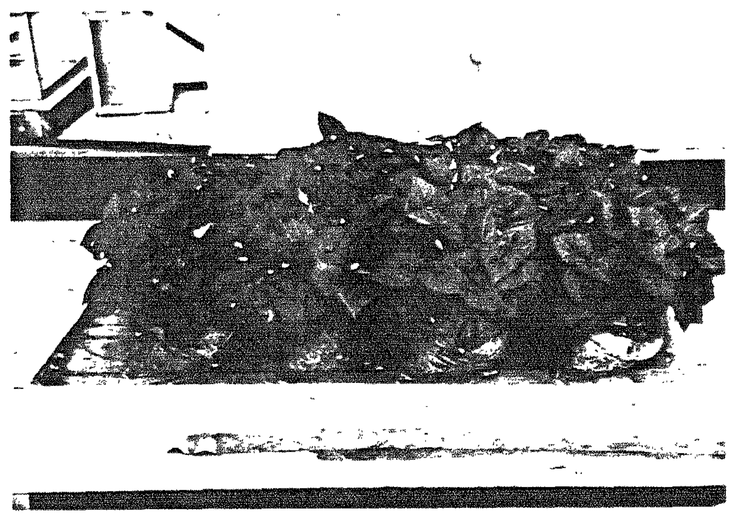

Figure 2. Lima bean plants grown in polyethylene bags and coarse vermiculite for rearing predatory phytoseiid mites to control citrus thrips (photo by M. E. Badgley).

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bag, and punctured along the bottom for watering (Fig. 2). After two weeks the seedlings were inoculated with a mixed population of twospotted spider mite, *Tetranychus urticae* and pollen from the ice plant, *Malephora crocea* (Jacq.). Fresh ice plant pollen was dispensed over the plants every 3-4 days. With this system we produced an average of 25 *E. tularensis* life stages per plant per week after four weeks. The plants were then separated and tied into four bundles of 10 plants each, transported to the field and placed within the canopy of citrus trees.

Biology and Distribution of Citrus Thrips and Phytoseiid Predators

The distribution of *E. hibisci* and *E. tularensis* in California is shown in Figure 3. The first species is common to avocado and citrus grown in the coastal and inland valley chaparral biome while the latter species is common on citrus grown in the temperate grassland biome of the Central Valley and the more arid regions of the coastal inland chaparral. Except for their absence in the irrigated areas of the Sonoran Desert, the distribution of both phytoseiids is nearly identical to that of the citrus thrips (Fig. 4). It is thought that both species of *Euseius* are subtropical and Bailey (1964) considered citrus thrips to be endemic to the arid lowland valleys of the southwestern United States.

The adult citrus thrips measures 0.9 mm (female) and 0.7 mm (male); the male is somewhat smaller and not as robust as the female. Both are a yellow-green color. First and second instars measure 0.4 and 0.9 mm, respectively, and the latter instar will actively seek a pupation site between soil particles in litter under the tree canopy. An overwintering generation of eggs is laid in new leaves of the fall growth flush and hatches in the spring. There are 8-12 generations per year in California and development from egg to adult ranges from 13-15 days; females live for 15-20 days and may lay 200 to 250 eggs (Tanigoshi et al. 1981).

Figure 3. Distribution of *Euseius hibisci* (shaded area) and *E. tularensis* (outlined area) in California (from Congdon & McMurtry 1985).

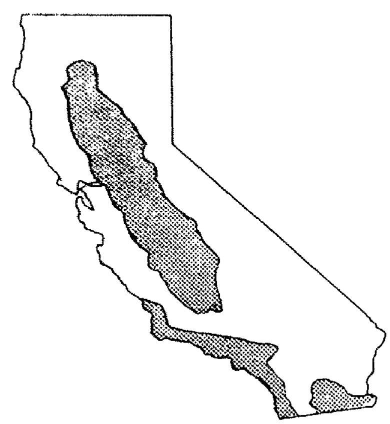

Figure 4. Distribution of *Scirtothrips citri* (shaded area) in California (from Tanigoshi 1981, Tanigoshi & Nishio-Wong 1982).

Citrus Thrips Damage

The critical injury period of citrus fruit for damage by citrus thrips is nearly coincident with the emergence of second generation citrus thrips (Fig. 5). The critical injury period for navel orange fruit scarring extends from early May to about 1 July, after which fruit of >4 cm diameter becomes unfavorable to citrus thrips and they shift their feeding and ovipositional activities to summer flush foliage.

