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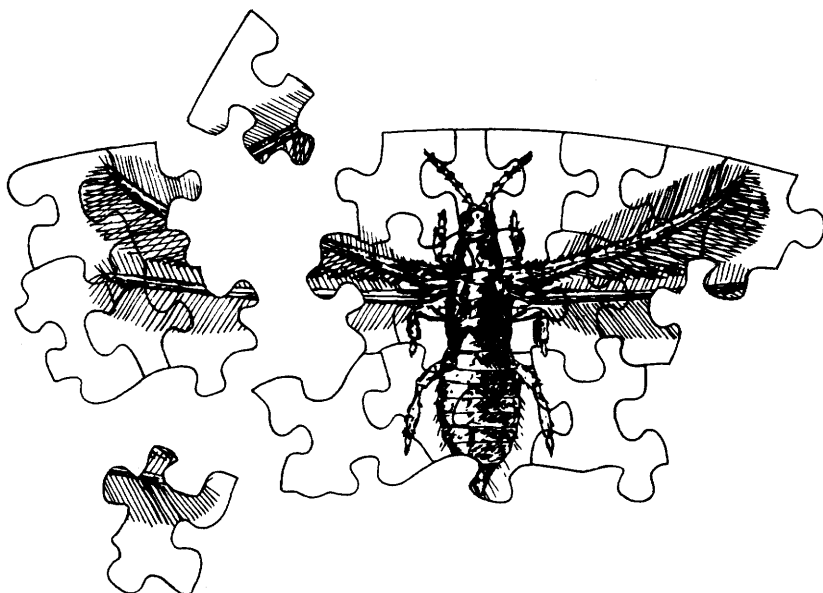
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General Technical Report NE-147

# Towards Understanding Thysanoptera



**Editors:**

**Bruce L. Parker  
Margaret Skinner  
Trevor Lewis**

## **ACKNOWLEDGMENTS**

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# **TOWARDS UNDERSTANDING THYSANOPTERA**

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Trevor Lewis, Institute of Arable Crops Research

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Nick J. Mills, CAB International Institute of Biological Control

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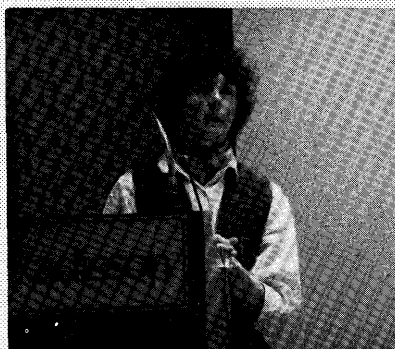
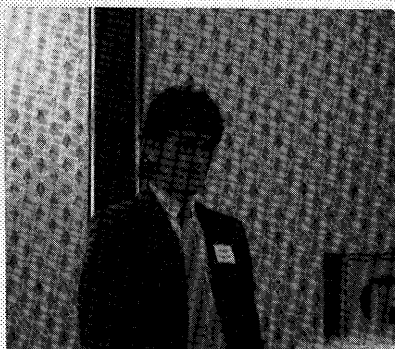
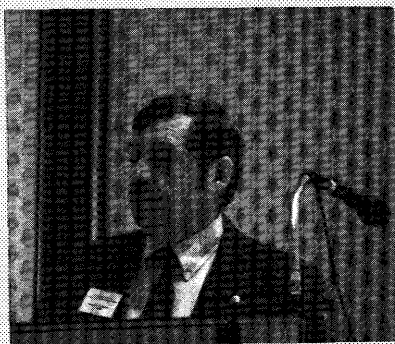
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## APPENDIX

List of conference participants



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.

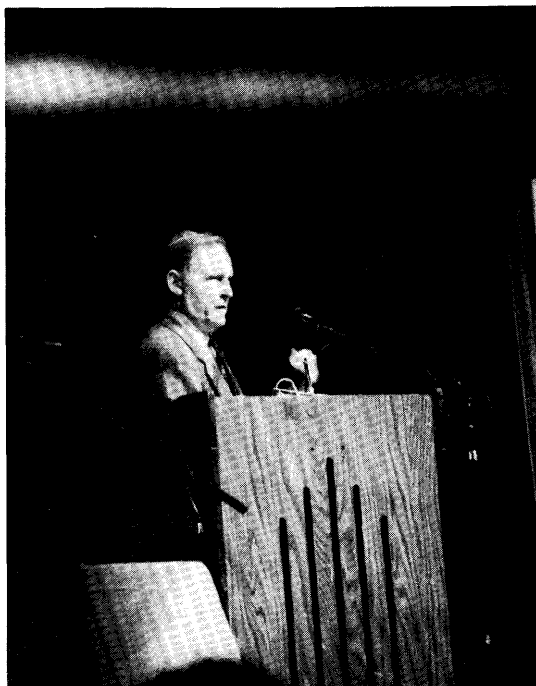
As Vermont's research efforts got underway, it became clear that much could be learned from scientists familiar with other thrips species. The goal of this conference was to gather these specialists together to present their ideas on thrips survey and management methodology, particularly as it related 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.

**AN INTRODUCTION TO THE THYSANOPTERA**

**A SURVEY OF THE GROUP**





Professor Trevor Lewis, Director of Research  
Institute of Arable Crops Research  
Rothamsted Experimental Station

## AN INTRODUCTION TO THE THYSANOPTERA A SURVEY OF THE GROUP<sup>1</sup>

Trevor Lewis

Institute of Arable Crops Research  
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I acknowledge with gratitude the invitation of Bruce L. Parker, Margaret Skinner and the organizers of this meeting to open the proceedings. It is a great pleasure to be asked to enthuse about a group of insects for which I have long had a particular affection - the Thysanoptera. My problem is that relatively few of the world's entomologists - less than 0.2% - appear to share this interest; it is therefore particularly gratifying to have an entire conference devoted to a thrips and to be able to meet with like-minded colleagues to focus on a serious economic problem.

I do not claim any special knowledge of pear thrips - indeed I expect many of you here to be more informed than I, but from my long experience of the biology and ecology of the order, I hope I might today provide a useful background to the group, and tomorrow highlight more specific thoughts and discussions relating to thrips and sugar maples. I believe it appropriate to open this conference with emphasis on the basic biology of the order, for without such knowledge applied work will not develop.

The recent impressive progress made by a few thysanopterists on a broad front over the last 20 years has raised the status and importance of the order from relative insignificance to one capable of providing excellent experimental techniques and material for a whole range of studies from fine structure to community structure relevant to the Insecta as a whole. Indeed, despite their small size and apparent

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<sup>1</sup> Adapted from the author's presidential address given to the Royal Entomological Society of London, 1987. Antenna 11:92-99.

unpopularity among entomologists, the thrips might reasonably be presented as a microcosm of progressive entomological thought in many fields. My aim is to convince you of this.

At the outset I acknowledge the generous help given by fellow thysanopterists in discussions, and particularly for providing photographs and slides without which the emphasis on "living" thrips and their habits would have been difficult.

### **Microtechniques, Functional Morphology and Anatomy**

A major technical challenge is posed by the diminutive size of individuals; almost all the temperate Terebrantia are only 1-2 mm long and relatively few of the predominantly tropical Tubulifera exceed 10 mm. As for all insect orders, scanning electron microscopy (SEM), has transformed the appreciation of their fine structure (Fig. 1). In two recent studies, on feeding (Chisholm & Lewis 1984) and flight (Ellington 1980) using SEM on dead specimens and technically innovative cinematography on living individuals, there has been a leap forward in knowledge.

Perhaps more than any other feature, thrips are characterized by their unique mouthparts, consisting essentially of a single left mandible, paired maxillary stylets and labral pad. The static interrelationships between these structures has been clearly revealed by plasma-ashing (Thomas 1974) the mouthcone before SEM - a technique that might well be useful for examination of structures in many other orders (Chisholm & Lewis 1984). Cinematography of the mouthparts of individuals filmed as they fed in specimen chambers on clear liquid containing polystyrene marker particles, enabled rates of cibarial pumping and ingestion to be measured accurately (Chisholm & Doncaster 1982). Thrips filmed feeding on protoplasts in liquid suspension revealed how spherical chloroplasts are elongated by the suction pressure of cibarial pumping as they pass up the very narrow maxillary canal. In addition, Kirk's (1984) recent careful observations of eight species of thrips feeding on fresh pollen from 12 species of flowers have confirmed how widely exploited is this food source by the



Figure 1. Cereal thrips in feeding position on leaf (photo by I. Chisholm).

order, the thrips rapidly piercing and sucking the contents of many individual grains per minute, then discarding the empty exine. Only one other insect, a ceratopogonid fly, *Atrichopogon pollinivorus*, is believed to remove the contents of individual grains rather than consume them whole (Downes 1955).

Thrips wings, too, are distinctive and pose intriguing questions about the mechanism and evolution of flight in small insects. In the Terebrantia, fore and hind wings consist of a membranous spar fringed with cilia, which when extended comprise about 80% of the wing area. The cilia on the trailing edge of *Thrips physapus* Linneaus wings are inserted into elongated, "figure of eight" sockets, whose shape and elasticity lock them into different positions at an angle to the membrane when the wings are folded or extended during flight. The extreme alignments of the cilia to the wing axis vary from 15-20° when the wings are folded along the back with cilia lying alongside the body, to 55-80° when unfolded (Ellington 1980). Ellington's elegant cine film records show that preparatory to take off the cilia are combed and locked into the extended position by abdominal flexing which draws them through combs and setae on the sides and posterior edges of several abdominal tergites. At the late stage in this process, which may be completed in 0.3-0.4 s or last up to a minute in some species, the fore and hind wings become coupled at an angle of 30° to their longitudinal axes when a hooked seta on each hind wing passes around two long setae from the posterior base of each forewing. The wings are then clapped together dorsally, the thrips raises the thorax and lifts off with a jump of the hind legs. During flight the wings clap together at the dorsal end of the cycle then fling open to begin the subsequent downstroke (Ellington et al., unpublished data). Because the hind wings lag behind the forewings in the cycle there may be a phase difference making the fling a two-stage process.

In the wider evolutionary context, one wonders why the smallest flying insects from the Thysanoptera, Coleoptera and Hymenoptera have converged on a wing design with a central membranous spar and long fringes. Ellington speculates that the enhanced circulation of air created

by the fling is more persistent if a small amount of flow through the wing is possible; further study of thrips may provide answers to this broader entomological question.

In the early days of pheromonal studies, during the 1960s and 70s, various types of sternal glands in the Isoptera and Coleoptera were identified as sources of sex pheromones (Percy & Weatherston 1974). It is noteworthy, therefore, that 60 years ago (Klocke 1926) described sternal glands in male *Thrips physapus* believing they had a role in mating. More convincing evidence for the presence of a pheromone in thrips were provided by Bode (1978) who showed the ultra structure of the sternal glands of *Thrips validus* to be consistent with the likelihood of these being pheromone glands. Histochemical tests showed the secretions to consist principally of lipids with some acid mucopolysaccharides.

Another recently discovered glandular area in the dorsal region of the head of male *Merothrips* (Moritz 1984) is reminiscent, at least in position, of the alarm pheromone-producing gland in the head of soldier termites (Nasutiterminae) (Moore 1969). The ultrastructure of this gland resembles that of the abdominal sternal glands in thripid males; it has added interest because it appears to have displaced the brain completely from the head capsule into the prothorax. Its function remains unknown.

Many more excellent studies, comparable with those made on any other order, have been made on the ultrastructure of the rectal papillae, peritrophic membrane and spermatozoa by Bode (1977, 1979, 1983) and on embryogenesis by Moritz (unpublished data), but I would like to draw particular attention to an aspect of the microstructure of the chitin. Presumably such small creatures are at risk from prolonged submersion by dew or rainfall. The presence of elaborate cuticular arrays around and within many abdominal and thoracic stigma (Moritz 1985a, Palmer & Mound 1978) seem capable of trapping a film of air to produce at least local areas of plastron, permitting respiration whilst temporarily submerged. The one known species of aquatic thrips, *Organothrips bianchi* which lives in slime at the base of Taro stems, has no such arrays in its abdominal stigma, and only very simple ones in the

mesothoracic stigma, but the cuticle of the II and IV abdominal segments is pale and only slightly sclerotised suggesting that cutaneous respiration supplements the more normal spiracular method.

### Behavior and Ecology

I can best illustrate how thrips are contributing to the mainstream of modern ideas on behavioral ecology by reviewing a few aspects of their reproduction and the intraspecific relationships arising from it.

The Thysanoptera is the only insect order, apart from the Hymenoptera, to be entirely haplodiploid, the males being derived exclusively from unfertilized eggs (Whiting 1945, Stannard 1968). In the sub-order Terebrantia the eggs are inserted singly by the valved ovipositor into plant tissue and larvae emerge with the help of hatching spines on the embryonic cuticle over the head. Despite high population densities of adults on plants, particularly on flowers, the insects' behavior is essentially solitary showing minimal social interaction. Eggs are ignored by females after laying; individuals meet randomly for mating, then part; aggregation appears to be almost, if not entirely, a response to features of the habitat (odor, scent, moisture content) rather than to other individuals. By contrast, members of the sub-order Tubulifera have no ovipositor so lay their eggs on the surface of plants, often in clumps which may be guarded by the female or, in a few species, by both sexes. There are reported instances of such maternalism in at least seven tubuliferous species; in *Bactridothrips brevitubus*, an adult male usually, and sometimes a female, or both, sit close to the egg mass (Haga 1973). Sometimes two or more females contribute to the same egg batch which may eventually contain more than 200 eggs. Parents remate after eggs hatch and as hatching occurs sequentially instars from different parents are mixed. Other species such as *Gigantothrips elegans* guard the eggs more aggressively, the female displaying by waving her abdomen to produce a visual, or possibly olfactory, signal to deter other thrips and predators (Mani & Rao 1950).

A striking and distinctive feature of many tubuliferans is the sexual dimorphism in the size and complexity of the forelegs. The larger (oedymorous) males have massive, almost grotesque, fore-femora with pointed teeth at the tips of the fore tarsi, while smaller (gynaecoid) males, more like females, have relatively slender forelegs with less prominent teeth. Such dimorphism is most pronounced in gregarious species living in galls or under bark (Stannard 1957, Ananthakrishnan 1970) with strongly female-biased sex ratios. Furthermore in polymorphic species the large males are often wingless or short-winged and the short-winged individuals have the weaker forelegs. Crespi's (1986) patient observations on territoriality and fighting in *Haplothrips pedicularis*, a common British species living in *Stereum* shelf fungus, show vividly the use to which such strongly armoured forelegs are put. Several females contribute to communal egg masses and males fight in territorial defence of these oviposition areas, grasping and stabbing each other with their forelegs. Fights between males of similar size escalate into prolonged battles persisting for an average of 5 minutes before the loser moves away. In each combat the larger male usually wins and thereby secures 80% of the matings, taken most frequently during oviposition periods with a laying female. Smaller, subordinate males attempt "sneak" copulations and, after such, occasionally challenge the dominant males. Such fascinating behavior poses several intriguing questions in behavior ecology. Defence of oviposition sites is common among insects and often involves last male precedence. The increased rate of copulation by *H. pedicularis* males during oviposition and their success at mating last before eggs are laid, all suggest that the last male to mate before oviposition is likely to fertilize the eggs. There are as yet no data on sperm competition in thrips to confirm this but given that techniques are already developed to handle and study the ultrastructure of thrips sperm and histogenesis (Bode 1983) it should be possible to resolve this question.

Game theory models, which seek to characterize optimal fighting strategies, predict that contestants should be able to assess each others fighting ability, so the more vigorous fighter can escalate his effort (Parker 1974, Maynard Smith 1982). The substantial escalation of battles between *H. pedicularis* males of similar size and the lower



frequency of challenges by small subordinates suggest that potential contestants do indeed assess their opponents size. Whether they do this visually, by the intensity of stabs or abdominal waggings, or even audibly (Hood 1950) is unknown. If the first, do fights occur in the dark situations in which many polymorphic species live? Furthermore, why do males with large forelegs tend to be wingless? Does this allow nutritional resources to be diverted towards weaponry and increased sperm production? Suffice to say that speculation on these points (Hamilton 1964, 1979) contributes to the important debate on the genetical evolution of social behavior.

Another thrips that contributes to an understanding of the interactions between intrinsic genetic and extrinsic ecological factors in the evolution of sociality is the Panamanian *Anactinothrips gustaviae* (Kiestler & Strates 1984). "Colonies" of 15-75 individuals of this species occupy a permanent resting site on the bark, from which they move out on apparently well co-ordinated foraging missions, each lasting about an hour, before returning to the same site. Adults and I and II instar larvae move together in a closely knit group up the trunk of the host tree, pausing to browse among lichen patches. When the main group moves on, any stragglers scurry to rejoin it. Eventually the colony descends the trunk and returns to the original site. When moving, the adults wave their raised abdominal tips to and fro continuously. Contact is probably maintained by scent perhaps dispersed from the waving abdomen, which may be a supplementary visual signal. Insofar as the "group" behavior appears to cover care for the young, an overlap of generations, and a possibility of a division of reproductive labor between oedymorous and gynaecoid individuals, the species seems to be on the fringe of being truly social. Such diversity of complex behavior within the order was barely imagined even 20 years ago, other perhaps, than by the far-sighted J. D. Hood.

Of course, thrips have the usual wide range of interspecific interactions with other invertebrates, including many predators and hymenopterous parasites, and allantonematids causing ovarian degeneration (see Lewis 1973). Nor are thrips free from infection by pathogenic fungi. In glasshouses *Entomophthora thripidum* causes

epizootics in populations of *Thrips tabaci*, infected individuals dying as the fungus breaks through the abdominal integument (Samson et al. 1979). The aquatic Taro thrips may carry as a symbiont a sessile ciliate *Propixidium moritzi*, similar to species found on the cuticle of hydrophilid beetles and water bugs (Moritz 1985b).

Some species are themselves predatory on other thrips, and particularly the eggs, instars and adults of mites, eggs of small moths and immature coccids and aleyrodids. One puzzling relationship occurs in Malaysia between the cacao thrips, *Selenothrips rubrocinctus*, a *Psilogaster* sp. (Eucharitidae) and ants. All species of this family of tropical chalcids are believed to be parasitic on the larvae and pupae of ants, and lay their eggs remote from the ant host. This species of *Psilogaster* lays 50 to 100 eggs in a circle around a single egg of a cacao thrips. When the thrips hatches, it tries to escape from the surrounding palisade of *Psilogaster* eggs, thereby stimulating some of them to hatch, and the emerging planidia attach themselves to the young thrips larva (Kirkpatrick 1957). It is not known how this behavior enables them to reach their ant host but some ants do occasionally carry larvae of cacao thrips in their jaws (Callan 1943), and this might provide an opportunity for the planidia of *Psilogaster* to transfer.

### Applied Aspects

The pest status of thrips which can cause serious damage to crops in dry environments centers on their feeding and the effects this has on plant tissue. Members of both sub-orders probe vegetation with their stylets and suck sap from the pierced cells, though by a somewhat different muscular action in each sub-order (Heming 1978, Chisholm & Lewis 1984). Many tubuliferans cause galls but most pests are terebrantians, with relatively short maxillary stylets which probably penetrate not more than 60 $\mu$ m after a hole has been punched into the tissue by a thrust of the mandible. Radiographic studies of ingestion from artificial diets and vegetation by *Thrips tabaci* (Day & Irzykiewicz 1954) and *Limothrips cerealium* (Haliday) (Chisholm & Lewis 1984), species that normally feed respectively on di- and monocotyledonous plants, suggest that phytophagous thrips ingest 10-20% of their body

weight per hour, presumably losing water by respiration and excretion at a comparable rate. The gross external effects on plants of such feeding are easily detectable and well known; silvered patches develop under areas of concentrated punctures, and damaged leaves and petals eventually become discolored, distorted and brittle, sometimes falling from the plant in hot dry weather. The external and internal microscopic effects on plants are less obvious and appreciated. SEM reveals that surface leaf wax is removed around probing sites by the adpressed labral pad and the leaf cuticle, so exposed, wrinkles due to plasmolysis of the underlying epidermal cells (Fig. 2). The holes made by the stylets in the leaf tend to be "figure-of-eight" shaped presumably to accommodate the mandible and maxillary tube.

Internally, cells lying just beneath the epidermis, are emptied of their contents by light infestations, and after feeding there is little seepage from them indicating that each cell is emptied completely before the thrips probe again. After intensive feeding over a small area, the internal cell structure becomes completely disrupted. Epidermal cells, and especially the bulliform cells likely to be involved with water conservation in cereals, shrivel; many mesophyll cells disappear completely, others retain no cytoplasm or cell contents. The direct effects of such heavy attack are desiccation and death of the plant. In Britain, there has been considerable concern recently about the appearance and spread of *Frankliniella occidentalis* in glasshouses, where ornamentals, particularly chrysanthemums, can be made unsalable by relatively light infestations.

Kirk (1987) has estimated that a single pollen feeding thrips could destroy 0.2-0.7% of a flower's pollen in a day, and extrapolation of these daily feeding rates using the numbers of thrips likely to occur on flowers and estimates of pollen production, suggest that damage to pollen by thrips may reduce the yield and fitness of some crop plants.



Figure 2. External appearance of feeding lesions. Surface leaf wax removed; "figure of eight"-shaped hole reveals point of insertion of single mandible and linked maxillary stylets (photo by I. Chisholm).

Five species of thrips have so far been identified with virtual certainty as virus vectors, the principal virus being tomato spotted wilt virus (TSWV) which produces a range of symptoms on crop plants worldwide, often causing serious losses. Tobacco ringspot virus has also been transmitted in laboratory conditions (Messiaha 1969).

Not all plant feeding by thrips is disadvantageous. In 1930 *Liothrips urichi* Karny was introduced into Fiji from Trinidad to control the weed Koster's curse (*Clidemia hirta*) (Simmonds 1933) and the thrips has provided control ever since over wide areas - not by killing the weed directly, but by inhibiting its growth so that it cannot compete with the surrounding vegetation. More recently attempts have been made to control alligator weed (*Alternanthera philoxeroides*) in Florida by *Amynothrips andersoni* imported from Argentina. The weed forms dense mats of interwoven stems that block drainage canals, impede navigation and crowd out wildlife. Feeding by the thrips produces scarred lesions along the margins of terminal leaves which curl to provide further protection for feeding thrips. There are hopes that the thrips will prove useful along with a flea beetle and phytocid stem borer (Maddox et al. 1971).

My last example of the economic impact of the order arises from the strongly thigmotactic behavior of cereal thrips, mainly *Limothrips cerealium*. Clusters of this species forming behind the glass of framed pictures are a common household nuisance in Britain and Europe, and there are even records of watches being stopped by their ingress. But the newest problem is associated with automatic fire detection systems now widely installed in hospitals, institutional homes, offices and industrial premises. When female thrips fly from drying cereals in late summer to seek hibernation sites, they are blown into buildings and in seeking crevices may find their way into smoke detectors. Many thousands of false fire alarms occur annually, especially in arable farming areas. For example, over a four-day period in July in Suffolk in 1985, insects were responsible for 70% of false alarms. As fire brigade units may charge £100 for a false turnout, the problem is clearly expensive on a national scale, as well as making the systems unreliable and thus

dangerous and inconvenient to occupants of buildings. One private hospital in southeastern England claims to have had about 100 false alarms in a single summer.

Twenty-five triggered detectors examined after incidents all contained *Limothrips* with up to a maximum of about 300 individuals in a single device. Detectors that respond to optical scatter by smoke are most susceptible, and probably a single thrips in the right position will trigger some of these models, but ionization types are also at risk. Woven gauze covers, fine enough to exclude thrips also tend to exclude smoke particles, so one possible solution to the problem depends on changing the geometry of covers to prevent entry, or the internal configuration to prevent thrips triggering a sensor even if they enter it.

### Resumé

The evidence presented clearly shows the immensely diverse range of entomological science at basic, technical and applied levels encapsulated in the study of the Thysanoptera. For such a small order, with only 5,000 or so named species, and one which has received relatively little attention from entomologists, this is remarkable. It is for these reasons that I suggest the thrips can be regarded as a -- "microcosm" of the Insecta, worthy of much wider study. Thysanopterists are not "beyond the fringe", and there is much beyond the "fringes!"

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### Discussion Period

Comment: I have had trouble with insects getting into my smoke detector, and I put Tanglefoot inside so they couldn't crawl in. Have you considered that?

Lewis: Yes, I didn't mention solutions to the smoke detector problem. There are several possibilities. One is to put a sticky material around the outside because the thrips tend to enter the detector by climbing up the walls and crawling across the ceiling. The trouble with this solution is the detector gets very mucky after a while. Another possibility is to incorporate a repellent or a slowly vaporizing insecticide in the plastic. All of these alternatives have been investigated and in some cases incorporated. However, the best solution is to change the detector design itself so there isn't a gap that a thrips can crawl into that would set off the alarm.

Question: I'm from Pennsylvania and we've had pear thrips damage there even longer than Vermont. We have noticed an apparent direct correlation between thrips damage and the flowering of the maple trees. It seems almost cyclic in nature in relation to the flowering of the tree. Do you think there is a direct relationship between the increase in thrips populations and the flowering of the tree?

Lewis: I don't know if there is a correlation or not, but this basic question should be investigated. In the last 4 to 5 years much research has been done on pollen feeding by thrips, predominantly by one person, Dr. W. D. J. Kirk, who is now in England. He claims there could be a significant decrease in fertility of attacked plants due to aborted flowers.

Comment: Considering all the pollen grains that most plants produce, it is hard to believe that thrips can seriously affect flowering. The insect would have to be a good scavenger to deplete the entire pollen crop. However, I admit I don't know much about the fundamentals of pollen and pollen dispersal, particularly in relation to maple trees, to know whether a 10, 15, 50 or 80% reduction of pollen would be enough to make any difference in seed set.

Comment: In response to this, I've been working on western flower thrips and we have definitely found a strong correlation between the number of flowers in blossom, the number of open flowers and the number of western flower thrips. I think it is mostly the effect of dispersal. The thrips come from the coast, and move into the apples at that time.

Question: Just for clarification, one fact I remember from past literature on thrips is that they rasp the leaf tissue. Based on your presentation, this is not the case. Would you say that the past information is incorrect?

Lewis: Yes, it is. They do not rasp in the traditional sense of the word, though it depends on your definition of rasp. Rasping to me means that something is scraped. Thrips don't scrap the leaf surface, they puncture the leaf and suck the plant juices out. I brought a film that shows thrips punching a hole in the leaf, inserting the stylet and sucking out the plant fluid. You can see the liquid pulsing within the thrips head. They certainly do not rasp. This belief emanates from work on thrips by Wardle & Simpson published in 1927. Thrips feeding looked like rasping, until more sophisticated high power magnification techniques showed what was really occurring. The literature needs to be updated. Unfortunately, I propagated the myth further. When I wrote my book, I copied diagrams from Wardle & Simpson, but they were wrong.

Question: Is the appearance of the rasping-like damage due to the feeding on the embryonic tissue whereby a lot of damage on the smaller leaf parts gives the appearance of a rasping like action?

Lewis: I suppose very young plant tissue that has been fed upon by thrips, could, once expanded, develop into a hole. Aphid damage sometimes appears as holes in the leaf, not because aphids make holes but because when they feed on very young buds with delicate tissue, pierced areas eventually die resulting in a hole in the expanding leaf.

Question: Based on your feeding studies did you ever find any thrips injecting substances into the leaf tissue, or do you think it's possible, based on your previous studies?

Lewis: Yes, I think it is. Tomorrow you will see a sequence in the film on thrips feeding that suggests that saliva enters feeding punctures.

Question: At what stage in the life cycle of the thrips is it attacked by pathogenic fungi?

Lewis: I know of evidence that all stages, except eggs, can be attacked, depending on the species.

## **EVOLUTION AND SYSTEMATICS**

**SPACE, TIME AND THRIPS:  
BIOGEOGRAPHIC ISSUES IN THE  
EVOLUTIONARY ECOLOGY OF THYSANOPTERA**

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**Introduction**

Most participants of this symposium will be concerned with understanding thrips ecology primarily in order to develop practical and effective control strategies. Questions dealing with historical aspects (evolution) may seem of only isolated "theoretical" interest with little significance for everyday pragmatic concerns. Evolutionary theory is widely presented, however, as a cornerstone of modern biology and this position implies that evolutionary considerations can and do provide a direct input into our understanding of both ecosystems and individual organisms. Most evolutionary perspectives on living organisms are derived from specialist studies such as ecological, genetic or developmental systems. Data from these studies are extrapolated to represent evolutionary processes in reference to some general theoretical or metaphorical framework (e.g., natural selection) that also has its source in the same kind of observations.

In evolutionary ecology the course of evolution is often separated out from the living present so that the historical "past" and the ecological "present" of evolution never seem to quite come together (Gray 1990). This arbitrary division between past and present may provide an implicit, and little recognized, barrier to effective synthesis between evolution and ecology in the study of modern-day organisms. I will address this problem with respect to the general biogeographic problem of incorporating space into evolution and the potential significance for future work on thysanopteran ecology.

## Evolutionary Characters

An important component of evolutionary approaches to natural processes is the construction of a comparative framework for identifying information content. Comparative information is expressed by the establishment of a particular taxonomy representing what we understand of the real natural world through systematic analysis of characters (Nelson & Platnick 1981). There is unfortunately a dearth of comprehensive comparative phylogenetic and evolutionary information on the Thysanoptera (cf. Lewis this proceedings, Nakahara this proceedings) although the range of contributions in this symposium referring to many different situations suggests that this information could develop. However, systematics/taxonomy remains one of the most threatened of disciplines in the natural sciences suffering continuing attrition in funding, diminished emphasis in university courses and uncertainty about its scope and content from both systematists and non-systematists in the natural sciences (Whitehead 1990).

Understanding the role of systematics may represent the weakest link in establishing the discipline as a relevant component of general biological studies (Whitehead 1990). The systematic component most familiar to non-systematists is the taxonomy that provides an ordering of information within which organisms may be compared and specific issues identified. There is the danger, however, that this familiarity may degrade taxonomy as being nothing more than a convenient labelling system for the indifferent use of ecologists, environment managers etc. This perception overlooks the theoretical content of taxonomy that concerns the question of genealogy as shared evolutionary history (Fig. 1). Taxonomy is a direct representation of a natural process (evolution) and provides a summary, a statement about the current knowledge of that process (Nelson & Platnick 1981). It is through the process of evolution that systematics may be recognized as an indispensable component for any meaningful biological study whether phylogeny or ecology.



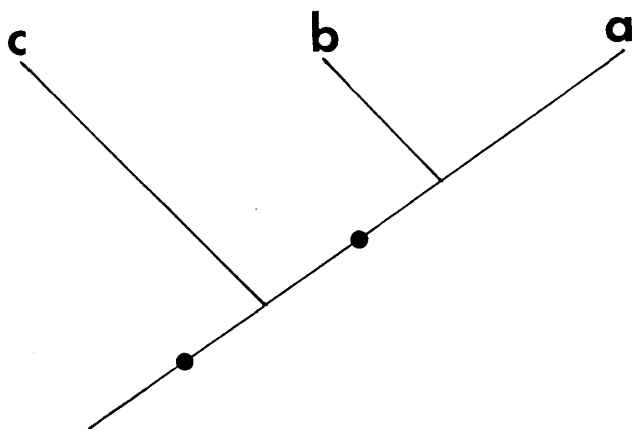


Figure 1. Simplified conceptual relationship between taxonomic category (taxa a, b, c) and phylogenetic evolution. Taxa are positioned according to inferred historical relationship. Taxa "a" and "b" are more closely related to each other than either taxon is to "c". Solid circles represent unique shared characters defining taxonomic and phylogenetic relationships (modified from Nelson & Platnick 1981).

At present there are insufficient detailed comparative studies on the ecology and phylogeny of Thysanoptera to establish an analytical approach for a narrative on thrips evolution. In optimistic anticipation of this future development I will briefly consider the important issue of space/time arising from systematic and biogeographic studies of evolution and examine the implication for understanding the evolutionary relationship between ecology and history.

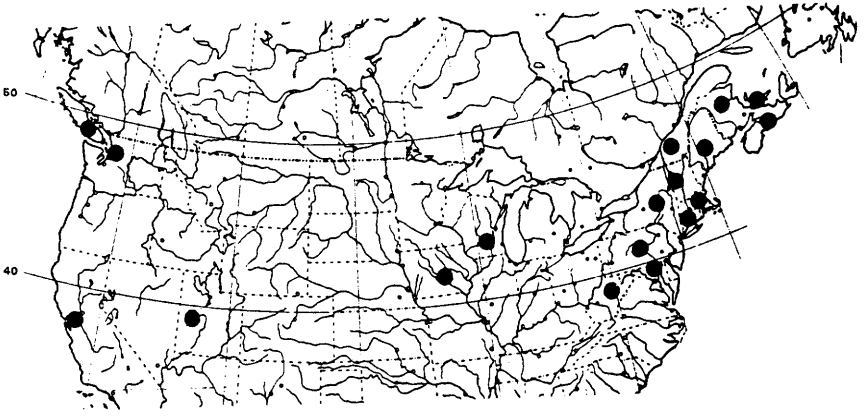
### Spatiotemporal Characters

The study of space/time in evolutionary biology is nominally the field of biogeography - the investigation of animal and plant distributions. Biological or evolutionary studies often give only tacit or implicit recognition to the existence of "space" and "time" and rarely does this concern receive critical appraisal outside biogeography. The implicit acceptance of space and time "as read" assumes a separate, discrete existence for each - a separate time (like an arrow of time) and

a separate space (such as a defined area). While this "common sense" appreciation is based on an original separation, in practice we conceive of space in a temporal sense--a particular moment in time (this moment being the present, the "now" in which we think). Conversely time is thought in relation to a sequence or spacing of particular moments (Derrida 1982). Each, therefore, becomes a necessary counterpart to the other, and instead of referring to space *and* time in evolution it is be more appropriate to think of space/time (Craw 1988). This joining is significant for how we approach ecology and history which traditionally separates and isolates past (time) from present (place).

Distributions are explicitly spatiotemporal and show that organisms do not evolve only in their physical form, but have a real geographic existence with their evolutionary boundaries (ecological and historical limits) being determined or "defined" by space/time (Fig. 2). Biogeography has often assumed space and time to represent a separate stage or container that provided the environment in which organisms actively migrate and evolve so that organisms evolve, environments do not (Craw & Page 1988, Gray 1988). Migration stories were constructed largely on the belief that individual attributes of organisms (e.g., flying, walking, rafting etc.) are responsible for their different distributions (Darwin 1859, Wallace 1876). This evolutionary framework effectively exiled organic distributions from having any real existence in evolution. Instead of forming a data base in their own right, distributions were treated as an ephemeral manifestation of differing migratory abilities between of organisms. Without an explicit space/time dimension biogeography could not contribute anything much to evolution or ecology in general.

a.



b.

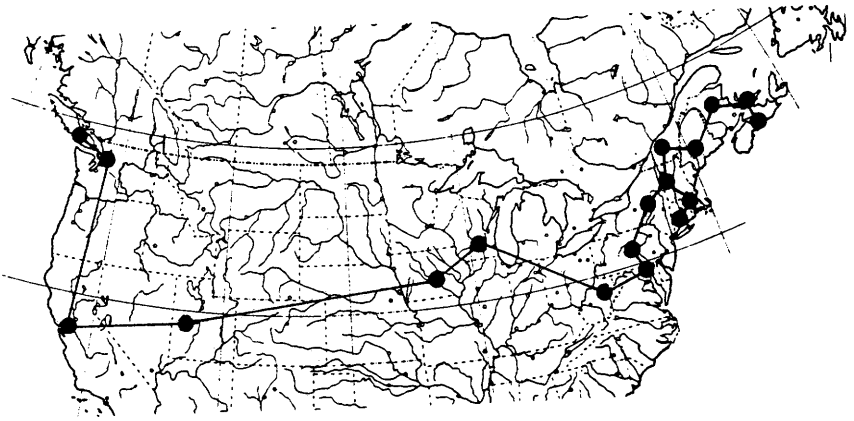


Figure 2. The biogeographic (space/time) evolution of organisms as represented in the range of the pear thrips (*Taeniothrips inconsequens*) in North America. (a) The range of pear thrips as a distribution emphasizing the general localities based on records of the insect. (b) The geographic localities represented as a biogeographic map of the space/time coordinates of the distribution filled in by lines. The lines connect the localities in the form of a minimal spanning tree. (distributional information from M. Skinner).

The treatment of space/time in evolutionary biogeography changed substantially in the 1950s through the establishment of panbiogeography (Croizat 1952, 1958). This form of biogeography examined distributions as providing a space/time data base - literally the "records of life" (Croizat 1964). Panbiogeography was concerned with developing an analytical framework for comparing the spatiotemporal characteristics of distribution patterns and deriving an understanding of the evolutionary relationship between historical events and the ecology of organisms with respect to present location. This geographic treatment of space/time provided an explicit role for evolutionary systematics by treating geographic information as characters amenable to analysis and interpretation (cf. Page 1987).

An important early finding in panbiogeography was that specific attributes of organisms, such as local means of survival (flying, walking, swimming, rafting etc.), were not general predictors of their present location on the globe. Just because an organism had the ability to fly did not mean that it was any more widely distributed than flightless beetle or worm. Croizat (1952, 1958) found that organisms with different migratory abilities could have the same pattern of distribution and suggested, therefore, that historical events were an important determinant of geographic range and the local ecology of organisms. Some organisms may appear to have greater freedom of movement and more expansive range than localized endemics, but their evolution in space/time was regarded as being fundamentally no different (Croizat 1964, Craw 1988). The common element of evolution for organisms with a "weedy" ecology (such as the pear thrips *Taeniothrips inconsequens* (Uzel)) and more specialized or localized forms concerns the role of actively changing ecological circumstances and their relationships with earth history. It is this interrelationship that concerns biogeography as a science investigating the space/time events that contribute to the evolutionary ecology of organisms.

### Biogeographic Events

How may these very general biogeographic considerations bear on specific approaches to thrips ecology and "management?" With pear thrips, for example, the present ecology involves two major developments: (1) the presumed human mediated introduction of pear thrips into North America (Bailey 1944) and (2) the association of pear thrips with, and recent prevalence on, sugar maple (*Acer saccharum* Marsh.). Both events involve changing spatial and temporal boundaries in thrips evolution. Comparative inferences on the evolution of pear thrips host-plant relationships are limited by the lack of detailed information on host-plant relationships of pear thrips in the European range (see Mills, this proceedings) although it is known to feed on members of *Acer* and the sugar maple does not necessarily represent a major host-plant "departure." The host-range expansion has involved host plants that could not be previously exploited (because of their absence) in the Eurasian range of pear thrips. These geographic changes, occurring within the present historical record, could be visualized as an active "colonization" by an aggressive or assertive organism making use of new environmental opportunities. This view would assume space and time to be separate from the organism and it could, therefore, be argued that the thrips has actively entered a "new" passive environment.

In a static space and time model of evolution the pear thrips entry onto sugar maple may be treated as an "invasion" or "colonization" and in a *de facto* sense this appears to be true. It requires, however, the underlying assumption of discrete separateness between the insect and host-plant - that the thrips alone defines the host while the host has no active role through its own spatiotemporal characters. This one-sided dichotomy in favor of thrips presents the thrips as the sole "active" evolutionary partner establishing initial contact. The separation of insect (organism) and host-plant (environment) has been modelled by Janzen (1968) in terms of "island biogeography" formalized by McArthur & Wilson (1967). Janzen (1968) argues that a species of plant is an island in evolutionary time to the insect species that feeds on it, but the individual plant may also be

analyzed in space and contemporary time to the individual insects that feed on it. The island concept presented by Janzen is explicitly based on space and time as containers (Fig. 3) and emphasized by the reference to McArthur & Wilson (1967) who view spatiotemporal evolution in the tradition of Darwin (1859) and Wallace (1876) where specific attributes of organisms are responsible for differential migration and colonization. Janzen (1968) extends this model to limit the plants role as the passive recipient to insect migration and affecting only the opportunity for establishment by character differences such as size, distance and chemical and structural composition.

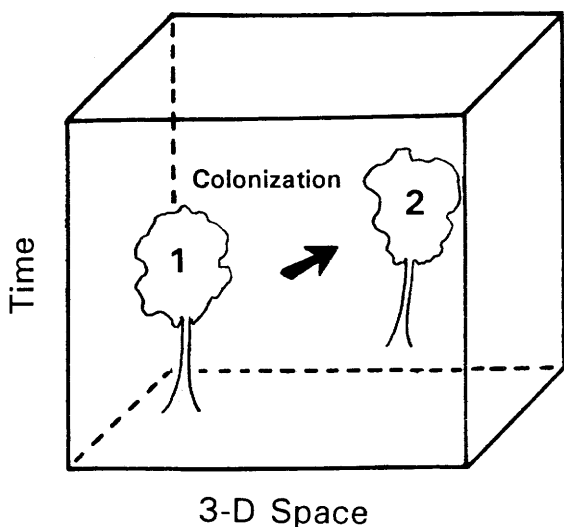
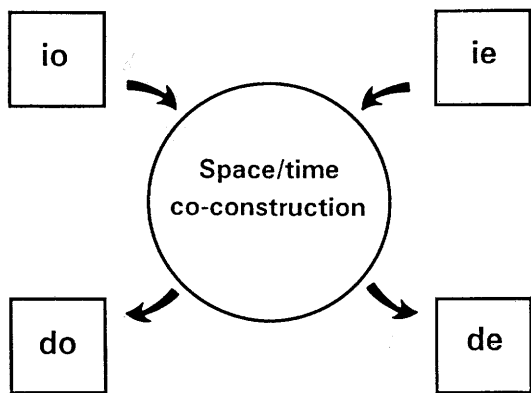


Figure 3. Host-plant relationships conceptualized for an organism/environment whereby evolution takes place within a container of absolute space and time. New host-plant relationships occur through the organism actively migrating from one environment location (1) to another (2) (modified from Craw & Page 1988).

If space/time is already present in the very existence of an organism (i.e., its ecological and developmental existence) the traditional division drawn between organism and environment is no more than an idealistic abstraction. Just as time may be thought of as space and

space as time, a particular "ecology" has no meaningful existence without reference to "organism" and organisms do not come into existence without an ecology (i.e., environmental relations) (Gray 1988). If organisms and environments (ecology) are seen as having a reciprocal character, their individual boundaries are mutually contingent. When interpreting ecological changes such as that of the pear thrips, the evolutionary process involves reorganization of space/time boundaries (the North American extension) that includes both the thrips as an organism and the thrips as an ecology. Thus, it is not the pear thrips alone as a separate "organism" that has entered North America, but an evolving pear thrips ecology (since the thrips organism did not travel at any stage without an environment). In this perspective it is possible to look at the evolutionary history of thrips as a co-construction of organism and environment (cf. Gray 1988). This differs from some traditions in evolutionary ecology that look at organisms and environments as closely interacting, but only as separate, distinct entities. Here they have no prior separate existence. In a co-construction context the evolution of thrips could be seen to involve a process of development in a particular place/time where inheritance involves "organism" and "environment" components as the raw materials in each thrips generation (Fig. 4). Rather than treating either or both of the inherited characters as the determinants of thrips ecology, it is the process of mutual construction that takes place during development that defines the apparently distinct thrips "organism" as we see it, and the separate ecology that we associate with the insect. Neither of these aspects have come into existence pre-formed, they were involved in developmental (or successional) processes and these processes of co-construction are contingent upon the place/time in which they occur (cf. Gray 1990, Grehan 1988, Oyama 1982).

a.



b.

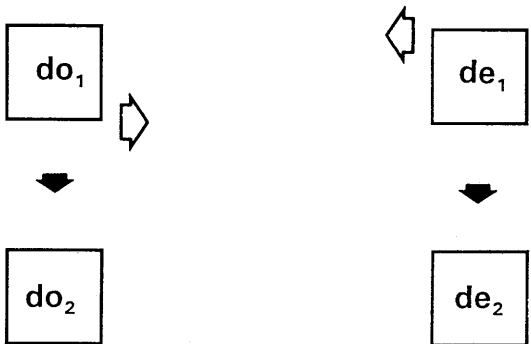


Figure 4. (a) A co-construction model of host-plant relationships. Evolution is contingent upon the interrelationship between space/time events (biogeography) and the initial "raw material" of inheritance in both its organism and environmental aspects (io = initial organic inheritance; ie = initial environmental inheritance). Through development there is a co-construction that results in the defined "organism" (do) and defined environment (de) which now may have the appearance of separate distinct entities. This can be contrasted to host-plant models (b) where evolution occurs through the interaction of separate organism (do<sub>1</sub>) and environment (de<sub>1</sub>) entities (here the host-plant is being treated as an environment with respect to a particular insect). The interaction may result in modification of either or both components (do<sub>2</sub>, de<sub>2</sub>).



The co-construction perspective has been recently formalized by Gray (1987, 1988, 1990) to help synthesize history and ecology in evolutionary studies. Co-construction is an important consideration because it places the historical context of evolution as being historically contingent upon when and where organisms and environments interact. Evolutionary systematics, through biogeography, is concerned with the spatiotemporal characters of evolution which may become important if not critical for understanding the present evolutionary ecology of organisms and how this may change in relation to the evolution of environments. Evolution in space/time may, therefore, be thought of as a process whereby ecology has history and history is mediated ecologically (Gray 1990).

In panbiogeography the incorporation of space/time in organism-environment relations leads to rejection of organisms as being representations of some kind of inner ideal that can be defined for all places/times (as in most approaches to species definitions). Instead organisms or natural taxa are seen as having a spatiotemporal existence whereby their individuality is diagnosable only with respect to particular places/times (Craw 1988). This contingency is developed as a general evolutionary framework whereby "earth" and "life" are seen to evolve together (Croizat 1964, Heads 1990) and biogeographic research is involved in the analytical and statistical ramifications (e.g., Craw & Page 1988, Craw 1988, Page 1987, Henderson 1990). The conceptual linking of space/time with the form of an organism allows the potential for interlocking the findings of different disciplines in evolutionary biology (Fig. 5) where ecology has for its immediate focus present spatial relations of an organism. These relations are, however, contingent upon spatiotemporal studies (biogeography), and developmental processes (which mediate organism-environment transactions). The conceptual model provides possibility for reciprocal insights to be developed between the disciplines.

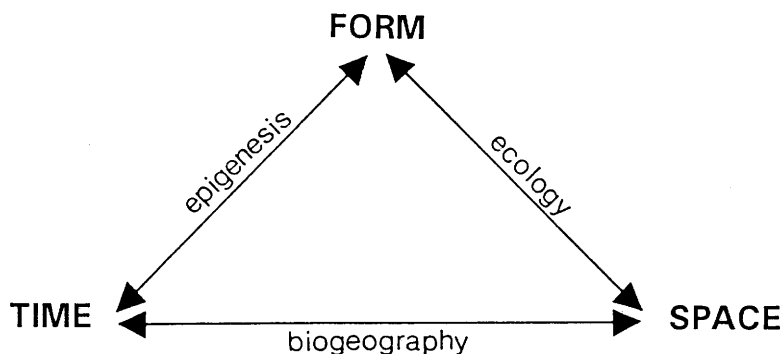


Figure 5. Model of the reciprocal relations between different evolutionary disciplines with respect to the contingent relationship of space/time with form. Biogeography may be regarded as having its primary focus with relative space/time and have a reciprocal relationship with ecology and developmental sciences (from Craw & Page 1988).

The *de facto* appearance of insects (or other animals) establishing relationships on plants and either maintaining a presence or not is not questioned here. The biogeographic problem concerns the metaphor of "island" which evokes a simplistic model of isolation and separation between entities that may be ecologically integrated. The establishment of pear thrips need not be interpreted as a lack or conquest of a barrier in the host-plant, but as a new ecological event contingent upon the mutual co-construction of evolutionary and ecological characters. In this sense the evolutionary "inheritance" of an insect concerns not just its genes or developmental characters, but also the environment characters. Each generation these characters do not appear already present and fully formed, but must be constructed in relation with each other through the development of the organism concerned. This interpretation involves a concept of space/time that is not only fluid, but totally contingent, a place where what is "organism" and what is "environment" is no longer quite as distinct as we might prefer from a pragmatic managerial standpoint.