Thrips feeding causes young leaf edges to become misshapened with two thick, white-grey streaks extending along both sides of the leaf midrib (Fig. 6). Stem-end ring scarring of the rind is commonly caused by citrus thrips feeding under and near the sepal when the fruit is pea-sized until it reaches 4 cm in diameter (Fig. 7). At harvest, mature navel oranges develop scabby gray or brown tissue around the stem-end, shoulders and stylar-end of the fruit (Fig. 8). This cosmetic injury is judged unacceptable for the fresh fruit market by Sunkist Growers of California. A cork-like scar tissue forms around citrus thrips ovipositional injury. This scarring, unlike that formed by their feeding activity, disappears when the navel fruit turns orange (Fig. 9).

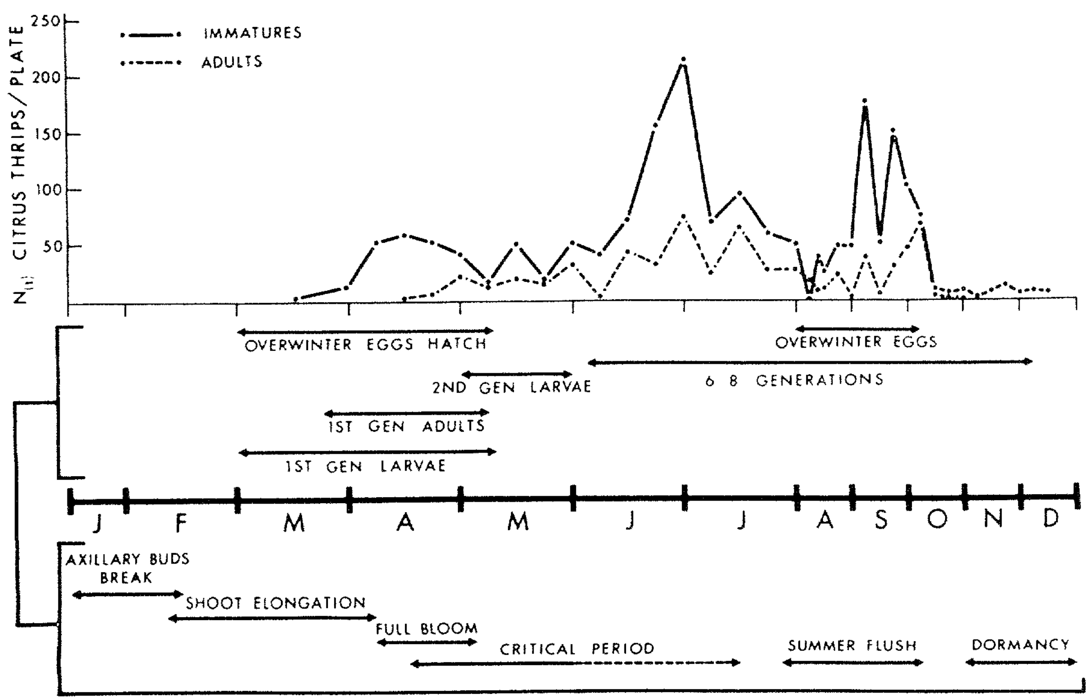

Figure 5. Phenograph of navel orange and *Scirtothrips citri* showing the critical injury period for developing fruitlets, Riverside, Calif., 1974.

Figure 6. Leaves scarred by citrus thrips feeding (photo by M. E. Badgley).

Figure 7. Citrus thrips injury to pea-sized navel oranges (photo by M. E. Badgley).

Figure 8. Stem-end navel orange injury (photo by M. E. Badgley).

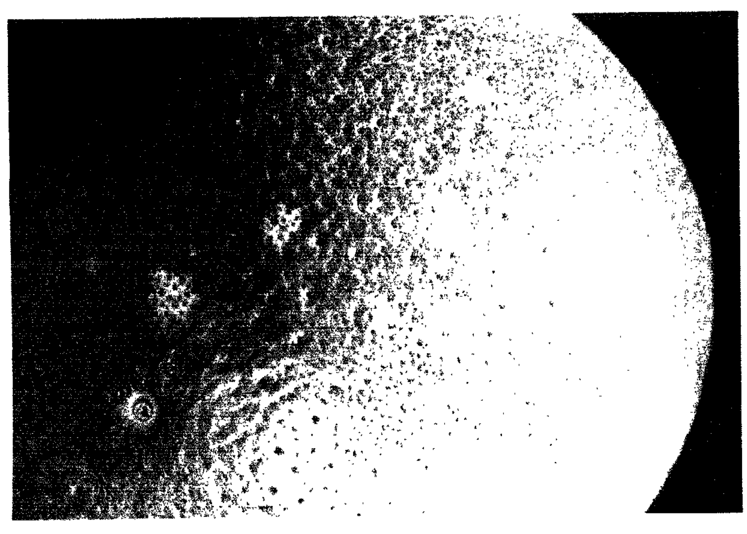

Figure 9. Citrus thrips ovipositional injury (photo by M. E. Badgley).

Thrips Monitoring Methods

To monitor thrips behavior, a modified dispersal-emergence trap was used, made from a 10-cm length of PVC pipe (inside diameter of 20.3 cm) (Fig. 10). A 430 cm^2 clear acetate plate, evenly coated with Tanglefoot (Tanglefoot Co., Grand Rapids, Mich.) was placed over the top of the trap. Therefore, we could continuously monitor migration of 2nd instars to the ground cover debris and adult migration back into the canopy (Tanigoshi 1981, Tanigoshi & Nishio-Wong 1982).

Figure 10. PVC-acetate dispersal-emergence trap for monitoring citrus thrips adult emergence from soil and larval descent into the litter (photo by M. E. Badgley).

This trap, with modifications, also may be suitable for monitoring the behavior of pear thrips, *Taeniothrips inconsequens* (Uzel), particularly for spring adult emergence and diel activity and dispersal patterns of late 2nd instars returning to the forest floor to overwinter. Ventilation ports in the side of the trap should be made to reduce condensation and possibly provide an exit for blackfly adults. Adhesive could be applied to the bottom of the acetate plate to monitor emerging adults and on the top to catch migrating larvae. The sticky acetate plates should be covered with a clear, oversized vinyl folder in the field to minimize contact with Tanglefoot and to allow the plates to be stacked in a refrigerator for later microscopic examination.

This trap could be useful to sugarmakers and researchers for determining the timing of pear thrips emergence on an area-wide scale. The presence of blackflies among emerging thrips would not hinder the determination of the timing of emergence, though thrips density might be difficult to assess. Later in the season when blackflies are absent, the trap could be used to measure diel migration patterns, population levels and dispersion trends of pear thrips larvae under or around a maple tree.

Colored sticky cards may also provide a method of effectively monitoring thrips behavior and density (Moreno et al. 1984). We found a good correlation between the number of citrus thrips caught on fluorescent yellow, polyvinyl cards (7.6 X 12.7 cm, suspended in the southeast quadrant of citrus trees) and PVC-acetate ground traps (Fig. 11). Experimentation with various shapes and color reflectances would

Figure 11. Fluorescent yellow, polyvinyl sticky card trap for monitoring citrus thrips (photo by M. E. Badgley).

be needed to determine the most effective trap design for attracting pear thrips (e.g., white is attractive to many thrips species) and discouraging attraction of other commonly occurring sugarbush insects.

Biological Control Potential of Phytoseiid Mites

I would like to briefly discuss data from 1981-82 supporting our hypothesis that the native phytoseiid, *E. tularensis*, provides economic biological control of early season citrus thrips (Tanigoshi et al. 1985). The hypothesis was tested with chemical exclusion using malathion to eliminate early spring *E. tularensis* predators in navel orange, lemon and grapefruit orchards in Riverside County, Calif. We used the concept of accumulated citrus thrips-days to correlate the duration of citrus thrips feeding to their population density. Populations increasing numerically will exhibit an ever increasing slope for their accumulated citrus thrips-days, while a controlled population will exhibit a flat slope. In addition, 55 outside canopy fruit were evaluated at harvest from each treatment and given a fruit damage index of 0-5. We conservatively estimated that an economic fruit damage index of about 0.300 will yield a minimum of 7-10% fruit cullage.

With the exception of early season population increases of citrus thrips immatures on navel orange control trees in 1981, accumulated immature and adult thrips-days from the other malathion treated navel orange, lemon and grapefruit trees were nearly of the same magnitude and with steeper slopes than that of the control trees where *E. tularensis* responded to early season population increases of citrus thrips (Figs. 12-13). For some unexplainable reason, in the navel orange control trees in 1981, the population of immature citrus thrips underwent an unusual increase from late April to petal fall compared with that of the malathion treated trees. However, the flat accumulated thrips-days curve from 100% petal fall through the critical injury period in the control trees for immatures and adults indicated that *E. tularensis* responded quickly to regulate those early escalating populations. This response occurred during the critical period of the navel orange after petal fall and was directly associated with the occurrence of nearly 1 *E. tularensis* per leaf in early May.