## Conclusion

Specialists may respond to this deconstruction approach of organism-environment relations by asking, "What practical difference does this make to my work?" My response is that it makes a difference only if a specialist is prepared to explore the foundations and implications that become apparent. Thus, it is not my purpose or intention to impose co-construction, but contribute an appreciation of space/time concerning concepts taken for granted in ecological studies that do have a bearing on our interpretation of the real, natural world and the solutions we construct for reaching practical solutions to ecological problems.

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## SYSTEMATICS OF THYSANOPTERA, PEAR THRIPS AND OTHER ECONOMIC SPECIES

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### Abstract

The systematics of the Thysanoptera, and several economic species in the United States and Canada (North America) are discussed briefly. Morphological characters to distinguish the six families in North America and the following economic species, pear thrips (*Taeniothrips inconsequens* (Uzel)), basswood thrips (*Thrips calcaratus* Uzel), western flower thrips (*Frankliniella occidentalis* (Pergande)), flower thrips (*Frankliniella tritici* (Fitch)), tobacco thrips (*Frankliniella fusca* (Hinds)), and onion thrips (*Thrips tabaci* Lindeman) are discussed.

### Introduction

The common name for the order Thysanoptera is thrips. Other common names that have been used are bladderfeet and woodlouse. There is also a genus *Thrips*, which is the oldest name in the order. In the United States and Canada (North America), there are about 700 described species of thrips. Mound & Houston (1987) estimate about 4,500 known species worldwide and probably another 4,500, mainly in the tropics, that have not been described.

Most thrips are tiny and barely visible. They usually are 1-2 mm long, the smallest are about 0.5 mm and the largest found in the tropics are about 14 mm (Lewis 1973). They are found in flowers and various parts of the plants, and often pupate or spend part of their life cycle in soil or ground litter. Thrips have elongate bodies, which are often slightly to strongly flatten dorso-ventrally (Figs. 1-2). Antennae are 4- to 9-segmented. The right mandible is vestigial and the left mandible is developed. Two pairs of elongate wings are fringed with long cilia. A bladder is located at the apex of each leg (Fig. 3). The abdomen is 10-segmented.

Currently, there are eight families of thrips in two suborders worldwide. The suborder Tubulifera consists of only one family, Phlaeothripidae, which includes about 350 species in North America. Members of this family (Fig. 1) can be recognized by the tubelike last or tenth abdominal segment, which has terminal setae; the female lacks an ovipositor. Also, the forewings, which lie crossed on the abdomen when at rest, lack veins and setae except at the base, and their surfaces are bare. Foretarsi are always one-segmented. The maxillary stylets are long and inserted inside the head (Fig. 4). Only a few species in this family are of agricultural importance. Many species feed on fungi or fungal spores and several species are predators. The life cycle includes the egg, two larval stages, three pupal stages and adult. The antennae of the larvae are not annulated and the last abdominal segment is tubelike and often sclerotized, and the antennae of the pupae lie along the sides of the head.

In the suborder Terebrantia, there are five families in North America. They differ from the phlaeothripids by having an ovipositor. Also, the forewings, which lie parallel over the abdomen when at rest, have veins with setae, and their surfaces are covered with microtrichia (Fig. 2). Maxillary stylets are short. The life cycle includes the egg, two larval stages, two pupal stages and the adult. The antennae of the larvae are annulated, and the last abdominal segment is variously shaped. Antennae of the prepupa project anteriorly but lie over the head in the pupal stage.

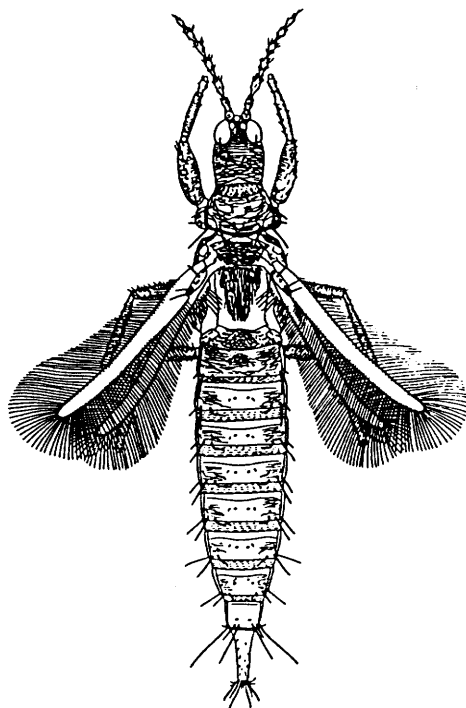


Figure 1. Phlaeothripidae adult (from Stannard 1968).

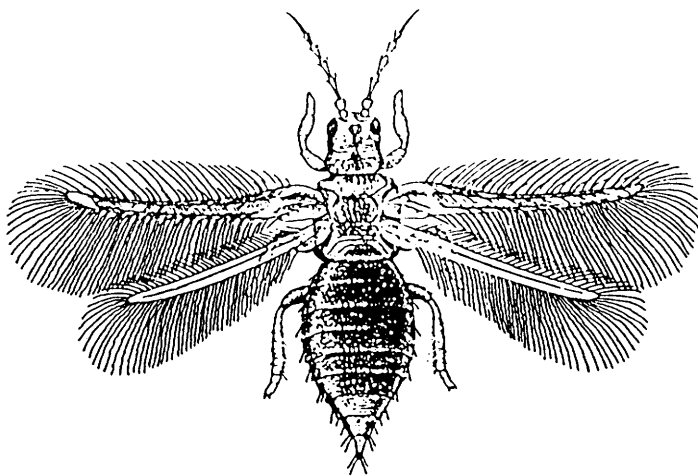


Figure 2. Thripidae adult (from Bailey 1938).



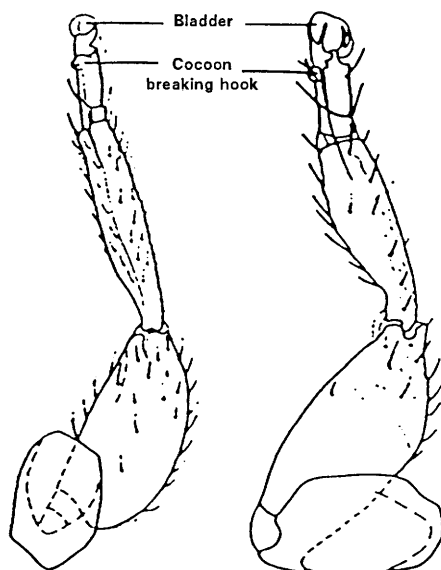


Figure 3. Bladder on the forelegs of Aeolothripidae (from Stannard 1968).

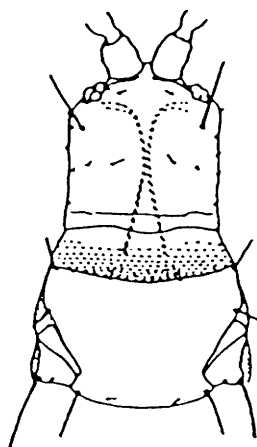


Figure 4. Maxillary stylets in head of Phlaeothripidae adult (from Stannard 1968).

Of the five families, the Adiheterothripidae with one species and Merothripidae with four species are seldom found and are not discussed further. The Heterothripidae (Fig. 5) with 20 species have strongly sclerotized bodies. The sides of the abdomen are reticulated and microtrichia are usually present. Posterior margins of the abdominal segments have a fringe of longer microtrichia. Antennae are 9-segmented with segments III and IV having small sensoria in rows or bands encircling the segments near the apices. Species in this family are found in flowers and on leaves but are not known to be of economic importance. There are about 57 species in the family Aeolothripidae; many are predaceous. They can be recognized by their large size and broad forewings, which are usually banded and their apices are usually broadly rounded (Fig. 6). Further, the antennae are 9-segmented; segments III-V are elongate and parallel sided, and the sensoria on III and IV are flat, linear or oval. The ovipositor is upturned (Fig. 7). None of the other families have upturned ovipositors.

The family Thripidae (Fig. 2) is the largest family in the Terebrantia with about 280 described species in North America. It is recognized by the down-turned ovipositor (Fig. 8), forewings are usually slender with pointed apices, and the sensoria on the antennae III and IV project either as simple or forked (trichome) sense cones. Most of the economic species are found in this family and the morphological characters to identify several of the species are discussed.

### Discussion of Adults

The following structures are some of the morphological characters used to identify thrips (Fig. 9). The antennae are located at the anterior part of the head. Between the compound eyes on the head are usually three ocelli (lens like organs) in a triangular arrangement. A crescent shaped coloration, the ocellar crescent, borders each ocellus. Normally, the crescents are orange to red. Also between the eyes are several setae, the ocellar setae. A pair of these setae in the ocellar area is known as the interocellar setae. The lateral margins of the head posterior to the eyes are referred to as the cheeks.

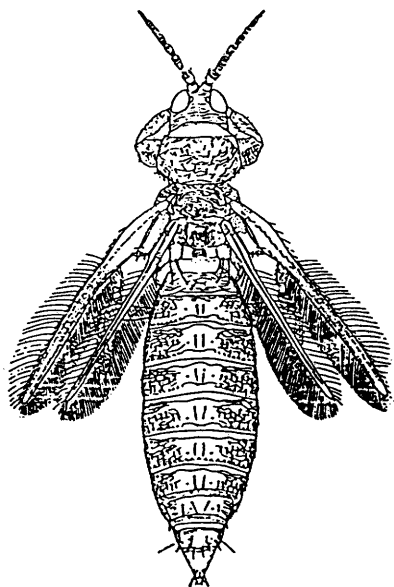


Figure 5. Heterothripidae adult (from Stannard 1968).

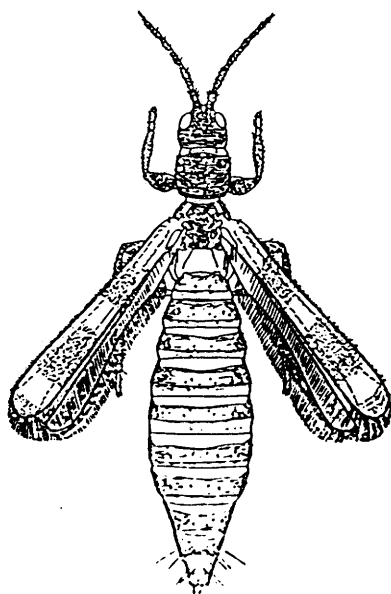


Figure 6. Aeolothripidae adult (from Stannard 1968).

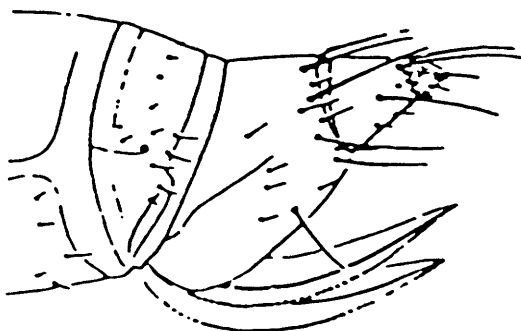


Figure 7. Ovipositor of female Aeolothripidae (from Kono & Papp 1977).

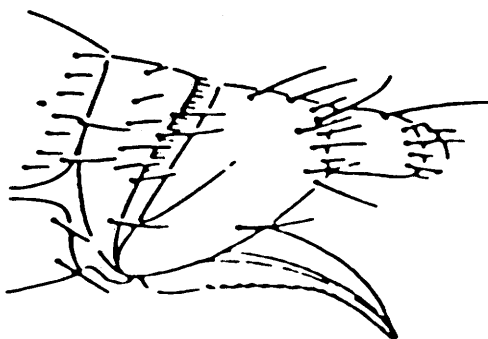


Figure 8. Ovipositor of female Thripidae (from Kono & Papp 1977).

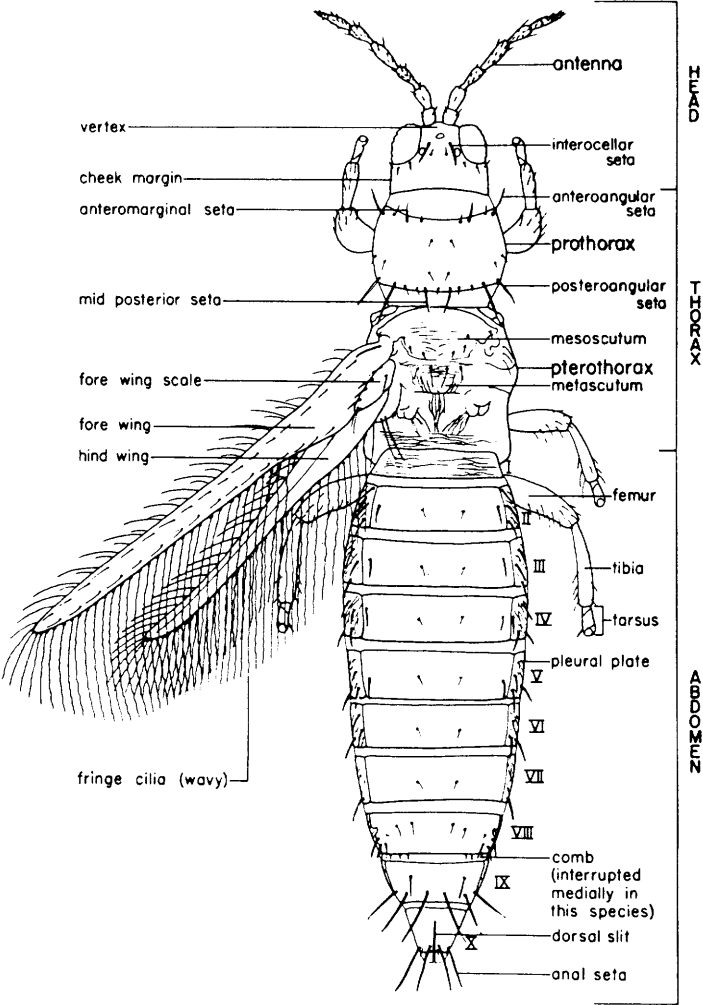


Figure 9. *Frankliniella tritici* (Fitch) (from Stannard 1968).

On the pronotum are various types of setae. One or two pairs of posteroangular setae, when present, are found on the posterior angular parts of the pronotum. Venal setae are present normally on two longitudinal veins on the forewings. The hind vein normally has a complete row of setae. On the forevein, the setae may be in a complete row or only a few irregularly spaced setae are found in the distal one-half. These setae are known as the distal setae. On the abdomen, the posteromarginal comb, which is a row of fine teeth, is found on the posterior margin of tergite VIII. A complete comb has a complete row of fine teeth, an incomplete comb lacks teeth from the median part, or the comb may be absent. Members of several genera such as *Frankliniella* and *Thrips* have a pair of submarginal ctenidia on abdominal tergites V-VIII. The ctenidium is a short row of fine teeth.

### Pear Thrips

The pear thrips, *Taeniothrips inconsequens* (Uzel) (Fig. 10), is known from Europe, Asia and in North America from British Columbia and Ontario in Canada and from Washington, Oregon, California, Utah, Maryland, Virginia, Pennsylvania, New York, Vermont, Connecticut, Massachusetts, New Hampshire and Maine in the United States. It has been reported from apple, pear, *Prunus* spp., maple and many other trees. This species has one generation per year, and lives most of its life in the soil.

The adult females have brown bodies. Antennae are 8-segmented, and the apical part of segment II and basal part of III are yellow or yellowish brown. Legs are generally brown; the tarsi and bases of tibiae and femora are yellow. Forewings are brown. The head has bulging eyes with the cheeks strongly arched, and two pairs of ocellar setae are present with the interocellar pair long and positioned between the posterior ocelli (Fig. 11). The distinctive feature of this thrips is the apical claw on the foretarsi (Fig. 12), which can be observed usually under the dissecting microscope. The pronotum has two pairs of long, well-developed posteroangular setae. Forewings have normally five to six setae on the distal one-half of the forevein.

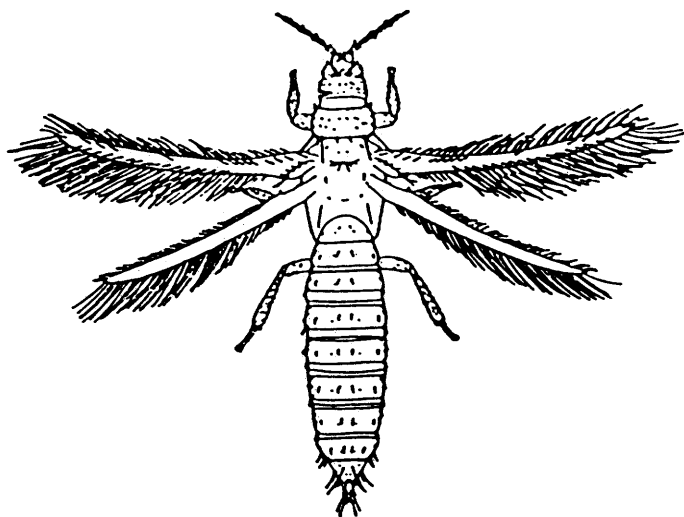


Figure 10. Pear thrips (from Bailey 1944).

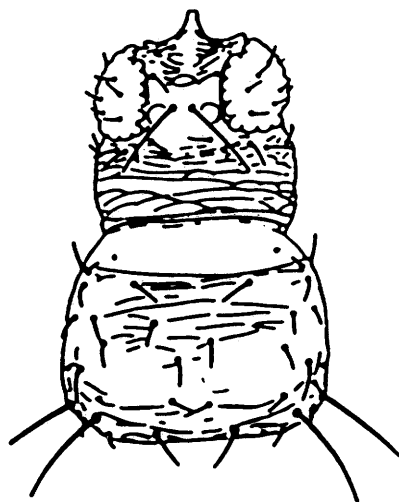


Figure 11. Head and pronotum of the pear thrips (from Mound et al. 1976).

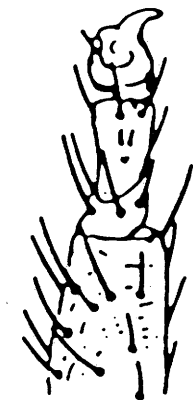


Figure 12. Apical claw on foretarsus of pear thrips (from Mound et al. 1976).



Figure 13. Tooth on foretarsus of *Thrips calcaratus* Uzel (from Mound et al. 1976).

The abdomen lacks ctenidia, tergum VIII has a well-developed posteromarginal comb, and only the median pair of posteromarginal setae on abdominal sternum VII is anterior to the posterior margin. The male has not been found in North America.

*Taeniothrips orionis* Treherne, a native species found in western North America, closely resembles the pear thrips in color and most characters; however, it lacks the apical claw and has three distal setae on the forewings.

### Basswood Thrips

*Thrips calcaratus* Uzel, the basswood thrips, was also introduced from Europe, and occurs in Ontario and Quebec in Canada and New York, Pennsylvania and Wisconsin in the United States. It infests various species of basswoods and other plants. Its life cycle is similar to that of the pear thrips.



The adult females have brown bodies. Antennae are 7-segmented; segment III, apices of II, and bases of IV and V are yellow. Legs have tarsi that are yellow and the tibiae are yellowish brown in the distal part. Forewings are grayish brown. The head has two pairs of ocellar setae, with the interocellar pair positioned between the anterior and posterior ocelli. The pronotum has two pairs of well-developed posteroangular setae. Instead of an apical claw, it has a distinctive thumb-like tooth on the distal tarsal segment (Fig. 13), which can be observed under the dissecting microscope. Forewings normally have three setae on the distal one-half of the forevein. The abdomen has ctenidia on tergites V-VIII, and tergum VIII has short, irregular spaced teeth on the posterior margin. Abdominal sternites III-VII have accessory setae. The male also has not been found in North America.

Some *Odontothrips* spp. have a small tooth on the foretarsi, but they also have one or two apical teeth or claws on the fore-tibiae, 8-segmented antennae, and lack accessory setae on the abdominal sternites. Most *Odontothrips* spp. feed on legumes.

### Flower Thrips and Tobacco Thrips

The western flower thrips, *Frankliniella occidentalis* (Pergande), another species of economic importance, is a vector of the tomato spotted wilt virus (TSWV). It varies in coloration from completely yellow to completely brown. The usual color form is yellow with brown blotches or shading on the abdominal tergites, and pale yellow forewings. Antennae are 8-segmented, and the pedicel of segment III is not angulate. The head has three pairs of ocellar setae. The pronotum has a pair of well-developed anteromarginal setae, which are almost as long as the anteroangular setae, and two pairs of posteroangular setae. Forewings have two complete rows of venal setae. Ctenidia are present on abdominal tergites V-VIII, and tergite VIII has a complete posteromarginal comb, which is short and sparse. The flower thrips, *F. tritici*, and several other common *Frankliniella* spp. may be confused with it. The flower thrips (Fig. 9) has a distinctly angulate pedicel III; the anteromarginal setae are usually one-half to two-thirds as long as the anteroangular setae, and the posteromarginal comb on tergum VIII

is incomplete, i.e. teeth are absent medially. The tobacco thrips, *F. fusca* (Hinds), is also a vector of TSWV and has a brown body, pale brown forewings when the wings are developed, and the posteromarginal comb is absent from abdominal tergite VIII. The tobacco thrips has brachypterous and macropterous forms.

### Onion Thrips

The cosmopolitan onion thrips, *Thrips tabaci* (Fig. 14), is a well known pest and a vector of TSWV. This thrips also varies greatly in color from pale grayish yellow to dark brown. The grayish brown ocellar crescent, which can be observed under the dissecting microscope, will separate it from most species in Thripidae, which have orange to red ocellar crescents. Other diagnostic characters are the 7-segmented antennae, short posteroangular setae present on the pronotum, forewings usually with four to five setae on the distal one-half of the forewings, and the posteromarginal comb on abdominal segment VIII with long, close-set teeth.

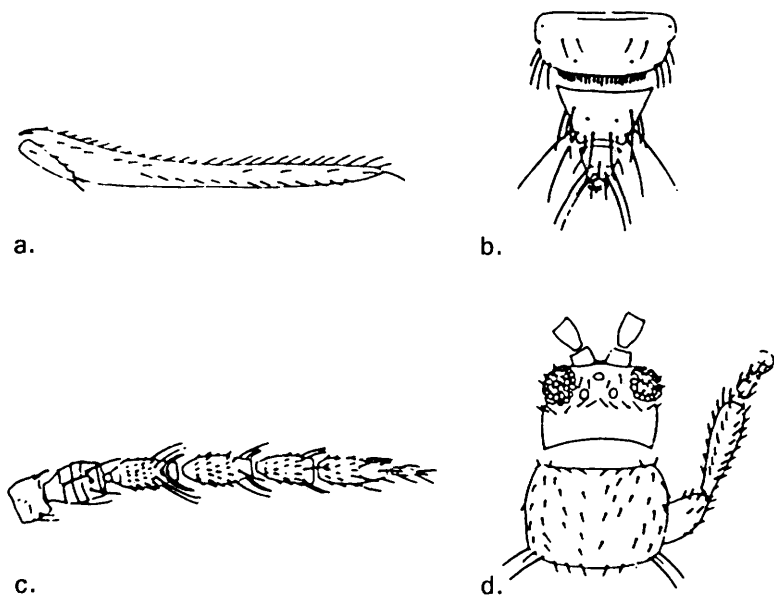


Figure 14. *Thrips tabaci* Lindeman (from Kono & Papp 1977); a. wing, b. abdomen, c. antenna, d. head and thorax.

### Discussion of Immatures

At present, only a few first instars can be identified to species, and pupae can not be identified specifically. Several papers have been published on the second stage larvae and some can be identified to specific or generic level (Speyer & Parr 1941, Vance 1974, Miyazaki & Kudo 1986).

Larvae of the Thripidae have 7-segmented antennae on the head, three thoracic segments with three pairs of legs and a pair of spiracles on the mesothorax, and a 10-segmented abdomen with a pair of spiracles on the second and eighth abdominal segments (Fig. 15). The first stage larvae differ from the second stage larvae by having six pairs of setae on the pronotum and four pairs of setae on abdominal segments III-VII. The second stage larvae have seven pairs of setae on the pronotum and six pairs of setae on abdominal segments III-VII.

The head and body of pear thrips larvae are pale and lack sclerotization except on abdominal segments IX-X. Abdominal segment IX has seven-eight large dorso-lateral teeth on the posterior margin (Fig. 16). The two medial teeth are smaller than the lateral ones. A ventral row of small teeth is present on the posterior margin.

The basswood thrips larvae also do not have sclerotization on the head or body, except on abdominal segment IX and X. Abdominal segment IX has 17-18 large dorso-ventral teeth on the posterior margin. The lateral teeth are larger than those dorsally or ventrally. A ventral row of 8-10 small teeth is present.

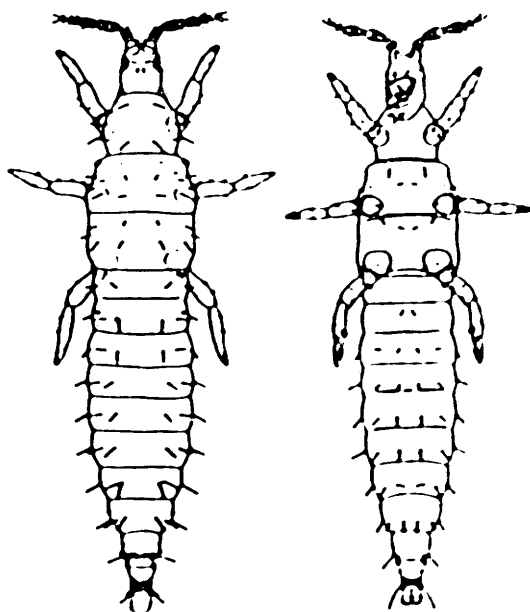


Figure 15. Second instar *Frankliniella intonsa* (Trybom) (from Speyer & Parr 1941).

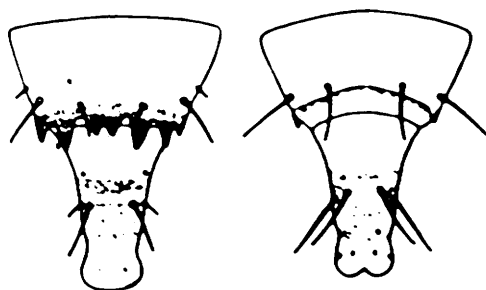


Figure 16. Abdominal segment IX-X of the second instar pear thrips (from Speyer & Parr 1941).

## Preserving and Mounting Specimens

Thrips may be collected and preserved in 60 or 70% ethanol. However, a better solution in which to collect and preserve thrips is AGA. This consists of eight parts of ethanol, five parts of distilled water, and one part each of glacial acetic acid and glycerine. This solution relaxes the wings and legs, which can be spread and aligned easily when the thrips are mounted on a slide. Specimens should not be kept over a year in AGA and should be transferred to 60% ethanol for longer storage.

When quick identifications are needed, temporary slide mounts prepared with Hoyer's or polyvinyl lactophenol may be used. These media will also clear the specimens. For permanent mounts, the specimens should be treated with sodium hydroxide and mounted in Canada balsam or other artificial media.

## Acknowledgment

I thank V. L. Blackburn, Plant Protection and Quarantine, USDA-APHIS, J. Neal, USDA-ARS, and R. W. Poole and M. B. Stoetzel, Systematic Entomology Laboratory, USDA-ARS, for their reviews of the manuscript and comments. I also thank the following authorities and colleagues for permitting me to use the illustrations included in this paper: L. M. Page, Illinois Natural History Survey (Stannard 1968); G. G. Bentley, Royal Entomological Society of London (Speyer & Parr 1941, Mound et al. 1976); J. Palmer, British Museum (Natural History) (Mound et al. 1976); and Mr. T. Kono, California Department of Food and Agriculture (Kono & Papp 1977).

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### Discussion Period

Question: How well is coloration maintained in preserved thrips specimens; is pigmentation retained for a long time?

Nakahara: Yes, color loss is not a problem; specimens do not fade after a year or more in solution. Thrips should be collected in AGA solution, but they will not hold up well for a long period of time and should be transferred to 60% ethanol after about a year.

Question: Is there an alternative to glacial acetic acid?

Nakahara: You can use vinegar, which is basically the same thing. One or two drops in a vial of alcohol is plenty. Acetic acid relaxes the thrips appendages which facilitates mounting, reducing the difficulties of spreading the wings.

Question: Is a typical thrips specimen obtained if collected directly from the soil as it emerges and mounted before it feeds on any plant tissue? Is the identifying color characteristics the same as those collected after they have fed on plant tissue?

Nakahara: Slight variation in coloration can occur among thrips. I have noticed colors ranging from yellow to reddish-orange among specimens of the same species. I don't know if this variation in color is a result of the plants they feed upon, but it may be. Thrips that have not yet fed often appear paler than those that have fed on plant tissue. However, the body pigments and basic distinguishing taxonomic features, such as the tarsal and abdominal structures will be present whether they have fed on plant tissue or not.

Question: What is the function of the sense cones, and the bladder on the foretarsi?

Nakahara: I haven't investigated the function of the sense cones, but I assume they are sense receptors of some sort. One theory is that the tarsal bladder is used to hold on to the host, which is a logical thought.

Question: Are you satisfied with the current state of thrips taxonomy, or do you believe that some groups need revision? Is there any work on thrips taxonomy underway presently?

Nakahara: I have just finished writing a manuscript on the Thripidae of North America. The last revision, which included 31 species, was done in 1968. Sixty species are included in my manuscript. It's a matter of the concept of what distinguishes a species. The taxonomy of thrips is evolving. For example, at one time the genus *Thrips* and *Taeniothrips* were only separated by the number of antennal segments, with eight segments in *Taeniothrips* and seven in *Thrips*. The problem that taxonomists faced was that you can get a specimen with seven segments on one antenna and eight segments on the other. Now what are you going to do in that case? Taxonomists now use other characters than the number of antennal segments to separate thrips genera. Therefore of the ten species originally in *Taeniothrips* only two now remain, and the rest have been put in different genera.

Question: Is anyone doing systematic work other than using morphology, such as DNA hybridization?

Nakahara: Not in the United States or Canada. Unfortunately I believe I'm the only person in this country doing systematic work on thrips. I'm glad to see so many people interested in thrips. It's been a long time since I've seen this many gathered together to talk about thrips.

Question: Are the drawings that you showed included in your manuscript, and when will it be published?

Nakahara: Probably in a couple of years, depending on funding. I work for a national agency, and therefore the availability of money is always a problem.



**BEHAVIOR AND BIOECOLOGY**

## FEEDING, FLIGHT AND DISPERSAL IN THRIPS

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### Introduction

The aim of this paper is to amplify some of the general points made in my introductory paper on the order Thysanoptera (Lewis 1990, this proceedings), with particular reference to feeding, flight and dispersal. These aspects of thrips behaviour are clearly of great relevance to the spread and effects of infestations of *Taeniothrips inconsequens* in New England, and although most of the work described has concentrated on another species, *Limothrips cerealium* (Haliday) (Lewis 1973, Chisholm & Lewis 1984) much of the information is probably applicable to terebrantian species of similar phytophagous habits and size such as the pear thrips.

### Feeding

During feeding on stem, leaf or flower sap, adult and larval thrips adopt a characteristic stance with the tip of the mouthcone pressed on to the substrate surface with which close contact is maintained by means of the labial pad (see p. 5, Fig. 1). The maxillary and labial palps are spread out on each side and just touch the substrate, presumably to provide sensory information (Fig. 1). Other hairs and sensillae on the front of the head and paraglossae, respectively, probably have a tactile and chemosensory function. When the insect is not feeding, the labral pad is withdrawn and covered by the paraglossa. As the thrips explores a feeding site these move aside to expose the horseshoe-shaped labral pad which rapidly unfolds to its full size as it is pressed against the substrate.



Figure 1. Side view of mouthcone of feeding *Limothrips*; maxillary palps (left) and labial palps (right) sense the leaf surface; the labral pad and paraglossal sensilla are pressed closely against it (x250).

The mandible is stout with a broad base apparently fused to the internal ridge marking the junction between frons and clypeus. In fact, it is articulated to this thickening at one point only, so as to make an initial opening in plant tissue. The whole head capsule, with the mouthcone serving as pivot, is thrust downwards and slightly backwards, then the mouthcone shortens, forcing the mandible to protrude about  $20\ \mu$  and rupture the epidermis of the plant tissue. The final penetrative stab is usually preceded by a series of less powerful exploratory thrusts.

Once the plant epidermis is pierced the mandible is largely withdrawn and the two styliform maxillae are inserted as a unit up to  $60\ \mu$  into the underlying cells. The two stylets can move independently, but because ridges on the right stylet fit into grooves bordering the left stylet they function jointly as an efficient tube through which cell contents are imbibed.

Cinematographic pictures of feeding (Chisholm & Doncaster 1982) show inflow confined to the end of the tube, but liquid can be taken through a sub-terminal orifice even when one stylet is extended a shorter distance than the other.

Muscular pulsations at 2-6/sec are visible through the pale head capsule of larvae, and the resulting pumping action draws in liquid and chloroplasts from the plant. The internal diameter of the maxillary tube in *L. cerealium* is only about  $1\ \mu\text{m}$ , far smaller than wheat protoplasts. However, the thrips easily pierce the plasmalemma enclosing each protoplast with their maxillae, gaining access to the chloroplasts. Even when these greatly exceed the diameter of the maxillary tube, the suction created by the muscular pumping is sufficient to distort them enough to allow their passage up the tube. This species appears able to ingest about  $8.5 \times 10^{-5}\ \mu\text{l}/\text{min}$  which equates to about 12.5% of its body weight per hour.

By contrast Day & Irzykiewicz (1954) estimated that *Thrips tabaci* Lindeman, a smaller species than either *L. cerealium* or *Taeniothrips inconsequens* imbibed about 17% of its body weight per hour; 10-20% would seem a likely average consumption for phytophagous Terebrantia.

The effects of stylet penetration by *Limothrips* are easily detectable microscopically on the surface and within leaves. Externally, probing sites are visible because the presence of the labral pad removes surface wax, and the leaf cuticle so exposed often wrinkles, indicating plasmolysis in the epidermal cells. Sometimes a "silvered" patch develops under an area of concentrated punctures as air penetrates the emptied plant cells. Many of the holes remaining after the stylets have pierced the leaf are approximately "figure-of-8"-shaped, presumably produced by the mandible and maxillae, though the extent to which this shape is attributable to probing or subsequent wrinkling of the substrate is uncertain (see p. 13, Fig. 2).

Within leaves, there is little sign of seepage of cell contents after feeding, indicating that the cells below the puncture are completely emptied. These empty cells are clearly visible, even where feeding has been light and where no surface silvering is visible. Emptied cells usually lie beneath a collapsed epidermal cell, and their appearance is the same whether the upper or lower epidermis has been pierced.

After more extensive feeding, when the plant tissue shows obvious external signs of damage, including widespread silvering, the internal cell structure is completely disrupted, the epidermal cells, especially the bulliform cells become shrivelled and distorted, a sign of extreme desiccation (Esau 1961). Many of the mesophyll cells disappear completely, others retain no cytoplasm or cell contents, and those that do show extreme plasmolysis with the cytoplasm contracting from the cell walls and deformed chloroplasts. The epidermal cells often collapse completely, with visible wrinkling of the outer cuticle. Cytoplasm contracts away from mesophyll cell walls which become flaccid. These effects are not directly attributable to feeding but flow from desiccation of the pierced and surrounding cells.

The effects of leaf-feeding by other terebrantian thrips on other crops can be much more obvious and serious. Heavily infested leaves of all ages shrivel, become discolored and brittle, and eventually fall, especially in hot, dry weather (Lewis 1973). To the extent that many of these harmful species, including *T. inconsequens*, are of a similar size to *L. cerealium* with mouthparts likely to penetrate to similar depths, the effects of feeding on leaves by thrips described above probably apply to most leaf-feeding species in the sub-order.

### Flight and Dispersal

Thrips are among the weakest flying insects, yet their finely fringed wings enable them to remain airborne long enough for the wind to blow them to great heights and for long distances. Indeed, migration by flight from breeding sites is a regular event in the life cycle of many species. Although it produces widespread scattering, resulting in the loss of millions of individuals, it nevertheless ensures that fresh food is found for breeding populations, and sheltered sites for protection during unfavorable seasons.

The upper limit to which thrips are carried is unknown but, in Louisiana, using sticky traps fitted to aircraft, Glick (1939) caught one *Frankliniella tritici* (Fitch) and one *Haplothrips graminis* Hood above 3,100 m (10,000 ft) and 89 specimens representing at least 16 species at lower altitudes above 6 m (20 ft). At Darango, Mexico, *Stomatothrips flavus* Hood and *Caliothrips phaseola* Hood were caught at 1,200 m (4,000 ft). An interesting and surprising feature of the data from Louisiana is the number of thrips caught at night, representing 35% of the total when catches from 150 m (500 ft) are included. Five out of the six night-flying individuals caught by Glick were at 150 m, but a *Sericothrips* sp. was caught at over 1,500 m (5,000 ft). Night flight can prolong the migration of other insects, for example aphids (Berry & Taylor 1968), and small insects may often fly at night in continental regions where warm, low-level jet streams develop above nocturnal inversions enabling individuals carried upwards earlier in the day to remain airborne during darkness.

There are a few indications that the migration of some thrips species over large continental land masses might be associated with frontal winds. In the United States *F. tritici* may be blown northwards every year. It has never been recorded hibernating in Illinois, yet large numbers of this species appear suddenly in spring (Stannard 1968), and similarly in Maryland it was suddenly abundant in June, 1957 (Henneberry et al. 1961). In view of the major displacements of leaf hoppers, bugs and aphids by large-scale weather systems in North America, it seems probable that flying thrips could likewise be carried by frontal winds.

Notwithstanding Glick's (1939) records, most flight usually occurs during the warmest period of the day (Lewis 1973) so the insects are airborne when ascending convective movement is greatest and many are blown upwards and away from their breeding or overwintering sites. Tree-dwelling species or those emerging from the ground beneath a tree canopy, as is the case with pear thrips in a sugarbush, may represent a special case in that the emerging population in spring is subject to less convective air movement than populations emerging in more exposed habitats. Nevertheless, it would be surprising if there were not some significant movement of such species over long distances, particularly of individuals from the edges of the stands, and trapping with suction and/or sticky traps (Lewis 1973) at different distances from sugarbushes should resolve this question. Important details of the design and placement of traps and interpretation of trap catches are given by Lewis (1973). White traps are known to be particularly attractive to several species of *Taeniothrips* (Lewis 1961). Vertical profiles of aerial density, corrected as appropriate for wind speed at different altitudes (Johnson 1957, Lewis 1959, 1964) would also indicate the propensity of pear thrips to disperse long distances. Concentrations of pear thrips populations around the edges of sugar maple stands may occur if individuals are widely distributed by aerial currents, as is the case with *Taeniothrips laricivorous* Kratochvil on the edges of larch stands (Zenther-Møller 1965).

Some species are renowned for "mass" flights, usually occurring when populations build up on host plants, then take off in response to favorable weather (Lewis 1964, 1965). In England some species of *Taeniothrips* behave in this way. A careful study of the effect of weather on mass flights of *L. cerealium* in southern England (Hurst 1964, Lewis 1964) showed that six meteorological criteria were likely to pertain. These were: no rain or drizzle during the day, maximum temperature at least 20°C, day mean temperature above that of the previous day, low dry adiabatic lapse rate with no convection above about 1,600 m (5,000 ft), at least 1 h of sunshine, and dew point between 5 and 15°C. However, *Taeniothrips* spp. were among those that did not always conform to these criteria, and they sometimes flew in more humid and cooler conditions. A study of the flight habits of *Taeniothrips inconsequens* in New England in relation to weather would therefore be a novel and probably rewarding exercise.

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**STRUCTURE OF THE MOUTHPARTS OF  
*Frankliniella bispinosa* (Morgan) (THYSANOPTERA: THIRIPIDAE)**

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**Introduction**

Thrips are increasingly recognized as potentially serious pests in a number of different agricultural, ornamental and sylvan commodities worldwide as indicated by the papers presented at this conference. The small size of thrips, their large numbers, capacity for flight and wind dispersal, wide host ranges, poorly understood life histories and probable potential for pesticide resistance exacerbate the timely development of control strategies. Thrips feed on pollen, leaves, flowers or young fruit and oviposit in various plant tissues. Some thrips feed on other arthropods or on fungal spores or hyphae. Plant injury is characterized by chlorosis, distortion or galling of leaves, spotting of leaves or fruit with fecal droplets, scarring of young fruit, premature fruit loss, or reduced yields from excessive reduction by feeding in the quality or quantity of viable pollen (Palmer et al. 1989). Several thrips species also function as direct or indirect vectors of certain viral, fungal or bacterial diseases (Ananthakrishnan 1980). These problems focus on the need for a better understanding of thrips including the structure and function of their mouthparts relative to plant injury and disease transmission.

Studies by Mound (1971), Heming (1978), Milne & Manicom (1978), Chisholm & Lewis (1984) and others have conclusively shown that thrips have piercing-sucking mouthparts. Excellent morphological studies of a limited number of thrips species have been completed including the larvae of *Haplothrips verbasci* Osborn by Heming (1978), *Limothrips cerealium* (Haliday) by Chisholm & Lewis (1984), *Scirtothrips citri* (Moulton) by Wiesenborn & Morse (1988), *Frankliniella occidentalis* (Pergande) and *F. schultzei* (Trybom) by Hunter & Ullman (1989).

Thirteen species of thrips have been identified in association with citrus flowers and developing buds in Florida with *Frankliniella bispinosa* (Morgan) the prevalent species (Childers et al. 1990). Injury to citrus flowers and buds by *F. bispinosa* has been documented (C.C.C. & D.S.A, unpublished data). Chemical control programs are in progress to evaluate the impact on fruit set following suppression of thrips during the citrus flowering cycle.

The object of this paper is to review the structure of the mouthparts of *F. bispinosa* illustrated by a series of light, scanning and transmission electron micrographs. This will provide additional information to identify or compare structures with those of other species of thrips.

### Materials and Methods

At frequent intervals between February and April 1988, thrips were collected from open flowers or swollen buds in a "naval" orange grove directly into one pint or one quart Mason jars filled with 70% ethanol and returned to the laboratory. Open flowers and swollen buds with live thrips were collected directly into paper bags in the field, placed in an ice chest and returned to the laboratory for processing.

**Light Microscopy.** Whole-mounts of thrips were prepared using Hoyer's mounting medium (Krantz 1978). Light micrographs were taken through a Zeiss compound microscope equipped with a Minolta 35mm camera on Panatomic X ASA 32 film.

**Scanning Electron Microscopy (SEM).** Chloroform was applied directly to the blossom on which selected individual thrips were feeding in the laboratory. Dead or inactive thrips were then transferred into micro-tissue capsule tubes enclosed by 150 mesh grids and placed in 3% glutaraldehyde or Hallam's variation of Karnovsky's fixative with a 0.1 M potassium phosphate buffer at pH 7.2 for 3-4 hr (Hallam & Chambers 1970). Post-fixation was in 2% osmium tetroxide in the same buffer for 4 hr at 25°C. Samples were dehydrated in ethanol and critical point dried in a Ladd Critical Point Drier using carbon dioxide. Thrips were mounted ventral side up on stubs, sputter coated with 150-200 Å gold in a Ladd Sputter Coater and examined and photographed with a Hitachi S530 Scanning Electron Microscope.

**Transmission Electron Microscopy (TEM).** Individual thrips were fixed as above, dehydrated in acetone and embedded in Spurr's plastic (Spurr 1969). Gold and silver sections made on an LKB Huxley Ultramicrotome were stained with methanolic uranyl acetate (Stempack & Ward 1964) for 15 minutes and post-stained with lead citrate (Reynolds 1963) for five minutes. Grids were examined with a Philips 201 electron microscope. For light microscopy, one micrometer transverse sections of embedded thrips mouthparts were prepared using glass knives. Each section was collected and counted from the first identification of stylets. Sections were stained with 0.1% toluidine blue before observation (O'Brien et al. 1964).

## Results and Discussion

Numerous setae are evident on the frons (f) and genal (g) areas of the head and mouthcone of *F. bispinosa* (Fig. 1) while the clypeus (c) is free of setae. The mouthcone of *F. bispinosa* is typical for terebrantian thrips and is characterized by the presence of the labrum (lm) in front, two distally tapered lobes, the maxillary stipites (ms), that form the sides of the mouthcone and the labium (=prementum (pm) and postmentum (psm)) behind (Heming 1978) (Figs. 1, 2). The mouthcone is about 130 µm long in the adult female *F. bispinosa*, is situated towards the basal end of the head capsule, and projects ventrally between the prothoracic legs (Fig. 2).

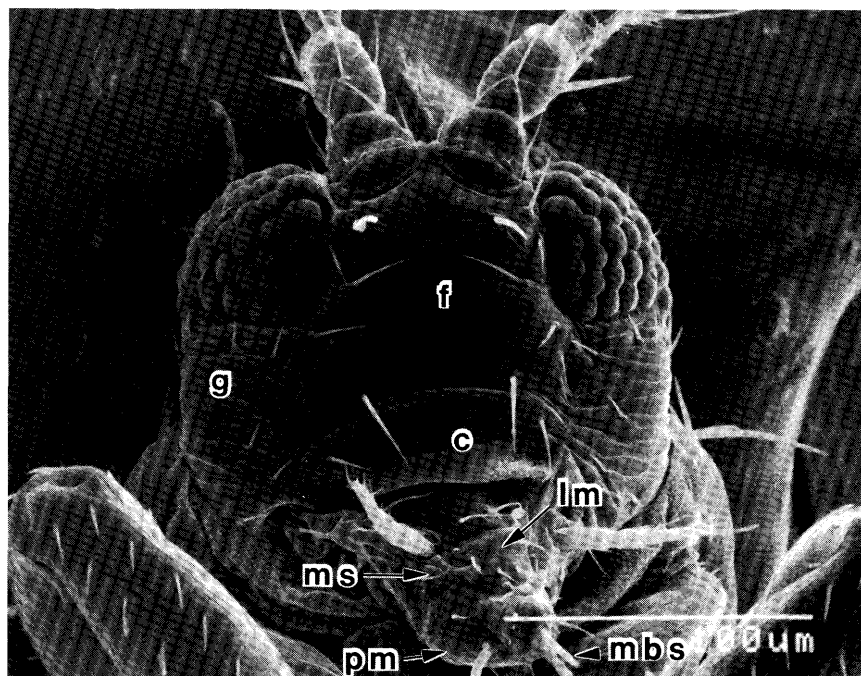


Figure 1. Scanning electron micrograph (SEM) of the head capsule of an adult female of *F. bispinosa* showing: (g) gena, (f) frons, and (c) clypeus. Mouthcone showing: (lm) labrum, (ms) maxillary stipes, (pm) prementum and protruding (mbs) mandibular stylet.

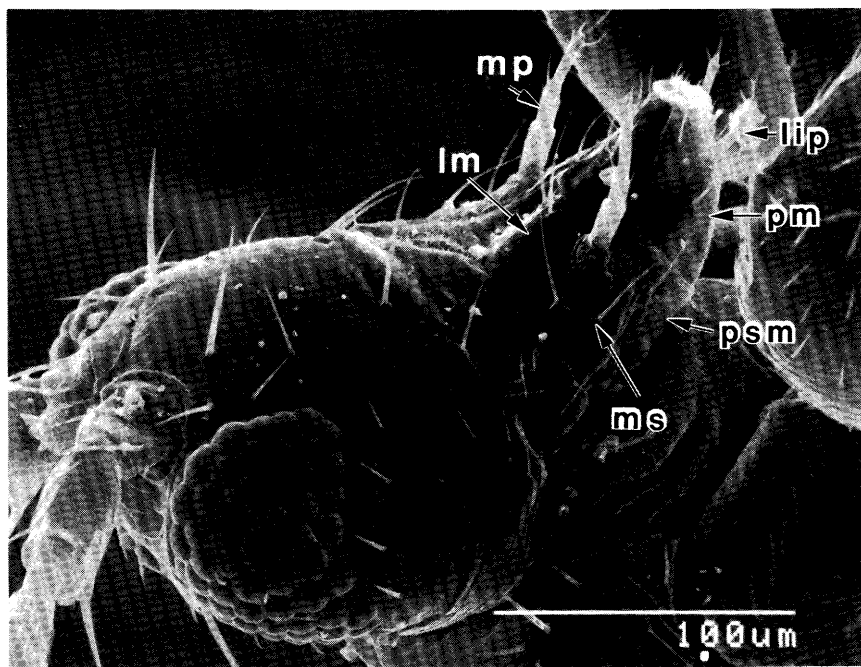


Figure 2. SEM of the lateral aspect of head capsule showing: (ms) maxillary stipes, (pm) prementum, (psm) postmentum, (lip) labial palp, (lm) labrum and (mp) maxillary palp.