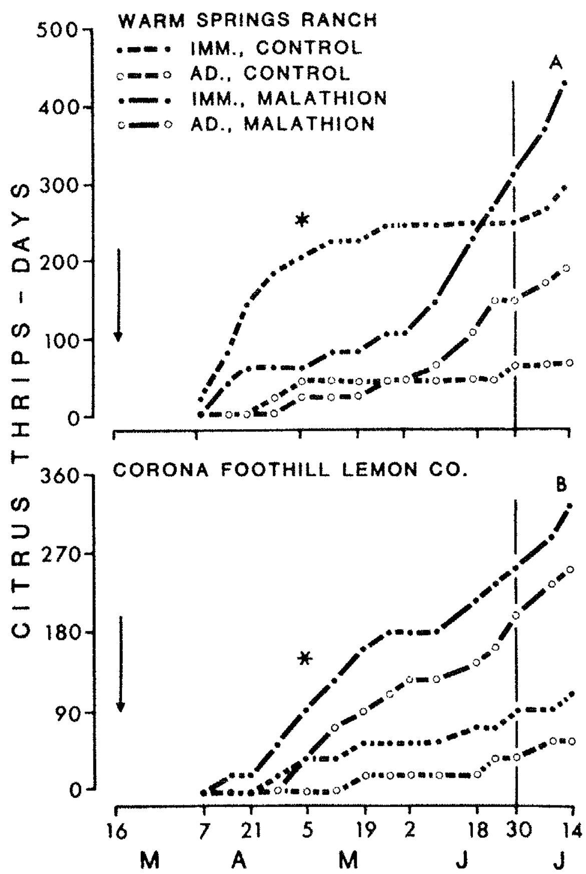

Figure 12. Accumulations of *Scirtothrips citri*-days on PVC-acetate traps placed under navel orange (A) and lemon (B) trees in 1981. Imm. = immatures, Ad. = adults, arrow = treatment date, * = 100% petal fall, vertical line = end of critical injury period (from Tanigoshi et al. 1985).

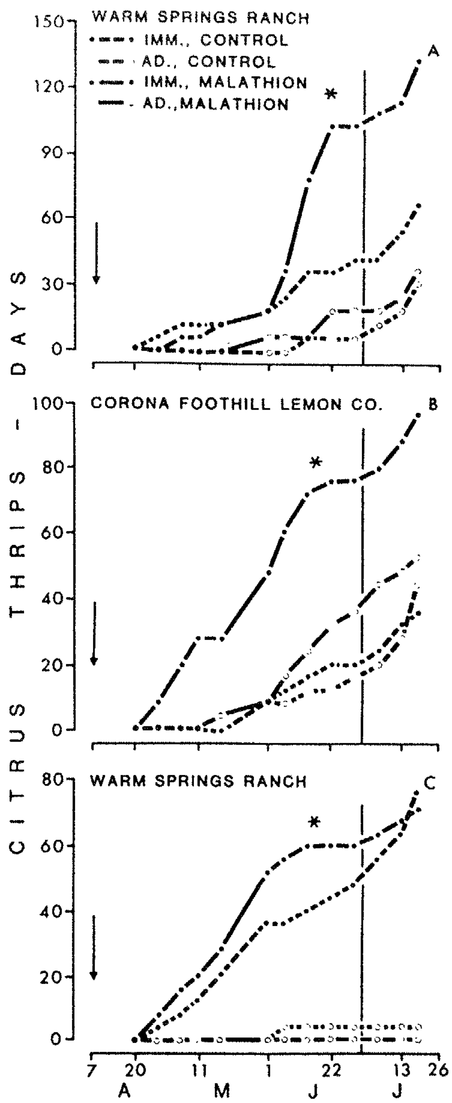

Figure 13. Accumulations of *Scirtothrips citri*-days on PVC-acetate traps placed under navel orange (A), lemon (B), and grapefruit (C) trees in 1982. Imm. = immatures, Ad. = adults, arrow = treatment date, * = 100% petal fall, vertical line = end of critical injury period (from Tanigoshi et al. 1985).

The average fruit damage indices shown in Table 2 indicate that navel orange and lemon fruit in the chemical exclusion plots were economically important and significantly higher than those in the control in 1981. However, because citrus thrips populations in 1982 were low area wide, there were no economic reductions or significant differences in fruit damage indices, though chemical exclusion plots for both orange and lemon were more scarred. These results and population trends of *E. tularensis* support our conclusion that field populations of greater than 0.5 phytoseiids per leaf at petal fall will regulate citrus thrips populations through the citrus fruits' critical injury period.