The principal feeding structures contained within the mouthcone resemble those of hemipterans and consist of cibarial and salivary pumps, and elongate hypopharynx, two maxillary stylets and the left mandibular stylet (Heming 1978). Thrips differ from hemipterans in having maxillary and labial palpi, lacking both mandibular plates and a salivary canal between their protracted maxillary stylets and in having only the left mandibular stylet (Heming 1978).

The larger maxillary palpi (mp) are inserted into the maxillary stipites (ms) about midway down the mouthcone while the smaller, labial palpi (lip) are at the tip of the prementum (pm) (Fig. 2). Located at the distal end of the mouthcone are two paraglossae (pg) (Fig. 3). When a thrips is not feeding, the paraglossae press against each other providing a protective cover over the tip of the mouthcone. Each paraglossa bears a series of three morphologically distinct types of sensilla comprising (1) sensilla basiconica without a distinct cuticular collar (sbo) (2) sensilla basiconica with a distinct cuticular collar (sbc) and (3) sensilla trichodea (st) (Figs. 3, 4) (Richards & Davis 1977, Chisholm & Lewis 1984). Hunter & Ullman (1989) demonstrated that these sensory pegs are innervated. Their position and proximity to the feeding site suggest an olfactory and gustatory function (Chisholm & Lewis 1984). Arrangement, number and type of sensory pegs in females of *F. bispinosa* are similar to those of *F. occidentalis* (Hunter & Ullman 1989). However, Chisholm & Lewis (1984) reported only nine individual sensilla on each paraglossa of *Limothrips cerealium*.

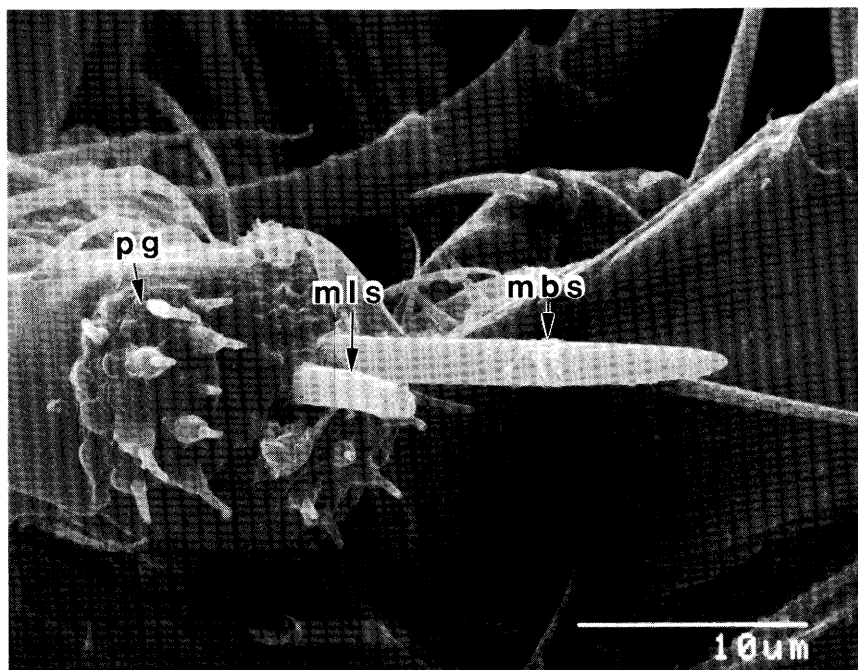


Figure 3. SEM of the tip of mouthcone showing: (pg) paraglossa with sensory pegs, (mls) paired maxillary stylets and (mbs) single mandibular stylet.



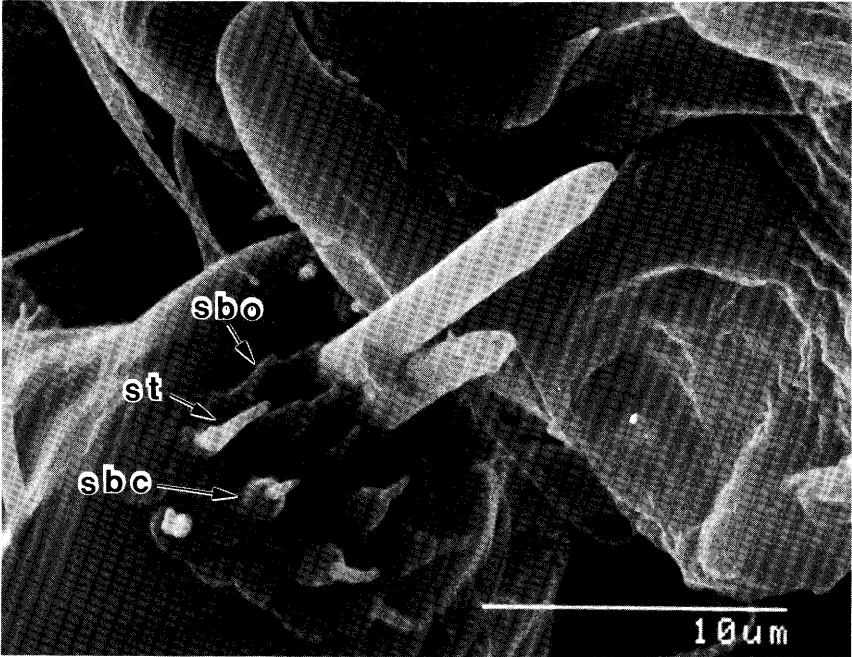


Figure 4. SEM of the mouthcone showing paraglossa with: (sbo) sensillum basiconicum without a distinct cuticular collar, (sbc) sensillum basiconicum with a distinct cuticular collar and (st) sensilla trichodeum.

When the paraglossae open laterally, they expose the ventral surface of a horse-shoe shaped labral pad (lp) bearing elongate papillae about its dorsal and lateral margins (Figs. 5, 6, 7). A second set of more slender papillae (p) are situated along the ventral edge of the pad. The function of these papillae is not known (Chisholm & Lewis 1984). The labral pad of *F. bispinosa* females is around 11  $\mu\text{m}$  across.

A thrips presses the tip of its mouthcone against the plant substrate in preparation for feeding. This close contact is maintained by means of the labral pad. According to Chisholm & Lewis (1984) the only function presently attributed to the labral pad is to support the slim maxillary stylets as they are protracted into plant tissue. Thrips use the single mandible to make an initial opening by punching through the plant cuticle before feeding. Entry is achieved by a characteristic rocking of the head and a forceful downward and backward thrusting of the head capsule (Chisholm & Lewis 1984).

Based on studies by Heming (1978), the mandible is capable of only limited movement due to its orientation, musculature and articulation within the head capsule. He indicated that maximum protraction of the mandible is about one-third of its length. Chisholm & Lewis (1984) found that adult females of *L. cerealium* never extended the mandible beyond 20  $\mu\text{m}$  even though its overall length was 102  $\mu\text{m}$ . Maximum observed protraction of the mandibular stylet was 41  $\mu\text{m}$  for one *F. bispinosa* adult exposed to chloroform while feeding (Figs. 8, 9). The mandibular stylet lacks an opening or food channel and is used principally to punch a hole in the substrate followed by insertion of the paired, tongue-in-grooved maxillary stylets (Fig. 10).

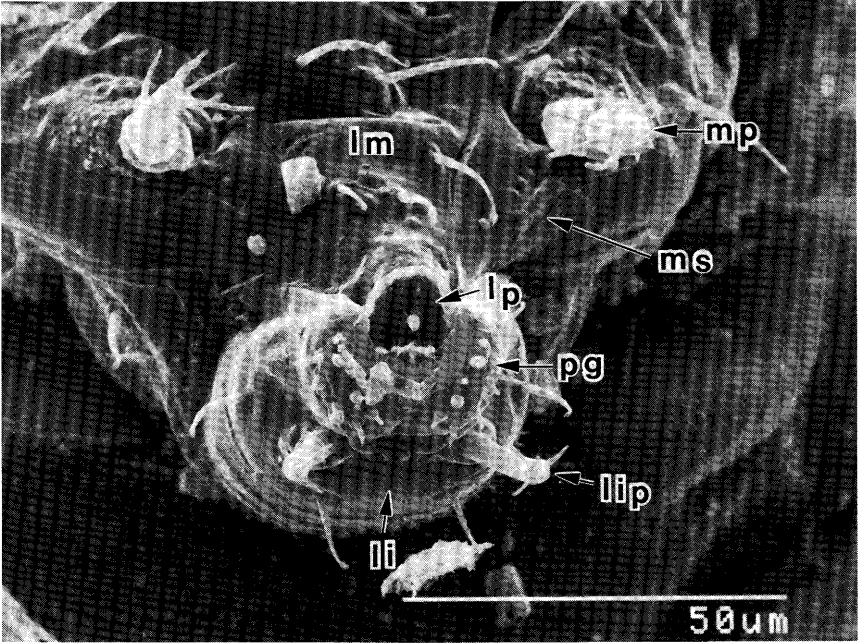


Figure 5. SEM of the frontal aspect of mouthcone showing: (lm) labrum, (mp) maxillary palp, (ms) maxillary stipes, (lp) labral pad, (pg) paraglossa, (lip) labial palp and (li) labium.

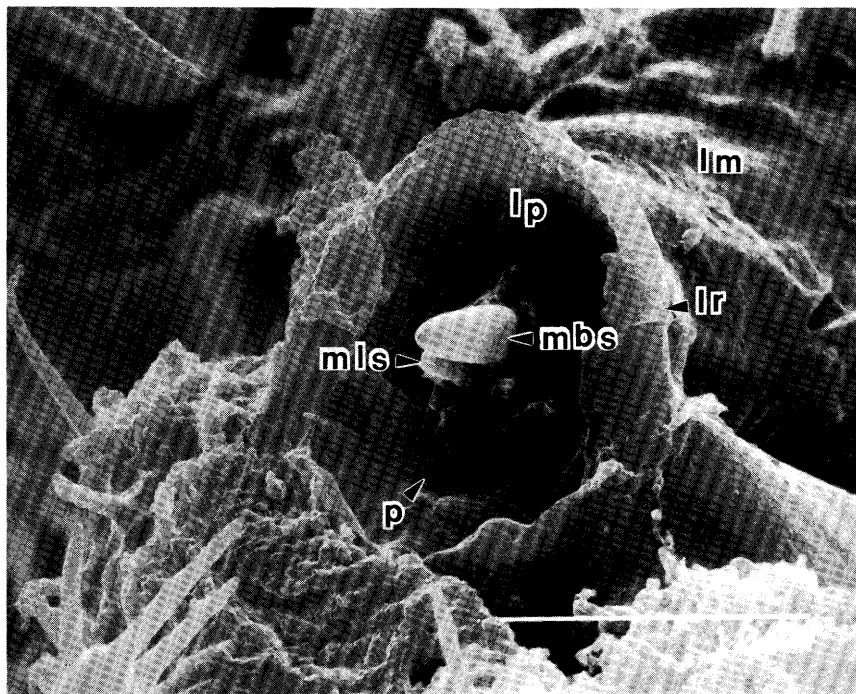


Figure 6. SEM of tip of mouthcone showing: (lm) labrum, (lp) labral pad, (lr) ring of papillae, (mbs) tip of mandibular stylet, (mls) paired maxillary stylets and (p) ventral papillae associated with part of glossa.

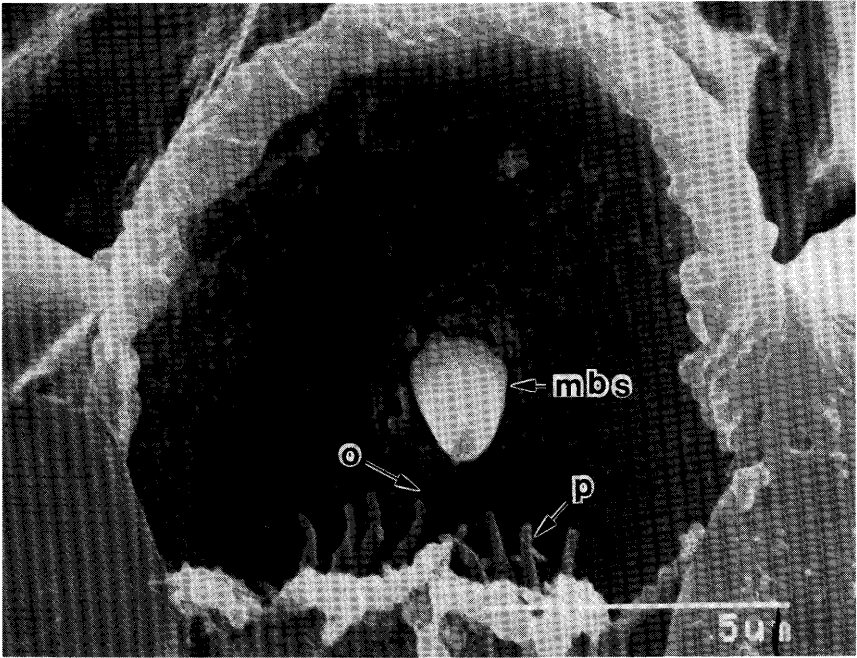


Figure 7. SEM of labral pad showing: (mbs) tip of mandibular stylet, (o) opening in pad for stylet protraction and (p) ventral papillae.

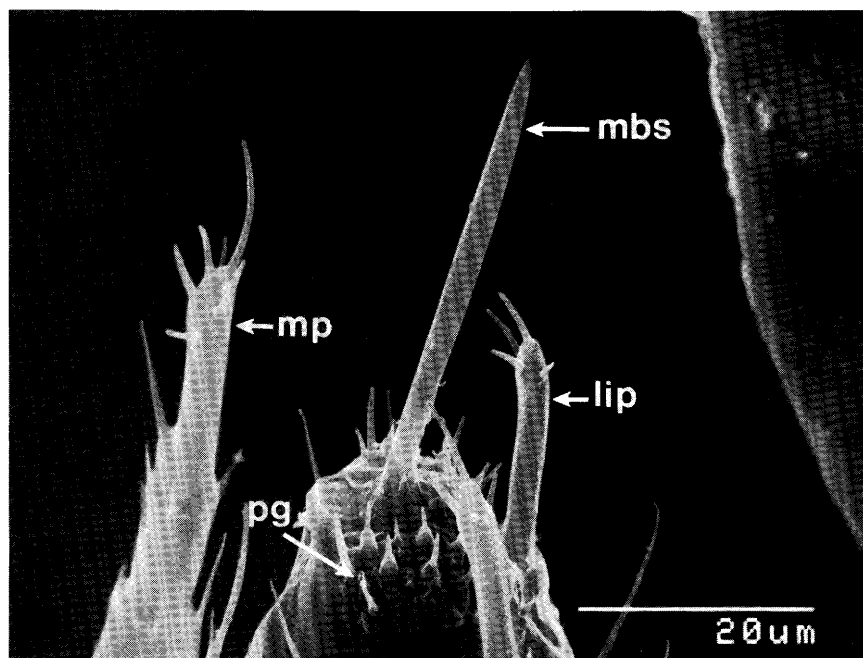


Figure 8. SEM of mouthcone showing: (mbs) protracted mandibular stylet, (lip) labial palp, (pg) paraglossa and (mp) maxillary palp.

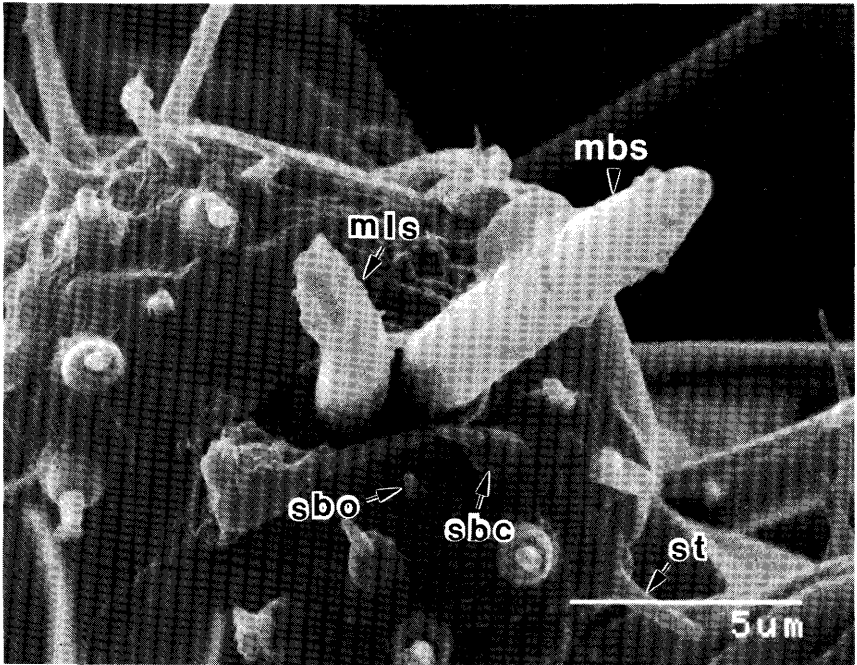


Figure 9. SEM of tip of mouthcone showing separating paraglossae: (mls) curved pair of maxillary stylets, (mbs) single mandibular stylet, (sbo) sensillum basiconicum without a distinct cuticular collar, (sbc) sensillum basiconicum with a distinct cuticular collar and (st) sensilla trichodeum.

The maxillary stylets are capable of being extended or withdrawn singly (Fig. 10) or together (Figs. 9, 11) and each is equipped with an internal longitudinal groove that, when the two stylets are interlocked, provides a hollow tube for withdrawing food material from the underlying cells (Mound 1971). Adults of *F. bispinosa* have a subterminal opening (so) on the maxillary stylets (Fig. 10) and their tips are asymmetrical (Figs. 10, 11). The right stylet tip is larger and slightly broader than that of the left. Maximum observed protraction of the maxillary stylets was 50  $\mu\text{m}$  for one *F. bispinosa* specimen that had been exposed to chloroform while feeding. This length corresponds to the average depth of feeding injury observed in citrus flowers and developing buds (C.C.C. & D.S.A., unpublished data).

A light micrograph of the somewhat flattened mouthcone of a *F. bispinosa* female is shown in Figure 12. The labral pad (lp) and ring (lr) were distorted and pulled out of position in this preparation allowing a clearer view of several otherwise overlapping structures. The hypopharynx (h) is exposed as well as the food canal (fc) in its anterior surface and (e) indicates the tips of the two maxillary stipites (Fig. 12). The sclerite of the labial glossae including associated sensilla is indicated by (slg).

Cross sections were prepared for TEM and provide a clearer view of the arrangement of the principal internal structures of the mouthcone to illustrate their position and relative size (Figs. 13-15). Figure 13 shows a cross section of the mouthcone around 10  $\mu\text{m}$  above its apex. The outer two elements are the labial paraglossae (pg). Anteriorly, the fused glossae (fg) are surrounded by the labral pad (lp). The labrum (lm) is located in the center and encloses the two irregular, broadened tips of the maxillary stylets (mls) and three parts of the irregular tip of the hypopharynx (h) in this section. The mandibular stylet (mbs) contains three diverging sensory dendrites (d). At this level, the food and salivary canals are not present.



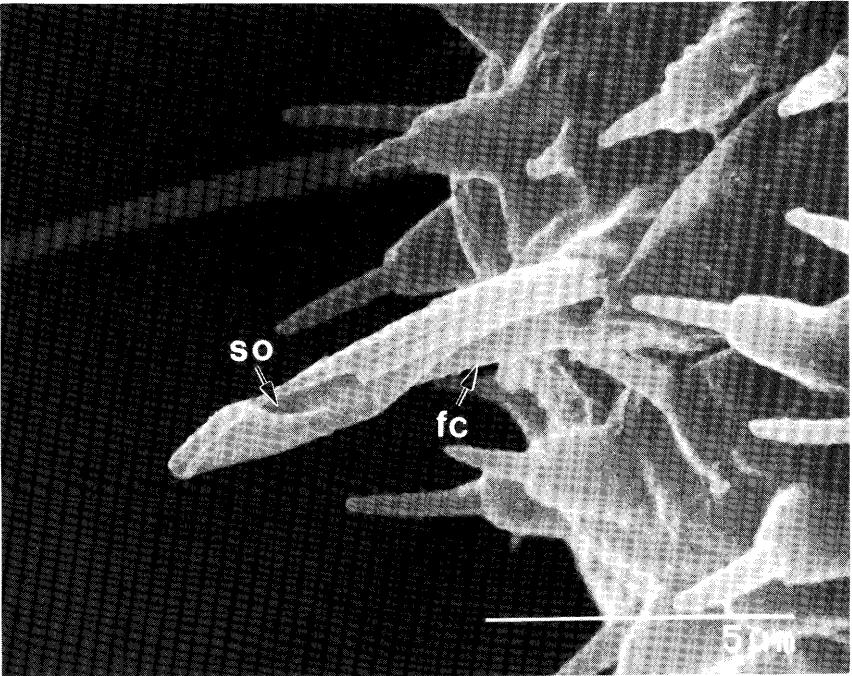


Figure 10. SEM of tip of mouthcone, showing the irregular shape and (so) subapical opening of the right maxillary stylet with its grooved interior (fc) forming half of the food channel.

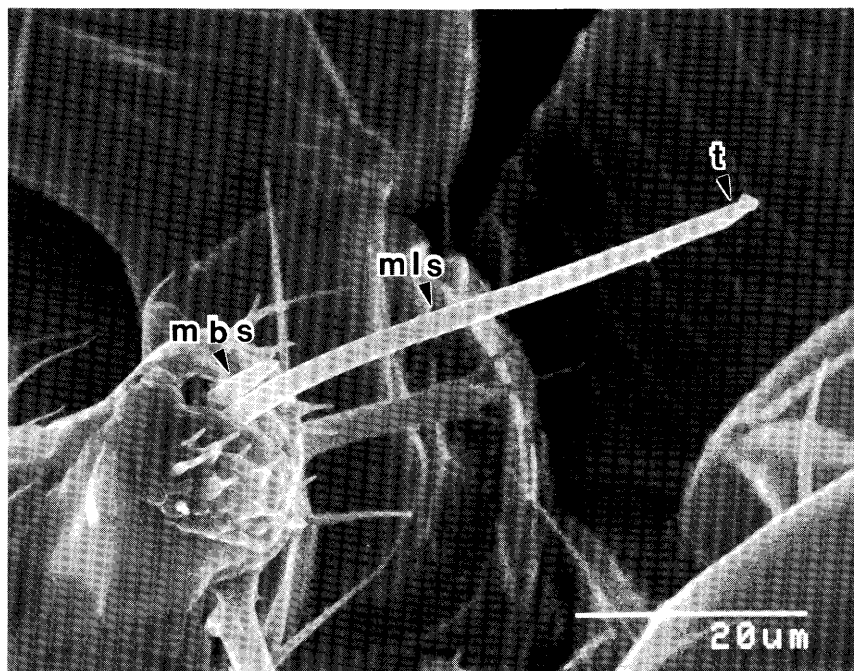


Figure 11. SEM of tip of mouthcone showing: (mbs) tip of mandibular stylet, (mls) paired maxillary stylets and (t) irregular-shaped tip of stylets.

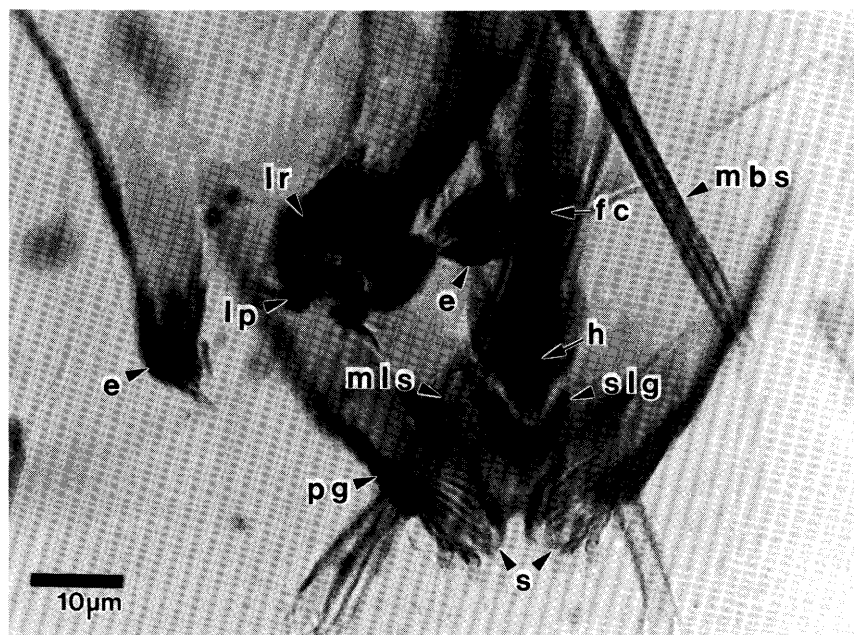


Figure 12. Light micrograph of whole mount preparation of the mouthcone of *F. bispinosa* showing: (lr) labral ring, (lp) labral pad, (slg) sclerite of labial glossa, (s) sensilla of labial paraglossae, (e) tips of maxillary stipites, (fc) food canal in anterior wall of hypopharynx (= precibarium), (h) hypopharynx, (mbs) mandibular stylet, (mls) maxillary laciniae and (pg) base of paraglossa.

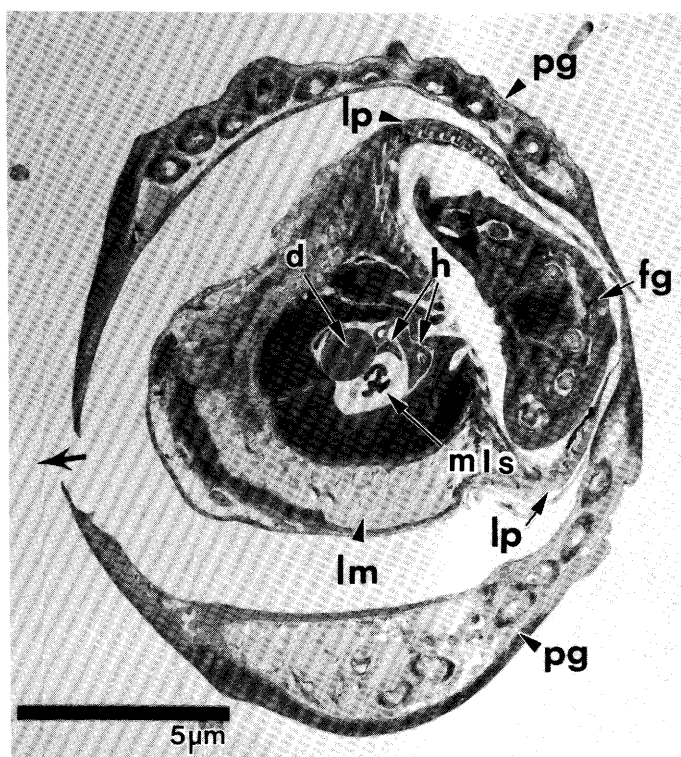


Figure 13. Transmission electron micrograph (TEM) showing cross section of the mouthcone of *F. bispinosa* about 10  $\mu\text{m}$  from the tip with: (pg) labial paraglossae (lm) labrum, (fg) fused glossae, (lp) labral pad, (d) mandibular stylet with three sensory dendrites, (mls) tips of maxillary stylets and (h) hypopharynx. Large arrow points to front of insect.

The next cross section (Fig. 14) is around 40  $\mu\text{m}$  proximal to the tip of the mouthcone and clearly shows the presence of both food and salivary canals. The labrum (lm) is situated anteriorly (Fig. 14) with the two maxillary stipites (ms) on either side and the prementum behind (pm). The hypopharynx (h) is located in the center with the food canal (=precibarium) (fc) in its anterior wall and the salivary canal (sc) in its posterior wall. Located on either side of the hypopharynx are the two maxillary stylets (mls). The larger, single mandibular stylet (mbs) is located anterior to the left maxillary stylet. It is supported by grooves in the hypopharynx and in the inner, membranous wall of the left maxillary stipes (Fig. 14). A similar arrangement occurs in larvae of *H. verbasci* (Heming 1978). Both maxillary stylets have recessed areas in the inner walls of the adjacent stipites that appear to also provide a degree of support. Closer examination of the stylets reveals the presence of four sensory dendrites in each lacinia and a central bundle of three dendrites (d) in the mandibular stylet (Fig. 15). The mandibular stylet of *H. verbasci* appeared to lack sensilla when viewed by SEM (Heming 1978). The mandible of *F. bispinosa* is solid with the exception of the small innervated channel and not hollow as previously reported for *L. cerealium* by Chisholm & Lewis (1984) and for *S. citri* by Wiesenborn & Morse (1989).

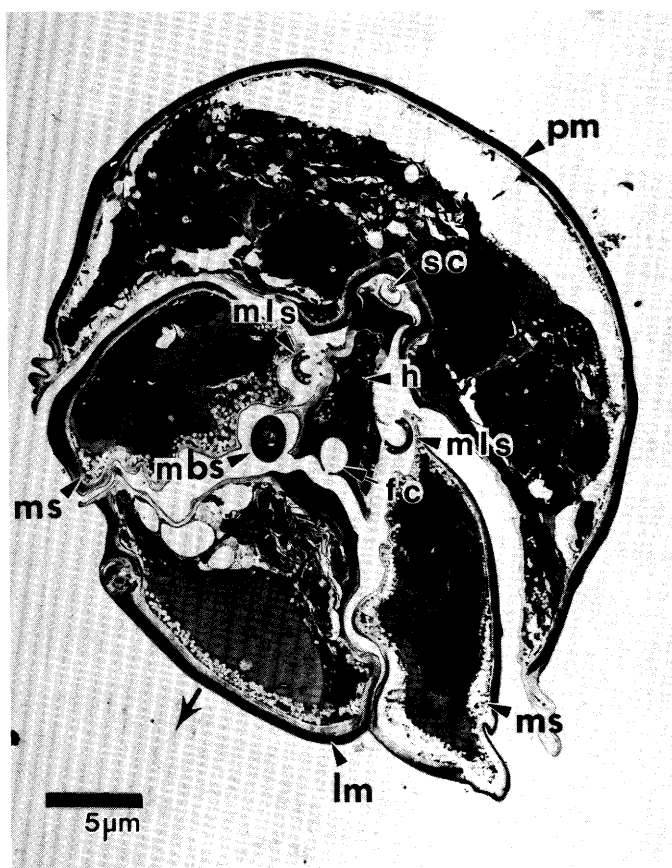


Figure 14. TEM of cross section of mouthcone of *F. bispinosa* taken about 40  $\mu\text{m}$  from tip, showing: (lm) labrum, (ms) maxillary stipites, (pm) prementum, (h) hypopharynx, (mbs) mandible, (m/s) maxillary laciniae, (fc) food canal and (sc) salivary canal. Large arrow points to front of insect.

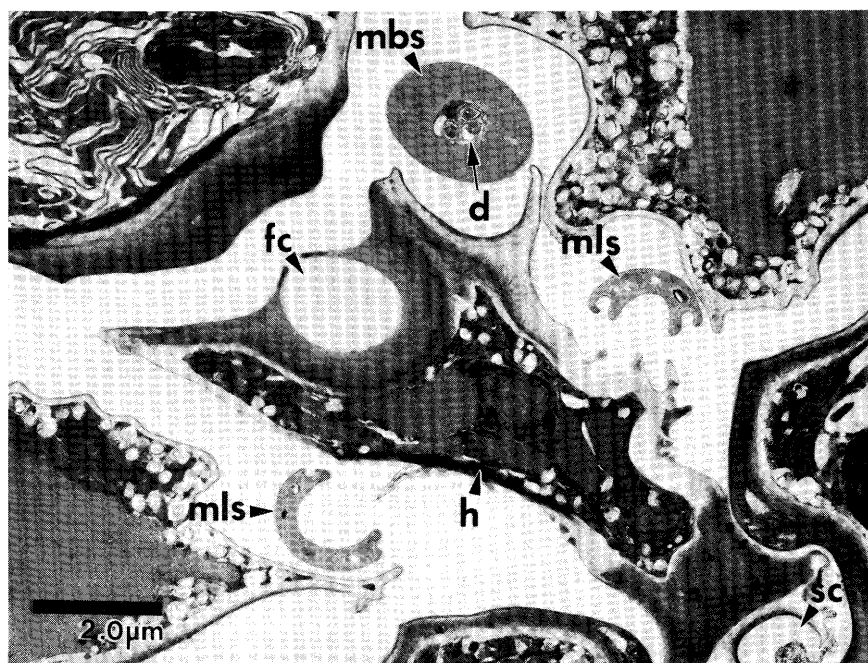


Figure 15. Enlargement of previous TEM showing: (mbs) mandible with (d) three sensory dendrites, (mls) maxillary laciniae with associated dendrites, (fc) food canal, (h) hypopharynx and (sc) salivary canal.

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## CHEMICAL ECOLOGY OF THE THYSANOPTERA

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### Abstract

The chemical ecology of the Thysanoptera is identified with a variety of natural products discharged in anal droplets during confrontations with adversaries. These exudates are fortified with defensive allomones that may function as repellents, contact irritants, or in some cases, fumigants. Thrips synthesize a large diversity of allomonal products that include hydrocarbons, acids, esters, aromatic compounds, and monoterpenes. Most of the exudates contain mixtures of natural products whose defensive efficacies may reflect synergistic interactions of selected compounds. That the anal secretions of thrips are highly effective repellents for a variety of ant species probably reflects the fact that formicids are the major predators against which these exocrine products have been evolved.

### Introduction

Many species of thrips form dense aggregations that could constitute a bonanza for a variety of predators. In particular, ants would appear to be ideally suited to prey on thrips as a consequence of their ability to rapidly recruit large numbers of workers to good food finds. However, although thysanopterans are delicate insects, many species may be protected from predation by chemical defenses that are identified with anal discharges (Lewis 1973). Significantly, research in the last decade has demonstrated that many species of thrips are versatile natural-product chemists that biosynthesize a large variety of defensive allomones.

In the present report, the chemical ecology of thrips species is examined in terms of the chemistry of their defensive exudates. In addition, the roles of the compounds in the anal exudates are examined in terms of sympatric predatory species of ants. Hopefully, the elegance of thrips in blunting the attacks of very efficient predatory insects by utilizing chemical arsenals, will be clearly manifest.

### Defensive Allomones of Thrips

Studies on the natural products generated by thysanopterans have been undertaken on species belonging to 12 genera (Tables 1-5). It appears that all identified compounds are present in anal discharges of species of Phlaeothripidae. In order to focus on the virtuosity of thrips as allomonal synthesizers, their natural products are fractionated into the major chemical classes to which they belong. The deterrent functions of these compounds are examined in the penultimate section.

#### Esters

Five aliphatic esters have been identified as natural products of thrips in five genera (Table 1). Included in this grouping are two lactones,  $\Gamma$ -decalactone and 4-octadec-9-enolide, which are also classified as cyclic esters.

$\Gamma$ -Decalactone is distinctive in being one of two thrips defensive allomones that are in themselves the only compounds present in the secretions. This compound, a product of the Cuban laurel thrips, *Bagnalliella yuccae* (Hinds), is secreted by both adults and larvae, the former producing about twice as much as the latter ( $0.27 \pm 0.15$  vs.  $0.12 \pm 0.10 \mu\text{g}$ ). No glandular cells could be identified with the synthesis of  $\Gamma$ -decalactone (Howard et al. 1983).

Two *Gynaikothrips* species, *G. ficorum* (Marchal) and *G. uzeli* (Zimmermann), produce three of the five esters characterized from thrips secretions (Table 1). Whereas tetradecyl acetate is a major allomone in *Varshneyia pasanii*, esters identified in the other species are minor constituents (Suzuki et al. 1988, 1989; Blum et al. 1988).

Table 1. Esters in thrips exocrine secretions

Compound	Occurrence	Authority
Γ-Decalactone	<i>Bagnalliella yuccae</i>	Howard et al. 1983
Tetradecyl acetate	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
Hexadecyl acetate	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
4-Octadec-9-enolide	<i>Euryaplothrips crassus</i>	Blum et al. 1988
Octadecyl acetate	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989

## Aromatic Compounds

Four aromatic compounds have been detected in anal exudates of thrips in four genera (Table 2). Two compounds, phenol and phenylacetaldehyde, are minor concomitants of the major allomones that dominate the secretions of *Arrhenothrips ramakrishnae* and *Euryaplothrips crassus* (Blum et al. 1988).

Mellein, the only compound detectable in the exudate of *Haplothrips leucanthemi* (Schränk) (Blum et al. 1990), is a characteristic sex pheromone of male ants in the genus *Camponotus* (Brand et al. 1973). This anal product, which is an aromatic lactone, has also been identified in the defensive secretions of termite soldiers in the genus *Cornitermes* (Blum et al. 1982).

Juglone, a major constituent in the acid-rich secretion of *Elaphrothrips tuberculatus* (Hood) (Blum et al. 1987), is the only 1, 4-quinone identified as a thrips natural product. This quinone, a well-known allelopathic agent produced in walnut leaves (Rietveld 1983), is synthesized *de novo* by *E. tuberculatus* as the first example of the production of this compound by an animal.

Table 2. Aromatic compounds in thrips exocrine secretions

Compound	Occurrence	Authority
Phenol	<i>Arrhenothrips ramakrishnae</i>	Blum et al. 1988
	<i>Euryaplothrips crassus</i>	Blum et al. 1988
Phenyl-acetaldehyde	<i>Arrhenothrips ramakrishnae</i>	Blum et al. 1988
	<i>Euryaplothrips crassus</i>	Blum et al. 1988
Mellein	<i>Haplothrips leucanthemi</i>	Blum et al. 1990
Juglone	<i>Elaphrothrips tuberculatus</i>	Blum et al. 1987

## Monoterpenes

The three monoterpenes identified as defensive allomones of thrips, have been detected as products of species in six genera (Table 3). Perillene, a furanomonoterpene produced by several ant species (Bernardi et al. 1967, Longhurst et al. 1979), has been characterized from the exudates of thrips in five of the six genera in which monoterpenes have been demonstrated to be present (Suzuki et al. 1988, Blum et al. 1988). This compound, which is generally present in admixture with several other compounds, varies in concentration from 23% in *Liothrips piperinus* to 2% in *Varshneyia pasanii* (Suzuki et al. 1986, 1988).

$\beta$ -Acaridial, a novel monoterpene only previously known as a product of a mold mite (Leal et al. 1989), is a major constituent in the anal exudates of all three species of thrips from which it has been identified (Table 3) (Suzuki et al. 1989). The function of this highly unstable dialdehyde is not known.

Rose furan, an isomer of perillene, is the major constituent in the secretion of *Arrhenothrips ramakrishnae* (Blum et al. 1988). It is accompanied by perillene in this exudate, along with two minor aromatic compounds (Table 2). *A. ramakrishnae* is the first animal demonstrated to synthesize this distinctive plant natural product.

Table 3. Monoterpenes in thrips exocrine secretions

Compound	Occurrence	Authority
$\beta$ -Acaridial	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
	<i>Varshneyia pasanii</i>	Leal et al. 1989
	<i>Liothrips kuwanai</i>	Leal et al. 1989
Perillene	<i>Varshneyia pasanii</i>	Suzuki et al. 1986
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
	<i>Liothrips piperinus</i>	Suzuki et al. 1988
	<i>Teuchothrips longus</i>	Blum et al. 1988
	<i>Arrhenothrips ramakrishnae</i>	Blum et al. 1988
	<i>Schedothrips</i> sp.	Blum et al. 1988
Rose Furan	<i>Arrhenothrips ramakrishnae</i>	Blum et al. 1988

### Hydrocarbons

Seven hydrocarbons fortify the anal exudates of thrips species in three genera (Table 4). Several of these compounds are always present in each secretion and they may constitute either major or minor allomones. For example, pentadecane is one of the two major compounds secreted by *G. ficorum*, whereas the other three alkanes are relatively minor constituents (Howard et al. 1987). Similarly, tridecane accounts for 66% of the secretion of *V. pasanii* whereas dodecane and tetradecane are trace constituents (Suzuki et al. 1986, 1988). It may be significant that all of these hydrocarbon producers are gall-inhabiting species.

*V. pasanii* is distinctive in producing six of the seven hydrocarbons identified in thrips anal exudates (Table 4) (Suzuki et al. 1986, 1988). However, all species in the genera *Varshneyia*, *Liothrips*, and *Gynaikothrips* produce a diversity of alkenes and/or alkanes, emphasizing that the members of these three taxa stress the production of allomonal hydrocarbons.

Table 4. Hydrocarbons in thrips exocrine secretions

Compound	Occurrence	Authority
Dodecane	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
	<i>Liothrips piperinus</i>	Suzuki et al. 1988
Tridecane	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
	<i>Liothrips piperinus</i>	Suzuki et al. 1988
Tetradecane	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1988
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
(Z)-7-Pentadecene	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
Pentadecane	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
(Z)-8-Heptadecene	<i>Liothrips kuwanai</i>	Suzuki et al. 1988
	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989
Heptadecane	<i>Gynaikothrips ficorum</i>	Howard et al. 1987
	<i>Gynaikothrips uzeli</i>	Suzuki et al. 1989



## Acids

Seven aliphatic acids have been characterized as natural products of thrips in four genera (Table 5). Two species, *Hoplothrips japonicus* and *Dinothrips* sp., are distinctive in producing anal exudates that each contain solely two acids (Table 5) (Haga et al. 1989, Blum et al. 1989). All the other thysanopterous species produce acids as either major or minor concomitants of other classes of defensive allomones.

For example, the anal discharge of *V. pasanii* is dominated by hydrocarbons and the single acidic constituent, 2-methylbutyric acid, a defensive product of swallowtail (*Papilio*) larvae (Eisner et al. 1965), is a trace constituent. On the other hand, the C<sub>12</sub> and C<sub>14</sub> acids fortifying the secretion of *E. tuberculatus* (Hood) (Table 5), are quantitatively significant constituents that accompany a 1,4-quinone (Table 2) (Blum et al. 1987). Similarly, decanoic and dodecanoic acids are the major constituents in the secretion of *Euryaplothrips crassus* and the aromatic and lactonic constituents (Tables 1 and 2) are minor products (Blum et al. 1988).

Table 5. Acids in thrips exocrine secretions

Compound	Occurrence	Authority
2-Methylbutyric acid	<i>Varshneyia pasanii</i>	Suzuki et al. 1988
Isovaleric acid	<i>Dinothrips</i> sp.	Blum et al. 1989
Decanoic acid	<i>Euryaplothrips crassus</i> <i>Dinothrips</i> sp.	Blum et al. 1988 Blum et al. 1989
(E)-3-Dodecenoic acid	<i>Hoplothrips japonicus</i>	Haga et al. 1989
(Z)-5-Dodecenoic acid	<i>Hoplothrips japonicus</i>	Haga et al. 1989
Dodecanoic acid	<i>Elaphrothrips tuberculatus</i> <i>Euryaplothrips crassus</i>	Blum et al. 1987 Blum et al. 1988
5,8-Tetradecadienoic acid	<i>Elaphrothrips tuberculatus</i>	Blum et al. 1987
(Z)-5-Tetradecenoic acid	<i>Elaphrothrips tuberculatus</i>	Blum et al. 1987

## Roles of Exocrine Compounds

Although relatively few studies of the functions of thrips semiochemicals have been undertaken, it is evident that some of these compounds are defensive compounds against predatory insects such as ants. An examination of their main defensive roles clearly establishes their effectiveness as deterrent allomones.

### Repellency

$\Gamma$ -Decalactone, the only compound in the anal discharge of *B. yuccae*, repels workers of *Monomorium minimum* from entering treated tubes under both laboratory and field conditions (Howard et al. 1983). Similar results were obtained with workers of *M. pharaonis* and *I. humilis*. The offensive nature of this lactone for ants was further illustrated by its ability to induce workers (*M. minimum*) to deflect their antennae away from food sources on which they attempted to feed.

Suzuki et al. (1988) similarly reported that workers of *Pristomyrmex pungens* are repelled by the perillene-rich secretion of *V. pasanii*. This exudate also contains 2-methylbutyric acid, a known insect repellent (Eisner et al. 1965), and it is suggested that perillene may function as an alarm pheromone for *V. pasanii*. On the other hand, perillene was demonstrated to be a highly active repellent for workers of *M. minimum* and *I. humilis* under laboratory conditions (Blum et al. 1989).

Mellein, the only compound detected in the anal exudate of *H. leucanthemi*, is an effective repellent for hungry fire ant (*Solenopsis invicta*) workers (Blum et al. 1990). A dosage of 2  $\mu$ g at a food source results in a significant reduction in the numbers of feeding workers.

The anal discharge of *G. ficorum* (4 thrips equivalents) deterred workers of the aggressive myrmicine ant, *Wasmannia auropunctata* (Howard et al. 1987). Treated filter papers, held 1 mm from feeding ants, reduced the number of ants at the bait by 60-80%, under field conditions.

## Contact Activity

The deterency of allomones in the anal secretions of thrips species appears to be considerable. Adults and larvae of *B. yuccae* apply their  $\Gamma$ -lactone-pure exudate to predatory ants with elongate setae that form a paint brush at the tip of the abdominal tube (Howard et al. 1983). Treated ant workers (*M. minimum*) quickly withdrew from the scene of the encounter, wiping exposed body parts on the substrate while exhibiting other grooming behaviors.

Similarly, the anal tube of *G. ficorum* bears several spines that function as an effective brush for transferring the anal exudate to attacking ants (*W. auropunctata*) (Howard et al. 1987). Significantly, thrips are able to resorb unused anal droplets back into the rectum, thus conserving this important defensive secretion. Treated ant workers withdrew from the scene of the encounter, flattening against the substrate while dragging themselves forward. Ants frequently bit at the substrate and were sometimes attacked by sister workers. In addition, the thrips secretion appears to also function as a distracting adhesive, with debris frequently adhering to the cuticle of treated workers.

Both hexadecyl acetate and pentadecane, the major constituents in the secretion of *G. ficorum*, induced typical dragging behavior in ant workers after topical administration (1 thrips equivalent) (Howard et al. 1987). The ester was more active than the alkane, but a mixture of the two compounds was considerably more active than either compound alone at equivalent concentrations, indicating that the two allomones were interacting synergistically.

Mellein, the single defensive allomone produced by *H. leucanthemi*, has previously been demonstrated to be an excellent contact deterrent for ant workers (Blum et al. 1982).

## Conclusions

The Thysanoptera would appear to constitute a veritable cornucopia of interesting exocrine compounds. Although the chemistry of only 14 species has been investigated, nearly 30 compounds have already been identified (Tables 1-5). Natural products such as  $\Gamma$ -decalactone, juglone, and rose furan constitute new animal natural products, and  $\beta$ -acaridial has not previously been detected in insects. Considering how few thrips species have been chemically analyzed, it will not prove surprising if subsequent investigations provide additional evidence for the biosynthetic virtuosity of these insects.

The deterrent efficacies of the thrips allomones provide grounds for considering these insects as an excellent source of new insect repellents. These compounds have been "tried and tested" in evolutionary time, and obviously provide their producers with the chemical arsenals needed to blunt the attacks of omnipresent aggressors such as ants. In the case of aggregative species of thrips, communal living enables them to pool their allomonal resources in order to challenge predators with an emphatic message of deterrence (Howard et al. 1983). In addition, it seems likely that gall-inhabiting species, living in confined environments, may utilize their defensive exudates in a fumigatory capacity as well (Howard et al. 1987).

Finally, it has been suggested that perillene, a product of *V. pasanii*, functions as an alarm pheromone (Suzuki et al. 1988), and similarly, (*E*)-3-dodecenoic acid, a product of *H. japonicus*, is believed to be an alarm and/or aggregation pheromone (Haga et al. 1989). Pheromones may be widespread in the Thysanoptera, an order that is characterized by a large number of aggregative species. Considering the fact that many species of thrips are of considerable economic importance, this possibility should act as a spur for analyzing the chemical ecology of these insects in great depth. And the sooner the better!

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### Discussion Period

Question: How do you handle thrips for extraction purposes?