Table 2. Average fruit injury indices for citrus thrips in citrus plots designed to evaluate the biological status of *Euseius tularensis*

Cultivar	Treatment	1981	1982
Orange	Control	0.2200	0.040
	Chemical	1.2000*	0.104
Lemon	Control	0.1130	0.052
	Chemical	0.4350*	0.072
Grapefruit	Control		0.024
	Chemical		0.043

* Significantly different within cultivar ($P < 0.05$; Student's t test).

The first commercial attempt at colonization and augmentation of phytoseiid predators in the field for control of citrus thrips was initiated in 1978 in Riverside County, Calif. (Tanigoshi & Griffiths 1982). Rather than mass rearing predators, "Valencia" orange terminals infested with *E. tularensis* were taken to six centrally located trees/4 ha. These predators quickly increased and dispersed in and between contiguous trees and adjacent groves within one season. From 1978 to 1981, thripsicide application was reduced from 800 ha to less than 120 ha in this commercial grove. We applied sabadilla (14-16 kg/ha) and sugar (6 kg/ha) to adjust for unfavorable citrus thrips:phytoseiid predator ratios while minimizing negative impact on biological control of scale insects by aphelinid parasitoids.

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Orius insidiosus (Say) AND ENTOMOPATHOGENS AS POSSIBLE BIOLOGICAL CONTROL AGENTS FOR THRIPS

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The entomology program in ornamental floriculture at the University of Georgia places primary emphasis on commercial production of flowering and foliage plants under greenhouse conditions. Thrips management is a major part of that program. Several species of foliage and flower inhabiting species are pests on greenhouse crops. The western flower thrips, *Frankliniella occidentalis* (Pergande), has become the most important pest of the thrips complex during this decade. Other thrips species have also become more difficult to control or occur more frequently on greenhouse crops in different areas of the country.

The subject of this paper is the potential use of natural enemies for the management of thrips under greenhouse and other environments. The use of predatory mites for thrips management is discussed in the previous paper and we will focus on two other potential natural enemies: entomopathogens and a hemipteran predator in the genus *Orius*. Neither of these natural enemies have been utilized in commercial programs for thrips control in greenhouses in the United States but both occur as natural enemies limiting populations of thrips in their respective environments. They should both be considered as potential tools for thrips management.

Entomopathogens

Entomopathogens are organisms utilized for management of insect populations and the fungi are the only group of pathogens which have been studied for thrips control. There have been three genera of fungi reported from thrips: *Verticillium*, *Entomophthora*, and *Paecilomyces*. *Verticillium* sp. are widespread with epizootics in many insects but primarily in the Homoptera. *Verticillium lecanii* (Zimmermann) Viegas has been developed into a commercial formulation for application against insects. Two strains have been selected, "Vertelac" for aphid control and a strain for whitefly "Mycotal" (Cavallero 1987). A strain has been isolated which has activity against thrips but it is not commercially available (Gillespie 1987). There are other pathogens which have been developed for commercial use, but not for thrips. These include *Metarhizium* for Homoptera in sugar cane, *Beauveria* for Coleoptera and Lepidoptera, *Nomuraea* for Lepidoptera and *Hirsutella* for mites (Poinar & Thomas 1984). The *Entomophthora* are widespread but are more host specific than the *Verticillium* and have not been developed in a commercial product. The *Paecilomyces* have only been investigated as a potential commercial product in the last few years. They are general pathogens for many insects. In this paper we will compare the advantages and disadvantages of two potential pathogens: *Verticillium lecanii* and *Entomophthora* sp. for use under protected culture.

Verticillium lecanii is non-fastidious and will grow on conventional mycological media (Sabouraud and potato dextrose) and can be produced in fermentation columns allowing commercial production of the pathogen (Hall 1981). It does best at 20-25°C and will not grow at 37°C. The greatest weakness in the commercial use of *V. lecanii* is the need for very high relative humidity for best results, even free moisture on the leaf surfaces in some situations (Milner & Lutton 1986). The need for high humidity limits the practical use of *V. lecanii* unless strains can be selected which are more active at lower relative humidities. *Verticillium lecanii* is compatible with most insecticides and some fungicides (Khalil et al. 1985). The proper timing of applications of *V. lecanii* following application of fungicides (Gardner et al. 1984) could allow their use even if not compatible. Therefore, *V. lecanii* could be incorporated with conventional pest management programs fairly easily. Under ideal conditions an epizootic can spread through a pest population rapidly and reduce the pest population to near zero. Remaining pests can be infected by spores produced from individuals which have been infected by the initial application of the fungus.

There are two known species of Entomophthorales that could have a potential place in thrips management: *Entomophthora parvispora* and *E. thripidium* (Wilding 1981). These fungi cannot be produced by conventional mycological methods. There has been research to develop culture methods but the lack of these tools prevents needed research into their use. There is not a method to produce the fungus in volume outside of actual insect culture. Therefore, it cannot be commercially produced until techniques are developed. The Entomophthorales fungi are more host specific and only infect a limited number of hosts. This would limit the hazard of infection of non-target insects such as other natural enemies. They germinate best at temperatures between 16 to 27°C, but have a broad range of 5 to 30°C (Wilding 1981). High relative humidities required by *V. lecanii* are not a necessity for Entomophthorales. Conidia have been reported to eject at relative humidity as low as 50% (Wilding 1981). The best results are obtained at higher humidities. There is limited information on the use of these fungi and the compatibility with pesticides and other management strategies. They are effective and need further investigation.

The future for pathogen use depends on the development of strains and mass production. The isolation and production of the toxins produced by fungi might also be a method of taking advantage of the pathogenicity of fungi for insects. Some toxins have been developed for commercial use in insect control, including abamectin (Avid), a material utilized for western flower thrips control. Under greenhouse conditions, with controlled environment, there is an excellent potential for the use of commercial formulations of fungi. In the open environment, such as in a sugarbush, there is less potential for success. The management of thrips in the sugarbush by pathogens would probably have to be directed toward treatment of soil for control of immature thrips.

Orius

Orius is a group of predators commonly referred to as the minute pirate bugs. They are common predators in many agro-ecosystems and feed on many insect and mite hosts. Among their prey are many thrips species and in some ecosystems thrips are their primary prey (Letourneau & Altieri 1983, Isenhour & Yeargan 1981). They colonize a variety of flowering plants, including numerous crops. They are quite mobile and readily move from one area of the greenhouse to another or from native ecosystems into agricultural crops. They have been investigated as possible natural enemies in agro-ecosystems but have not been studied in greenhouse systems. We started an investigation on *Orius* as possible tools for managing thrips populations in ornamental crops grown in the greenhouse in 1985. A natural infestation of a greenhouse population of *Echinothrips americanus* Morgan occurred and *Orius insidiosus* (Say) completely eliminated the thrips population. Soon after that we acquired an *O. insidiosus* culture from a colleague and began looking at it as an alternative management strategy for *Frankliniella occidentalis*, the western flower thrips. Experimentation is being conducted on the use of an *Orius* sp. on greenhouse vegetable crops (L. Gilkeson, personal communication).

There are several advantages to the use of *O. insidiosus* for flower thrips control in protected crops. They are aggressive predators and will seek out thrips even in close protected areas such as deep within the flower. They are attracted to flowers where the major pest of protected crops, *F. occidentalis*, is most abundant. Both adult and immature *O. insidiosus* are predators on all active stages of thrips. The more mature the *O. insidiosus* the more thrips they kill in a 24 hr period and the greater the density of thrips the greater is the number of thrips killed (Isenhour & Yeargan 1981). *O. insidiosus* remain on the plants, when searching for prey, in the greenhouse and spend very little time flying up to the plastic trying to exit. They also feed on other pests of greenhouse ornamentals such as aphids, whiteflies and mites.

There are also disadvantages to the use of *Orius*. The major one is that they cannot be easily mass reared for release in the greenhouse. They must be reared either on living insects and eggs or frozen or fresh killed insect material. An artificial diet would increase the ability to mass rear *O. insidiosus*, but a caging system would also have to be developed to prevent crowding. They will readily feed on siblings if crowded or starved. Large numbers of predators are needed for a successful release program.

Orius are general feeding insects, so they could be detrimental to populations of other natural enemies by feeding on them. The compatibility of *Orius* and natural enemies needs more study. In ornamental crops the habit of searching flowers for prey may be a disadvantage if most of the population is removed when flowers are sold from the greenhouse. This would not be the situation with greenhouse vegetables. In greenhouse vegetable production it would be a real advantage. More research is needed on the management of thrips on protected crops with natural enemies. *O. insidiosus* may fit into the system developed on some of these crops.

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