Blum: There are two ways. One way is simply to pickle them in a special solvent. Another way is to collect droplets secreted directly from the thrips. Some interesting volatile compounds are secreted in these droplets. We collect the droplets from the thrips on a slit of filter paper under a microscope and add a little of the solvent and then analyze it. We only need about 5 or 10 thrips when we treat them that way. With this method, you can pin down the source of the compounds. As I indicated before, we currently have no idea where these compounds are made but they do accumulate in the hind gut.

Question: Do the chemicals come from the host plants?

Blum: No. We haven't found any correlation whatsoever. We have investigated numerous thrips species that feed on fungi. We have also analyzed the fungi but have not found any of the thrips compounds in the fungi. These little insects are marvelous chemists in their own right and I want to give them all the credit they deserve. Though our findings indicate that they are making the compounds, this does not mean that we won't encounter species that do use compounds found in plants. If you work with enough insect species you are bound to find exceptions to the rules. I have a friend who studied chemical defenses in beetles and he thought he had everything worked out until he looked at one more species. This species was not making any of the typical defensive compounds. Instead, it was sequestering plant compounds and then secreting them for its own defense. I'm sure we will find this in a thrips sooner or later, but currently we have no evidence that the thrips are not making the compounds themselves.

Question: What about looking at precursors of the compounds in the fungi?



Blum: One could do that, but it would be a very difficult task. It depends on how far back you want to go. A friend of mine is a fungal chemist and I try to keep up with what he and his colleagues are doing. The fungi are absolutely bizarre in what they synthesize so I would hate to get involved in trying to analyze fungal chemicals. Fungi do things that seem to make no sense. You can obtain from fungi everything from psychedelic compounds to some of the most deadly poisons in the world. These fungal products are very complex molecules.

Question: The examples you've shown are of thrips producing defensive chemicals. Have you ever heard of a thrips producing a chemical that was attractive?

Blum: You've raised a very good question. I feel that I've given you a very inadequate picture in most cases of what we have done. We obtain the material from thrips, and that is often a one shot thing. We may get eight vials of the extracts and then we do the bioassays in our laboratory on the defensive potential of the compounds against ants. Ants may not be the most appropriate insect to work with but we feel these compounds have to be taken back into the context where these thrips are and where they are interacting with other organisms. This is almost never done. A Japanese study is the only other one that tried a similar approach. Based on their bioassays, they believed that the compound was an alarm pheromone, but we've isolated the same compound from another thrips species and it's a very good repellent. It was previously known to be an excellent repellent for insects. However, with the thrips species we worked on, it shows no dispersing activity.

What we need is a collaboration between those working with a particular thrips species and those doing the chemical extraction and analysis. As the saying goes, you must know your enemy (or your friend) and research is desperately needed to increase our knowledge about thrips so that sensitive and complex studies can be conducted. These studies haven't been done. I believe that many of the compounds that we have worked on may have multiple functions, but we don't have the field work to confirm this hypothesis. More

chemical, behavioral and biological collaboration is needed in this field. Many thrips species produce obvious anal exudates which need to be analyzed so that they can be made available for behavioral and ecological studies.

Question: Do you think these secretions are more common in social species than in those that live independently?

Blum: I don't know. Right now we are at the very beginning of understanding the chemical ecology of thrips and almost anything that we can do now is a sizable contribution to a very limited base of knowledge. There are almost no data on this topic.

Question: Have you looked at the volatility of these compounds?

Blum: I believe that some of the compounds that thrips give off are functioning as fumigants. For example, some are given off in plant galls and I think they would effectively repel potential predators. Most of these compounds are very stable.

In contrast, the compound produced by an African species isn't so stable. However, once it hits a predator's antennae, that predator will probably not be able to smell for some time because the compound may immobilize olfactory proteins. The predator will have to synthesize new proteins to reactivate its sense of smell. Remember, any time you have a system that blunts the olfactory system of a predator that is dependent on olfaction, that predator is essentially blind, even when it is right beside its prey. These compounds are really good repellents in that sense. I have the feeling also that thrips may be beating the ants at their own game because of the congruency of thrips defensive compounds and ant compounds. The same compounds occur over and over again, which makes me think the thrips may be chemically mimicking the ants, thereby driving them into a dispersing frenzy with the compounds that the ants normally utilize for the same function.

Question: We have noticed in the field that some people seem to attract more thrips than other people. Do you have any clues as to why this occurs?

Blum: Of course this is something that always intrigues entomologists. We all know that mosquitoes attack some people more than others. One person may be very attractive to mosquitoes whereas another person may not be attractive at all. I think the answer is partly related to the odorants and other compounds that we put on our bodies. Many of these compounds are identical or very similar to natural products produced by insects and other animals and cause them to react accordingly.

I'll give you an example. We were in downtown Washington, D.C. with our daughters and they wanted popsicles. Each one got an orange popsicle and as we walked along they were suddenly engulfed with a swarm of honey bees. The attraction was very strong. I felt this was not coincidence, there had to be something volatile in the popsicles that was stimulating the bees. Four years later scientists at Agriculture Canada in Ottawa found that citral, an ingredient in orange popsicles, was produced in a gland on the abdomen of the honey bee workers, and that in large quantities it was a strong attractant for honey bees. My point is that compounds like this may be put into fragrances and polishes, and these compounds may sometimes be identical to pheromones which insects produce.

## POTENTIAL CAUSES OF THE PEAR THRIPS OUTBREAK IN SUGAR MAPLE

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### Introduction

No one knows what caused the 1988 outbreak of pear thrips, *Taeniothrips inconsequens* (Uzel), in sugar maple, *Acer saccharum* Marsh., in the northeastern United States. As an entomologist and ecologist who knows even less about this insect than most of the authors of this volume, I cannot presume to understand the causes of this event any better than anyone else does. This essay will of necessity be highly speculative.

Nonetheless, I will outline the kinds of things that must have happened to generate such an outbreak by this insect. There are really two issues involved in this particular case. This pest is called the "pear thrips" because it feeds primarily on plants in the Rosaceae, mainly in orchards (Parker et al. 1988). So the first question we might ask is "How has this insect come to feed on plants in quite unrelated families?" The second question that arises is the same one asked about every pest, namely, "Why are there so many of them?" After all, a pest is a species that is too abundant in a place where it is unwanted.

I will begin by reviewing current ideas about how insect species may add new host species to their diets. Then I will examine some common general hypotheses concerning causes of pest outbreaks and attempt to relate them to the pear thrips situation.

### Colonization of Sugar Maple

The literature suggests that maple may be a relatively new host for the pear thrips (Cameron et al. 1916, Simons 1985, Stannard 1968). It is very difficult to be certain about such an assertion. Information in the pest management literature suggests that pear thrips feeds heavily on 15 or more forest tree species, but quantitative data are lacking (Lewis 1973, Simons 1985). We will have to assume for the moment that the favored and probably the original hosts for this insect were orchard trees in the Rosaceae (Borror et al. 1981). That makes it a bit surprising that beginning around 1979 pear thrips was observed doing quite well on maples in northeastern Pennsylvania (Simons 1985).

Pear thrips appears to have acquired the ability to complete its life cycle on sugar maple, which means the insect has acquired the ability to recognize, oviposit, feed, develop and reproduce successfully on the plant. The probability of combining all of the traits necessary for success at each step, as well as accumulating the correct combination of genes for this, should be quite low. Even if the female recognizes and oviposits on the plant, the offspring have to be able to recognize that plant to accept it and begin feeding. Feeding stages must have the right physiological traits, including biochemical adaptations for digestion, detoxification and development on that food. Solving the "chicken and egg" problem of how phytophagous insects integrate behavioral recognition with physiological adaptation when they colonize new hosts continues to elude theoreticians and field biologists (Futuyma 1983).

The taxonomic, evolutionary, and likely chemical distance between sugar maple (Aceraceae) and rosaceous hosts exacerbates this problem in the case of pear thrips. Although there are exceptions, we generally expect the chemical features of closely-related plants to be more similar than those of distantly-related species. When these features influence acceptability and suitability of the plant to an insect species (e.g., allelochemicals), we expect any insect species to switch among closely-related hosts more easily. This scenario seems unlikely for the possibly recent addition of sugar maple to the pear thrips' diet.

Maples and rosaceous trees do produce some of the same broad classes of allelochemicals. Both families produce a range of phenolic compounds, and members of each may produce alkaloids (Gibbs 1974, Barbosa & Krischik 1987). However, the alkaloidal structures differ substantially between the two families, and we know little about the phenolics of either. Members of the Aceraceae produce a fairly novel class of tannins ("acertannins") not found elsewhere (Bate-Smith 1977). Apples (genus *Malus*) produce a nearly unique set of monomeric phenolics (e.g., phlorizin) and other rosaceous trees produce species specific flavonoidal compounds (Robinson 1980). Rosaceous tree species, but not maples, commonly also produce cyanogenic glycosides (Robinson 1980, Gibbs 1974). These observations suggest that there may be substantial biochemical barriers to exploitation of maple by rosaceous-adapted thrips.

Allelochemicals do not present the only barriers to host plant use. Many biological and physical factors interact to determine the likelihood that an insect species may "colonize," or develop the ability to complete development on, a new host plant species. Janzen (1968) suggested an "archipelago model" of adaptation to host plants, in which the degree of similarity between any two plant species in a variety of traits influencing insect success indicates the "ease" with which the two plants may be incorporated into the same insect's diet over ecological or evolutionary time. Factors of importance include refuge from physical factors, susceptibility to natural enemies, seasonal and spatial availability of suitable tissues, and physical traits of the plant (e.g., leaf surfaces). In this model, plant species are visualized as "islands," the distances among which are defined by similarities and differences in features influencing insect use. Similarity in one or more features may reduce barriers to colonization, but could be balanced by differences in others. Unfortunately, we cannot yet rank the importance of these various influences in any useful way (Bernays & Graham 1988, Smith et al. this proceedings).

Of course, the host's environment can also influence the likelihood that an insect will survive to oviposit again on the same host. Habitat parameters, both climatic and edaphic, may determine this

barrier independently of host plant traits as food. In the case of pear thrips, low overwintering success in soil or litter could reduce the likelihood of adapting to host species growing in marginal habitats. Use of either or both hosts would then depend on the presence of tolerable or favorable physical conditions (e.g., soils, litter depth and moisture, etc.) in stands of both hosts.

Herbivore susceptibility to natural enemies (parasites, predators and pathogens) often differs dramatically among hosts (Brower 1958). An insect species' ability to exploit a new plant species could be blocked by increased risks there, but it could also be facilitated by increased "risk-free space" (Brower 1958, Bernays & Graham 1988). In the case of maple and orchard trees, we have no information to help infer a conclusion about this effect, and the impact of enemies on pear thrips appears to be unknown, even in orchards. One could imagine that pear thrips might escape an enemy important in orchards by colonizing maple, but of course this would require overcoming other barriers to the use of maple.

The product of the probabilities of overcoming all of these barriers must be rather small. Obviously, the pear thrips has overcome what might be significant barriers to become successful on sugar maple. What factors may have facilitated this?

Frequent encounters with a new host species probably facilitate dietary expansion or switching (Futuyma 1983). Although originally far more abundant in the western United States than in the East, the pear thrips has no doubt been present in eastern orchards for some time. The large number of orchards within the distribution of sugar maple must have provided ample contact with maple and plenty of opportunities for colonization. Futuyma (1983) has pointed out that the more frequent such encounters become, the more likely it is that individuals possessing traits necessary for success on the new plant will remain there to reproduce. Indeed, repeated colonization attempts and failure on the new plant ought to comprise strong selection favoring any adaptations to the new host that may arise. The spread of pear thrips through orchards in contact with maple may have provided these

opportunities, especially if gravid females are often blown out of orchards into surrounding maple stands. Expanding orchards would have a similar effect.

Cultural procedures may also play a role (Scriber & Hainze 1987). One might speculate that the ability to deal with maple chemistry could evolve as a form of cross resistance arising from selection exerted by pesticide use in orchards. The inverse situation, in which cross resistance to pesticides is induced as a function of feeding on different apple cultivars, has been observed in other pest insects (Yu 1986). Although we don't know enough about the biochemical basis of plant exploitation by thrips to draw serious conclusions, it is possible that the expanded development of new cultivars, or changing pesticide use, may have selected for thrips genotypes capable of exploiting new host species.

Dramatic changes in forest composition also have occurred since apple orchards became common in the eastern United States. More than half of the observed forest pest outbreaks in the Northeast occurred after the major logging events and changes in forest structure that occurred from 1860 to 1900 (Nothnagle & Schultz 1987). We don't know that there is a functional relationship here. However, between 1860 and 1900 many trees were damaged during removal of other trees, and the forest structure changed. Among other things, forest succession was pushed back to earlier seres, of which sugar maple would be a minor component. The New England forests are now returning to the older, climax forest type as agricultural land use decreases. Perhaps the increasing dominance of sugar maple in recent years has increased contact with orchard insects like the pear thrips. Alternatively, the physical environment may also have been changed in such a way as to make various tree species susceptible to pests.

One feature of the pear thrips that could facilitate host switching and the development of high population densities is its parthenogenic mode of reproduction. Bush (1974) proposed a model of host race formation by herbivores in which he pointed out that switching is facilitated if mating by adults is linked to the host. This link (e.g.,



mating on or near the oviposition site) ensures that male and female genotypes containing mutations permitting exploitation of a new host are combined in offspring feeding on the new host. This would increase the representation, and hence population size, of "preadapted" genotypes among offspring starting out life in a new environment (host), and should increase the likelihood that a new population capable of exploiting the new host becomes established.

Parthenogenesis in the pear thrips may provide an alternative means of increasing the genetic similarity among sibs produced by a single mother colonizing a new plant. Since that mother must recognize the new host to oviposit there, she places her genetically-similar offspring, which are likely to share most of her genes, together on the new host. If the mother's ability to recognize and oviposit on the new host (sugar maple) has a genetic basis, it is likely that most, if not all, of her offspring will carry the same trait. This would establish an entire population of "preadapted" thrips almost instantaneously, compared to outcrossing insect species in which many of the sibs may not carry the host-recognition genes of the maternal parent. Because parthenogenic species can establish larger populations of potentially adapted individuals when colonizing a new host, I suggest that adaptation barriers may be overcome by them more quickly than by sexually reproducing species. This may help explain what appears to be a sudden, explosive appearance of pear thrips on sugar maple.

It is impossible to determine the course of host-switching by an insect herbivore without knowing the details of plant traits and insect feeding, behavior, life history and habitat requirements. It is also important to put this information in a phylogenetic context, with comparative studies of related species. Research has not been extensive or intensive enough to provide a good basis for conclusions about pear thrips on sugar maple. However, given that the switch has occurred, what factors may influence the success of pear thrips on sugar maple trees and result in apparent "outbreak?"

### Possible Outbreak Causes

There are almost as many hypotheses about the causes of pest outbreaks as there are investigators (Barbosa & Schultz 1987). I can focus here on only a few very popular ones. We need to beware of the use of the word "causes," because truly mechanistic studies are rare. The literature on pest outbreaks is instead dominated by correlative studies that generally serve to refine hypotheses rather than test or refute them.

For example, climate and weather variables are often identified as triggers, cues or actual causes of pest outbreaks in a particular forest system (Martinat 1987). The hypothesis that drought stress is a cause of pest outbreaks in forests is as old as outbreaks themselves (Mattson & Haack 1987). In the particular case of the pear thrips, there is some evidence that populations increase in orchards during drought years. There are, however, no studies of mechanisms that may be involved. We might speculate that superior overwintering success could be involved, or that reproduction improves. The possibility that stress may make hosts either nutritionally superior or more poorly defended chemically is popular at present (Mattson & Haack 1987). Interestingly, however, the plant physiology literature tells us that almost anything can happen to tissue quality under drought stresses, particularly in woody plants. That is, there are published examples of plant species that become better or worse nutritionally, and that increase or decrease putative defenses under presumably stressful conditions.

In the case of the pear thrips, there are virtually no studies on what characteristics of the host plant make it better or worse as food for the insect. Low rainfall in the years during or prior to the recent observation of thrips on Vermont maples may or may not have influenced tree quality. Depending on tree species, presumptive defense compounds may increase or decrease under drought stress (Gershenson 1984). In some species protein or amino acid contents

may change, altering food quality. Any guesses about what host stress will do in sugar maple to make the plant better or worse for pear thrips comprise sheer speculation at this point.

Climatic events can also shift plant phenology, including leaf chemistry and nutritional value. Because species like sugar maple undergo dramatic seasonal changes in leaf traits (Schultz et al. 1982), there may be periods of time during which sugar maple leaves resemble leaves of other species chemically, perhaps including orchard species. For example, the distinctive acertannins in maples do not develop higher concentrations until mid- to late-summer; early in the season, the phenolic chemistry of maples tends to be dominated by monomeric phenolics that may be more similar to those of rosaceous trees (Schultz et al. 1982). If maple (or orchard tree) phenology were shifted by climatic events for one or two seasons, this could open a "window of opportunity" for colonization and growth success by thrips. This in turn would facilitate both colonization of maple and population growth and might produce an outbreak.

Climate could also have impacts on pest insects independent of the host (Mattson & Haack 1987, Martinat 1987). However, such host-independent effects ought to occur in orchards as well as in maple stands. There is no evidence that pear thrips populations are increasing in orchards concurrent with the present sugar maple infestation, although the heavy use of pesticides in orchards could obscure effects of natural enemies or other factors.

Once thrips is feeding successfully on maple, its populations could escape regulation by various factors important in orchards. In this case, we would say it has entered what some evolutionary ecologists call a new "adaptive zone" (Ehrlich & Raven 1965), or at least a way of life in which the insect experiences few barriers to population growth. Natural enemies and pesticides comprise common barriers in the orchard setting, and these may be absent on maple. Ordinarily, in natural systems it is not clear that the failure of natural enemies leads to pest outbreak, even if the pest population appears to be regulated by enemies at low density (Southwood & Comins 1976).

However, if pear thrips escapes an effective regulatory agent while living on maple (and if maple is suitable food), then its populations may achieve higher densities than are usually seen in orchards. Considering the degree to which insect populations in orchards are usually suppressed by pesticides, colonization of maple could produce an "outbreak" merely by eliminating that factor. If sugar maple were truly superior food, then rapidly growing pear thrips populations could even escape the regulatory impact of an enemy that followed it there. Information about the influence of food quality on thrips reproduction and about natural enemies is far too inadequate to propose more specific hypotheses.

In this light, it is important to consider the possibility that the pear thrips populations we observe in sugar maple stands do not comprise an "outbreak", i.e., they do not represent "unusually" high densities. Present thrips densities on maple may represent the overall carrying capacity of maple for this insect. We may continue to observe unabated high densities for the foreseeable future, now that the insect has managed to colonize this species.

Recent theory suggests that insects whose intrinsic rate of natural increase and certain other attributes conforms to certain theoretical criteria may be destined to exhibit irruptive population dynamics. It is difficult to demonstrate statistically that any pest outbreak is periodic, i.e., that it has a demonstrable cycle of " $N$ " years. Hence, mechanisms that yield outbreak need not produce regular periods in outbreak cycles. May (1985) has suggested that pest species represent an adaptive type, or a particular way of life in which high reproductive rates and other traits combine to yield outbreak dynamics in chaotic fashion. In either case, density-dependent regulatory factors are usually operating, at least during the crash of epidemics. Anderson & May (1980) point out that use of artificial controls (e.g., pesticides) in such cases may be self defeating, in part because density-dependent regulation (e.g., via disease) is thwarted.

In attempting to control pear thrips on the sugar maple, we need to keep in mind the possibility that the commonly applied pesticides may fail on the new host plant. In particular, biological pesticides may fail because of the chemistry of the host (Schultz & Keating in press). Integrated pest management should account for the specific interactions among the plant, insect, and insect's enemies.

It is abundantly clear that no control program can succeed until we understand what the pear thrips eats, what food quality factors are important to its success, what role natural enemies play, and the importance of physical factors. Our information on all of this is woefully inadequate; we barely understand the basic biology of this insect. We must be prepared to assemble a major research effort (with significant support), and to spend significant time studying the basics of this system if we hope to design effective and environmentally sound control efforts.

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### Discussion Period

Question: We're used to thinking of host plant chemistry attributing to outbreaks, are you suggesting that under some circumstances the host plant actually welcomes some new pests, and that the attributes of the host plant somehow contribute to the accumulation of pests?

Schultz: I think that almost all sugar maple trees very likely pass through windows of opportunity for colonization, ecologically and perhaps in terms of age. Apparently certain aged trees are more susceptible to this insect than others. My guess would be that this insect wouldn't be able to cross over as easily if maple didn't pass through a phase either each year or during its life time that made it much more like a pear than it is otherwise. I suspect there has been selection pressures on this insect for the ability to deal with the tree. It probably has a window of opportunity, though it appears to be doing well on both sides of the window as well. In 1909 Moulton hypothesized that the reason pear thrips were so successful on pears is that it has clustered flowers. Maples also have clustered flowers. In fact, there must be 150 species of trees in northeastern North America that have clustered flowers. Therefore the flower type alone must not be the characteristic that distinguishes maples from other potential thrips hosts.

I tend to focus on leaf feeding because that is my specialty. I think the suggestion that availability in spacial distribution of a resource like the flowers is interesting but there are other maples that have similar flower clusters and I'd be curious to know if the insect is successful on those. However, maples differ greatly in their secondary chemistry which may also influence host susceptibility. This must be integrated with other host information.

Question: Do you assume that there is genetic variability between the pear thrips on pears and those on maples?

Schultz: Certainly that is possible, but I have no idea. There are many potential sources of genetic variation. The statement that all of the genetic offspring of a female are identical to her is not strictly speaking true. Considering the number of generations of pear thrips in North America, I am sure we are now looking at other genotypes. I don't assume that the maple feeders are a different genotype but they probably are. If not, there is a tremendous congruency of characteristics between maple and pear.

What makes this question so interesting to me is I can't figure out how an insect that is a good Rosaceae feeder switches over to a different host so successfully. For other insects that feed on a wide variety of plants, when a new plant is introduced into the system, the insect may just include it in the host range and there is no fundamental difference in population structure. That could apply here.

David Jenson pointed out that leaf eating insects eat leaves and that is determined by the unique characteristics of the leaves and all the other ecological circumstances that may be available. Until we know what the requirements are for thrips success we can in no way indicate what plants should and should not be hosts. It is just astonishing to me that we have no idea how this insect makes its living. I assume that nitrogen is important to it, and secondary chemicals can influence it as well.

Comment: I want to mention a few points about the genetics of thrips. Thrips have what we call myotic parthenogenesis, whereby the polar body fuses with the opening so you actually get very little genetic variation. It is possible however that pear thrips males do occur in the United States. They might be so short-lived that they have not been found. I worked on a species of thrips in Colorado that only occurs for a very short time and in very localized populations each season.

In some species of thrips the males are not very important to female reproduction and there are other species in which the males are present and needed for reproduction.

Question: Are there any comprehensive genetic studies that really identify the system of inheritance in thrips?

Answer: No.

Question: Has anyone investigated the correlation between the outbreak of this pest and the stress on sugar maple trees caused by acid rain?

Schultz: I'm not aware of anyone doing such work associated with acid rain and the pear thrips outbreak. I haven't seen any evidence that there is a significant relationship between any major insect outbreak and acid rain, and quite frankly I wouldn't expect there to be much of one. I see the contribution of acid precipitation to the leaf as minor.

A possible factor contributing to this outbreak might be drought. A one-to-three year drought could have a profound effect on the physiological state of sugar maple trees and make them unusually susceptible to thrips. I do not know however why maple might be susceptible and beeches and birches are not. One report I found in the literature pointed out that pear thrips is particularly successful and prone to outbreaks in orchards during drought years, presumably as a result of higher winter survival.

The effect of tree phenology on thrips success and damage remains an important question. We watch the buds burst and the leaves get bigger, but many things are going on inside the leaf at different rates that we don't see. Chemicals are coming and going. In oak trees the composition of the molecules in the young leaves changes daily over the first 10 days of leaf expansion. If one of those compounds is essential to one of these insects, the synchrony of the insect and tree becomes critical. Because we do not yet know what is crucial to the survival of pear thrips, it is impossible to know what characteristics of maple phenology are important? One of the crude changes that occurs during leaf development is that the leaves get tougher day by day. I think the issue of phenology is critical. Maples may go through a stage in which they are not like other Rosaceae trees.

The question remains why pear thrips haven't been a pest problem for the past 20 years. I'm really curious about that. We've had apples, pears, and sugar maples in the Northeast for a long time and the insect has been in the Northeast since the turn of the century. So I don't know why all of a sudden it has managed to find sugar maples suitable. These facts suggest to me that a significant shift has occurred in the thrips ability to deal with this host. Perhaps the trees have changed since the thrips arrived, possibly due to some predisposing factor associated with this outbreak.

## **SURVEY AND DETECTION**

## AGROECOLOGICAL NICHES AND THRIPS (THYSANOPTERA: THIRIPIDAE) DYNAMICS<sup>1</sup>

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In 1975, Illinois experienced an exceptionally mild winter, followed by a warm spring. This sequence of climatic events resulted in a massive outbreak of the soybean thrips, *Sericothrips variabilis* (Beach), along with large numbers of the flower thrips, *Frankliniella tritici* (Fitch). The outbreak covered an area of over 600 thousand hectares (1.5 million acres) of soybean and was particularly heavy in the southern third of the state. In areas where thrips densities were particularly high early in the season, entire fields of young soybean seedlings began to die, causing panic within the farming community. In their attempts to resolve the situation, growers applied large quantities of pesticides to over 20,200 hectares (50,000 acres) during the first week after the crop had begun to emerge.

Heretofore, massive invasions of thrips had not been recorded in soybean; therefore, damage potential and yield reductions resulting from thrips attacks on this crop had not been quantified. Furthermore, the possibility existed that one or both species of thrips were capable of transmitting tobacco ringspot virus (Messieha 1969, Bergeson et al. 1964) from wild hosts or soybean, where it is transmitted through seeds of infected plants, to soybean. Infection by tobacco ringspot virus dramatically reduces the quality and quantity of soybean grain.

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<sup>1</sup>I wish to thank Dr. Bruce L. Parker and Dean Donald L. McLean for involving me in this important symposium and for providing such cordial hospitality. I am also grateful to the State of Vermont for providing the funds so that I could participate. I dedicate this paper to the memory of the late Dr. Lewis J. Stannard, a thrips systematist whose life was dedicated to enhancing the knowledge base of North American thrips.

Extension specialists had only tentative responses to farmer requests for information regarding the thrips outbreak in soybeans because no knowledge base existed.

The following commentary does not address the virus transmission issue. (As a point of information, tobacco ringspot virus was subsequently found not to be a consideration because *S. variabilis* apparently does not transmit the virus and *F. tritici* does so only very inefficiently.) Instead, this paper recounts the outcome of several experiments undertaken between 1975 and 1977 to determine the ecological niches occupied by those two thrips species in relation to soybean phenology (Irwin et al. 1979). This information should prove useful to the entomological community of Vermont and other sections of northeastern North America as they mobilize to resolve the problem of the pear thrips on sugar maple.

### Phenology of Soybean and Developmental Stages of Growth

Soybean, *Glycine max*, is a very dynamic, widespread crop in the midwestern and north central United States. It was introduced into the United States from China in 1765, but only became known throughout the eastern and central portions of the United States after the end of the 19th century (Howell 1983). Like most annual row crops, soybean plants change dramatically as the season progresses. These changes are important to the spatial and temporal distribution of both thrips species and, thus, must be defined. What follows is a brief description of soybean growth, each stage of which is followed, in parentheses, by a code identifying that stage, adapted from Fehr & Caviness (1977).

Upon germination, the soybean plant emerges as a pair of thick, green cotyledons ( $V_0$ ), followed about a week later by a pair of unifoliate leaves ( $V_1$ ). Thereafter, throughout the first half of the growing season, the plant puts out a series of alternate trifoliolate leaves that are coded  $V_2$  through  $V_n$ , the larger numbered trifoliolate leaves appearing later in the season and higher in the canopy. Depending upon soybean cultivar and local climate, flowers first appear ( $R_1$ ) at around 40 days after

planting. The field reaches full flowering ( $R_2$ ) shortly thereafter. When a plant has at least one pod that is 5 mm in length at one of the four uppermost nodes on its main stem, it has reached the "beginning pod" stage ( $R_3$ ). It reaches the "full pod" stage ( $R_4$ ) when at least one pod at one of the four uppermost nodes on the main stem reaches 20 mm in length. The "beginning seed" stage ( $R_5$ ) is reached when seeds in one of the pods at one of the four uppermost nodes on the main stem reach a length of 3 mm. When the green seeds in those pods completely fill the pod cavity, the "full seed" stage ( $R_6$ ) has been reached. The beginning of maturity ( $R_7$ ) is reached when one normal pod on the main stem has a mature, brownish or grayish pod color. "Full maturity" ( $R_8$ ) occurs when 95% of the pods have reached their mature pod color. A coding of  $V_{12}$ ,  $R_4$ , then, indicates that twelve nodes and thus twelve layers of leaves exist along the main stem and the plant is in the "full pod" stage of development.

Soybeans grow rather evenly, the heights of the different plants in a field being very similar; thus very even foliage with a smooth canopy is the rule. Soybean growth is dynamic. Plants begin as seedlings, increasing dramatically in terms of niches, both above and below ground, that are potentially occupied by fauna. Towards the end of the season, the leaves senesce and the plant becomes a naked frame containing bountiful pods at its nodes, each pod enclosing about three seeds. Thus, the niches available for thrips increases throughout most of the growing season, then decreases rapidly as the plant begins to senesce. The temporal component of niche availability is thus dictated by plant phenology.

### Biology of Both Thrips Species

Adults of both species are probably migratory; they immigrate from the southern region of the central United States perhaps even Mexico. Early season migrant *S. variabilis* colonize alfalfa and other broad leaved plant species, then move to and reproduce on soybean throughout much of the growing season. Similarly *F. tritici* is found on many grass and broad leaved host plants, but, for the most part,



colonizes flowering parts of these plants. *F. tritici* is attracted to maize when it is silking, but before and after silking, it often colonizes soybean.

Eggs of both species are laid in leaf tissue. First instars emerge from eggs and begin feeding by sucking fluids from individual plant cells, leaving silvery, streaked feeding damage. The first instar is followed by two further larval stages, the last of which, after having finished feeding, drops to the ground, enters a prepupal stage, then pupates in the soil, and ecloses as an adult a week to ten days later. After mating, egg laying commences.

#### Alighting Distribution of Thrips within a Soybean Field

Landing activity was monitored by sticky-coated green tile traps (Irwin 1980) set horizontally at canopy height within soybean rows (Irwin & Yeargan 1980). These traps have a reflectance spectrum very similar to soybean leaves; thus, the thrips should behave as though they were landing on foliage, neither being attracted to nor repelled from the traps. These traps, therefore, measure landing activity, not population abundance or density in the canopy.

In 1976, ten green tile traps were placed at 50 m intervals along a transect across an 3.2-hectare field of soybean, cv. Williams, in Tolono, Ill. The first and tenth traps were placed in grass strips outside of the field. Three species of thrips were trapped abundantly, the two that colonize soybean and a third, *Frankliniella fusca* F., that does not. For the two species that colonize soybean, a relatively uniform landing rate occurred across the field, but outside the field in the grassy strips, landing rates were relatively low. The reverse occurred for the *F. fusca*, a grass-inhabiting species. It is clear that both species that colonize soybean are more abundantly trapped within the field, while the species that does not colonize is most abundantly trapped in the grassy strips (Fig. 1). Furthermore, both soybean-colonizing species had relatively uniform landing rates within the field, when averaged over the growing season.

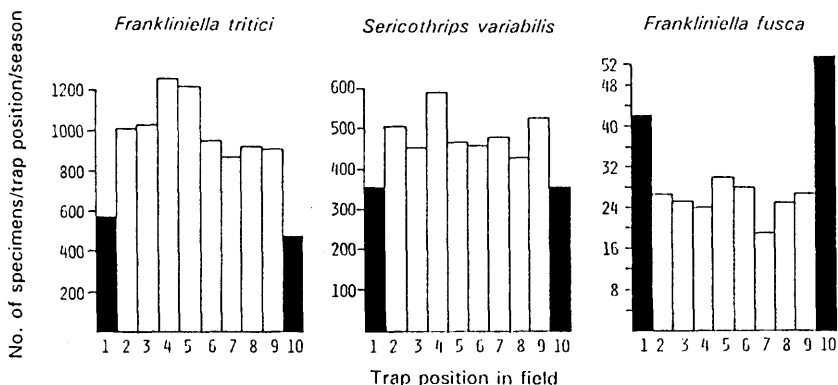


Figure 1. Distribution of three species of thrips in a south (S) to north (N) transect of a field of soybean, cv. Williams, in Tolono, Ill., 1976. Total specimens captured on horizontal green sticky traps during the growing season. Black bars represent traps located outside of the soybean field in grass borders. White bars represent traps located within the soybean field.

### Seasonal Landing Rates of Thrips in a Soybean Field

The same soybean field in Tolono, Ill., was monitored for landing activity using horizontal sticky green tiles over two seasons, 1976 and 1977. Trends (Fig. 2) indicate a double activity peak of *F. tritici* both years even though there was a temporal displacement in peak activity one year over the other. A single peak of *S. variabilis* activity occurred each season; it too was displaced from one year to the next, earlier in 1977, later in 1976. I postulate that this may be due to a much colder winter preceding the 1976 than the 1977 season.

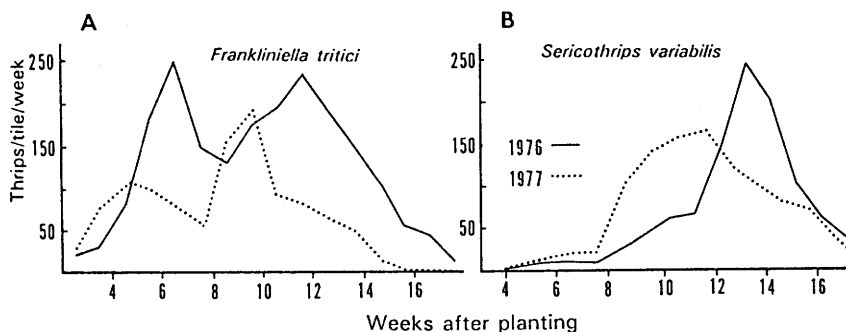


Figure 2. Flight activity curves of two thrips species in soybean for the 1976 and 1977 growing seasons Tolono, Ill. (A) *Frankliniella tritici*; (B) *Sericothrips variabilis*.

### The Influence of Wind on Flight Direction

Thrips movement directly above the soybean canopy was monitored with a specially designed wind-directed trap. This trap (Fig. 3) was composed of a vein and shaft, which kept the axis oriented into the wind; and a set of four, small, clear plastic cups cut vertically in half—one half centered windward, the other centered leeward—and positioned perpendicular to the shaft. The cups were covered with vaseline and changed daily. The trap was very sensitive to wind changes, thus allowing us to compare the numbers of thrips adhering on the windward and leeward sides of the cups.

Over the entire soybean growing season, most *F. tritici* were found on the leeward side, with far fewer on the windward side, whereas *S. variabilis* showed the opposite trend (Fig. 4). Most *S. variabilis* were found on the windward side, with far fewer taken on the leeward side.

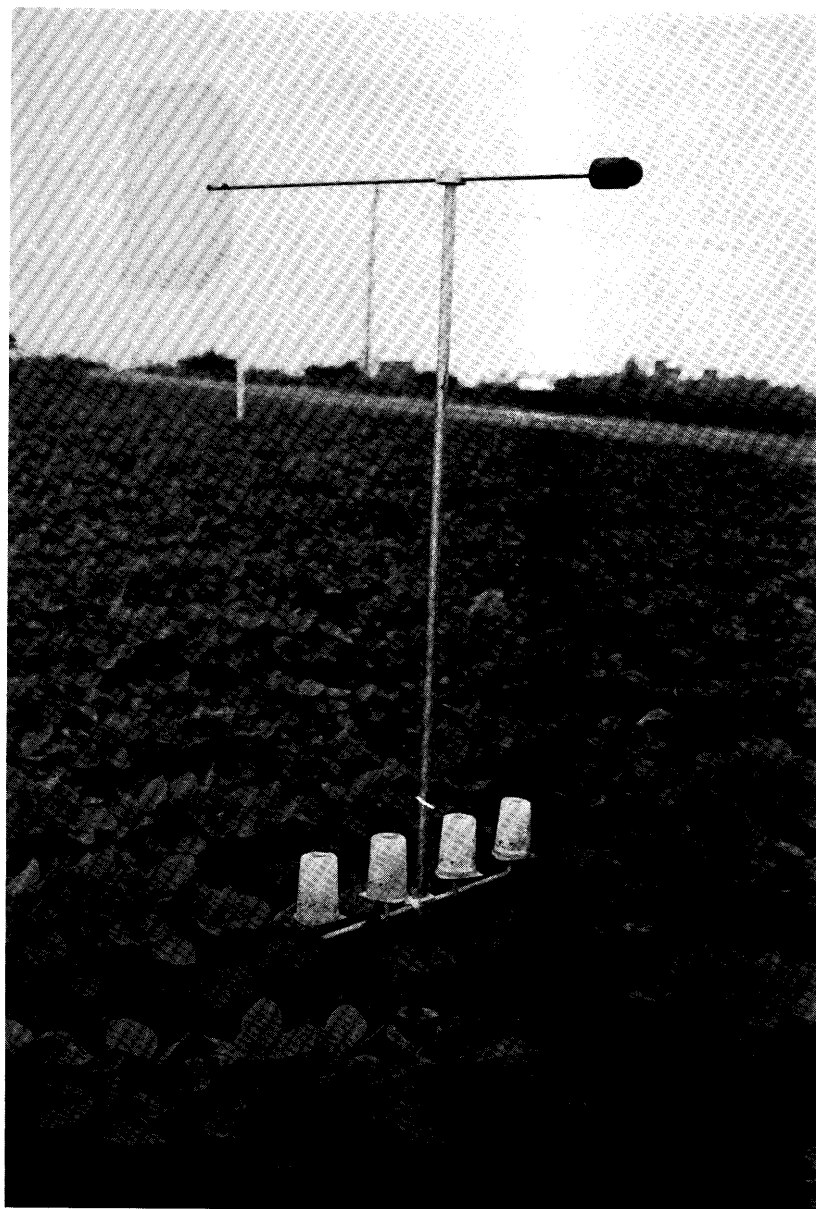


Figure 3. Modified wind-directed, vertically oriented trap for capturing small insects on windward and leeward sides of cylindrical, sticky-coated polyethylene cups.

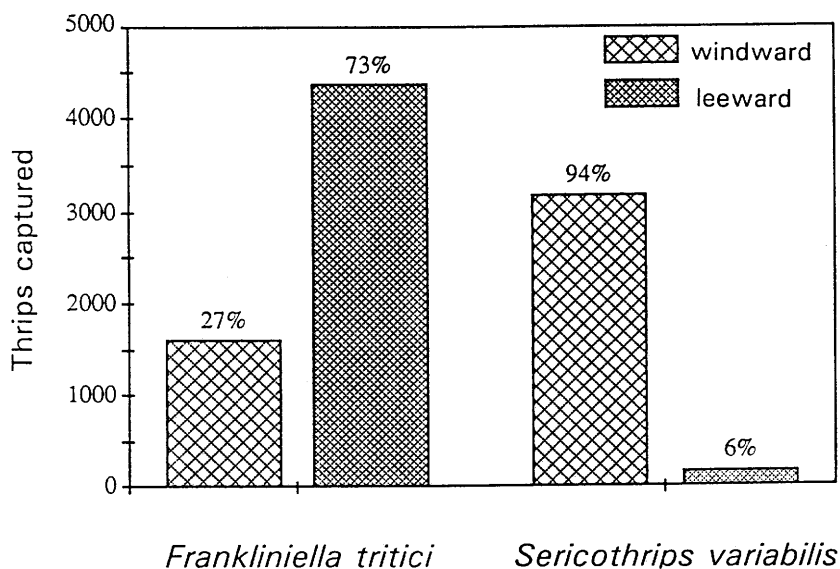


Figure 4. Proportion of two species of thrips captured on a vertically oriented cylindrical sticky trap in soybeans during the 1975 growing season, Urbana, Ill.

It seems most reasonable to postulate that those specimens collected on the windward side were being blown with the wind while those collected on the leeward side were flying against it. Because thrips are such weak flyers, those that were collected on the leeward side were probably flying at times when wind speeds were very low. This great difference in flight behavior between the two soybean-colonizing thrips species serves to point out the dangers in generalizing from one species to another.

#### Vertical Stratification in the Canopy

The within-canopy stratification of both soybean-inhabiting species of thrips was resolved so that a simplistic sampling plan could be devised that would best track the field population trends of these pests. To determine the stratification of each thrips species, the center leaflets of each main stem trifoliolate of ten plants from each plot were placed

in a bottle containing a solution of water with a drop of detergent. The bottle was shaken thoroughly, the leaves were removed and rewashed, and the effluent was placed into the bottle. The bottles, four (one per plot) for each vertical node on the soybean plant, were taken to the laboratory where the liquid was put through a fine sieve, thereby concentrating the thrips, which were identified, sexed, counted, and tabulated.

The results of this set of experiments (Fig. 5), conducted over two soybean growing seasons, were quite interesting. *S. variabilis* adults were concentrated near the top of the soybean plant, at about the second leaf down from the terminal. Because adults oviposit there, by the time the first and second instars develop, they are concentrated on about the fifth and sixth leaves down from the top, particularly early in the season when soybean plants are putting out one to two new leaves per week. Therefore, to sample for *S. variabilis* adults, the second trifoliolate from the top is most appropriate, but to sample for first or second instars, the fifth or sixth trifoliolate from the top is most appropriate. When new nodes are no longer produced, this species begins to emigrate from the plant and from the field in large numbers.

The findings were quite different with *F. tritici* (Fig. 6). Adults and larvae of this species concentrate heavily in terminals (meristem tissue) prior to the formation of buds and flowers, but once buds and flowers appear, a large-scale shift occurs into them. When flowering ceases, a shift occurs back to the terminals. Therefore, to sample *F. tritici*, terminals and flowers must be monitored. The two soybean-inhabiting thrips species, thus, occupy very different parts of the plant. Experiments conducted concurrently demonstrate that specimens of neither species move very much during a 24 hour period.

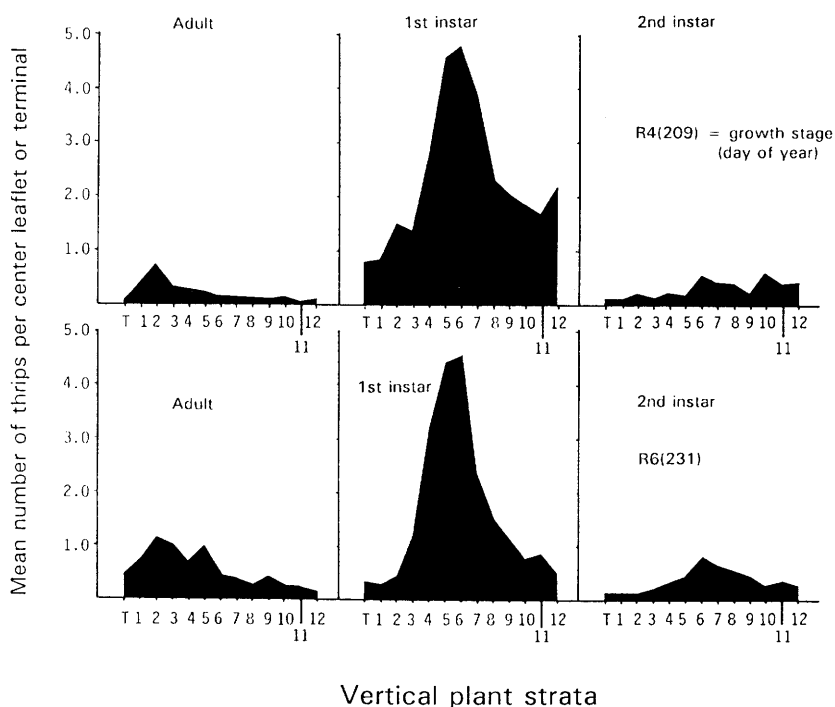


Figure 5. Within plant stratification of *Sericothrips variabilis* by life stage on soybean cv. Williams at growth stages R<sub>4</sub> (209 days post planting) and R<sub>6</sub> (321 days post planting), Urbana, Ill., 1976. T = terminal, 1-12 = center leaflets at nodes from uppermost expanded trifoliolate (1) downward on the main stem of the soybean plant.

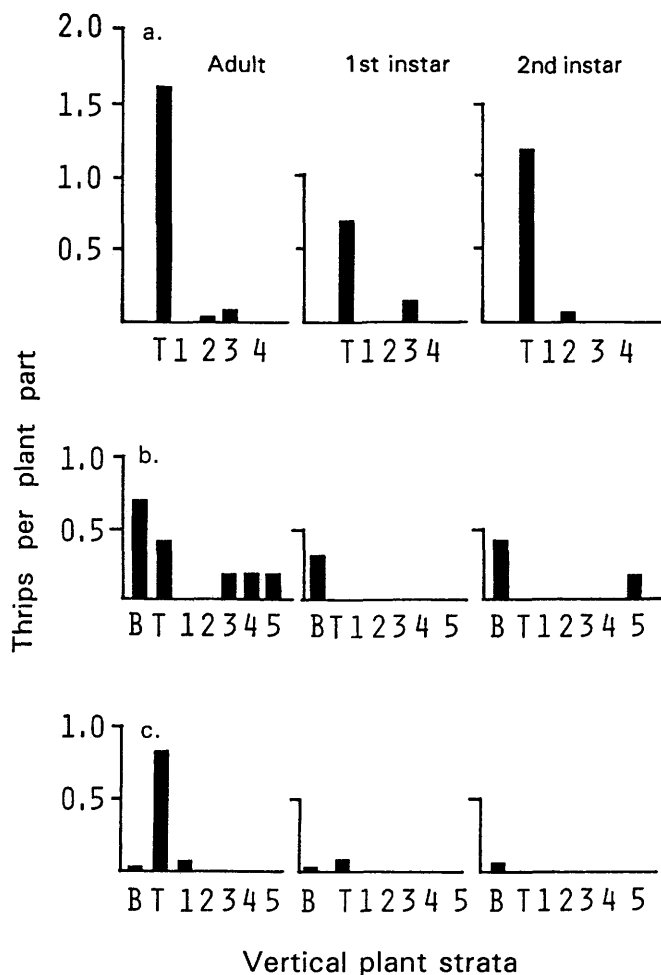


Figure 6. Within plant stratification of *Frankliniella tritici* by life stages on soybean cv. Williams at growth stages  $V_5$  (a),  $R_2$  (b), and  $R_5$  (c), Urbana, Ill., 1976. B = blossoms, T = terminal, 1-12 = center leaflets at nodes from uppermost expanded trifoliolate (1) downward on the main stem of the soybean plant.



Seasonal Phenologies:  
Within Canopy Abundance vs. Flight Activity

During the 1976 soybean growing season, thrips were monitored in Illinois for flight activity and for population density measurements. Flight activity was monitored with horizontal sticky green traps set just above the canopy and population density was assessed by leaf and terminal sampling (see previous section). Both sampling techniques resulted in very high catches of adult *S. variabilis* and *F. tritici* when compared with all other species. A comparison of these two methods illustrates the differences in the proportions of specimens of these two species sampled throughout the season. The leaf and terminal sample technique, used to determine the relative abundance of these two species within the canopy, showed that *S. variabilis* was four times more abundant overall. The sticky trap technique, however, indicated that *F. tritici* was twice as abundant overall (Fig. 7).

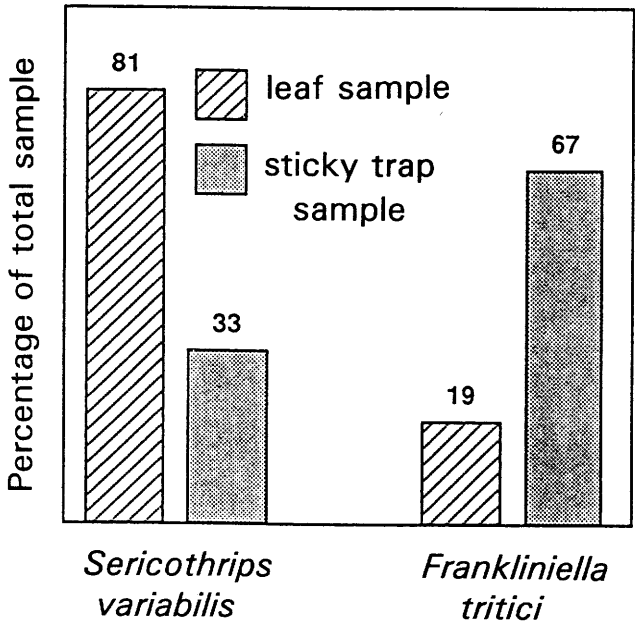


Figure 7. Proportional catches of the two most commonly collected thrips species in soybean cv. Williams, Tolono, Ill., 1976, using two methods: horizontal green sticky trap and plant part sampling.

This apparent paradox can be resolved. If the phenologies of adult thrips are plotted using the two sampling techniques, the picture becomes clearer (Fig. 8). For *F. tritici*, there are apparently two major peaks of flight activity, although from leaf samples there is but one population density peak in soybeans. The entire second peak of flight activity is most likely a product of population buildup on other host plants, thus accounting for a greater proportion of *F. tritici* in horizontal sticky traps than in terminal samples. The patterns of *S. variabilis* can also be explained. It is our contention that fewer adults immigrate, but these reproduce more successfully on soybean than *F. tritici*, and adults become active only late in the season as soybean plants begin to senesce. Thus, horizontal sticky trap samples suggest a flight peak of *S. variabilis* after the adult population within the soybean canopy begins to decline.

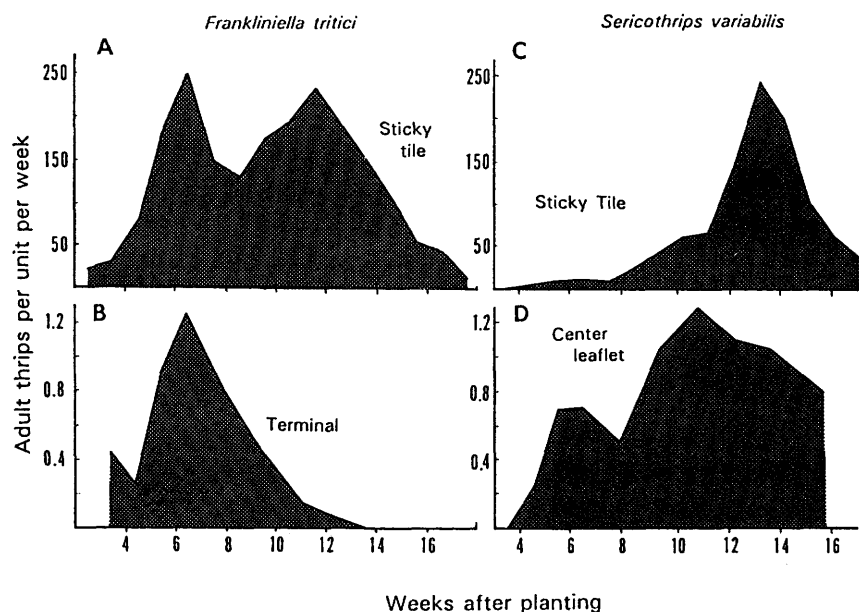


Figure 8. Seasonal phenologies of adult *Frankliniella tritici* (A, B) and *Sericothrips variabilis* (C, D), comparing abundances between flight activity patterns ("sticky tile," A, C) and population fluctuations within the soybean canopy ("terminal" and "center leaflet," B, D).

## Conclusions

Thrips colonize and build up in a habitat in a very dynamic fashion. It is important to understand the factors that drive this process and therefore experimentation involving sampling strategies must be undertaken. From the study presented on the biological dynamics of two species of thrips in soybean, it is clear that if one lacked comparative data from horizontal sticky traps and plant part samples, it would be possible to wrongly conclude that *F. tritici* was the more abundant species in soybean and that it reached peak abundances in soybean twice during the season. I believe that this points to the dangers of using a sampling technique to accomplish an objective for which it was not designed.

I caution that sampling strategies for the pear thrips in sugar maple be tailored to the aspects of the biologies you wish to determine. It is far too easy to devise a sampling strategy that will provide bogus information, setting your program back by several seasons.

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DEVELOPMENT OF SAMPLING METHODS  
FOR THE SLASH PINE FLOWER THIRPS

*Gnophothrips fuscus* (Morgan), (THYSANOPTERA: PHLAEOTHIRIPIDAE)

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**Abstract**

Slash pine flower thrips typically destroy about 24% of the flowers (cones) present in slash pine seed orchards. The seasonal distribution and abundance of slash pine flower thrips are being investigated and methods for sampling field populations of the insect are being evaluated for potential use in integrated pest management strategies. The efficacies of several sampling methods, including Berlese funnel extractions of host plant materials, suction apparatus, scouting, flight traps, and soil emergence samplers are reported.

**Introduction**

There are 5.18 million hectares (12.8 million acres) of slash pine, *Pinus elliottii* Engem. var. *elliottii*, in the southern United States (Sheffield et al. 1983). Genetically improved seeds for regeneration and reforestation of this species are produced largely in more than 75 southern pine seed orchards encompassing about 1,214 hectares (3,000 acres) (Department of Agriculture 1982). Through intensive management, these orchards are expected to yield over 50 pounds of seeds per acre per year (van Buijtenen & Hanover 1986). In the absence of pest management, however, total losses of slash pine cone crops average about 55% (Fatzinger et al. 1980).

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The slash pine flower thrips (SPFT), *Gnaphothrips fuscus* (Morgan), (Thysanoptera: Phlaeothripidae), is a major pest of slash pine in southern pine seed orchards. The insect has been reported to damage pine in eastern Canada (MacNay 1957), Rhode Island and New York (nursery stock of Austrian pine, *P. nigra* Arnold) (Crawford 1938), and Florida and has been collected in Massachusetts and Virginia (O'Neill 1965). Thrips-like damage has been observed on loblolly pine, *P. taeda* L., in Louisiana (Goyer & Nachod 1976) and on sand pine, *P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg., in Florida.

### Life History and Biology of SPFT

Ranasinghe (1981) estimated that in north Florida the SPFT has three overlapping generations a year with an average generation time of 46 days at 22°C. Ranasinghe & Wilkinson (1988) found all stages of the insect on young slash pine seedlings during the spring and summer; insect numbers decreased during the fall. They found macropterous adults in the crowns of mature pines during warm weather.

### Damage Caused by SPFT

Damage caused by the SPFT is not readily observed in the field because it occurs in the upper crown during the early stages of flower development (DeBarr 1969). Infestations appear to be more prevalent on young female strobili (flowers) of open-grown trees than on those in forest stands (Ebel 1963). Differences in susceptibility to attack between clones of seed orchard trees have been observed (DeBarr et al. 1972).

SPFT feed externally on flowers for a period of about 1 month when the flowers are succulent (bud stage until pollination) (Ebel 1965). Little damage occurs after pollination because the flowers quickly become leathery enough to resist additional feeding (Merkel & Ebel 1961, DeBarr 1969, Ebel et al. 1975). Feeding sites are marked with

small beads (exudates) of oleoresin (Ebel 1961, 1965) (Fig. 1). Severe feeding activity results in the destruction of scales and bracts (Ebel 1961). When feeding is severe, the flowers are killed, dry rapidly, and fall from the trees (DeBarr 1969). Feeding activity that does not kill flowers does kill scales, causing cone distortion due to asymmetrical growth; seed yields are only about one-third those of healthy cones (DeBarr & Williams 1971).

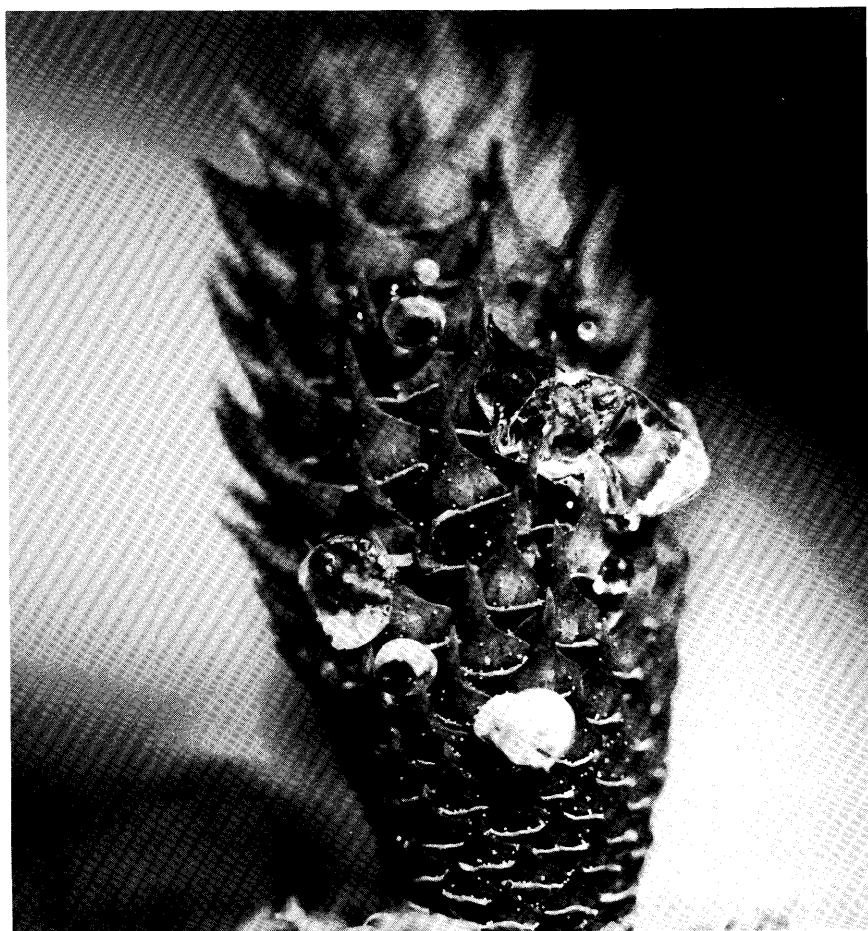


Figure 1. Adult slash pine flower thrips on female strobilus (flower) of slash pine. Small beads of oleoresin mark feeding sites.

SPFT damage an average of 24% (range 2-46%) of the flowers initially present in slash pine seed orchards (Fatzinger et al. 1980). The maximum SPFT damage we have observed was 90% of the flowers initiated during 1988 in an area of a slash pine orchard in northwest Florida that was not treated with insecticide.

### **Control of SPFT**

Two insecticides (Cythion and acephate) are currently registered for control of SPFT. Since SPFT damage levels cannot be predicted, an insecticide is routinely applied twice during the early stages of flower development to reduce SPFT damage. Applications are timed by repeatedly observing development of female strobili: the first application is made when flowers are in the twig-bud stage and the second application is made about 2 weeks prior to maximum flower receptivity to pollen.

### **Current Studies**

The objectives of studies we have underway are:

- 1) to evaluate the use of estimated SPFT populations to predict subsequent damage in slash pine seed orchards;
- 2) to determine the seasonal distributions and abundances of SPFT in mature and young pines;
- 3) to distinguish similar damage symptoms caused by other factors;
- 4) to simplify techniques for identifying the insect;
- 5) to develop degree-day models for timing of insecticide applications.



Methods for sampling field populations of SPFT were needed to achieve these objectives. We began evaluating several methods for collecting SPFT that are flying, on branch tips of slash pine, and in soil samples under infested trees. Techniques evaluated included Berlese funnels, a suction apparatus, scouting, beating branch tips, flight traps, and soil emergence samplers.

#### **Berlese Funnels for Extraction of SPFT from Branch Tips and Soil Samples**

Commercially available Berlese funnels were modified to hold 10 slash pine branch tips (about 25 cm long). A sheet metal cylinder (76 cm long) was used to extend the distance from the funnel to the light source (70 watt incandescent lamp). Preliminary studies, conducted during 1987 and 1988, indicated that the majority of thrips, including *Frankliniella bispinosa* (Morgan), *F. tritici* (Fitch), *Leptothrips pini* (Watson), *Oxythrips pini* (Watson), *O. pallidiventrtris* Hood, and SPFT were extricated from branch tips within 2 weeks (Fig. 2). During this period, we recovered up to 26 thrips per sample of 10 branch tips. Inspections of the surface soil and litter for presence of SPFT will begin this year. The seasonal distribution and abundance of SPFT are being investigated by estimating the population densities of the insect at 2-week intervals for 2 years. Population densities are estimated by counting SPFT present on 10 branch tips collected from the upper crowns of 10 mature pines, on 10 tips collected from the entire crown of 10 young pines (less than 1.8 m tall), and in 10 soil samples collected beneath the crown of infested trees.

### Scouting for SPFT on Young and Mature Pines

SPFT were counted visually on intact branch tips of young and mature pines throughout 1988 using magnifying lenses and the unaided eye. Once SPFT were observed on a branch, it was collected and placed in a Berlese funnel for extraction. The results varied widely with weather conditions and with differences in observers' abilities to locate SPFT on host plant material. SPFT often crawl under bark scales, inside needle fascicles, and into bud scales during cold or rainy weather and are difficult to locate. The scouting method appears to be suitable for determining the presence or absence of SPFT in various habitats, but it is unsuitable for quantitative measures of the insect's population.

### Beating Branches

Thrips were dislodged from host plants by striking branches with a stick while the branches were held over the inner surface of a white dissection tray. The majority of thrips collected were *L. pini*; only a few SPFT were dislodged from the branches.

### Flight Traps

Flight traps described by Ranasinghe (1981) and Ranasinghe & Wilkinson (1988) were tested during the summer and winter of 1988 and spring of 1989 at four heights in the crowns of orchard trees (Fig. 4). Each trap consisted of four white plastic discs (15-cm-diam, coffee can lids) suspended on a piece of string at intervals of about 10 ft. Each disc was sprayed on one side with Tanglefoot (Tanglefoot Co., Grand Rapids, Mich.). Sixteen traps were deployed by tying one end of the trap string to the center of a second string attached between the tops of two adjacent trees; the other end of the trap string was fastened to a stake in the ground. Captures of macropterous adults averaged less than one per trap. Total SPFT captured by the 64 traps ranged from 2 to 39.

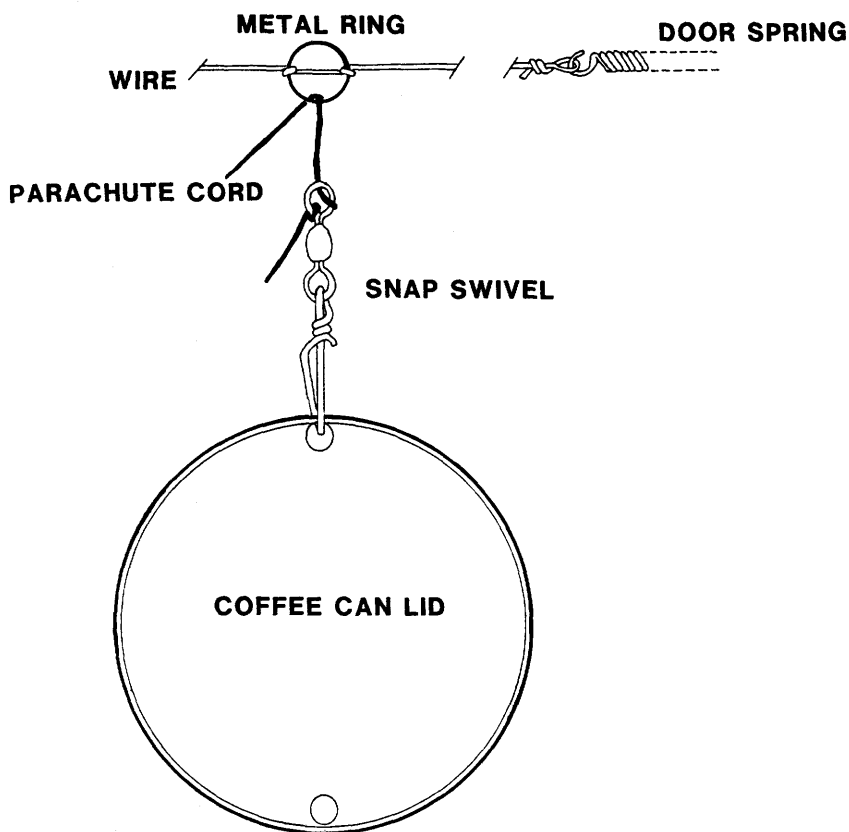


Figure 4. Components of flight trap used to collect winged adults of slash pine flower thrips.

### Soil Emergence Samplers

It is currently unknown whether SPFT spend part of their life cycle in the soil or litter. Ranasinghe (1981), however, did not recover SPFT from the top layers (5.0 to 7.5 cm) of soil beneath three mature slash pines. In addition to Berlese funnel extractions of soil samples, we began using soil emergence traps for SPFT during February, 1989 (Fig. 5). The emergence traps were constructed by gluing the large end of a plastic funnel (10 cm diam) over a 9-cm-diameter hole cut in the bottom center of a plastic bucket (20 cm in height, 28 cm diameter at top, 23 cm diameter at bottom). The small end of the funnel (1.5 cm diam) was glued through a 1.5-cm-diameter hole cut in the lid of an inverted vial (140 ml) at the top of the trap. The traps are placed with their open ends on the ground beneath infested trees to collect insects emerging from the soil. The traps have been operated for only 2 weeks thus far, and no SPFT have been observed among the insects captured.

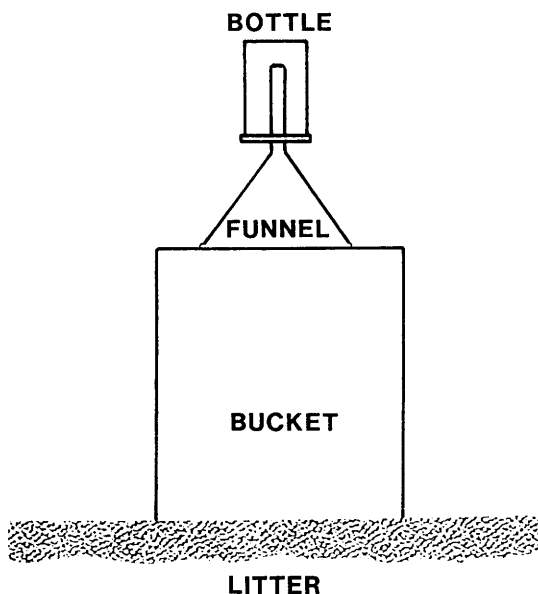


Figure 5. Soil emergence traps for collecting thrips and other insects.

### **Degree-Day Model**

Our other sampling effort is concerned with the development and evaluation of a degree-day model for the timing of insecticide applications for control of SPFT. Three trees of each of four clones of slash pine known to be highly susceptible to SPFT attacks are being observed from late-November through early-March to determine the onset and end of SPFT feeding activity. These data will be used in conjunction with on-site temperature records to develop and evaluate a degree-day model for predicting SPFT feeding periods on female strobili in slash pine seed orchards.

### **Clarification of SPFT Damage Symptoms on Host Plant Materials**

Several other insects and certain abiotic factors are capable of causing damage symptoms similar to that caused by SPFT. In an effort to further elucidate the damage symptoms caused by SPFT on female flowers and other host plant materials, SPFT are being caged on individual clusters of female flowers in a slash pine seed orchard and on potted seedlings in a greenhouse. Cages containing up to six SPFT and other cages without thrips were installed on the orchard trees in January, 1989 during the twig-bud stage of female flower development. The flowers will be photographed weekly during the period of SPFT feeding activity and monthly thereafter until the cones mature in September, 1990. The photographs will be used to trace the development of damage symptoms caused by SPFT feeding activity and to further elucidate the effects of nonlethal feeding activity on seed production.

### **Acknowledgment**

The authors thank Harold Denmark, Bureau of Entomology, Div. of Plant Industry, Fla. Dept. of Agriculture and Consumer Services, Gainesville, Florida, for identifications of SPFT, and Edward P. Merkel for valuable suggestions and technical assistance during the course of this study. This research is funded in part by the Integrated Forest Pest Management Cooperative, USDA Forest Service, and the Univ. of Fla.

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**SOIL SAMPLING AND EXTRACTION METHODS  
WITH POSSIBLE APPLICATION TO  
PEAR THRIPS (THYSANOPTERA: THIRIPIDAE)**

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**Abstract**

Techniques are described for the sampling and extraction of microarthropods from soil and the potential of these methods to extract the larval stages of the pear thrips, *Taeniothrips inconsequens* (Uzel), from soil cores taken in sugar maple stands. Also described is a design for an emergence trap that could be used to estimate adult thrips populations as they move from the forest floor into the tree canopy.

**Introduction**

The pear thrips, *T. inconsequens*, was introduced around 1904 from Europe to America where it became established on such hosts as maple, basswood, birch, beech, ash, and black cherry (Simons 1985). Since 1984 there has been a dramatic rise in the number of pear thrips infesting sugar maple trees such that the resulting damage has become a major concern among sugarmakers in the major syrup producing regions in the northeastern United States.



Very little documented work is available on pear thrips (Skinner 1988) particularly with regard to its economic importance on sugar maple. One of the problems facing workers is to develop a reliable monitoring system that will enable establishment of a threshold value for damage. Once this is determined it may be possible to monitor the number of viable larvae at emergence and warn sugarmakers of the likelihood of damage and its severity. This will allow farmers to take the recommended action against the pest before serious economic damage is done to the sugar maples.

Adult thrips attack the sugar maple at the bud stage, damaging the bud and causing the characteristic deformation of newly opening leaves. Eggs are laid in veins of the foliage and in the stem. Newly hatched larvae feed for a short time and then drop to the ground. A large proportion of their life cycle is spent below the soil surface prior to pupation and emergence of new adults the following season (Fig. 1). At this stage it is possible to use techniques currently employed in the extraction of soil arthropods, to obtain the larvae from soil cores taken in sugar maple stands. The number of larvae obtained from these soil cores can be used to assess overwintering mortality and the number of viable larvae that will become the next season's pest. In conjunction with sampling the population of adult thrips present in the tree, it may be possible, over a number of seasons, to calculate an "economic damage threshold value."

Simultaneously these techniques will enable researchers to obtain valuable qualitative and quantitative data on the soil mesofauna for use in the development of a "Total Forest Ecosystem Monitoring Program" (Teillon 1988). This would be especially important if chemical methods of thrips control, eg. carbaryl, are used because the effects of such chemicals on beneficial, as well as, non-beneficial soil arthropods may be significant.

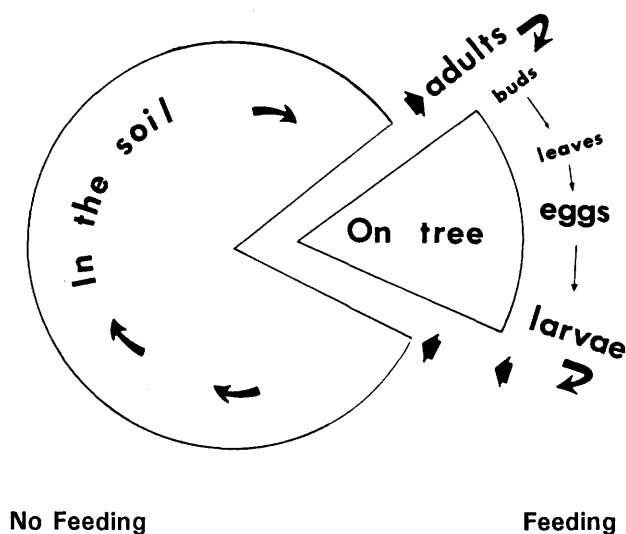


Figure 1. Probable life cycle of pear thrips in Vermont sugar maple stands (from Parker et al. 1988). For more specific life cycle information, see Skinner & Parker, poster presentation, this proceedings.

## Materials and Methods

### Soil Sampling and Extraction of Microarthropods

The large acreages of sugar maple that are infested will require many soil samples to obtain accurate data on numbers of viable larvae present. A sampling pattern must be designed that is statistically sound with a standardized sample size. This is usually a 5 cm diameter, 15 cm deep soil core, which is about 250-300 ml of soil. Commercial equipment is available to take the soil cores, eg. golf course hole cutters and bulb planters, both of which are relatively inexpensive and easy to use (material suppliers listed on page 173).

To extract a large number of soil cores efficiently and quickly requires specialized methods and equipment. A number of options are available such as heat extraction, flotation and grease film extractions (Table 1).

Table 1. List of dry funnel and flotation methods of extraction of soil arthropods (after Edwards & Fletcher 1971)

Dry Funnel	Flotation
Simple plastic funnels (Edwards & Fletcher 1970)	Simple brine flotation (Edwards & Fletcher 1970)
Rothamsted controlled gradient funnels without heat (Edwards & Fletcher 1971)	Salt and Hollick flotation (Salt & Hollick 1944)
Rothamsted controlled gradient funnels with heat (Edwards & Fletcher 1970)	Mechanized flotation (Edwards & Heath 1963)
Split funnels (Murphy 1962)	Grease film extractor (Aucamp & Ryke 1964)
High-gradient funnels (moist regime) (MacFadyen 1962)	
High-gradient cylinder extractor (MacFadyen 1962)	
Infra-red extractor (Kempson et al. 1963)	

In 1971, eleven of the most commonly used techniques were compared (Edwards & Fletcher 1971) and data were collected on the efficiency of these methods to extract soil arthropods, including Thysanoptera (Table 2). Of these eleven methods the controlled-gradient (with heat) extraction technique proved to be the most efficient for retrieving the major groups of arthropods and thrips. This method is used by many soil ecologists today.

Two controlled-gradient extractors are currently in use at the Ohio Agricultural Research and Development Center (O.A.R.D.C.), Wooster, Ohio. The first extractor built was a self-contained 80-sample

Table 2. Comparison of methods of extracting Thysanoptera from clay-loam soil under three types of management (after Edwards & Fletcher 1970, from Lewis 1973) [Mean number of thrips per soil core (10 cm diam x 5 cm deep) is expressed as  $\log (N+1)$ .]

	Method <sup>a</sup>												Variance	
	Dry funnel							Flotation						
	A	B	C	D	E	F	G	H	I	J	K	s.e. <sup>b</sup>	I.s.d. <sup>b</sup>	ratio
Woodland	0.029	0.048	0.000	0.000	0.067	0.048	0.056	0.086	0.019	0.322	0.111	0.042	0.110	4.436 <sup>c</sup>
Pasture	0.000	0.019	0.019	0.029	0.019	0.000	0.056	0.000	0.169	0.481	0.000	0.044	0.116	11.270 <sup>c</sup>
Fallow	0.000	0.000	0.000	0.000	0.019	0.000	0.038	0.086	0.094	0.056	0.049	0.026	0.068	1.799

\* A. Simple plastic funnels (Edwards & Fletcher 1970)

B. Rothamsted controlled gradient funnels without heat  
(Edwards & Fletcher 1970)

C. Rothamsted controlled gradient funnels with heat  
(Edwards & Fletcher 1970)

D. Split funnels (Murphy 1962)

E. High-gradient funnel (moist regime) (MacFadyen 1962)

F. High-gradient cylinder extractor (MacFadyen 1962)

G. Infra-red extractor (Kempson et al. 1963)

H. Simple brine flotation (Edwards & Fletcher 1970)

I. Salt and Hollick flotation (Salt & Hollick 1944)

J. Mechanized flotation (Edwards & Heath 1963)

K. Grease film extractor (Aucamp & Ryke 1964).

<sup>b</sup> s.e. = standard error of means. I.s.d. = least significant difference.

<sup>c</sup> Significantly different at 0.01% level.

machine, which generates and maintains a heat gradient within the soil sample using a compressor, heat exchanger and pump to provide cooling to the bottom of the sample and electric light bulbs (25 watt) to supply heat to the top of the sample. A heat-gradient of about 15°C between the top and bottom of the soil sample gives the best results. A smaller 36-sample extractor was also constructed and housed in a controlled temperature room to provide cooling (21°C). Electric light bulbs (15 watt) provide heat (38°C) at the top of the sample. This heat gradient causes the soil sample to dry out from the top downwards. The arthropods respond by moving down the sample to avoid desiccation, eventually moving out of the sample, falling through the mesh bottom of the sample holder where they are collected in vials containing a mixture of 70% ethanol, 5% glycerol and 25% water.

Trials have shown that both machines operate at similar efficiencies. The major difference between the two is cost. The self-contained extractor can be constructed at a cost of \$3,500, the major expense (about \$2,500) being the compressor, heat exchanger and pump. The smaller 36-sample extractor can be built for \$160 (about \$320 for a machine capable of extracting 72 samples) but this does require a temperature-controlled room. Both machines are suitable for extracting Thysanoptera.

### Emergence Trap

**Trap design.** Information needed to help develop a monitoring program for pear thrips can be obtained from the numbers of adult thrips emerging from the soil in the spring and migrating to the maple trees. To obtain these data, a suitable emergence trap is required. A number of methods have been evaluated with some success (Laudermilch 1988). The following emergence trap design would enable researchers to obtain data on emerging thrips as well as other soil arthropods in one operation.

Due to the large numbers of samples required, low cost and ease of use in the field and laboratory were key elements in the design. The trap consists of two parts: a soil unit which is a mesh cylinder capable of holding a soil core, and a trapping unit which is attached to the top of the mesh cylinder. Materials and method of construction are shown in Figure 2.

Some positive aspects of this design are:

1. The soil core is kept in as natural a condition as possible during the trapping period. The mesh cylinder and perforated bottom allow gasses, moisture and arthropods normal movement in and out of the soil core.
2. The whole unit is relatively inexpensive and easy to assemble using readily available laboratory equipment.
3. The unit is durable and lightweight so large numbers of traps can be carried to the experimental site with little effort, and should last for a number of trapping seasons.
4. Both the soil core and emergence catch can be transported to the laboratory easily and the catch quickly dispensed for storage or sorting.
5. Set out and retrieval of traps can be carried out easily by one person.
6. Traps are reusable and are easily dismantled, cleaned and stored.

Apart from the cylinder mesh which can be purchased at most hardware stores, all other components are readily available from biological suppliers. The total cost of a single trap is \$7.00, but this can be reduced if funnels and bottles are bought in bulk.

## Key to Figure 2

1. Perforated stopper.
2. 2 1/2" (6.25 cm) Nalgene powder funnel. Press on or glue in place to the Nalgene bottle.
3. 4 oz (125 ml) Nalgene bottle. Cut hole in bottom to make a tight fit with funnel spout.
4. 2 1/2" (6.25 cm) plastic funnel with 1/4" diam.-tapering spout. Cut down spout so that when in position 1/4" protrudes through the bottom of bottle (3).
5. Cap from 4 oz (125 ml) Nalgene bottle. Cut out center using a hot scalpel blade. Heat seal mesh to outer surface, ensuring threads are facing away from mesh cylinder.
- 6 & 7. 1.5 x 1.8 mm fiberglass window screen. Form into tube and heat seal seam with soldering iron fitted with a flat tip. The diameter should be 2" and the length can be cut to suit specific experimental needs.
8. Heat seal mesh to outer surface of lid. For extra strength use pipe clips on both caps.
9. Cap from 4 oz/125 ml Nalgene bottle. Perforate with small holes for drainage.

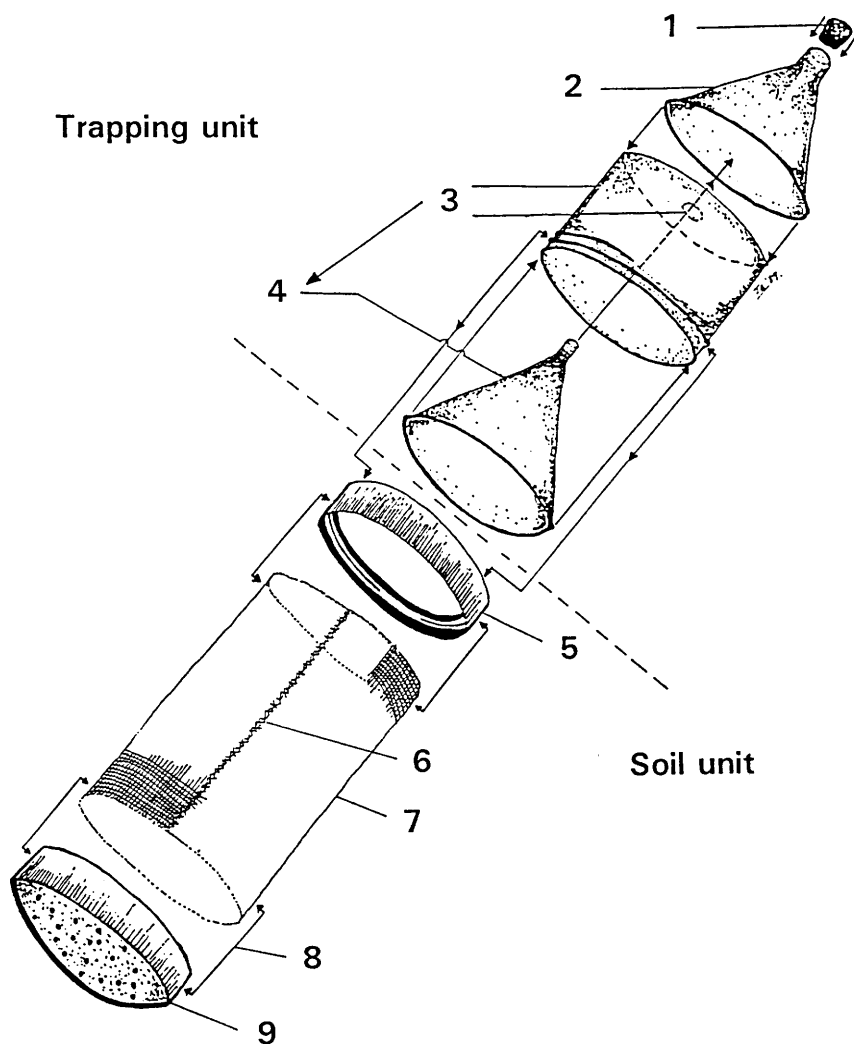


Figure 2. Diagram showing assembly of emergence trap.



**Trap operation.** A suitable size soil core is taken and placed surface side up in the mesh cylinder. This unit is then put back into the hole left by the soil core having the top flush with the soil surface. The trapping unit is then screwed into place on top of the soil unit and left for the desired trapping period. To retrieve the catch, the trapping unit is unscrewed and capped quickly with an intact bottle lid. A new unit may be attached to the mesh cylinder or it may be capped off for retrieval of the soil core. Both units can now be returned to the laboratory for processing.

The trapping unit should be inverted and placed in a cold room to immobilize the catch. To dispense catch, the stopper is removed allowing the catch to fall into storage vials or counting dish. The soil core is removed from the mesh cylinder and processed by the controlled-gradient extraction method described earlier. This will yield viable soil arthropod numbers and any remaining viable thrips. The soil core can be further processed to obtain dead arthropods, pupae, and eggs, data which the controlled-gradient extraction cannot provide. This is best accomplished using a heptane flotation method (Walter et al. 1987).

## Results

The emergence trap is currently being evaluated in the field so no data is available at this time. If the method proves successful, the following data will be obtained from a single soil core:

- A. Emerging adult thrips
- B. Process soil core by controlled-gradient extraction method to obtain any remaining live thrips and all other live soil arthropods.
- C. Final extraction of the soil core by the heptane flotation method will yield dead soil arthropods including thrips as well as pupae and possibly eggs.

These data will provide valuable input into a "Total Forest Ecosystem Management Program."

### **Material Suppliers**

**Soil augers:** Bulb planter (short handle and wide) any garden supplier  
Bulb planters (2" diam, 6" deep, long handle)

Smith & Hawken  
55 Sunnyside  
Mill Valley, California

**Nalgene bottles:** 4 oz (125 ml) with 70 mm cap diam  
(cat. # 11-823-30)

Fisher Scientific  
461 Riverside Ave.  
P.O. Box 376  
Medford, Massachusetts

**Plastic funnels:** Nalgene PF 65 (cat. # 10-348A)  
PF 45 (cat. # 10-347D)  
Fisher Scientific

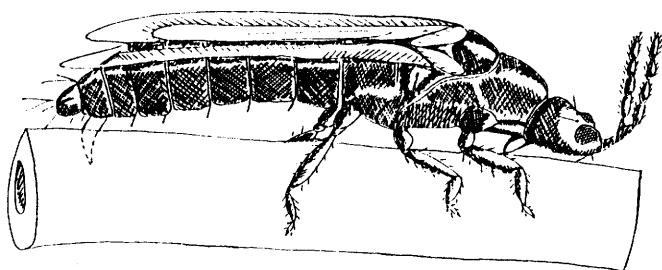
**Cylinder mesh:** 1.5 x 1.8 mm fiberglass window screen available at  
most hardware stores

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## PEAR THRIPS IN VERMONT



*Taeniothrips inconsequens* (Uzel)

## THE PEAR THRIPS PROBLEM

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As entomologists, we sometimes like to think of an insect pest problem as simply a problem with an insect and its host. Our jobs would be much easier if that were the case, but of course, it is never that simple. There are many other factors besides the insect, and each one must be fully considered to understand the problem and develop effective management solutions. In this case I see many factors facing us besides the pear thrips and the sugar maple tree. (Fig. 1).

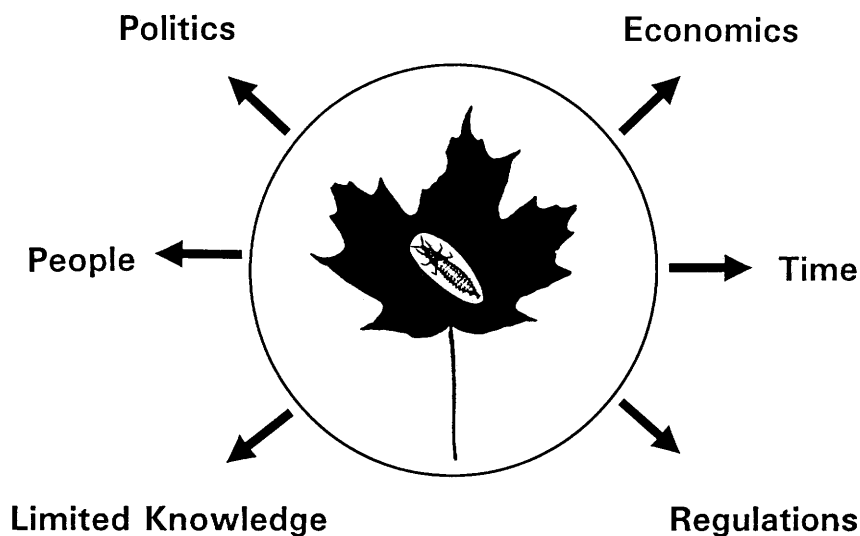


Figure 1. Key factors associated with the pear thrips problem.

There are the *people* who are affected both directly and indirectly by damage caused by thrips. To name only a few, there are farmers and sugarmakers who make maple syrup and the industries that supply sugarmakers with their equipment; there are loggers who harvest and mill the maple timber; there are tourists who come to experience the brilliant fall foliage and the many indirect beneficiaries of tourism; and finally, just as important, there are the homeowners who cherish their big old maple in the front yard.

The *politics* of pear thrips is also a complex factor that partly governs our research and management activities. Without the power of politics we would often go without the funding needed to conduct essential research. The people mentioned above, who own the trees we are trying to protect, play an important role in communicating their needs, and ours, to the politicians who make the funding decisions. Yet politics, for better and for worse, play a decisive role in the *regulations* that are imposed upon our management activities. These regulations, though generated for the greater good, sometimes present major research and management challenges with which we must deal.

Because pear thrips is a relatively new forest pest in New England, I am continually frustrated and at the same time excited by our *limited knowledge* about this insect and its bioecology. As an entomologist, it is a unique opportunity to investigate an organism that is so little understood. Everything we learn is new. However, as a forest pest manager, I am frustrated that we have so much to learn before we can answer how best to manage this insect.

*Time* plays a crucial role in the problem of pear thrips in two respects. First, consider the life cycle of this insect; it is active above ground for such a short period, about two and one-half months. That gives us very little time to carry out the essential research to find the answers needed to develop management strategies. Studying the insect below ground is also needed and presents additional unique complications in accessibility. Secondly, most people, especially those who are worried about something important to them, want answers *now* to their questions about how to protect their trees from this new



pest. It is hard to explain to these people that pest problems are complex, involving many interrelationships, all of which must be investigated and that takes time. There is just no "silver bullet."

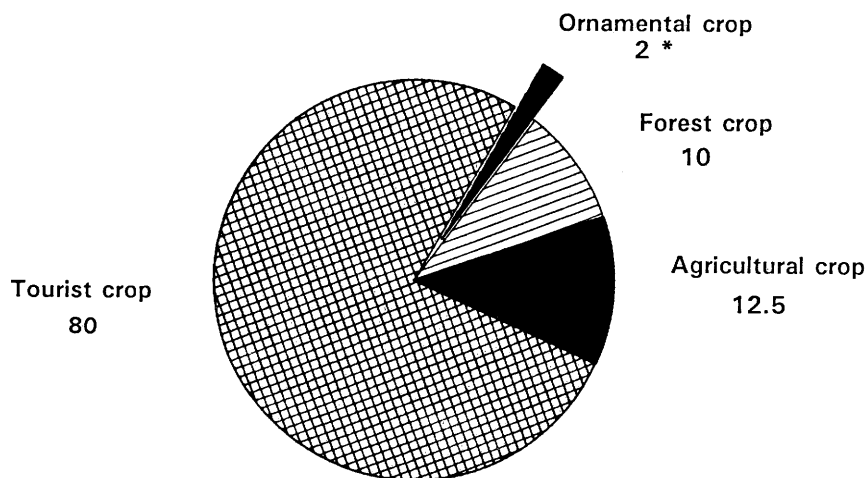
Finally, there is *economics*. I mentioned economics as it relates to people and politics, but one must also consider economics relative to the Vermont environment and the actual dollars involved. The magnitude of a pest problem is usually assessed by the abundance of the threatened crop and the economic impact it imposes. In 1983 there were about 405 million trees in Vermont, and about 124 million of them were sugar maple; one out of every three hardwoods was a sugar maple (Department of Forests, Parks and Recreation 1988). This represents an almost inexhaustible food source for this pest as well as an important source of revenue for Vermont and other northeastern states. It also presents a massive area that could potentially require protection.

Though the sugar maple is generally considered a hardwood forest tree, it also falls within the agriculture system by virtue of maple syrup production (Parker et al. 1977). Therefore management strategies that are developed for pear thrips must address issues associated with this host as a widespread forest tree species as well as a food crop, requiring adherence to food tolerance restrictions associated with pesticide use. This is very different from other forest pest problems, such as the gypsy moth, *Lymantria dispar*, or spruce budworm, *Christoneura fumiferana*, which primarily attack forest tree species.

It is extremely difficult to place an exact value on the sugar maple resource in Vermont and the eastern United States. The high attendance at this conference attests to the concern we have for this cherished tree, but an attempt to assess the value of sugar maple must be made to justify the worth of investing in its protection.

The sugar maple resource in Vermont can be divided into four general economic categories (Fig. 2). First there is the revenue from maple syrup. In 1989 over 12.5 million dollars were made in Vermont

from the sale of maple syrup alone, and exceeds 40 million dollars regionally. This does not include revenue generated indirectly from maple syrup products, such as maple candy, or from industries that supply sugaring equipment and supplies.



\* Millions of dollars

Figure 2. The value of sugar maple in Vermont in 1988.

There is also the sugar maple forest crop. In 1989 about 32 million board ft of sugar maple timber was harvested in Vermont. This has a value of about 2.6 million dollars on the stump, and over 7.3 million at mill delivery (H. B. Teillon, personal communication). This value is again increased following milling.

Probably the largest industry that pear thrips damage could impact, though indirectly, is the tourist industry. This industry is highly dependent on the condition and duration of fall foliage colors. Pear thrips damaged leaves, rather than turning a brilliant red or orange, turn brown and fall prematurely. In addition, tourism associated with forest recreation, such as hiking, camping and hunting, could be negatively

affected by the reduced forest health resulting from thrips damage. Tourism is estimated to bring about 80 million dollars annually into Vermont (H. B. Teillon, personal communication).

The one other segment of the pie I call the ornamental crop. This is the shade tree crop and includes your backyard tree. It is difficult to assign a dollar value to that yard tree, but considering the time and money expended to protect these trees from gypsy moth defoliation, the value is significant. When revenues from these four industries are combined we get a total of over \$100 million dollars raised annually from the sugar maple in Vermont. This represents a significant portion of Vermont's overall annual revenue. Considering the contribution sugar maple gives to this State's income, one can appreciate our great concern for its well being.

#### **The History of Pear Thrips Damage in Pennsylvania and Vermont**

Pear thrips was first positively identified causing damage to maple in Pennsylvania in 1979 (Laudermilch 1988). For a number of years forest managers had noticed what we now know to be characteristic thrips damage (Fig. 3 & 4), but called it "Maple Malady" because they didn't know the cause. This seems to be a common trend; even in California when pear thrips were first introduced, it took about 4 years before they were actually identified as the causal agent (Bailey 1944).

The Pennsylvanians began mapping thrips damage in 1979 (Fig. 5). Thrips damage fluctuated greatly from year to year, gradually increasing over time. Even in the years when defoliation did not warrant mapping there was generally at least light thrips damage in some areas (G. Laudermilch, personal communication). The heaviest damage in Pennsylvania occurred in 1988 when a dramatic increase in the area of defoliation was observed, over 400 thousand hectares (one million acres).

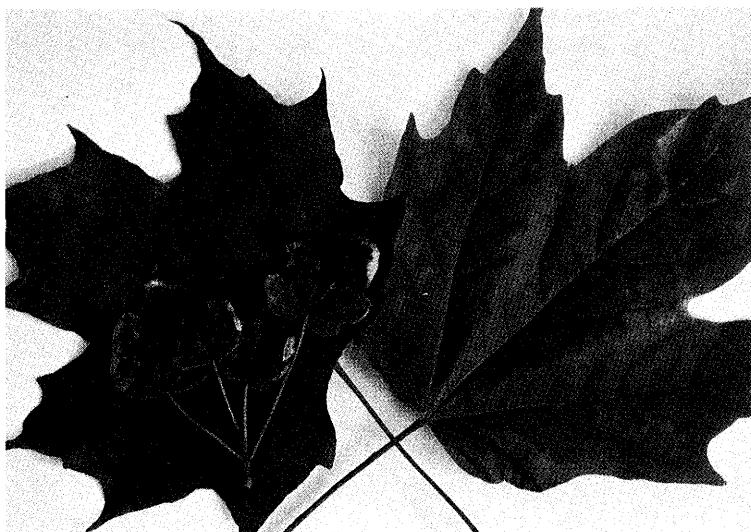


Figure 3. Healthy and pear thrips-damaged maple leaves.



Figure 4. Aerial view of severe pear thrips damage in southern Vermont, June 1988.

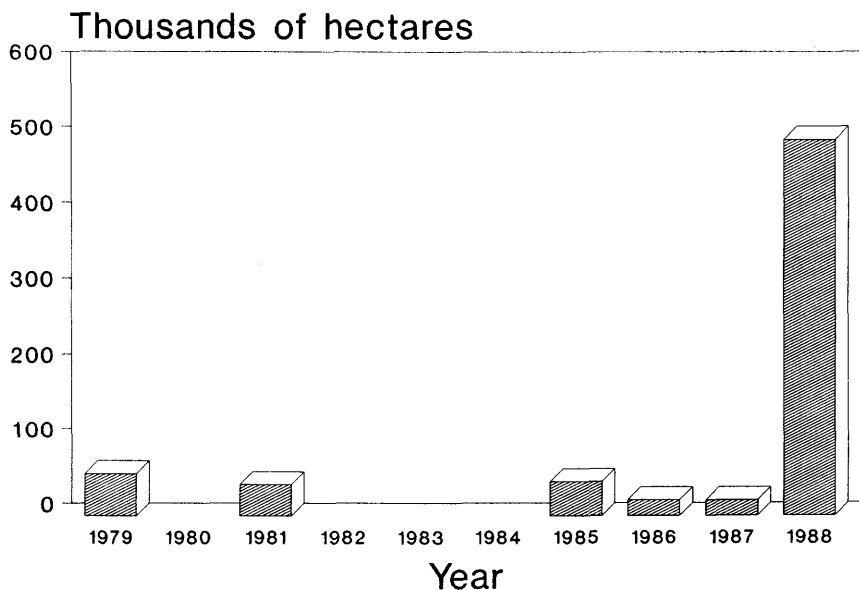


Figure 5. Pear thrips damage in Pennsylvania, based on aerial sketch mapping.

In Vermont, a similar pattern occurred. Pear thrips were positively identified here in 1985 (Teillon et al. 1985). However, many sugarmakers recall observing thrips-like damage as early as 1978, but they diagnosed it as frost injury (J. Vinton, personal communication). Mapping of damage was initiated in 1985 as a result of widespread thrips defoliation (Fig. 6). In 1986 there was no visible defoliation, but in 1987 thrips were again evident with about about 9,000 hectares (22,000 acres) of noticeable damage (Teillon et al. 1986, 1987). It was the severe damage of 1988, however, that alerted forest managers, entomologists, sugarmakers and the general public to the serious threat pear thrips posed to the Vermont maple.

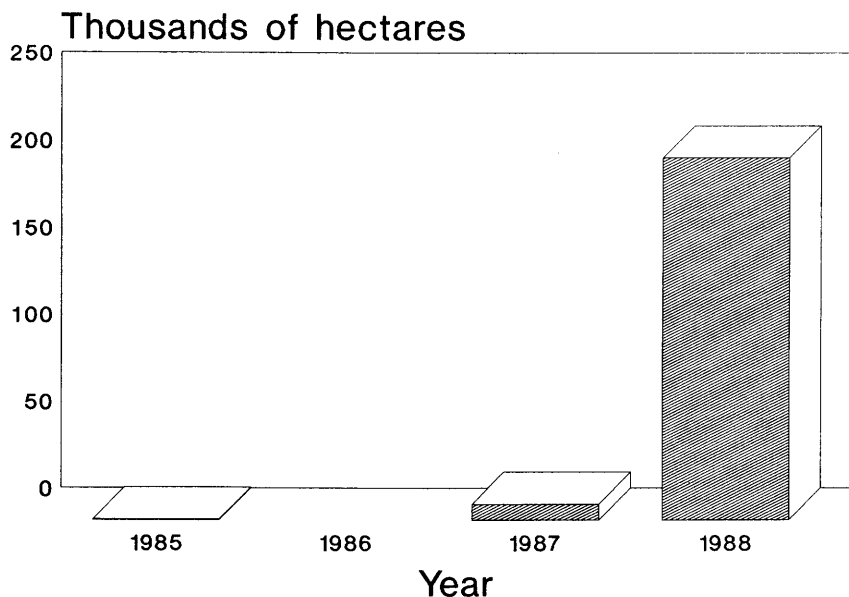


Figure 6. Pear thrips damage in Vermont, based on aerial sketch mapping.

Damage caused by this insect was centered in the central and southern areas of Vermont, and in these areas the damage was extensive (Fig. 7). Hardly a maple was spared, and in many cases all of the leaves on individual maple trees were destroyed, requiring complete refoliation. From the air the forest floor in severely damaged sites was visible through the canopy as if it were winter. The actual impact to the sugar maple of this severe defoliation early in the growing season is still unknown (Houston et al. 1988). Research is needed to answer this basic question. Until this answer is found we can only hypothesize as to the potential impact, but repeated thrips damage year after year must take its toll on tree health, and pear thrips damage in the spring followed by a late-season defoliator such as saddled prominent, *Heterocampa guttivitta*, or forest tent caterpillar, *Malacosoma disstria*, could be devastating.

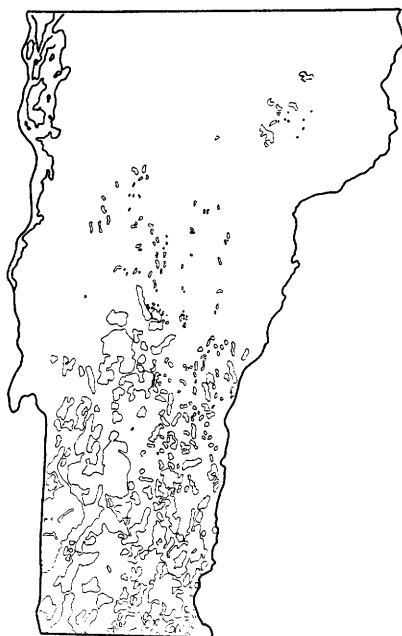
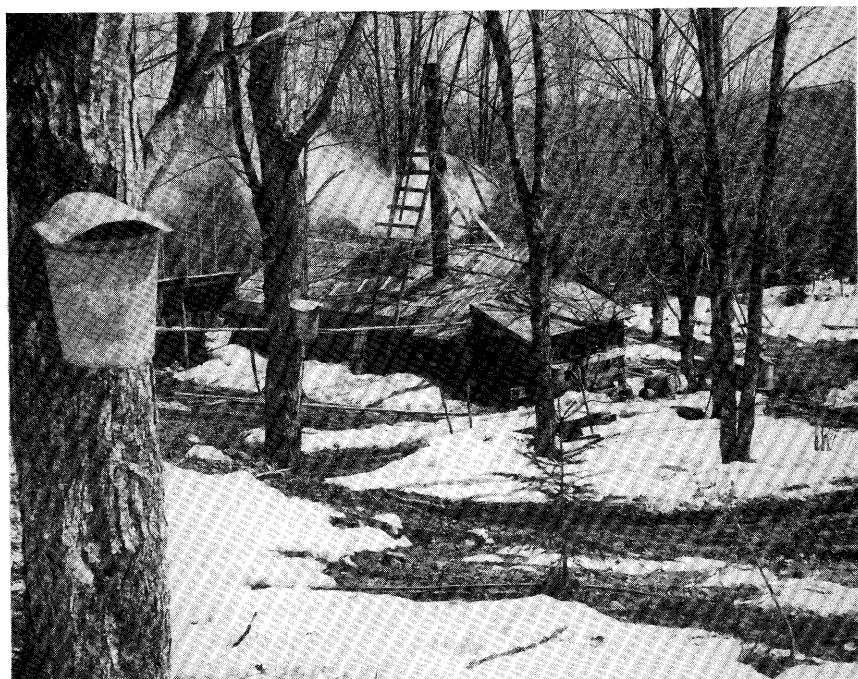


Figure 7. Areas of severe pear thrips damage in Vermont determined from aerial sketch mapping in 1988 (Teillon et al. 1988).

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Sugaring in Vermont  
(photo from Vt. Development Dept.)



## WHAT'S A SUGAR MAPLE WORTH?

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What is a sugar maple worth? This is an interesting question and not one which is easy to answer. I have some thoughts on this subject to share with you. Many of these have been discussed with county and district foresters, sugarmakers and people from the community who appreciate the maple tree very much.

### Wood Products

**Firewood.** One use for the sugar maple is firewood, though it may not be the highest priority. Sugar maple is one of the finest firewoods, burning very cleanly when dry. Based on figures compiled by the district foresters of the Vermont Division of Forestry, a 12-inch (30.48 cm) diameter tree could yield one-fourth of a cord<sup>1</sup> of wood; a 20-inch (50.8 cm) diameter tree, up to one cord. If we consider it's value in the woods as stumpage, \$10.00 per cord is a reasonable figure. Therefore, the value of a 12-inch tree just for firewood stumpage is \$2.50, and on a retail basis firewood from a 12-inch tree would sell for around \$20-\$25.

**Timber.** This is another valuable source of income from the sugar maple. A 12-inch diameter tree should yield about 75 board feet (22.86 m); a 20-inch tree about 200 board feet (60.96 m). The current stumpage price for maple wood, the price a landowner will receive for sawn timber prior to manufacturing, is about \$200/1,000 board feet (304.8 m), or \$15.00 for a 12-inch tree and \$40.00 for a 20-inch tree. Maple lumber is preferred by many crafts people, and is used for a wide range of products, including fine furniture, gun stocks, bobbins and toys.

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<sup>1</sup>A cord of firewood measures 4 ft x 4 ft x 8 ft, and sells for about \$80-100.

## Maple Syrup Production

Maple syrup is the most familiar product associated with the sugar maple tree. Let us consider the value of an individual tree in terms of the syrup it produces. A maple tree is "tapped" by drilling a hole, (7/16 in. diameter [1.1 cm], 2.5-3 in. [6.4 - 7.6 cm] deep) in the bole of the tree, into which is placed a spout to collect the sap for making syrup. Only trees with a diameter of more than 12 inches should be tapped. We recommend one tap hole for a 12-inch diameter tree, and two for a 20-inch tree, though this may be more conservative than is commonly practiced. In an average year, one quart of syrup can be produced per tap from the 12-inch tree, or around \$10.00 per "tap" at current syrup prices (Fig. 1). Syrup provides revenue annually whereas timber products give only a one-time income.

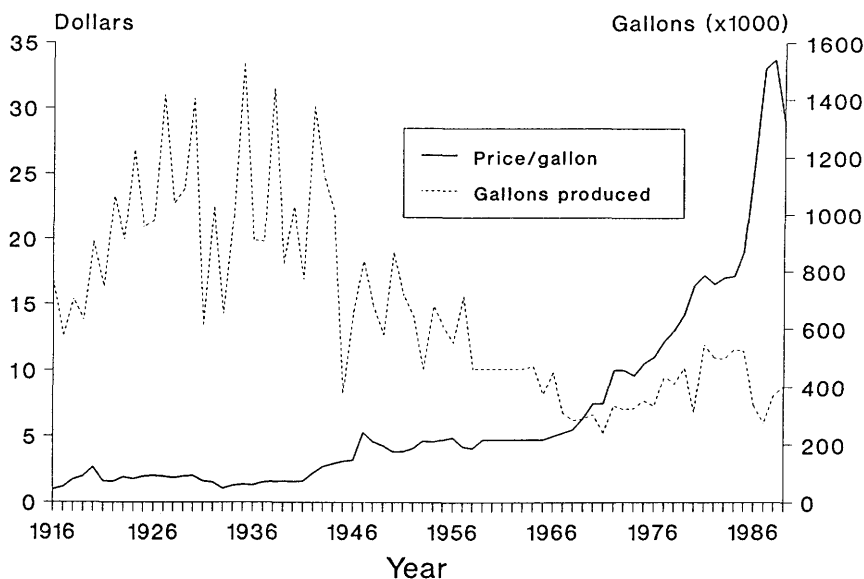


Figure 1. Average price per gallon of maple syrup and the number of gallons produced in Vermont from 1916 - 1989 (from VT Department of Agriculture).

In 1988 Vermont produced approximately 370,000 gallons of maple syrup, which at \$35.00/gallon, amounts to approximately 12.5 million dollars (Department of Agriculture 1989). It is interesting to note that whereas the price of syrup has risen markedly since 1916, syrup production has declined (Fig. 1). Despite the drop in production, Vermont still produces more syrup than other states. Actually the value of maple syrup to Vermont is even more than 12.5 million dollars when one adds in the revenue from other products that are made from the syrup and income generated from industries related to syrup production, such as evaporating equipment and syrup containers.

Who are the sugarmakers? There are all kinds, from the backyard sugarmaker working under the stars late into the night, to the large, commercial operators who put in over 25,000 taps and make more than 3,000 gallons of syrup a year. In Vermont alone there are over 2,500 sugarmakers based on current VT Department of Agriculture estimates (E. Willard, personal communication). That the University of Vermont maintains one of the oldest on-going maple research stations in the country attests to the importance of this industry to the people of Vermont.

### **Aesthetics and Tourism**

The aesthetic value of the sugar maple is more difficult to assess than syrup or timber production, yet this is an important factor to which almost every speaker here has referred. Maples make the Green Mountains of Vermont green, which is one reason the sugar maple is our state tree. In the fall, they also provide a beautiful backdrop of color for which Vermont is famous and which attracts many tourists annually. If you look around, most photographs and paintings of scenic Vermont include the beautiful sugar maple. In a national survey when asked "What do you think of when you think of Vermont?," the overwhelming majority said, "We think of maple."

Tourism is a primary source of revenue in Vermont and the sugar maple plays an important role in attracting tourists here. In 1987, according to the Vermont Tourist Industry Travel Bureau, 8.4 million visitors came to Vermont. Between mid-September and mid-October tourist facilities are booked to capacity. While here, tourists spend over 1.2 billion dollars annually on goods and services of all types. We must consider the impact on the tourist industry when we assess the worth of our maples.

The overall environmental value of a maple must also not be forgotten. A healthy canopy shades the forest floor, providing suitable habitat for many other species that live in the forest. It keeps the soil cool and protects our groundwater supply.

All of the sources of income provided by the sugar maple that I have mentioned ultimately provide jobs for Vermonters--jobs for foresters, loggers, sugarmakers, restaurant owners and many more. Even the occasional entomologist may benefit from the sugar maple!

So what is that sugar maple worth? Many things to many people. As Ken Campbell of Morrisville, VT put it, "How do you place a value on something like that? Maples are part of our heritage." We've got to do everything we can to make sure they are here for our children and our children's children. I just can't imagine what it would be like without our maples. We have a important challenge and responsibility at this conference to put to work what we learn here to protect our heritage.

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## BIOECOLOGY OF PEAR THRIPS: DISTRIBUTION IN FOREST SOILS

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### Abstract

The vertical and horizontal distribution of pear thrips in Vermont sugar maple forest soils was investigated. In the fall, about 86% of the thrips were found in the upper 10 cm of soil, though a few were found as deep as 20 cm. No thrips were found in the leaf litter. Soil sampling tools to determine thrips populations within an entire forest were tested and a standard hand-held bulb planter was found to be the most effective. No consistent pattern in thrips distribution around individual sugar maple trees was found. Pear thrips distribution within a forest stand predominating in sugar maple appeared to be random, but clumped, and variation in the density of pear thrips among individual samples was relatively high. For conducting soil sampling on a statewide scale, ten soil samples per sugarbush was found to be sufficient for estimating pear thrips population levels within an acceptable error range.

### Introduction

For the past several years in Vermont, widespread defoliation of sugar maple (*Acer saccharum* Marsh.) has occurred in the early spring as a result of feeding by the pear thrips, *Taeniothrips inconsequens* (Uzel). In 1988 alone, over 200 thousand hectares (500 thousand acres) were severely defoliated (Parker et al. 1988). A cooperative research and management project, coordinated by the University of

Vermont and the VT Department of Forests, Parks and Recreation, was initiated in September, 1988 to address this potential threat to the health of sugar maples. The question raised most commonly at meetings of landowners and sugarmakers around the state was "How many pear thrips are there in my sugarbush<sup>1</sup>?" and "Will pear thrips cause damage in my stand next year?"

In an effort to address these questions and to begin to design an integrated pest management plan, a method of predicting thrips damage was needed. Because pear thrips remain in the soil for 10 months of the year (Bailey 1944, Moulton 1907), from mid-June until mid-April in Vermont (Skinner & Parker, poster presentation, this publication) we felt this was potentially an ideal location for population monitoring, as it provided information about thrips population levels prior to their emergence in the spring, allowing sugarmakers an opportunity to take appropriate action.

Information on the distribution of pear thrips in forest soils is limited. Most previous research on this subject was done in California orchard soils. In cultivated, porous soils such as these, pear thrips were found to a depth of 61 cm, though most were at 15-30 cm below the soil surface (Bailey 1944). In uncultivated soils, pear thrips were found predominantly in the top 5-7 cm, at the interface between the grass roots and soil (Moulton 1907). The horizontal distribution pattern of pear thrips in soil was entirely unknown. The objectives of this research were to determine the vertical distribution of pear thrips in forest soils, their horizontal distribution within a sugar maple stand, and the number of samples needed to estimate thrips populations in a forest stand. Reported here are results from soil sampling conducted in 1988.

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<sup>1</sup> A sugarbush is a hardwood forest stand with sugar maple comprising 75% or more of the basal area. Maple trees in these stands are tapped to produce maple syrup.

## Materials and Methods

### Vertical Distribution

A 2-hectare forest stand predominating in sugar maple, located in central Vermont, was chosen for the research site (called Perry site). This site was selected because it was known to have a relatively homogeneous fine, sandy loam soil and a large thrips population. This soil type was unusually deep in the region, reaching to a depth of over 1.5 m in the Perry site, which was generally well-drained, having no unusually wet or swampy areas. The sugar maple trees averaged 23-30 m in height, and 35-40 cm in diameter and had received about 70% defoliation due to thrips feeding in the spring of 1988.

Eight sample plots (each 12.5 cm<sup>2</sup>) were established about 3.5-4 m from the bole of eight dominant or co-dominant sugar maple trees. The direction of the plot from the tree, north, south, east or west, was determined on site based on suitability for excavation.

The sample plot was marked and the loose litter layer removed and placed in a plastic bag. Soil samples were then taken at 2 cm intervals to a depth of 18 cm; each sample was bagged separately. To facilitate sampling, a trench, about 30 cm wide and 40 cm deep, was dug 5 cm from the plot on three sides. A steel box, 12.5 x 12.5 x 2.5 cm, having a top with a 5.5 cm<sup>2</sup> opening cut in the middle, and no bottom, was used for sampling (Fig. 1). The lower edge of the box was sharpened. A piece of sheet metal 15.5 x 17.5 cm was hammered to a depth of 18 cm on the plot side lacking a trench. The box was then lightly hammered into the soil to a depth of 2 cm. A putty knife having a 12 cm blade was used to cut under the box and remove the soil sample. This process was continued until 10 samples, including the litter sample, were taken.



Figure 1. Pit sampling to determine vertical distribution of pear thrips in forest soil.

Prior to extraction, samples were stored in a refrigerator at 4°C. Thrips were extracted in the laboratory, using the magnesium sulfate flotation method<sup>2</sup> modified from Edwards & Fletcher (1970) (Parker et al. 1989), and counted with the aid of a microscope (8x) to determine the number of thrips per sample. Extraction was completed within one month of collection. All samples were collected within a three-month period between September and December 1988. The mean percentage of thrips at each depth was determined.

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<sup>2</sup> For the first 6 months of our research, thrips extraction from soil was done with magnesium sulfate flotation. We later found flotation using heptane to be more efficient and this process was used for subsequent extractions (see Grehan & Parker, poster presentation, this publication).



## Spatial Distribution

**Distribution around a tree.** Four dominant or co-dominant sugar maple trees were selected randomly for sampling in the Perry site. One soil sample was taken with a hand-held bulb planter (about 5.72 cm diameter, 10.16 cm in length, 261 cm<sup>3</sup> volume) at 1, 2 and 4 meters from the bole of each tree in the four cardinal directions ( $n = 22$  samples per tree). Each soil sample was extracted individually to determine the number of thrips per sample. This sampling was replicated around the same trees one month later. A square-root + 0.375 transformation was done to normalize the data prior to analysis of variance (ANOVA) to determine significant differences in the mean number of thrips by direction and distance from the tree.

**Distribution within a sugarbush.** Two 2-4 hectare sugarbushes, having relatively high thrips populations in the soil, were selected for intensive sampling to determine the pattern of thrips distribution within an entire sugarbush. These sites, the Williams and Perry sites, were located on fairly flat terrain about 0.4 km apart and both were bordered on the north and south by open pasture land (Fig. 2).

A grid system for sampling was established within each site. In the 2-hectare Perry site, grid points were established every 25 meters, and the nearest dominant or co-dominant sugar maple tree at each grid point was selected for sampling (total of 34 sample trees) (Fig. 2). Because the Williams site covered approximately 4 hectares, grid points were established every 50 meters (total of 37 sample trees) (Fig. 2).

Two soil samples were taken with a bulb planter, one at 2 m and one at 4 m from the south side of each sample tree. Each sample was bagged separately and then stored and extracted as described previously.

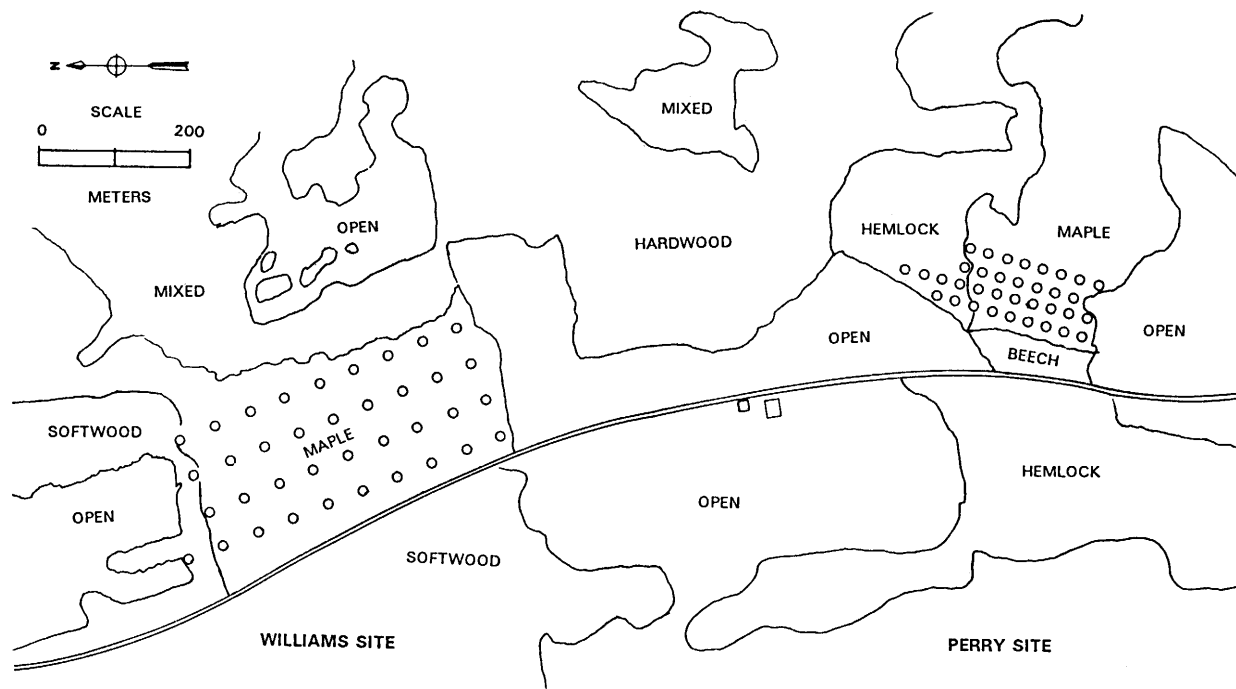


Figure 2. Sampling grid system in pear thrips research sites to determine thrips distribution in forest soil; open circles indicate location of sample tree. Predominant vegetation type within and adjacent to sites are indicated, Mixed = mixture of softwoods and hardwoods, open = pasture land (drawn by J. R. Lackey).

## Results and Discussion

### Vertical Distribution

Approximately 86% of the pear thrips extracted from the pit samples were found in the upper 10 cm of the soil (Table 1). No thrips were found in the leaf litter layer. The number of thrips decreased as soil depth increased with the exception of samples from 4-6 cm, where the greatest percentage of thrips, 27.4%, was found (Table 1). This is the approximate location of the interface of the soil and roots of understory vegetation. Similar results were obtained in California in uncultivated, sod-covered soils (Moulton 1907). It is possible that pear thrips prefer the soil conditions at this depth. Further research to characterize the features of this strata could explain this apparent distribution pattern. Though few thrips were found at a depth of 18 cm, additional sampling to 30 cm will be done to determine exactly how deeply pear thrips go. Large variation in thrips density occurred among sample trees. The number of thrips per pit (total number of thrips found from all samples in one pit) ranged from 14 to 394 among the four sample trees.

Previous research has indicated that the vertical distribution of pear thrips varied with soil type, texture and moisture content. Pear thrips penetrated deeper into light, well-drained soils than into heavy clay or gravelly soils (Bailey 1944). The light, well-drained soil at our research site suggests that the vertical distribution there is likely to be deeper than that of other sugarbushes in Vermont, which are located on heavier or shallower soils. Research is underway to further evaluate vertical distribution in water-logged, clay, sandy and shallow soil types to more completely characterize patterns of pear thrips vertical distribution.

Table 1. Vertical distribution of pear thrips in a Vermont sugarbush soil

Depth	Mean # thrips/ sample depth	Thrips/sample (%) <sup>a</sup>	Cumulative % thrips
0 cm (litter)	0.00 ± 0.00	0.00	0.00
0 - 2 cm	32.88 ± 62.60	19.86	19.86
2 - 4 cm	27.88 ± 27.62	16.84	36.70
4 - 6 cm	45.38 ± 52.07	27.42	64.12
6 - 8 cm	19.50 ± 23.00	11.78	75.90
8 - 10 cm	17.25 ± 18.43	10.42	86.32
10 - 12 cm	9.50 ± 12.80	5.74	92.05
12 - 14 cm	5.13 ± 6.31	3.10	95.16
14 - 16 cm	4.00 ± 5.34	2.42	97.58
16 - 18 cm	4.00 ± 5.18	2.42	100.00

<sup>a</sup> Percentages were calculated from the mean number of thrips per sample depth from eight pit sample plots in the Perry site in Randolph, Vt.

**Selection of sampling tool.** Using results from this research we evaluated soil sampling tools to select the best one for large scale intensive sampling to determine the horizontal distribution of thrips within a sugarbush. Three tools were used, a bucket auger, a tube sampler and a hand-held bulb planter (Fig. 3).

With the bucket auger, a sample was taken to a depth of 18 cm, which was a greater depth than most thrips were found. This tool provided a relatively large volume of soil (1,368 cm<sup>3</sup>) that took over an hour to extract. This tool was therefore rejected. The tube sampler was also judged unsatisfactory for surveying thrips populations. This tool gave us a sample to a depth of ca 30.5 cm (394 cm<sup>3</sup>), which was deeper than was needed based on the vertical distribution of pear thrips. In addition, this tool sampled a very small surface area, which we felt would not accurately reflect thrips density over a large area.

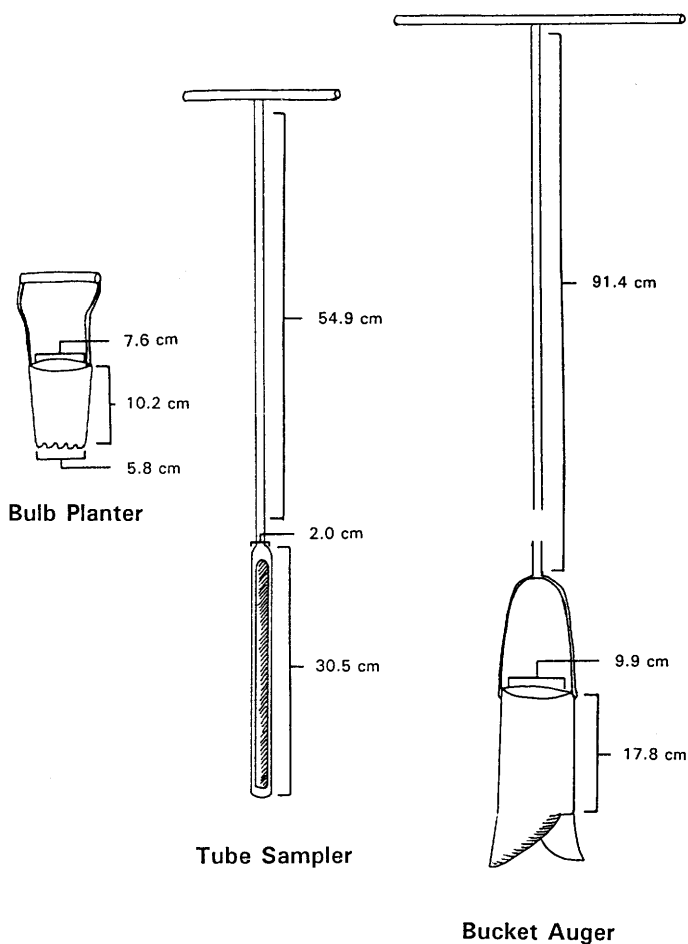


Figure 3. Soil sampling tools tested for sampling pear thrips in Vermont forest soils (drawn by L. Cravedi-Cheng).

The standard hand-held bulb planter, 7.6 cm in diameter and 10 cm long, was judged the most suitable for our large scale soil sampling purposes. This tool sampled the soil to a depth of 10 cm, which was the region within which the majority of thrips were found. The volume of soil obtained from this tool,  $272 \text{ cm}^3$ , was small enough to allow relatively rapid processing, approximately one-half hour per sample. Finally, it was inexpensive (around \$5.00) and readily available at most hardware stores, making it ideal for use in a large scale sampling program conducted by many people statewide.

## Spatial Distribution

**Distribution around a tree.** The mean number of thrips per sample tree (averaged among 24 samples) ranged from 4.2-9.7. A range of 2.87 thrips per sample (2 m from south side)-15.8 thrips per sample (4 m from south side) was obtained from the four sample trees (Fig. 4). Though differences in the mean number of thrips per sample were significant among sample trees ( $P = 0.001$ ), differences in the number of thrips obtained at the four cardinal directions were not significant. There tended to be more thrips in samples taken at 4 m from the tree than in samples taken at 1 m, though these differences also were not significant. The distance from a tree at which a sample was taken was confounded by the fact that the bole was sometimes located within the sample distance of other adjacent maple trees. For example, a sample that was taken 4 m from the sample tree may have been only 2 m from another tree. This effect will be considered in subsequent analyses.

Results indicate that the distance and direction from the tree does not significantly affect the distribution of thrips in the soil. However, for standardization we chose to take soil samples for further distribution studies from the south side of the tree at 2 and 4 m.

**Distribution within a sugarbush.** An average of  $10 \pm 12$  thrips per sample and  $5 \pm 4$  thrips per sample was found in the Perry and Williams sites, respectively. When the number of thrips per sample was compared separately within rows and columns in each sugarbush, densities were not significantly greater inside the sugarbush than at the forest edge (Figs. 5 and 6). Despite previous reports that thrips damage tended to be highest along the sugarbush edge, we did not find higher thrips populations there in the soil. Different rates of bud development within and at the edge of forest stands or migratory patterns of the insect may be responsible for differences in the damage levels within a sugarbush rather than their density in the soil.

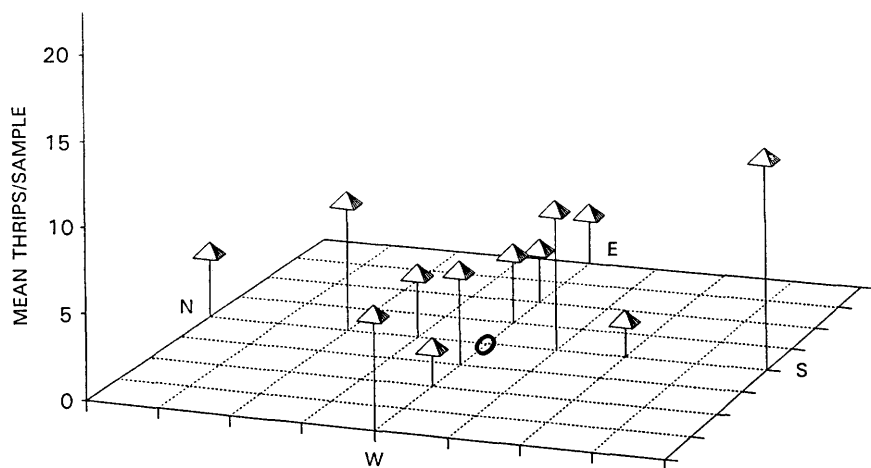


Figure 4. Mean number of pear thrips per sample at 1, 2 and 4 m from the bole of sugar maple trees at the four cardinal directions (mean derived from four sample trees). The center circle represents the bole of the sample tree and the pyramids indicate the mean number of thrips at each sample location. Grid points in this figure are spaced 1 meter apart.

The number of thrips per sample varied from tree to tree and from sample to sample around a tree. For example, at one tree, 43 pear thrips were found in the sample taken at 2 m and 10 thrips were found at 4 m, and at another 35 thrips were found at 2 m and 73 thrips at 4 m (Fig. 5). The reasons for this variation in thrips density between samples is as yet unknown. No observable differences in soil or vegetation type existed that could have explained these differences. Further characterization of thrips distribution in a sugarbush is currently underway.

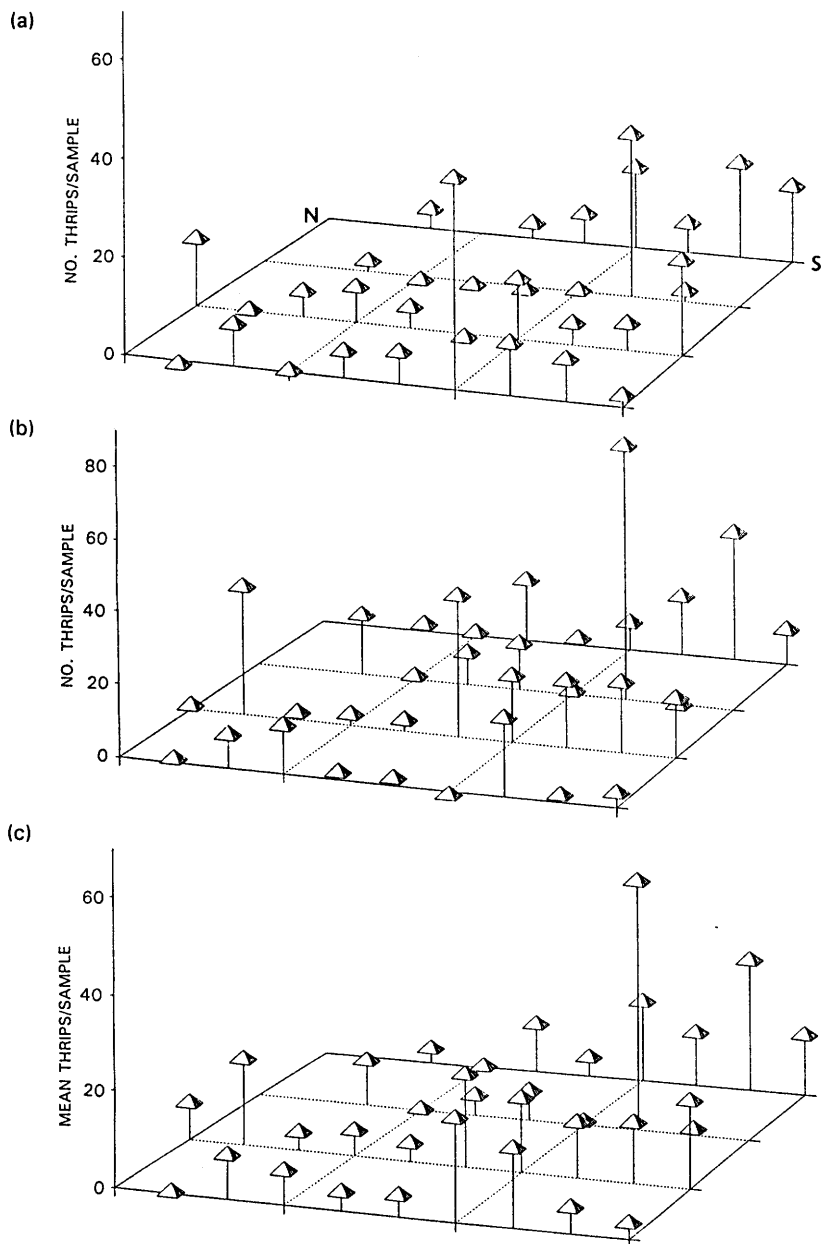
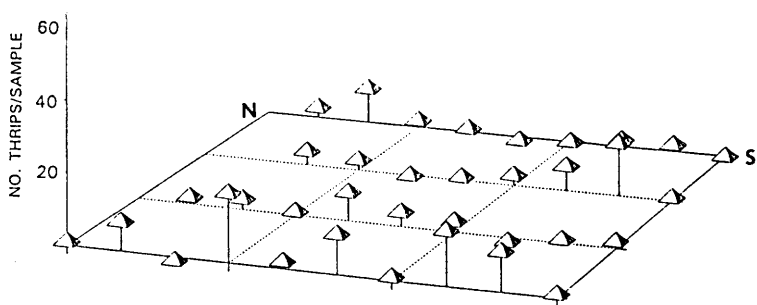


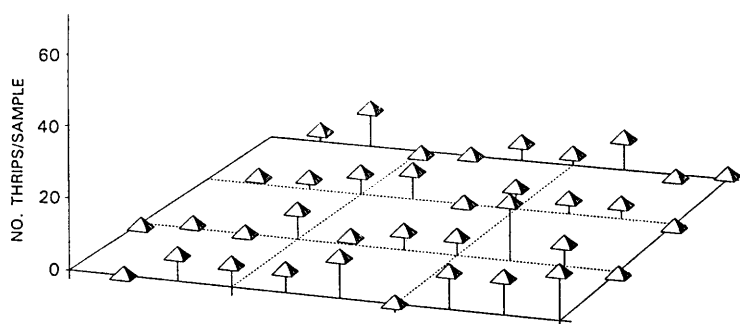
Figure 5. Number of pear thrips per sample in the Perry sampling grid (see Fig. 2) at (a) 2 m from the tree, (b) 4 m from the tree, and (c) the mean from samples at 2 and 4 m. All samples were taken on the south side of each tree and trees were located about 25 m apart.



(a)



(b)



(c)

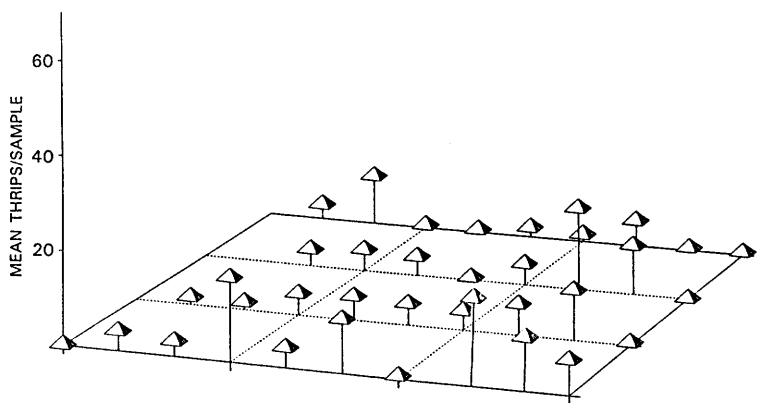


Figure 6. Number of pear thrips per sample in the Williams sampling grid (see Fig. 2) at (a) 2 m from the tree, (b) 4 m from the tree, and (c) the mean from samples at 2 and 4 m. All samples were taken from the south side of each tree and trees were located about 50 m apart.

## Statewide Soil Survey

Statistical analysis showed that, at the population levels found in the Perry sugarbush (an average of 5-10 thrips per sample), the thrips population could be estimated with 10 samples per sugarbush, with an error rate of  $\pm 6.5$  thrips. Further analysis is needed to determine the error rate in sites having higher and lower thrips populations than that found in the Perry site.

Based on the results of this research we developed a protocol to determine pear thrips density and distribution in Vermont and to determine if a relationship existed between the number of thrips in the soil and the amount of subsequent damage (Skinner & Parker 1989). Results from this work may prove useful for predicting damage based on thrips numbers in the soil. This survey was implemented by the Vermont Department of Forests, Parks and Recreation in January 1989. Though this is not an ideal time of year to take samples, it was the earliest we could develop the protocol. In future years, samples will be taken in September and October.

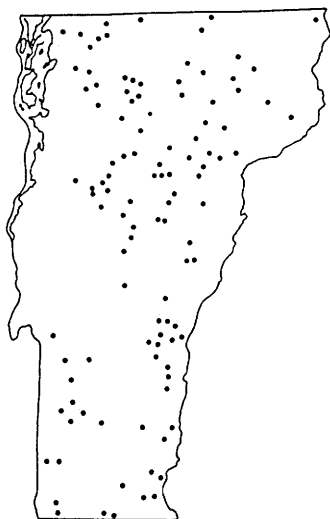


Figure 7. Map of Vermont showing the location of sites in which soil sampling was conducted for the Statewide Pear Thrips Soil Survey.

For this survey in each site, two soil samples, one at 2 m and one at 4 m from the south side of the tree, were taken around five dominant sugar maple trees duplicating the basic design used in the research on horizontal distribution studies. Over 100 sugarbushes were selected for sampling in areas showing low, moderate and heavy thrips damage in 1988 (Fig. 7). Our goal is to repeat this sampling and foliage assessment at the same sites for the next 3-4 years to gather information on population dynamics and the annual pattern of damage as it relates to thrips density.

### Acknowledgment

Special thanks to Jay Lackey, VT Department of Forests, Parks and Recreation, for locating sites, assisting with plot layout, soil sampling, and art work. We also appreciate the cooperation of Mr. and Mrs. David Perry and Mr. Duane Williams, who permitted us to conduct this research on their property. We thank the laboratory technicians who patiently extracted the many soil samples. Statistical analysis was completed by John Aleong and Diantha Howard, University of Vermont. This research was funded in part by the VT Department of Forests, Parks and Recreation.

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### Discussion Period

Question: Taking the soil samples is very easy but extracting and analyzing them is very time consuming. Would it be conceivable to use some kind of sequential sampling scheme whereby 25 samples per site are taken, five samples are initially processed to see what the thrips population is and additional samples are processed only if necessary?

Skinner: We don't know enough about how many thrips per soil sample are needed for damage to occur to be able to use a sampling system like that. However, it would certainly be nice to reduce soil extraction if possible.

Question: How many soil samples did you take at each distance from the tree?

Skinner: For determining the thrips population within a sugarbush, we selected five trees per site and took two samples on the south side of each tree, one at 2 meters and the other at 4 meters.

Question: Did you take only one soil sample from each sample distance? Did you check to see if taking samples in a cluster reduced the variation between samples or removed the chance of getting zeroes from your data?

Skinner: If the tree is considered the sampling point then we were taking two samples, but if you consider each distance a different point then we were taking one sample per location. We did not assess the value of taking samples in a cluster. It would have been nice to do but time was a factor. We needed to develop a sampling protocol within a few months and therefore could not test all sampling options.

Comment: We had a similar problem in variability and sample clustering reduced that variability.

Skinner: One problem with clustering to determine thrips populations within a sugarbush might be that less area within the entire site would be sampled. There are bound to be variations in thrips density as a result of environmental conditions. Sampling in only a few clusters would reduce the opportunity to determine that variation.

Comment: By clustering I meant taking a cluster of three samples rather than one at each site.

Skinner: Yes, I understand that, but this would significantly increase the number of samples needed to evaluate thrips density within an entire sugarbush. It was felt that 10 samples per sugarbush was feasible to use in a statewide survey. More samples per sugarbush would have required us to reduce the number of sites we surveyed.

Question: If you look at the number of thrips per sample at the 2 and 4 meter distances, was there any indication why you might find more thrips at 4 m?

Skinner: The drip line of the tree was generally at about 4 meters from the trees we sampled. This could have influenced the thrips density in the soil. You must also realize that other trees adjacent to the sample tree may have influenced the situation. Though the sample was taken at 2 or 4 meters from the sample tree, other adjacent trees were sometimes closer to the sample point. We have mapped the location and distance of trees within 8 meters of each sample tree in the research site. Ultimately we hope to analyze this information to determine the influence of these factors.

Question: Have you done any studies to relate thrips density to physical and chemical characteristics of the soil in which they reside?

Skinner: One reason we selected this particular site for thrips research was that the soil type and conditions were relatively homogeneous throughout. We hoped that this homogeneity would reduce variability in distribution due to soil conditions. We have not done any analyses of the chemical makeup or moisture content of the soil, but this would be interesting to consider.

Question: Do you think thrips can survive better in some soil types than others?

Skinner: I don't know. However, for the statewide thrips soil survey, we will collect information on soil type, elevation, basal area of sugar maple and the abundance of maple seedlings in the understory in each site, as well as the level of pear thrips damage last year. We hope to correlate these variables on a statewide scale.

Question: Do you miss thrips that are in the litter layer by removing this layer before taking the soil sample?

Skinner: No. In all of the research we have done on the vertical distribution of thrips in the soil, we have never found them in the litter layer.

Question: What about in the early spring when they begin to emerge from the soil?

Skinner: You are right, as thrips come out of the ground they must crawl through the litter on their way to the foliage. At the time we take soil samples for thrips population studies however, the thrips are still in the soil. If samples were taken in the spring, however, the litter layer would need to be extracted for the presence of thrips. Our plan is to take all samples early enough so that the thrips will not have moved up to the litter. We are also monitoring soil temperature at various depths in the research site. This will give us information on when soil temperatures begin to rise and when thrips begin to ascend.

Question: If there is no canopy on the south side of the sample tree is it part of the protocol to take the samples somewhere else?

Skinner: No. Generally there is enough of a canopy over the sampling area, so this has not been a problem. When developing the protocol we tried to keep the methodology uniform in an effort to reduce confusion. This also reduces the variability that must be accounted for in later statistical analysis.

## ANALYSIS OF THRIPS DISTRIBUTION: APPLICATION OF SPATIAL STATISTICS AND KRIGING

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### Abstract

Kriging is a statistical technique that provides predictions for spatially and temporally correlated data. Observations of thrips distribution and density in Vermont soils are made in both space and time. Traditional statistical analysis of such data assumes that the counts taken over space and time are independent, which is not necessarily true. Therefore, to analyze these data correctly we must account for the correlation structure in the data, which can be done with Kriging. The Kriging technique is reviewed and its use illustrated in determining the pattern of thrips distribution and density in Vermont by analysis of data from the Vermont Pear Thrips Soil Survey for the 1988-89 season.

### Introduction

Pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), is a serious problem in Vermont and other eastern states, causing severe foliage damage to sugar maple trees in the early spring (Parker et al. 1988). A research/management project was initiated cooperatively by the University of Vermont Entomology Research Laboratory and the Vermont Department of Forests, Parks and Recreation in 1988 to develop effective methods to survey and

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ultimately manage the pear thrips in sugar maple stands statewide. One of the highest priorities of this project was to develop a method to predict tree damage based on thrips population densities in the soil. A soil survey to determine the distribution and density of pear thrips was first conducted in Vermont in January 1989. Analysis of these data was necessary as a first step for management activities.

Kriging is a statistical technique developed for prediction of data values when the data are correlated in space and time. Thrips population data which are collected annually from soil surveys may be correlated spatially within and between time. Such a data set lends itself well to Kriging. The correlation in these data is a function of the distance between sample sites. Counts at neighboring or nearby sites should be more highly correlated than those at sites located further apart.

Cressie (1986, 1990) and Johnson (1990) give reviews of the theory and applications of Kriging, tracing its origin to geostatistics and the work of Matheron (1971) and Krige (1951). There are many applications for Kriging, including interpretation of rainfall data (Ord & Rees 1979), for soil mapping (Burgess & Webster 1980), and in groundwater pollution monitoring (Yates & Yates 1988). Kriging can also be a useful tool in the design and analysis of experiments, such as for uniformity trials to determine blocking mechanisms in agricultural experiments and to predict yields at unobservable points in fields using systematic samples (Johnson 1990). The purpose of this paper is to give a brief review of Kriging and to illustrate its application in the analysis of data on pear thrips population distribution.

## Materials and Methods

### Kriging Methodology

Following Johnson (1990), let  $x$  denote spatial location (i.e., the latitude and longitude of a point [sample site] at which the number of

thrips are observed). Let  $v(x)$  be the observed or unobserved number of thrips at location  $x$ , at a particular time. Thus, let

$$\mu(x) = E[v(x)] \quad (1)$$

where  $E$  denotes the expectation of  $v(x)$ .

$$\sigma^2(x) = \text{Var}[v(x)] = E[v(x) - \mu(x)]^2 \quad (2)$$

$$c(x, x') = E[[v(x) - \mu(x)] [v(x') - \mu(x')]] \quad (3)$$

and

$$\gamma(x, x') = 0.5E[v(x) - v(x')]^2 \quad (4)$$

Note that  $c(x, x')$  is the covariance between the number of thrips at locations  $x$  and  $x'$  while  $\gamma(x, x')$  is the *semivariogram*, with  $2\gamma(x, x')$  as the *variogram*:

$$\gamma(x, x') = \gamma(x - x') = \gamma(h) \quad (5)$$

i.e., the variogram is a function of the distance between  $x$  and  $x'$ .

For a particular time, let us sample thrips at locations  $x_1, \dots, x_n$ . Let  $v_i$  be the mean number of thrips per sample at location  $x_i$ , and  $i = 1, \dots, n$ . Given the data  $(x_i, v_i)$ ,  $i = 1, \dots, n$ , we want:

1. To estimate the number of thrips at an unobserved point  $x$ , with its standard error, and
2. To estimate the average number of thrips over some region in the state.

To estimate the number of thrips  $\mu(x)$  at an unobserved point, we consider linear combinations of  $\mu(x)$  at the observed locations. Let  $\hat{v}(x) = \sum a_i v(x_i)$  and select  $a_i$  such that:

$$1. E[\hat{v}(x) - v(x)] = 0 \quad (6)$$

and

$$2. \text{var}[\hat{v}(x) - v(x)] = E[\hat{v}(x) - v(x)]^2 \quad (7)$$

are minimized. If we find a vector  $a$  such that (6) and (7) are minimized then:

$$\hat{v}(x) = \sum a_i v(x_i) \quad (8)$$

is the Kriging estimate of  $v(x)$  and the Kriging coefficients are the vector  $a$ .

To use the Kriging method, we must estimate the variogram, i.e.,  $\gamma(x, x')$  or  $\text{cov}(x, x')$ . For the variogram we use the exponential model:

$$\gamma(h) = B + C[1 - e^{-h/a}], \text{ for all } h \geq 0. \quad (9)$$

The *sill* of this model, which is equal to  $B + C$ , is the maximum value that the variogram attains, and is the value of  $\gamma(h)$  as  $h$  goes to infinity. The *range* is the distance beyond which two points are uncorrelated. The *nugget* is the value of the variogram at  $h = 0$ .

Because data are taken annually, we can expand the notation to include both space and time. Let  $v_{ij}$  be the number of thrips at location  $x_i$ , and time  $t_j$  for  $i = 1, \dots, n$  and  $j = 1, \dots, k$ . The data will be given in the form  $(x_i, t_j, v_{ij})$ ,  $i = 1, \dots, n$  and  $j = 1, \dots, k$ . For any particular time  $j$ , the process  $v_{ij}$  is purely spatial, whereas for any fixed location the process  $v_{ij}$  is temporal. Because we are illustrating the Kriging methodology here with one year's data (1988-89) we will consider only a purely spatial process  $(x_i, v_i)$ ,  $i = 1, \dots, n$ .

## Thrips Data Collection

In January and February 1989, soil samples were taken with a hand-held bulb planter in sugar maple stands (those with sugar maple comprising more than 75% of the basal area) throughout the state to determine the distribution and relative density of pear thrips (Skinner & Parker 1989). Samples were taken in 91 stands in 13 of the 14 counties in Vermont (Fig. 1). Because pear thrips reside in soil from mid-June to mid-April (see Skinner et al., poster presentation, this publication), thrips in samples at this time reflect the potential population that entered the soil in 1988 and would emerge to cause foliar damage in the spring of 1989. In each stand soil samples were taken at 2 and 4 m from the south side of the bole of five sugar maple trees (Skinner & Parker 1989).

Stands were selected by personnel from the Vermont Department of Forests, Parks and Recreation using information from an aerial survey of pear thrips damage in 1988. Sites were selected in each county from each of three damage categories based on an estimate of leaf area reduction (light - 0 - 30% reduction, moderate - 31 - 60% reduction, and severe - 61 - 100% reduction).

Thrips were extracted from samples using a heptane flotation procedure (see Grehan & Parker, poster presentation, this publication). Residue from the extraction process was inspected under magnification to determine the number of pear thrips per sample. The total number of thrips per site was divided by the number of samples extracted from the site (generally 10 samples) and this mean number of thrips per sample was used for analysis.

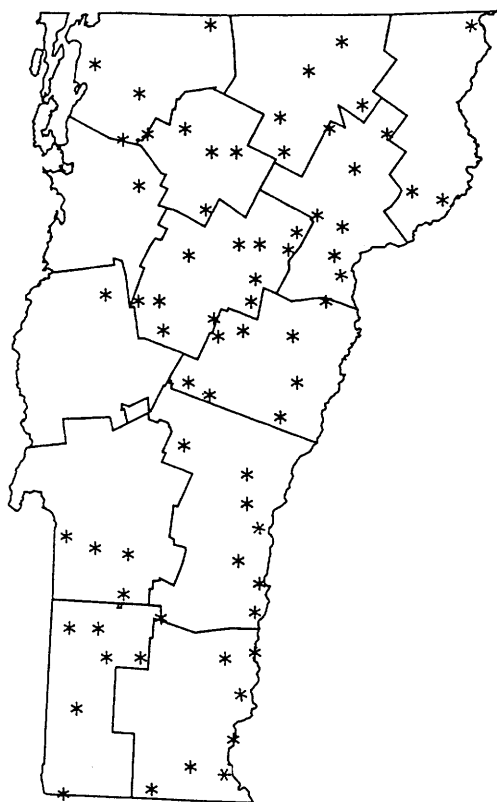


Figure 1. Townships (\*) in which samples were taken for the Vermont Pear Thrips Soil Survey in 1988-89.

### Data Analysis

The mean number of thrips per sample was determined for each township where soil samples were taken. Where more than one stand was sampled in the same town, the mean number of thrips was calculated by combining data from all stands within that town. Thrips data from 91 stands in 69 townships were used for Kriging analysis. Using the latitude and longitude coordinates for each town, mean thrips data were analyzed with software by Englund & Sparks (1988).

## Results and Discussion

Figure 1 gives the spatial location,  $x_i$  of thrips sample collection sites in Vermont in 1988 while Figure 2 shows the scatter diagram of the mean number of thrips per sample,  $v_i$ , at each site.

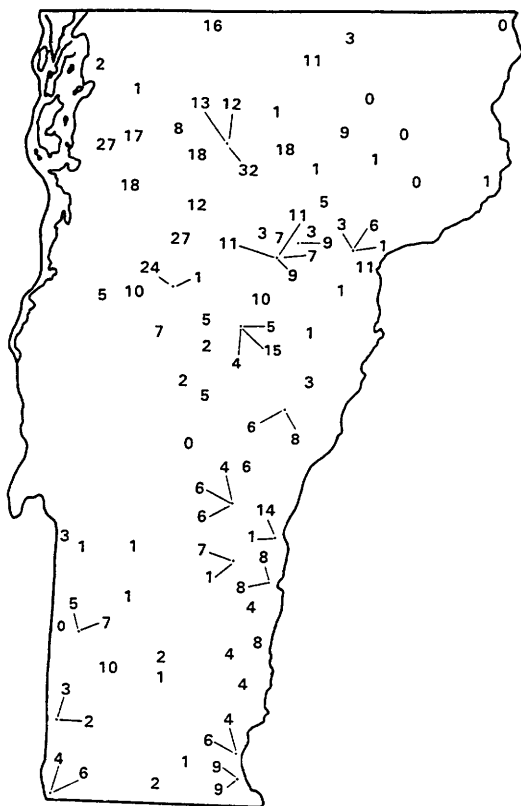


Figure 2. Scatter diagram of the mean number of thrips per sample in sites sampled for the Vermont Pear Thrips Soil Survey in 1988-89.

As expected, the histogram of thrips density data is highly skewed (Fig. 3a). Some of this skewness is corrected by the Anscombe transformation,  $\sqrt{v_i + 3/8}$ , where  $v_i$  is now the average thrips

count at a location, making a more symmetrical histogram (Fig. 3b). (All subsequent reference to a square root transformation in this paper is the Anscombe transformation.)

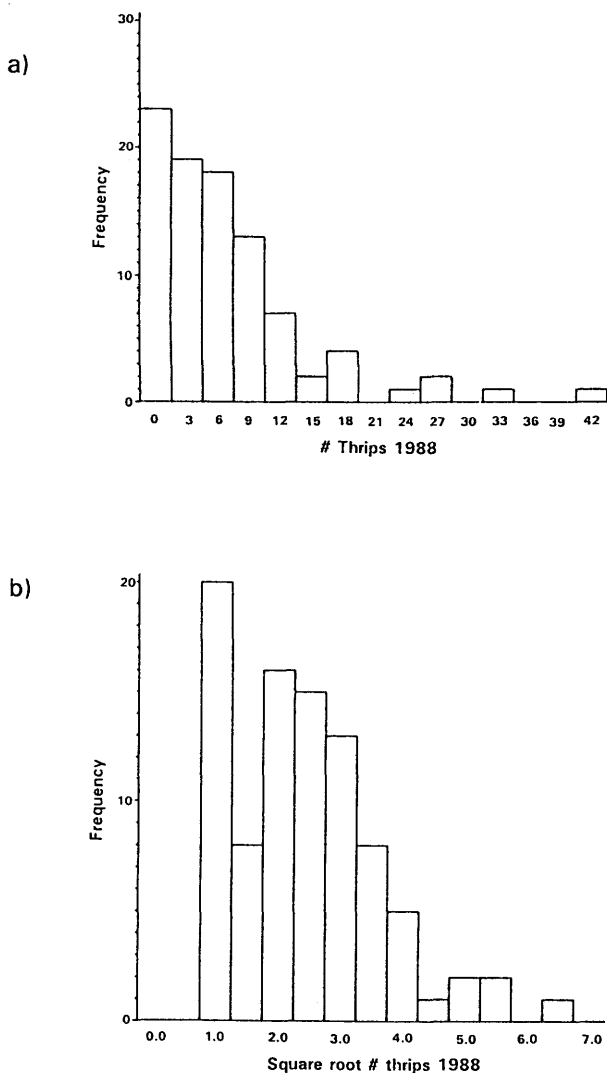


Figure 3. Histograms of the mean number of thrips per sample for each site sampled for the 1988-89 Vermont Pear Thrips Soil Survey, a) for the original data, b) for the transformed data,  $\sqrt{v_i + 3/8}$ .

A plot of the variance versus the mean number of thrips per sample for each site indicates that the variance is proportional to the mean (Fig. 4a), suggesting the suitability of a square root transformation for stabilizing the variance among sampling sites. The variance-mean plot of the transformed data show less proportionality (Fig. 4b).

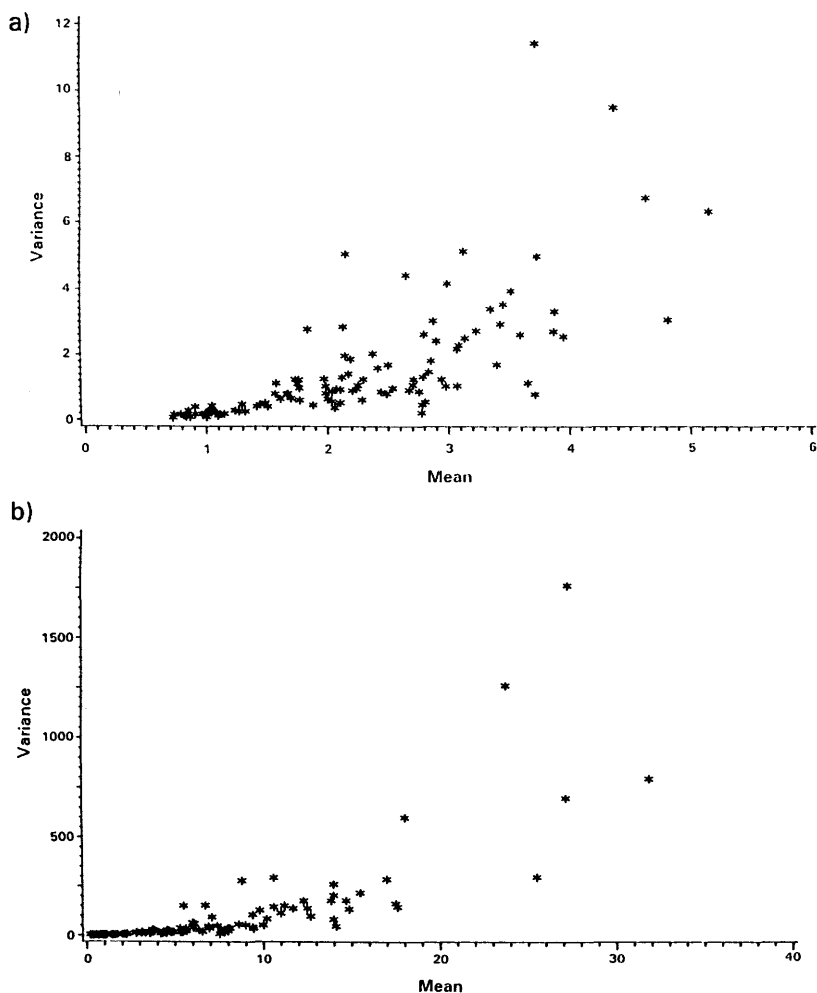


Figure 4. Plots of variance versus the mean number of thrips per sample from the Vermont Pear Thrips Soil Survey in 1988-89, a) for original data, b) for transformed data,  $\sqrt{v_i + 3/8}$ .



The variogram, as given in equations (5) and (9), is a function of the distance between sample sites and depends only on the relative position of the thrips count at locations  $x_i$  and  $x'_i$ . The plot of the variogram versus distance for the original data shows that the variance of the difference in thrips counts between two locations is a function of the distance between the two locations ( $R^2 = 0.92$ ) (Fig. 5a). Figure 5b gives the variogram using the transformed data.

The equation of the estimated variogram is  $\gamma(h) = 10.13 + 35.66 (1 - e^{-h / 0.2218})$  on the original scale and  $\gamma(h) = 0.3740 + 1.0576 (1 - e^{-h / 0.2694})$  on the square root scale. An examination of the plot of the transformed data shows that an exponential variogram seems to fit the data well with *nugget* = 0.37, *sill* = 1.43, *range* = 0.81 and  $R^2 = 0.92$ . The nonlinear regression models for the original and transformed data gave the same  $R^2$  (= sum of squares for regression  $\div$  total sum of squares). However, because the Anscombe transformation appears to have stabilized the variance of the thrips counts between sampling sites (Fig. 4), we will use the variogram on the transformed scale. Figure 5b shows that the variance of the difference between two thrips counts is small for nearby or neighboring sites but increases exponentially as the distance between two sites increases, until the variance approaches its asymptote.

Using the Kriging technique, the number of thrips at unobserved points in Vermont, having habitat characteristics similar to that in the sample sites, can be predicted based on available data. The thrips count at the observed points are given in Figure 2 and the predicted number of thrips at unobserved points are given in Figures 6 (original data) and 8 (transformed square root scale). The contours in these figures show the areas of high (northern and central Vermont) and low (southern Vermont) infestation of thrips. For each predicted value of thrips, the standard deviations are given in the form of contours in Figures 7 and 9 for the original and square root counts, respectively.

As discussed, this data set should be analyzed on the square root scale. Therefore the practitioner should use the analyses done on this scale to predict thrips density. For illustration, using Figures 8 and 9,

we can predict the mean number of thrips per sample in northeastern Vermont to fall between  $3.2 \pm 0.4$  to  $3.6 \pm 0.4$  (on the square root scale), which would represent a mean of approximately 9.9 to 12.6 thrips per sample after calculation back to the original scale.

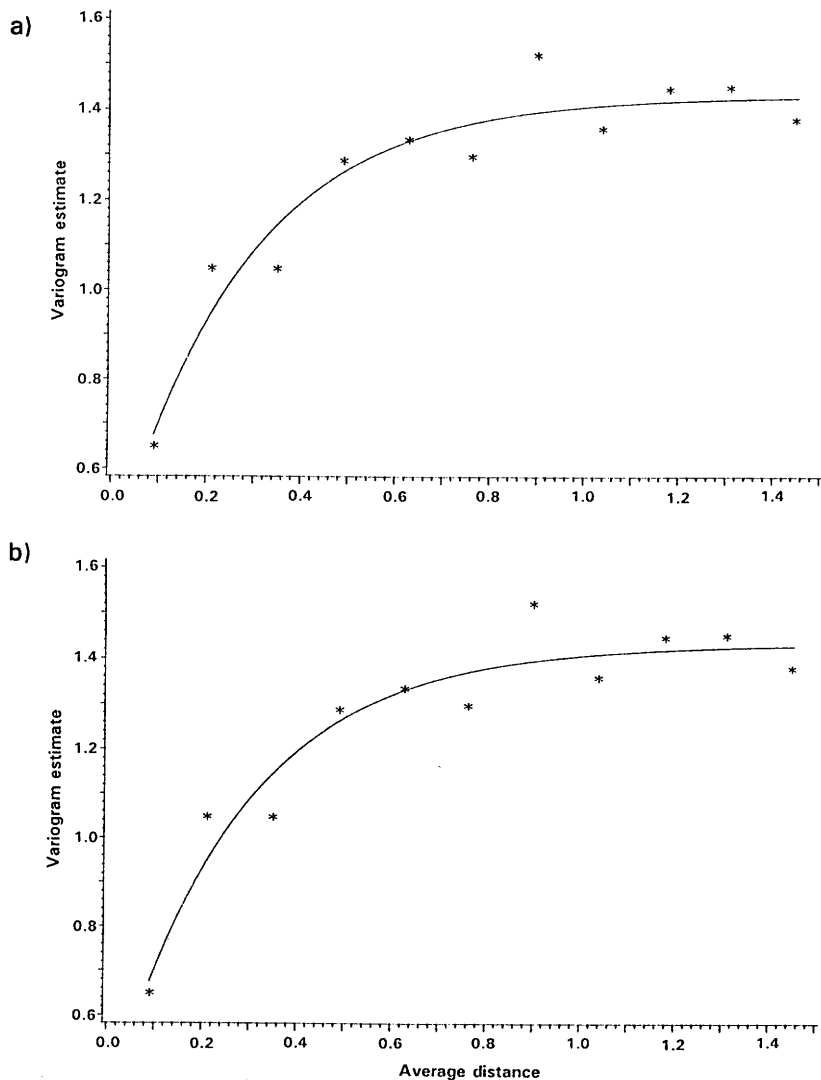


Figure 5. Variograms for data from the Vermont Pear Thrips Soil Survey in 1988-89, a) for original data, b) for transformed data,  $\sqrt{v_i + 3/8}$ .

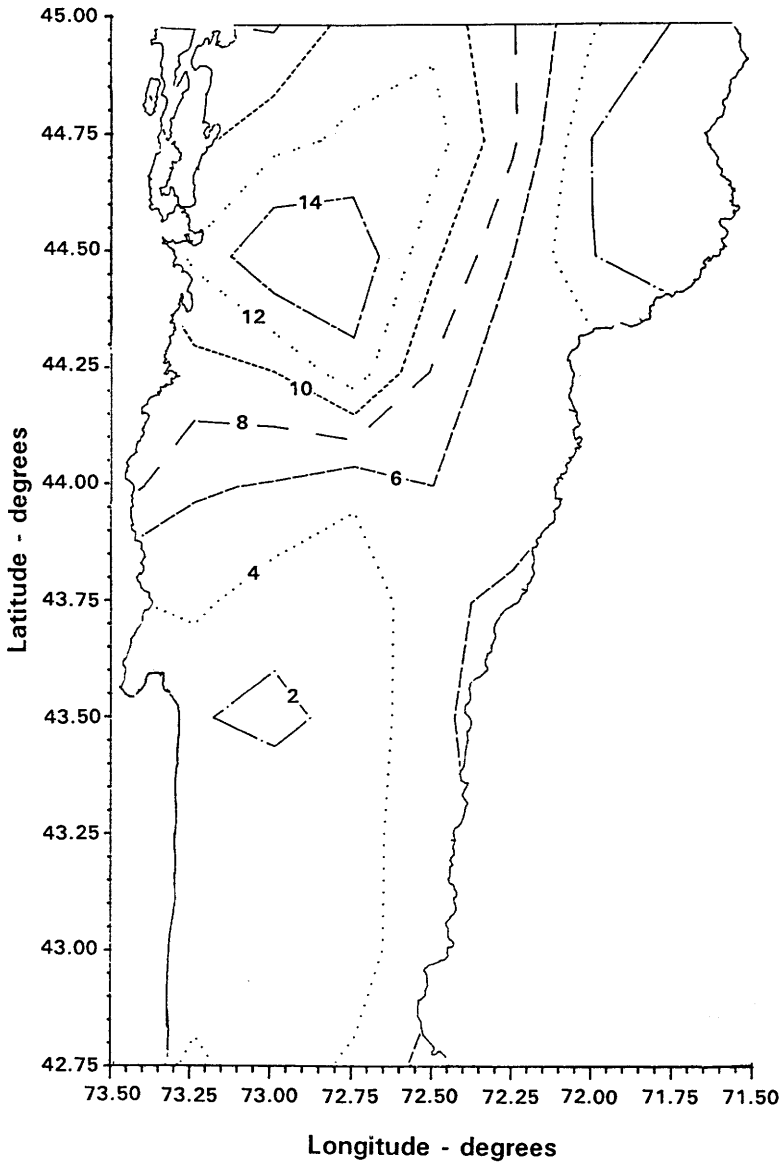


Figure 6. Map of Vermont showing contours for thrips density based on Kriging estimates from original data of the Vermont Pear Thrips Soil Survey in 1988-89.

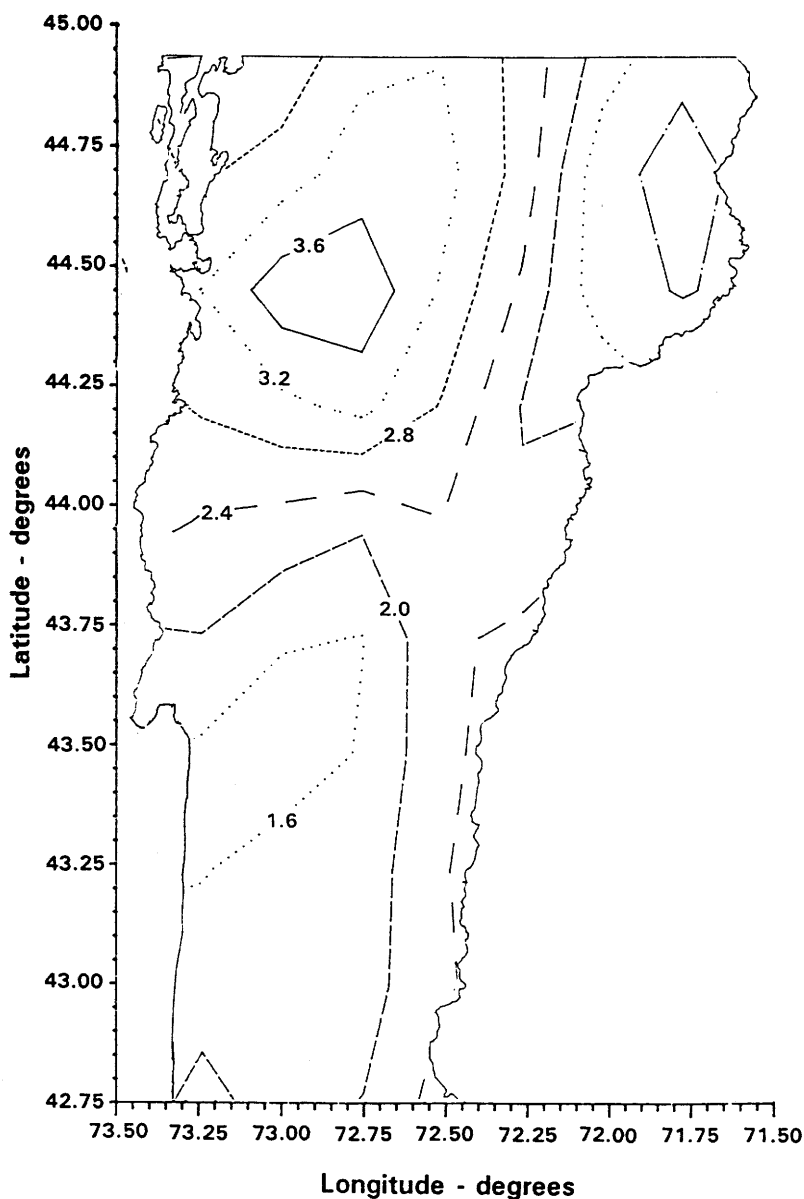


Figure 7. Map of Vermont showing contours for standard deviations of thrips density based on Kriging estimates from original data of the Vermont Pear Thrips Soil Survey in 1988-89.

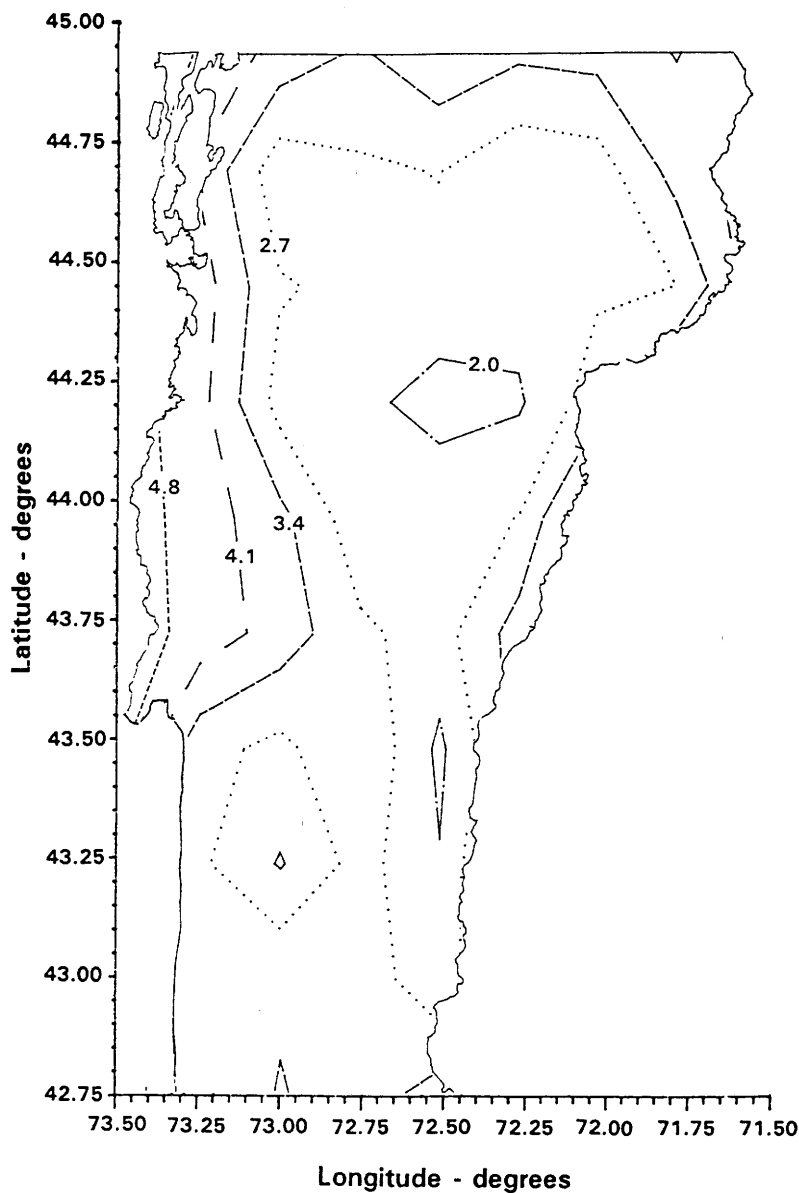


Figure 8. Map of Vermont showing contours for thrips density based on Kriging estimates from transformed data,  $\sqrt{v_i + 3/8}$ , of the Vermont Pear Thrips Soil Survey in 1988-89.

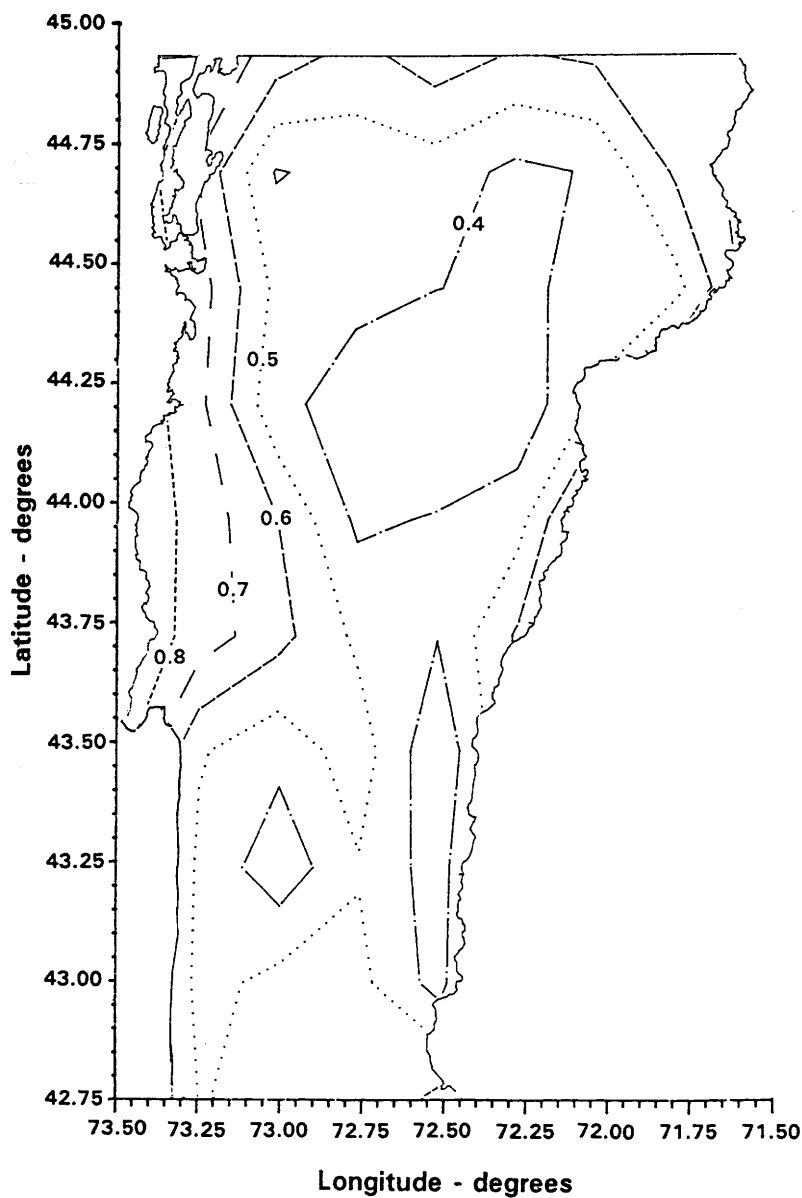


Figure 9. Map of Vermont showing contours for standard deviations of thrips density based on Kriging estimates from transformed data,  $\sqrt{v_i + 3/8}$ , of the Vermont Pear Thrips Soil Survey 1988-89.

This statistical method shows promise for estimation of pear thrips densities in the soil in areas where sampling has not been done, and ultimately for prediction of the extent of thrips damage statewide in the spring. More research is needed to assess the value of this methodology for pear thrips management. Firstly, verification of thrips density based on Kriging values is needed to determine if in fact it can be used to accurately estimate existing thrips densities.

Secondly, the relationship between thrips density in the soil and the resultant damage in the spring must be investigated. Preliminary results suggest that this relationship may be fairly weak, i.e., a low number of thrips in the soil does not guarantee that damage will not occur in the spring, and visa versa. Considering this, the value of thrips density as a predictor of damage may be questionable.

Thirdly, this Kriging method can be extended to a disjunctive Kriging method whereby we can calculate the conditional probability that the mean number of thrips per sample is greater than a critical level, i.e., the mean number of thrips at which severe damage would be certain to occur and when pest suppression is deemed an economic or environmental necessity. If we can model thrips population levels in the soil in relation to the damage in the spring, then these probabilities can be used in management of pear thrips by helping pest managers determine whether suppression action is warranted. In the future we intend to analyze thrips soil survey data from several years. This will provide information on the pattern of thrips population trends over time as well as space.

The Kriging methodology could be applied to other forest pests as well as the pear thrips. Information on thrips and other pest populations on a large scale is essential for effective pest management implementation. However, resources for monitoring pests on a statewide scale is often limited. Therefore, development of statistical methods that reduce the need for extensive sampling but also provide reliable predictions on pest population levels over a large area would be invaluable.

### Conclusion

Kriging is an easy graphical method that can assist entomologists design and analyze their experiments. It can be used to predict thrips infestations statewide from well-designed sample data. This will provide valuable information for making decisions for the management of pear thrips and other important insect pests. The validity of prediction should now be validated under field conditions.

### Acknowledgment

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## AERIAL SPRAY TRIALS FOR PEAR THRIPS MANAGEMENT FALL 1988

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The defoliation from pear thrips, *Taeniothrips inconsequens* (Uzel), in 1988 caused a great deal of public concern throughout the entire State of Vermont and the New England region (Parker et al. 1988). People demanded answers to very basic practical questions and requested that immediate action be taken. The state offices and the University of Vermont Entomology Research Laboratory were literally flooded with phone calls and requests for information. One of the major questions that foresters and sugarmakers asked was "what management strategies are available for use in a sugarbush and how can they protect their trees from another season's pear thrips feeding?" It was difficult to answer these questions because much of the information needed to develop management strategies was unknown. The urgency of the situation was typified by the fact that by January 1989 the Vermont Department of Agriculture had already received hundreds of requests for approval of aerial insecticide applications for thrips control in individual sugarbushes in the spring of 1989.

In the fall following the 1988 thrips defoliation, forest managers and sugarmakers were urged to spend time scouting their sugarbushes and evaluating individual maple trees for visual impact from this pest. It was stressed that conservative tapping should be the rule because no one knew what future populations of pear thrips would do.

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In response to this pest problem the Vermont Governor's Task Force on Pear Thrips decided it was essential to investigate the use of insecticides for protection of sugar maple trees from thrips damage. This was done realizing that it was not a total solution but merely a short-term strategy that would give researchers more time to develop other appropriate management techniques. Plans were made to conduct a large-scale insecticide efficacy trial in the spring of 1989 as thrips were emerging from the soil. Preliminary testing was done in the fall (1988) because the trees were dormant and our target was closed buds. We also felt that weather conditions in the fall would approximate those in the early spring and would be an accurate test of probable conditions we might encounter in our efficacy trial in 1989.

In sugar maple stands where syrup is made, federal and state regulations limit the use of many agricultural chemicals because a food crop for human consumption is produced there. It should be kept in mind that thrips defoliation was not confined to merely sugarbushes but was also very common in hardwood forests, urban backyards and along the roadsides. Each of these situations represents a unique management problem and ultimately needs to be addressed separately. To meet immediate management needs however, we first decided to evaluate the use of agricultural chemicals in the sugarbush environment.

Two materials have been approved for general use in the sugarbush. One is carbaryl (Sevin), a carbamate (Table 1) and the other is *Bacillus thuringiensis* (B.t.), a naturally occurring, commercially produced bacterium. The latter is used mainly for the control of lepidopterous forest defoliators and its use against Thysanoptera has not been tested. Carbaryl has broad spectrum use and has label approval for use against other thrips species and at the time of these trials was registered for aerial use in sugarbushes in Vermont (Rhone-Poulenc 1989).

Table 1. Agricultural chemicals registered for use against thrips on trees. Information from Vermont Department of Agriculture, Pesticide Registration Division, 30 June 1988

Target	Common Name	Composition
Ornamentals	Dursban	<i>O,O</i> -Diethyl <i>O</i> -(3,5,6-trichloro-2-pyridinyl)-phosphorothioate
	Orthene	<i>O,S</i> -Dimethyl acetylphosphoramid-othioate
	Cythion	<i>O,O</i> -dimethyl phosphorodithioate
	Mavrik	( $\alpha$ - <i>RS</i> ,2 <i>R</i> )-fluvalinate[( <i>RS</i> )- $\alpha$ -cyano-3-phenoxybenzyl ( <i>R</i> )-2-[2-chloro-4-(trifluoromethyl)anilino]-3-methyl-butanoate]
Fruit	Lorsban	<i>O,O</i> -Diethyl <i>O</i> -(3,5,6-trichloro-2-pyridinyl)-phosphorothioate
Sugarbush	Carbaryl	1-Naphthyl <i>N</i> -methylcarbamate
Forest	Cythion	<i>O,O</i> -dimethylphosphorodithioate
	Carbaryl	1-Naphthyl <i>N</i> -methylcarbamate

### Objectives

Our research was designed to address the following questions:

1. Using aerial application techniques would carbaryl droplets impinge on sugar maple buds?
2. What droplet size would maximize coverage on sugar maple buds and minimize drift to adjacent environments?

## Materials and Methods

A Cessna Ag Wagon equipped with six Micronair AU 4000 atomizers was used for aerial application. The plane was flown at 160 km/h (100 mph) approximately 15 m above the trees. Swath width was estimated at 30 m. Application rate was 2.2 liters/ha (32 oz/acre) of Sevin 4-Oil mixed with No. 2 diesel oil applied as 3.4 or 4.6 liters/ha (48 or 64 oz/acre) total volume. One percent Rhodamine WT dye, which fluoresced under ultraviolet light, was added to the tank mix to facilitate droplet identification on twigs and buds.

Twelve 4-hectare plots were set up at the U.S. Government Test Firing Range in Underhill, Vt. These plots were at least 1000 m apart and had a stand composition of mainly mature dominant or codominant sugar maple trees. We randomly selected nine plots for application (five to receive the 4.6 liter [64 oz] rate and four the 3.4 liter [48 oz] rate) and three plots for controls. Within each plot ten trees equidistant along a transect perpendicular to the flight of the spray plane were chosen for sampling. From each tree, at least 4 hours post-application, a professional tree climber cut two branches 45 cm long from the upper, middle and lower canopy. From each branch we randomly cut five twigs each having a primary bud. Twigs were cut 6-10 cm long and only the basal portion was handled. Twigs were bagged separately in zip lock bags.

In the laboratory, the number of droplets were counted on the terminal 2.5 cm portion of each twig (as measured from the tip of the primary bud towards the base of the twig). Droplets were recorded as either on the bud or on the stem portion. Counts were made under an ultra violet light which made the Rhodamine dye easy to see. Droplet dimensions were not taken because the relative spread factor on sugar maple buds and stems has not been calculated for this formulation.

## Results

The aerial application was made on 27 October 1988. Spraying started at dawn (approximately 6:30 AM) and was stopped at 4:00 PM. Winds during application were less than 3.2 km/h (2.0 mph) and ambient temperatures were approximately 2-5°C.

Equipment problems plagued the entire operation and in general it was felt that coverage was poor. The cold weather made the formulation very viscous and the Micronair atomizers plugged frequently. Several of the Micronair propellers broke causing delays for repairs. Branch samples were taken and data from plots sprayed at the 4.6 liter (64 oz) rate are given in Table 2. Aerial application of the 3.4 liter (48 oz) rate was not possible due to mechanical problems with the aircraft.

The data show that with the parameters of this aerial application we were able to get spray droplets on the stems and buds at three levels of the canopy of sugar maple trees. There were significantly more droplets on twigs taken from branches in the upper canopy than on twigs taken at the middle or lower canopy ( $P < 0.0001$ ). However, as mentioned previously, equipment failures confounded the experiment and reinforced the need for additional work. Our observations of the difficulties encountered during this aerial application, when the weather was cold and unpredictable, strengthened our recommendation to not use insecticides for management of this pest until some of these factors could be studied in more detail. We were not satisfied with the use of Micronair atomizers. We believe that drift spraying, as is the technique used with Micronairs, has limited use in Vermont because sugarbushes commonly are located on hillsides, have small acreages and are surrounded by homes. Adjacent landowners will not tolerate agricultural chemicals drifting onto their property. In addition, Vermont geography is such that most sugarbushes have small streams or ponds associated with them thus making it even more difficult to have environmentally sound aerial applications of insecticides.

Table 2. The mean number of spray droplets on sugar maple buds and stems from branches taken from the upper, middle and lower canopy of trees receiving an aerial application of Sevin 4-Oil at 4.6 liters/ha (64 oz/acre) with Micronair atomizers

Plot	Canopy Level	Number of Droplets <sup>a</sup>	
		Bud	Stem
A	Upper	4.8 ± 4.3	8.3 ± 9.8
	Middle	4.4 ± 7.0	3.0 ± 4.9
	Lower	3.3 ± 6.1	2.9 ± 5.2
B	Upper	61.6 ± 38.7	72.9 ± 34.9
	Middle	42.6 ± 20.2	48.4 ± 28.2
	Lower	27.9 ± 21.9	31.6 ± 14.7
C	Upper	99.2 ± 60.4	81.2 ± 53.8
	Middle	51.6 ± 44.4	39.0 ± 32.1
	Lower	32.3 ± 26.9	22.6 ± 21.8
Control	Upper	00.0 ± 00.0	00.0 ± 00.0
	Middle	00.0 ± 00.0	00.0 ± 00.0
	Lower	00.0 ± 00.0	00.0 ± 00.0

<sup>a</sup> Mean ± standard deviation.

Our future research and management plan includes a comparison of droplet deposition from pressure nozzles and rotary atomizers. This work will be done on rangelands in New Mexico in March 1989. Data will be taken from kromekote cards; mylar sheets; and horizontal, 45 degree and vertical plastic straws. The straws will be used to simulate twigs. These data will be used as the basis for a large-scale trial scheduled for April 1989 to determine the efficacy of carbaryl for management of pear thrips.

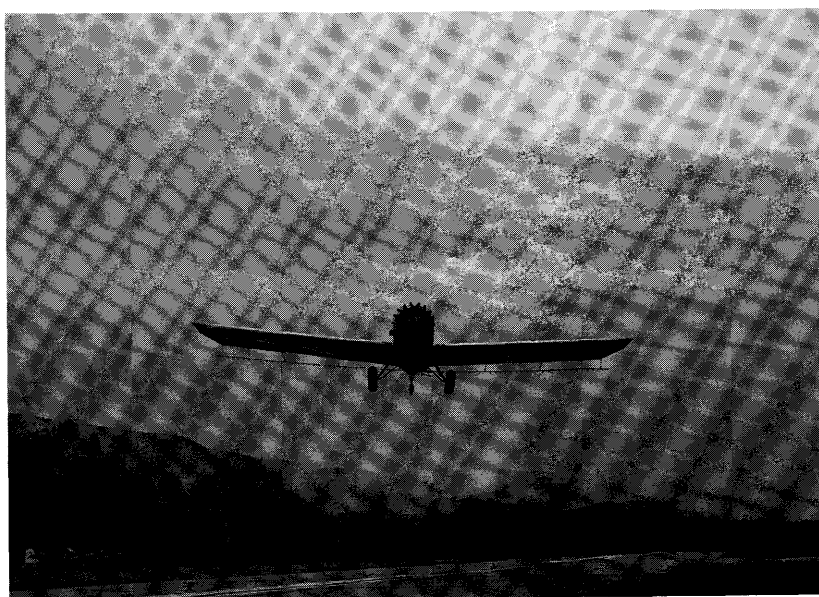
### Acknowledgment

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Calibration of Aircraft for 1988 Spray Trials in Vermont



# PEAR THRIPS DAMAGE AND IMPACT ON SUGAR MAPLE



Looking forward to a new sugaring season...  
(photo and caption by D. Lockhart)

**REMARKS ON THE PHYSIOLOGICAL EFFECTS OF  
DEFOLIATION ON SUGAR MAPLE  
AND SOME IMPACTS ON SYRUP PRODUCTION**

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The information I am going to present today is a conglomeration of some of the research on the effects of defoliation that has been done on sugar maple and oak. It involves work done by Drs. David Houston, Johnson Parker, Robert Gregory and me. Dr. Houston, a plant pathologist, and Dr. Parker, a plant physiologist, work with the USDA Forest Service in Hamden, Ct.; Dr. Gregory is a plant physiologist who is retired from the Forest Service in Burlington, Vt.

**Defoliation**

I will describe the effects of defoliation on sugar maple and some of the factors we need to understand about defoliation to anticipate its various effects. For example, defoliation can occur at different times of the year from a variety of causes and have different effects depending on the growing season. Early defoliation (budbreak to late May) can be caused by frost damage or defoliation by thrips. Defoliation can occur mid-season (early June to early July) from the forest tent caterpillar or occasionally the gypsy moth. Late defoliation (mid-July to mid-August) can occur from the saddled prominent caterpillar or leaf skeletonizers. Defoliations after mid- to late August are rare and have little adverse effect on the trees.

Trees can die after defoliation. However, whether a tree lives or dies depends on a number of factors. First, it depends on how severely a tree is defoliated. If the tree is defoliated severely, it usually will refoliate. Refoliation usually results if severe defoliation occurred from early through mid growing season. Defoliations that are severe enough to cause refoliation usually are more deleterious to a tree's health. If the tree does not refoliate, defoliation was not severe enough to cause the old leaf petioles to abscise and trigger the buds formed for next year to refoliate this year; or defoliation was late in the season and the next year's buds already were in the resting stage or dormant stage. Defoliations after mid-August usually do not trigger refoliation.

Another factor is the time of year in which the tree is defoliated. Time of growing season not only controls how trees respond to defoliation but also determines the length of time a tree has to recover. Trees defoliated early in the season have a longer time to recover. In the case of late-season defoliations, growth and carbon storage already has occurred prior to defoliation. Early and late-season defoliations that result in no refoliation usually have the least severe effect on trees. However, late-season defoliations that occur prior to bud dormancy and trigger refoliation can have the greatest adverse effects.

Other factors that determine the consequences of defoliation are health of the tree at the time of defoliation, growing conditions at the time of refoliation, growing conditions after refoliation, and the presence and aggressiveness of secondary organisms (other insects or pathogens that can cause tissue death and eventual tree mortality). These factors determine whether a tree is merely altered physiologically by a defoliation-refoliation episode or whether a tree is adversely affected by the defoliation. Moisture and temperature conditions during the refoliation period control how large the new refoliated leaves will be, while moisture and temperature conditions after refoliation will determine photosynthetic rate and how rapidly a tree will replace carbon lost during the absence of leaves.

The aggressiveness of secondary organisms will determine whether a single defoliation will weaken a tree to become susceptible

to the organisms. Health of the tree at the time of defoliation controls the overall response of the tree to defoliation; how rapidly it refoliates and how severely carbon lost during the absence of leaves will affect tissue vitality. Another important factor that determines the consequences of defoliation is the number of successive years of defoliation. Obviously, defoliation for several growing seasons will have a greater adverse effect than a single defoliation. The severity of a defoliation also influences the impact it ultimately has on the tree.

When a tree is defoliated severely it usually refoliates. That occurs usually when about 75% or more of the foliage is removed and the leaf petioles abscise. The buds that were developing for next year open and the leaves formed for next year begin to expand. Sometimes refoliation is prolific as with early defoliations or it can be scattered sparsely as sometimes happens with later defoliations. Defoliations in early August can result in scattered refoliation because some of the buds are already in the resting stage. Latitude affects when trees reach this stage.

### Refoliation

Refoliated leaves are only about one-half the size of a normal leaf but are more efficient photosynthetically; they process carbon dioxide faster, though total food production is reduced. A sugar maple leaf is normally about 80-100 cm<sup>2</sup> while refoliated leaves are only 35-40 cm<sup>2</sup>. For both normal and the refoliated leaves, size decreases with each successive year of defoliation. In addition to being smaller, refoliated leaves also are fewer in number.

Refoliated leaves usually are out of phase with the growing season depending on when defoliation and refoliation take place. Refoliated leaves are expanding during hotter and drier conditions than occur during normal spring foliation. In autumn, when normal leaves are going through fall coloration, leaves on defoliated-refoliated trees are green and thus are susceptible to the adverse effects of early winter damage from frost or snowstorms. Leaves may be killed quickly, and mineral nutrients and other compounds that normally are captured by the tree during normal autumn senescence before the leaves drop are

lost. As a result, the tree may enter the next growing season with deficient amounts of certain minerals.

Defoliated trees may be out of phase with the growing season the following spring. The normal foliation process may be delayed and defoliated trees may lag behind. Leaves on undefoliated trees may be approaching one-half full size while on trees defoliated the previous year, buds are just breaking and the leaves are just unfurling. One week later, leaves on undefoliated trees may be 80-90% expanded, while leaves on defoliated trees are only about half expanded. A defoliated tree is about a week behind in terms of energy capture. While leaves on undefoliated trees are producing enough energy to maintain themselves and new growth, leaves on defoliated trees are still utilizing energy reserves from the stem tissues.

The pattern of foliation the next spring is affected by when defoliation occurred during the previous growing season. Trees may refoliate only from terminal buds. This happens when trees are defoliated early in the season of the previous year. When trees are defoliated in early season, the terminal buds refoliate while the lateral buds formed on the new shoot prior to defoliation abscise. Thus, only the newly formed terminal bud is available for foliation the following spring. Trees defoliated later in the season also refoliate from the terminal buds but the lateral buds that formed on the new shoot prior to defoliation do not abscise. The new terminal buds formed on the refoliated shoot late in the season fail to survive the winter and only the lateral buds are available for spring foliation on the late-defoliated trees. Thus, foliation the next spring on trees defoliated early in the season is dependent on buds formed after defoliation, while on trees defoliated late in the season, foliation depends on buds formed prior to defoliation.

### **Fate of Buds**

The fate of the terminal bud is determined by plastochron duration (the time between formation of pairs of primordia at the apical meristematic dome of the growing tip) and the number of plastochrons after defoliation. These primordia become either scales or leaves. In

a normal bud there are about 12 to 16 pairs of primordia formed during a growing season; 8 to 12 pairs form scales and the others form embryonic leaves and undifferentiated primordia. Plastochron duration is short early in the season and increases as the growing season progresses. When a tree is defoliated, the plastochron duration shortens and a defoliated tree can produce primordia faster. An early-defoliated tree that refoliates can form up to 12 new pairs of primordia that become the scales and leaves for next year's bud. However, trees defoliated later in the season, even with a shortened plastochron duration, may only be able to form five pairs of primordia that become scales and leaf primordia. These buds formed late in the season are more susceptible to winter desiccation and winter freeze damage because they have fewer scales to protect the bud. That is why terminal buds formed after early season defoliation usually survive and those formed after late-season defoliation usually die, leaving the lateral buds to form the crown.

When terminal buds and branches dieback, both lateral buds and latent buds at nodes refoliate forming leaf clumps and clusters. These leaf clusters are less efficient photosynthetically, not because individual leaves are less efficient but because the architecture of leaf array is not optimum for capturing sunlight. Because the leaves are clustered close together, there is a greater amount of mutual shading than would have occurred under normal leaf distribution.

### **Impact on Leaves**

Leaves formed the year after defoliation are smaller in size and number. For example, defoliation in June can result in a 35-40% reduction after one year of complete defoliation, 50% after two years, and 60% after three years. Mid-season defoliations usually have a greater impact on leaf size than later or earlier defoliations. The number of leaf clusters also are reduced after defoliation--as much as 60% after three years of defoliation. Thus, a tree that is defoliated severely for three successive years may have much less than 50% of its original leaf area to capture light and CO<sub>2</sub> and manufacture food.

## Energy Levels

Defoliated trees have reduced energy levels. Reserve carbohydrates are used when the tree is without leaves, less leaf tissue is available for making new energy, and the growing season is shorter. In autumn, when healthy trees have large amounts of starch stored in ray tissue in stem and root wood, defoliated trees have low or depleted starch depending on how severe the defoliation was and when it occurred. Trees entering the dormant season with low or depleted energy reserves are vulnerable. Sometime between autumn and spring, energy levels may be depleted and tissues may die in both the root and stem.

Energy is important in the response of trees to wounding. The amount of bark and wood involved in the wound response is inversely proportional to the tree's energy level. If the tree is low in energy per unit volume of wood, larger volumes of wood become involved in compartmentalizing wounds. In an energy-deficient tree, the amount of tissue death around a wound and internal discoloration in the wood is much greater than in an energy-sufficient tree.

Defoliation reduces radial growth, the extent of which depends on when defoliation occurs during the season. Late defoliations have less of an impact on growth because the later in the season defoliation occurs, the more radial growth has occurred. Radial growth is reduced proportional to the severity of defoliation and the number of successive defoliations. Since there is a greater amount of dieback around wounds in an energy-deficient tree and there is less closure because that tree is growing slower, wounds put into defoliated sugar maple trees, including tapholes, will be larger and take longer to close.

The effect of defoliation on energy reserves depends on the time of defoliation. Early season defoliation depletes starch initially but the trees have longer to grow after refoliation and there is some recovery. Mid-season defoliation may deplete the starch. Because there is a shorter growing season in which to recover, there is little starch replacement and the effect is greater. Trees defoliated late in the



season are not affected nearly as greatly as with earlier defoliation because usually there is no refoliation. However, if refoliation does occur, the effect on energy reserves may be drastic because the remaining growing season is so short.

### **Sugar Concentrations**

Defoliation affects the chemical constituents of the bark and wood. Compared to undefoliated trees, defoliated trees have lower sucrose and higher concentrations of glucose and fructose, especially in the outer wood and cambial zone of the roots. There also is an increase in amino nitrogen compounds in these tissues. These nitrogen compounds give sugar maple syrup its so-called "buddy flavor;" however, there is no research data on the nitrogen content of sap collected for syrup production from defoliated trees.

The sugar concentration of sap in a tree usually increases in autumn as temperatures decrease and freezing temperatures occur. It continues to increase into early winter and then remains relatively constant as freezing temperatures occur continuously. Sap sugar significantly increases in late winter and early spring when alternating freezing and thawing temperatures occur again. Sap-sugar content then decreases as temperatures warm and trees begin to break bud. In experimentally defoliated trees, there were no significant differences in sap-sugar content between defoliated and undefoliated trees at a single point in time. Nor was there a relationship between absolute starch content and sap-sugar concentration. However, in some defoliated sugarbushes or defoliated maple stands, there was a significant reduction in sap-sugar concentration in defoliated trees.

As long as there is some starch in tissues, that starch will be converted to sugar whether it is a defoliated or undefoliated tree. Therefore, at the beginning of the "sugaring season," a defoliated tree may have the same or nearly the same sap-sugar concentration as an undefoliated tree. However, near the end of the season, there may be no more starch in a defoliated tree to convert to sugar and the sap-sugar concentration will decrease. This decrease in sap-sugar content in

defoliated trees probably is reflected in the anecdotal information that indicating that the number of gallons of sap needed to make a gallon of syrup is much higher from defoliated sugarbushes: 40 gallons for undefoliated bushes versus 80 gallons for defoliated bushes.

### Summary

To summarize, the effects of defoliation are determined by a number of physical, physiological, and environmental factors that interact in a variety of ways and determine how a tree responds to and is affected by defoliation. Because of this, it might be said that no two defoliations are alike.

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### Discussion Period

Question: We saw a slide showing heavy defoliation on one side of the road and no defoliation on the other that was controlled. The comment was made that next year the foliage would develop later in the area that was heavily defoliated. Is that because budbreak would be delayed? How would that effect thrips damage?

Answer: It is possible that thrips damage would be less depending on the developmental rate of buds. However, at this time there is no information on the relationship between thrips damage and bud development. No one has followed thrips activity relative to damage from budbreak to complete defoliation. We do know, based on observations and photographs, that leaves are slower to expand on trees that have been severely defoliated than those that were not defoliated. Whether bud break occurs at the same time in defoliated and undefoliated trees I don't know.

Question: Is anybody working on defense mechanisms in trees in relation to thrips damage?

Comment: Not that I know of. However, significant differences in damage levels between trees located side by side have been observed, suggesting that individual trees respond differently to thrips feeding.

This could be a result of a selection process by the thrips or due to differences in bud phenologies among trees. We know that sugar maple trees can differ genetically even though they are closely spatially related.

Question: Do you think that specific features of the tree determine the percentage of defoliation that occurs rather than the number of insects that are colonizing the individual tree?

Comment: I don't know. However, the results reported today show clearly that trees that were completely defoliated by this early season defoliator, ended up with higher starch levels in their roots than those that were only moderately damaged. These results suggest differences in the response of individual trees to insect attack.

## PEAR THRIPS DAMAGE AND IMPACT ON THE VERMONT SUGARMAKER

Daniel B. Crocker

Sidelands Sugarbush  
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I am a sugarmaker from southern Vermont. I became a sugarmaker because I wanted to establish a long-term project on my property from which I could make a living. The trees on my land are very healthy, as evidenced by the high volume of syrup I am able to produce. I have noticed the thrips damage for a number of years, but didn't know the cause until 1987. I would like to give you a brief history of what I have observed.

We had seen signs of maple decline as early as 1982, with smaller leaves and twig dieback throughout the tree canopy, and we had always thought it was caused by acid rain or maybe aphids. The first time I saw foliage damage was in 1984, and at that time I, like many others, thought it was frost damage. In 1985 after the leaves began to expand, I again noticed foliage damage, characteristic of thrips. There was about 50% defoliation in the sugarbush adjacent to mine, but interestingly damage was light on my property. Looking back now I am sure the damage was caused by thrips.

As Dr. B. L. Parker reported, damage in 1986 was very light. In 1987, I was cleaning tubing late in the spring, at about the time the buds were beginning to break. We had an outbreak of Norway maple aphid that year and I opened up one of the buds and out came a thrips- by then I had heard of pear thrips. I found about 1-2 thrips per bud that year and defoliation was fairly heavy.

This past spring (1988) I had a record syrup crop. I made 2,000 gallons of syrup from 5,000 taps, i.e., more than 1/3 gallon of syrup per tap, which is very good. This shows that my stand is very productive, one of the most productive in the region. Because of the aphid outbreak in 1987, I started inspecting my trees for aphids in early spring, but all I found was thrips. I contacted our local forest protection specialist, Barbara Burns, from the Vermont Department of Forests, Parks and Recreation, to ask her what to do. She said we would have to wait for the buds to break to evaluate the damage, but the buds on most of the trees never broke, and defoliation was 100%. Our sugarbush begins at an elevation of about 270 m (900 ft) and extends to the ridge at 390 m (1300 ft). Defoliation was heaviest on the ridge where the soil is shallow and particularly dry.

It is ironic that this major defoliation occurred following such a productive syrup year. I had felt that finally my syrup business was going strong, and then a few weeks later here I was with no leaves on my trees. So what do you do? You try to find the answer of what to do, and if you can't find the answer, you call the media. The local media should be commended for their efforts on this subject. They were instrumental in bringing the thrips problem to the attention of the public.

I'm a man of action. I'm not one to sit still and watch my trees as they decline, and I decided to do something to help my trees along so I could continue to produce syrup. In conjunction with studies on acid rain and twig dieback, the Canadians developed an organic fertilizer (3-6-8 [N-P-K] and 9% calcium) made from dried blood, bone meal and calcium to help sugar maples. I decided to follow their recommendation and bought a tractor trailer truck full of the material. I was the first in Vermont to fertilize land aurally. The fertilizer was applied to about 40.47 hectares (100 acres) of my sugarbush at the end of May, just as the trees were beginning to refoilate. Unfortunately it didn't rain for six weeks after the application, so it took longer for the fertilizer to enter the soil, but I believe it helped. I am not a scientist, and I didn't do a survey scientifically, but I believe the refoilated leaves on my neighbor's property were significantly smaller and lighter green than those on my

trees. In fact the foliage on my trees looked better than they have in the last four years. This fall I did a root starch test, and the results came out very well. I hope that with the help of fertilization I will buy time for my sugarbush, until the scientists can develop methods to manage this pest.

I think I can speak for most sugarmakers in Vermont when I say we are uncertain what course to follow after the 1988 thrips outbreak. To keep syrup production up we need to tap the trees more heavily, yet many sugarmakers are not tapping their trees at all this year because of the stress caused by last year's thrips defoliation. I had big plans to expand my syrup operation this year. I have just gotten married and I'd like to know what my future in syrup production will be. But for now I am waiting to see; it will be another year or two before we really know what impact these insects will have. I plan to fertilize again next year, but I am wary of the use of pesticides because the water for my home comes from the sugarbush.

I compare sugaring to final exam week in school. You work very hard for six weeks and then clean up. You are so exhausted you don't go into the woods for awhile. The thrips outbreak has changed all that for me. I now realize that we sugarmakers need to keep a closer watch on our trees. We also need to work more closely with our entomologists and help them by making observations of what is going on in our stands.

### Discussion Period

Question: Does fertilization seem to help the health of the maple tree? I wondered if this fertilization is preceded by soil testing. Are these factors in the soil hostile to the survival of pear thrips?

Crocker: I don't know whether fertilizers are hostile to thrips. I did test the soil for pH, and it was about 5.4. I don't know specifically whether the fertilizer will improve tree health, but I just decided to jump



to it and try it. I didn't see any harm in applying an organic fertilizer, at least no immediate harm, and any injury would be very minor. However, more care must be taken when applying chemical fertilizers.

Comment: This is an important point. Any application particularly with an inorganic material ought to be preceded with a soil test and a foliage test. There may be serious consequences from fertilizing improperly, such as fertilizing with the wrong element at the wrong time or on the wrong soil type. The literature reporting the results of fertilization of the sugar maple is contradictory. About 50% of them report ill effects or no effect from fertilization, and 50% report positive results in terms of an increase in growth. Therefore, foresters must proceed with caution with fertilization. I wish you had fertilized half of your sugarbush and left the other half untouched as a control. We could have had better answers to the fertilizer question in that case.

## **ROOT STARCH IN DEFOLIATED SUGAR MAPLES FOLLOWING THRIPS DAMAGE**

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### **Abstract**

Sugar maple root starch evaluations were done in 1987 and 1988 as a service to Vermont sugarmakers concerned about tree health. Trees were rated for starch content in late fall, using a visual iodine-staining technique. On the average, trees with heavy pear thrips damage in the spring of 1988 had higher levels of root starch the following fall than trees with light or moderate damage. Trees with heavy damage actually had more starch in 1988 than they had the previous fall. Starch in trees with light and moderate defoliation did not increase. Possible explanations for higher starch in heavily damaged trees include early refoleation, energy reserves from the first leaf flush, and 1988 drought conditions.

### **Introduction**

The health of sugar maples is a major concern to Vermonters. Previous research has shown that root starch is a useful indicator of tree condition. Starch rating could help sugarmakers decide whether trees are healthy enough to tap. This hypothesis was evaluated in a pilot test begun in 1987. The results of this test provide an indication of the impact on tree health of damage from the 1988 pear thrips outbreak.

## Materials and Methods

Root starch levels were evaluated from 152 trees in 19 sugarbushes during the fall of 1987. Most of the sugarbushes had been damaged by thrips the previous spring or were stressed by other factors. Root starch in these trees was evaluated again in 1988. Three undefoliated, healthy stands were added that year. In 1988, 276 trees from 22 stands were evaluated.

A visual iodine staining technique (Wargo 1977, 1988) was used to evaluate root starch. Samples were taken from large roots or smaller, thumb-sized roots below the soil line. In 1988, two roots were sampled from 150 of the sample trees. Root sections were stained with iodine and color-rated by comparison with published photographs (Wargo 1977). Although ratings were subjective, there were clear differences between roots rated high in starch and those rated low or depleted in starch.

Trees were rated in the summer of 1988 for thrips damage and crown dieback. Those having severely stunted leaves or no leaves at all were rated as heavily defoliated. Trees having thin foliage that was crinkled and deformed were rated as moderately defoliated. Trees with either moderate or heavy damage refoliated in June. When thrips-damaged trees refoliated, the new leaves were undamaged by pear thrips, but were slightly reduced in size.

Because starch ratings provided helpful management information, a starch testing service was offered in the winter of 1988-89 to Vermont sugarmakers. Based on starch ratings, participants were advised whether or not to reduce tapping or delay thinning. Sugarmakers were advised to tap conservatively, or not at all in sugarbushes in which over half of the trees were rated low or depleted in starch.

For statewide testing, defoliation ratings were reported by participating sugarmakers. Results are presented from 27 sugarbushes involved in this program.

## Results

A relationship was found between the root starch rating in the fall of 1988 and crown dieback the previous summer (Fig. 1). Trees having over 50% dead branches had roots that were either low or depleted in starch. Trees with no dieback were more likely to have roots with high or medium starch levels. This supports the assumption that root starch ratings provide valuable information about tree health.

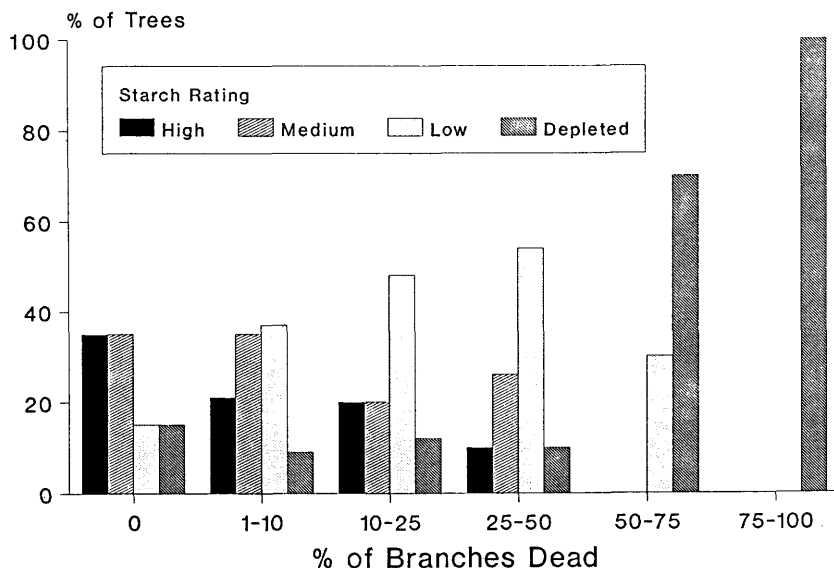


Figure 1. Percentage of trees in each starch rating category, in the fall of 1988 by crown dieback rating the previous summer.

In 1988, when two roots were sampled from each of 150 trees, only half the trees had identical ratings for both roots. In 35% of the trees, the starch content in the two roots differed by only one rating. This suggests that root starch levels are not uniform throughout the root system, and results from starch testing must be interpreted cautiously.

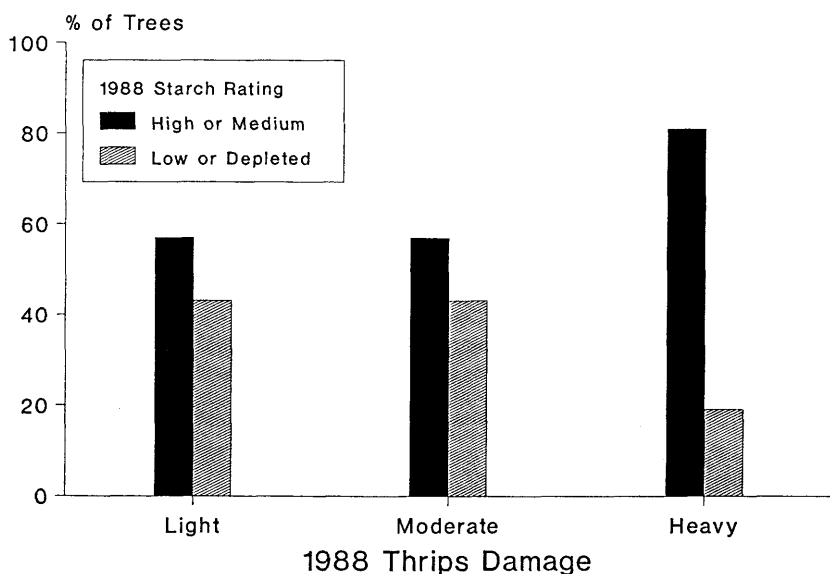


Figure 2. Percentage of trees in each starch rating group evaluated in the fall of 1988, by thrips damage the previous spring. Starch ratings are significantly different for heavily damaged trees ( $P = 0.01$ ).

Stands with heavy thrips damage in 1988 had higher levels of starch the following fall than stands with light or moderate defoliation ( $P = 0.01$ ) (Fig. 2). In fact, the 1988 root starch ratings from these heavily defoliated trees most often increased from 1987 levels ( $P = 0.01$ ). Starch levels in trees with light or moderate defoliation were equally likely to increase as decrease between the two years (Fig. 3). For example, in one sugarbush, each tree sampled in 1987 was depleted in starch. After heavy defoliation by pear thrips in 1988, and a complete refoleation, the average starch rating for the sugarbush was moderate.

In the statewide testing program, sugarbush starch ratings were similar whether thrips damage was reported as light, moderate, or heavy. Two-thirds of the sugarbushes had a majority of trees rated high or medium in starch.

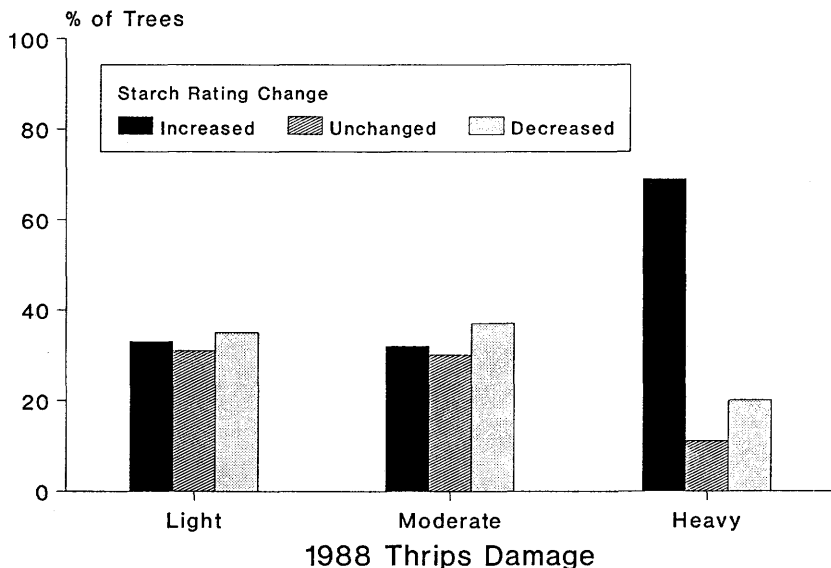


Figure 3. Percentage of trees with root starch levels that increased, stayed the same, or decreased between fall, 1987 and fall, 1988, by thrips damage in the spring of 1988. Change in starch rating is significantly different for heavily damaged trees ( $P = 0.01$ ).

### Discussion

Thrips damage occurs against a background of other stresses which also affect tree health. Much of the root starch data in this report were collected from sugarbushes that were already stressed prior to the 1988 defoliation. Prior stress was an important factor in 1988 because of low rainfall during that growing season. Stressed trees are particularly vulnerable to drought conditions.

There are several possible explanations for higher starch ratings in heavily damaged trees. One is the early refoilation of defoliated trees. Refoliation was complete by the end of June. The rest of the growing season was available for food production.

Another possible explanation is the severity of bud damage. Spring bud development in heavily damaged stands produced no leaves. Stored food reserves, which would have gone to the first flush of leaves, were still available when refoliation occurred.

Additionally, drought may have caused more stress to trees with a full complement of leaves than those which were defoliated in May and June. Trees with light or moderate damage continued to transpire during the period of little or no rainfall. Less soil water may have been lost, through transpiration, in stands which were heavily defoliated at that time.

Before management recommendations can be made, or pest control measures undertaken, it is important to know the significance of insect damage to tree health. Based solely on stored root starch levels, thrips damage in 1988 did not adversely impact sugar maple tree health in the sugarbushes sampled. In fact, trees in the heavily damaged stands had higher levels of starch than did those in light and moderately damaged stands. Further studies are needed to determine whether this relationship is found using a controlled sample and under different weather conditions. Other possible impacts, such as reduced radial growth or shoot elongation, were not evaluated but should provide further information about the impact of thrips damage. Further evaluation and standardization of root sampling and visual starch rating would be helpful to improve the reliability of root starch analysis.

### References Cited

- Wargo, P. M. 1977. Estimating starch content in roots of deciduous trees - a visual technique. USDA For. Ser. Res. Paper NE-313.
- Wargo, P. M. 1988. Judging vigor of deciduous hardwoods. USDA Information Bull. No. 418.

### Discussion Period

**Question:** In light of your findings that severe pear thrips damage followed by tree refoliation resulted in above average root starch levels, what tapping guidelines would you recommend to sugarmakers who had very severe thrips damage this past year? Should they tap conservatively as originally recommended and is the root starch level a valid test to use for determining tapping levels?

**Burns:** At this time we are still recommending that sugarmakers tap their trees conservatively in stands that were severely defoliated by thrips. These guidelines were written for sugarmakers this summer and are available from the VT Dept. of Forests, Parks and Recreation. We offered a starch testing program to sugarmakers this year, regardless of the defoliation that occurred in their stands. In sites showing relatively high or normal root starch levels, we did recommend that the sugarmakers tap as usual, following standard tapping guidelines. So the starch testing was used to override tapping recommendations based on foliage damage alone. However, we are still cautioning people to tap conservatively recognizing that thrips damage must stress trees to some extent.

**Comment:** I noticed that my tap holes are healing well and my trees look generally healthy, so why not tap them? One more tap hole isn't going to kill the tree, and I can't afford not to tap. In fact I think probably the year we shouldn't have tapped was the year before the defoliation rather than the year after. It seems logical that if the trees are going to be severely defoliated in the next few months, it would be better not to take sap out of the trees because they will need that sap and all the energy sources they have built up to refoliate. Therefore prior to a defoliation it is probably better not to tap.

**Comment:** I think you must be cautious in taking that approach because we only take out about 3% of the tree's total carbohydrate stores during tapping. Therefore a minimal amount of the stored carbohydrates is removed by tapping prior to defoliation. It is hard to believe that is going to significantly impact the tree.



Comment: The impact to the tree of tapping is not necessarily how much carbohydrate is removed but how much available energy there is for healing the tap hole wound. The biggest problem is that the more discolored wood there is in a tree, the less clean, clear sap there will be in future years. If the tree responds ten times as much in one year because of low energy reserves then ten times more wood is lost for tapping. So the problem lies not necessarily in what has been taken out of the tree, but what is being done to the internal tree system and how that affects the quality of the product you will be getting out in future years. All of this depends on genetics, available energy and the combination of those factors.

Question: What is the effect of vacuum systems on tree health?

Comment: Vacuum systems have not been in use long enough to make complete judgments on its long-term effects on trees. Based on anecdotal information, the areas that appeared to be suffering in terms of tree health were those areas in which the vacuum system was used. Critical studies need to be done on the long-term effects of vacuum systems on sugar maple trees. I am not sure that there is no effect.

Comment: So far we haven't seen any effect of vacuum on trees. In fact on steep slopes there seems to be about the same amount of suction pressure in a non-vacuum closed system as there is in a vacuum system. I agree there haven't been many years of experience with vacuum systems to state conclusively that there is no effect, but I haven't seen evidence or published results indicating that low amounts of vacuum pressure are harmful to sugar maple trees. Of course, if you destroy cell walls with high pressure, the effect could be very different.

Question: Has any testing of starch been done on branches or tree trunks rather than the roots; why can't you do that?

Answer: You can; starch is stored in the stems as well as the roots. The problem is that the period of time in which starch testing can be done in the stems is reduced because of diurnal fluctuations in temperature. These fluctuations can cause the starch in the stem

tissue to convert to sugar making the timing of testing critical. Temperature fluctuations are not such a problem in the roots. In addition, the starch concentration in the root system is much greater than that in branches or twigs, which increases the ability to distinguish among the different starch level categories and makes the test results more accurate.

## THE ECONOMICS OF A THREATENED TRADITION

Richard Matthews

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Writing a magazine article on thrips in November for an issue of *Country Journal* that would appear three months later was a considerable challenge, and I apologize now for any mistakes you may find in it. Yet in the process of researching it, I talked to dozens of farmers who count heavily on their annual maple syrup production to supplement their incomes. It is this research into the micro-economics of the small-scale sugarmaker, I think, that prompted Bruce Parker to ask me to speak here.

It's important to point out that I'm neither a scientist nor an economist. I'm a journalist and a writer of feature articles, which I suppose makes me a humanist. And as far as I'm concerned, the real front line of the thrips problem is the sugar house back in the woods and the people who work the land--people like Darwin Clark, my neighbor in Hawley, Massachusetts, who still gathers sap with a team of oxen and a sleigh and boils it in a lopsided sugar house that looks like it could topple over at any moment. Or Richard Chandler, of Ashfield, Massachusetts, who remembers when maple syrup sold for \$12 a gallon in 1976. Or Raymond Bisbee, who started sugaring 30 years ago when he was 10, with 50 buckets and a flat pan for boiling, and who now runs some 1,200 taps in the sugarbush where his house sits.

Darwin Clark is expecting a lower yield this year, but he's sugaring because he says he can't afford not to. Richard Chandler isn't sugaring, but he's buying maple syrup to supply customers who have been coming to his farm for years. Others are tapping, but reducing the

number of taps. One farmer had to cut his taps by more than half when the owner of the trees he rents said he didn't want to put his maples at risk. In one way or another, each of these people are facing losses they can ill afford.

And it is not a loss that can be compensated for by raising prices. Given the fact that nearly 75% of the world's maple syrup is boiled in Canada, and that some areas of New England have not yet been affected by thrips, any local declines in production will probably have small effect on the overall price of a gallon of syrup.

In the short term--which means the season that's almost upon us--the impact of local declines will be local. And the people who will be hit hardest will most likely be those who set a few thousand taps in the same sugarbush that was worked by their fathers and grandfathers. That's not to say syrup producers who have 600 acres of maples won't suffer--they certainly will--but a man trying to run his farm on a shoestring who loses 25 to 50% of his annual income in a succession of poor sugaring seasons may soon find himself talking to the land developers and real-estate agents instead of planning what crop to plant in the spring, or whether he can afford to increase the size of his dairy herd.

Some of these people are already feeling the pinch. A local survey in Franklin County, Massachusetts conducted by the newspaper where I'm an editor, determined that nearly 30% of local sugarmakers are not going to fire up their evaporators this season. Of the 70% who are sugaring, nearly all are reducing the number of taps they plan to set, or playing what one of them called "a waiting game" before they decide how much to cut back. A larger survey conducted last November in Vermont--by the same folks hosting this conference--shows more than half of the state's syrup producers were thinking about not tapping this season or reducing the number of taps.

The reasons they give are varied, but concern for the long-term health of trees and the prospects of a poor yield, weighed against time and money invested in a syrup harvest, predominate. Cynthia Cranston,

who sugars with her husband, Tom, in a small town in northwestern Massachusetts, says: "Sugaring has been in my family since the 1700s, and this is the first year we won't be tapping. We hope we can help the trees' healing process if we don't sugar this year. If we did sugar, we'd feel like we were jeopardizing the future."



Figure 1. Collection of maple sap for making syrup (photo from the Vt. Development Dept.).

Others aren't tapping because they anticipate low starch levels in the trees and feel that trying to strangle one gallon of syrup from 55 gallons of sap is just not economically sound. And those who are going ahead but cutting back will naturally produce less than in a normal year, whatever the sugar levels in the sap, or the vagaries in the weather.

However you figure it--good year or bad--it is reasonable to suppose that in the areas of New England affected last spring by thrips, the total production of syrup could be reduced by as much as 50% or more. In Massachusetts, where some sugarbushes were hit very hard, that could mean a state-wide loss as high as \$800,000 in the syrup crop. In Vermont, that figure may be even higher - 2 - 4 million dollars or more, which is significant when subtracted from the annual 12.5 million dollar production that is customary.

That's certainly a lot of money, but it is still the local farmer who will feel it the most. With no syrup at all--or reduced amounts--he either buys syrup from his neighbors or loses the customers he's acquired over the years. Or he takes the blow directly and sells nothing at all, in which case he's poorer this year by amounts ranging from a few thousand dollars up to \$25,000 or more.

There may be farms in New England capable of absorbing such losses, but if those declines come again next year, that number will be reduced. The fact is, most farmers count on syrup to put money in the bank, money that keeps some farms alive and well. Most people who boil syrup also raise cattle, mow hay and plant cash crops. But some of them also drive school buses, maintain strawberry patches, or hire out in the winter to flesh out incomes that are marginal at best. To lose a significant portion of the income provided by boiling syrup, especially if that loss persists over several seasons, will mean farms barely hanging on could go under. How many is impossible to say, but anyone who reads the newspapers knows that farmers are already in trouble and another blow to their pocketbooks is the last thing they need.

What is being faced this year by nearly everyone in the thrips affected areas is how to manage damaged trees. On the one hand, not tapping or cutting back means an immediate dollar loss; on the other, crashing ahead as if nothing is wrong could mean long-term damage to the overall health of trees--an option which will exact its toll one or two years down the line, especially if thrips return with a vengeance this spring.

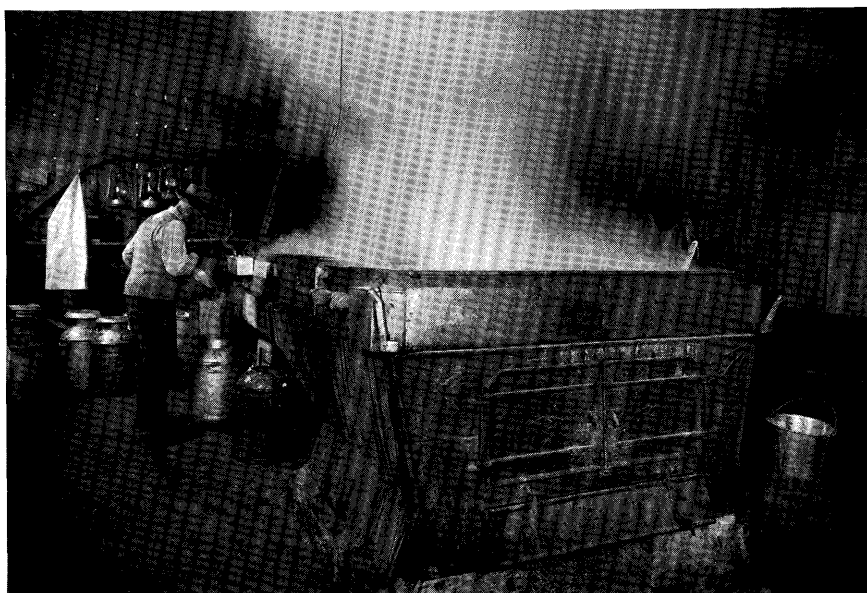
I certainly don't mean to sound like an alarmist. As I mentioned before, I'm not an economist, and therefore not qualified to frighten people. At this point, from everything I understand, there are just too many variables in the thrips situation to even begin suggesting an imminent economic crisis. Besides, it's probably fair to say that unless this year turns out to be a mega-disaster over widespread areas of New England, most farmers will weather a shortfall in production. After all, the planned decreases in production this year are voluntary, a matter of choice. It is the unpredictability that is worrisome. For if thrips damage continues and spreads, if general maple decline gets worse, if there is serious die-back on trees, if tapping damaged trees really does deplete them, then next year will mean trouble for some and hardship for many. And after that..?

Prediction is an unprofitable occupation, likely to be fraught with embarrassment; certainly in the course of researching this story, I found few who were willing to go on record about what might happen tomorrow. Yet there are people who are beginning to worry that one of New England's most characteristic traditions is being threatened. Imagine a New England spring with no steam rising from the sugar houses. Visualize a season of disappointed leaf peepers. For what is at stake in the maple industry is more than a mere formula of production figures and prices.

Or, to make the scenario more personal, imagine the family that took out a mortgage to build a new sugar house, or the farmer who last year invested in several miles of tubing and a new evaporator. There are those, too, who lease maples from people beginning to feel a tenderness for their trees--some non-sugaring tree owners are already beginning to call the state's maple phone numbers seeking advice about what to do. Selectmen in one town in western Massachusetts, the township of Leverett, have even asked farmers to cut back on taps this year--a trend, if it continues, that could limit the numbers of trees available to farmers.

If those farmers are already living on the edge--and many New England farmers are--their concern will justifiably increase if this season turns out to be a bust. And if the thrips continue to spread, and reach Canada, say, that may drive up prices in a market already beginning to show resistance to the cost of a gallon of syrup, which in some gift and specialty shops is already selling for \$45 to \$50 a gallon.

With the thrips diagnosis uncertain, and the prognosis even more so, trying to guess what the long-term economic impact of thrips will be is not easy. Yet some balance books are already hurting and a thin year will increase that pain. Figuring everything into the complex equation that is the maple syrup industry--thrips, acid rain, road salt, over-tapping, general maple decline, sugarbush management, cost of equipment--it is easy to see that somebody stands a chance of losing a lot of money.



Syrup Making in Vermont  
(photo from the Vt. Extension Service)



## THE RELATIONSHIP BETWEEN MEASURES OF TREE VIGOR AND PEAR THRIPS DAMAGE IN SUGAR MAPLE

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### Introduction

In this presentation I will address three points associated with pear thrips damage and sugar maple. First, I will describe the impact of pear thrips on sugar maple in Massachusetts, in both the sugarbush and the natural forest stand, based on root starch assays that were completed this fall (1988). Secondly, I will discuss the relationship between tree health and thrips damage, specifically addressing the question of whether this insect preferentially selects trees or stands of trees having high or low vigor. Finally, I will offer some speculative comments concerning the influence of air pollutants (e.g., ozone) on the sugar maple/pear thrips interaction.

Pear thrips damage has been most severe in areas of the state where sugar maple is concentrated (Fig. 1). Obvious feeding damage by the pear thrips was first reported in Massachusetts in 1987, although it had been present in the area for a few years previously. In 1988, the amount and severity of damage increased dramatically. Approximately 81,000 hectares (200,000 acres) were defoliated.

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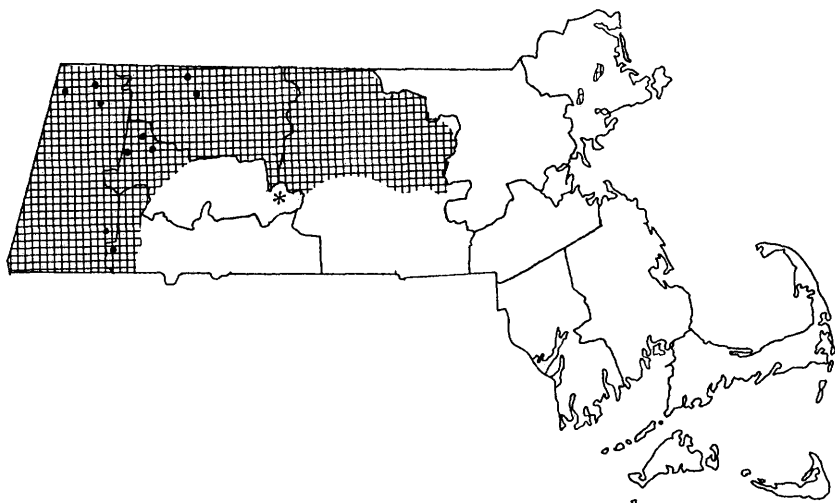


Figure 1. Map of Massachusetts with shaded portion showing area predominating in sugar maple where pear thrips damage has been most severe. Root starch analyses were conducted in permanent forest health monitoring sites (indicated by dots) and a control plot (indicated by asterisk).

### Materials and Methods

Ten permanent forest health monitoring sites were established in 1988 as part of the North American Sugar Maple Decline Project (NAMP) (Millers & Lachance 1989) (Fig. 1). The timing of plot establishment and the current thrips outbreak were coincidental but also fortuitous in that it allowed us to examine some specific relationships between sugar maple tree condition and thrips damage. Five of the ten plots were located in intensively managed sugarbushes and five were in unmanaged or natural forest stands. In addition, a control plot was established outside the region of severe thrips damage.

My discussion will focus on data (Table 1) collected on 334 trees selected at random from the ten permanent plots and 20 trees from the control plot that were rated for thrips damage.

Table 1. Field data collected for tree health in the North American Sugar Maple Decline Project\*

Site, Stand and Tree Characteristics
Site description
Stand description
Sugar maple inventory
- Growth measurements
- Tapping record
- Bole quality
- Branch and foliar characteristics
- Damage causal agents
Soil characteristics
Root starch analyses
Thrips damage ratings

\* Supported in part by the Mass. Dep. of Environ. Management.

Each sample tree was assessed for thrips damage using a standardized thrips damage rating system based on methods developed by the VT Department of Forests, Parks and Recreation (Table 2). Each tree was given a score from 1 to 3 depending on the percentage of the crown volume that had been defoliated by thrips and subsequently refoliated in June.

Table 2. Thrips damage rating system used in plots of the North American Sugar Maple Decline Project\* in Massachusetts

Numerical Rating	Rating Description
1	Defoliation greater than 60% of the tree  Refoliation greater than 60% occurring in late June, new leaves being smaller in size and lighter green in color than normal
2	Many leaves mottled with some stunting and browning  De/refoliation 30-60%  Refoliation occurring in June with new leaves smaller and lighter green in color than normal
3	Leaves mostly lightly mottled with some stunting  Defoliation less than 30% of the tree  Refoliation visible as scattered tufts of new leaves at the branch terminals

\* Based on rating system developed by the Vermont Department of Forests, Parks and Recreation, though numerical ratings differ.

Starch analysis was conducted on trees assessed for thrips damage from ten maple decline plots ( $n = 334$ ) and the control plot ( $n = 20$ ). The root starch assay was used as an indication of tree vigor and to assess the relative impact of thrips feeding on a tree's energy reserves (Wargo 1975).

## Results

### Damage Rating and Root Starch Assay

Most of the sample trees were in the first or third damage category (Fig. 2). Trees receiving a rating of 1 were severely defoliated by pear thrips and yet by late June had produced a second flush of leaves that provided a relatively full crown. In contrast, those trees receiving a rating of 3 retained the first flush of leaves although they were heavily damaged.

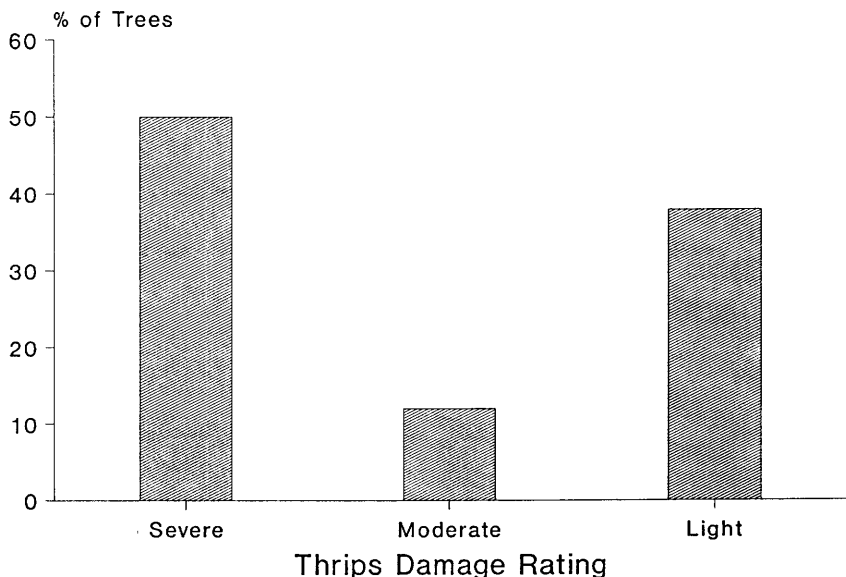


Figure 2. Rate of thrips damage in the summer, 1988 for sugar maple trees in ten permanent plots of the North American Sugar Maple Decline Project. Damage is a de/refoliation percentage: 1 = greater than 60%, 2 = 30 - 60%, 3 = less than 30%.

Some variation in thrips damage between trees within stands was observed. However, the majority of the trees within a given stand were generally found to be one of the three categories. This suggests that there may be some site or stand characteristic that strongly influences thrips damage. There was no strong indication that trees in the managed sugarbushes were more or less damaged by the pear thrips than the trees in the natural forest stands.

A majority of the trees from the ten permanent sites were assessed as having low or depleted starch reserves (Fig. 3). Only 56 of 334 trees received a high or moderate starch rating. In contrast, trees sampled from the control site, just outside the range of the thrips infestation, largely fell into the moderate starch category. These results suggest that pear thrips had a significant impact on tree vigor, whether or not they were completely or partially defoliated. (Fig. 3).

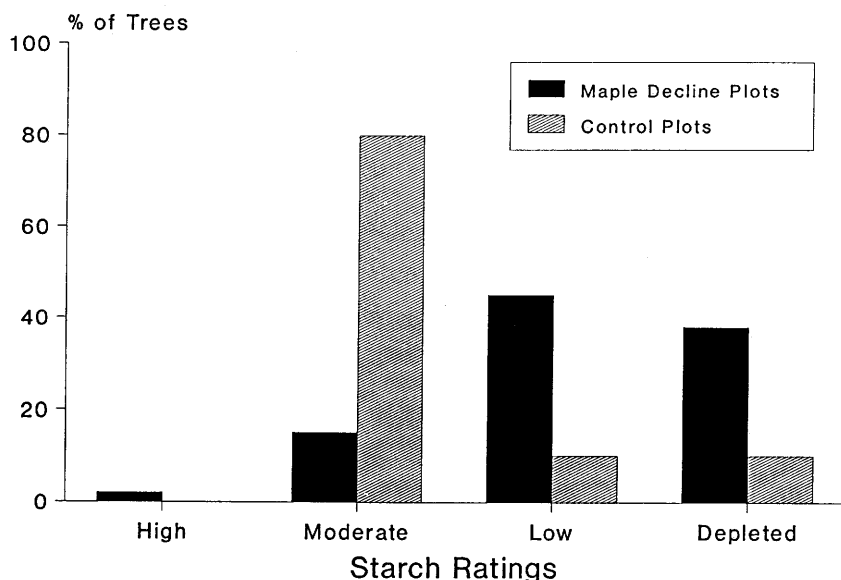


Figure 3. Mean root starch levels of sugar maple trees in 10 plots (within the area of thrips damage in 1988 [ $n = 334$ ]) of the North American Sugar Maple Decline Project and one control plot (outside the thrips-damaged area [ $n = 20$ ]) sampled in 1988 in Massachusetts.

All of the trees rated high in starch, and half of the trees rated moderate were in the highest or most severe defoliation class, which was an unexpected result. This suggests that a tree that is in relatively good health prior to a thrips attack may recover from severe thrips damage in one growing season. In fact, it may be better for the tree to go through a refoliation process and produce a second flush of relatively normal leaves than for it to rely on a first flush of heavily damaged foliage for all its energy needs. Presumably, this response is only possible because pear thrips is an early season defoliator.

These results are encouraging with respect to the long-term health of sugar maple. They imply that the impact of the pear thrips may be minimized by refoliation. They may also partly explain why the 10-year infestation of pear thrips in Pennsylvania has not resulted in a significant amount of tree mortality. Perhaps it is less the level of insect colonization than the response of a given tree to insect attack that determines the level of defoliation and subsequent impact on energy reserves.

### **Tree Vigor and Thrips Damage**

My second point addresses the question of whether or not the apparent vigor or decline status of a sugar maple stand might influence the amount or severity of thrips damage. This relationship is important because it may explain the tree-to-tree variation in thrips damage we have observed. It is not uncommon, for example, to find two trees standing side by side, one of which is severely defoliated by thrips whereas the other is only minimally damaged. This suggests that thrips may be preferentially selecting one tree over another. There could be many reasons for this variation, such as slight differences in bud development during the insect emergence period, or differences in tree vigor that influence the thrips colonization process.

In 1987, a preliminary survey of sugar maple tree health was conducted at 22 sugarbushes in Massachusetts. Four of these sugarbushes became part of the North American Sugar Maple Decline Project in 1988. We compared the decline of the trees evaluated in 1987 to the severity of thrips damage on those same trees in 1988 (Table 3).

Table 3. Comparison of decline status to thrips damage in plots of the North American Sugar Maple Decline Project<sup>a</sup> in Massachusetts

Plot location - Region	1987 Relative Decline Status <sup>b</sup>	1988 Thrips Damage Rating <sup>c</sup>
Williamstown - North West	Healthy	1.1
Tolland - South	↓	1.4
Chesterfield - Central		2.4
Worthington - Central		2.7

<sup>a</sup> Supported in part by the Massachusetts Dep. of Environ. Management.

<sup>b</sup> Based on foliar and branch characteristics using a system developed by the Ontario Ministry of the Environment.

<sup>c</sup> Mean rate of damage for all sugar maple trees in the stand using the damage rating system described in Table 2.

These data suggest that there is an inverse relationship between tree health and thrips damage, i.e., the healthier stands in 1987 had greater defoliation in 1988 (Table 3). However, this relationship could be explained by the geographic location of the plots relative to the population density of the insect. At this time, we have no data on insect population densities in Massachusetts so there is no way to validate this relationship.



## Discussion

### Pollution Stress and the Thrips Outbreak

Considering the relationship between tree vigor or decline and thrips damage, I would like to discuss whether air pollution stress is acting as a predisposing factor. Within the context of Paul Manion's conceptual framework for considering the types of stress factors that can contribute to a decline problem (Table 4), I could hypothesize the following: air pollutants, such as acid rain and ozone, have weakened the maple trees over time, making them more susceptible to pear thrips attack. Whether or not the combined stress of air pollution and pear thrips will push the maple forest towards a serious decline situation remains to be seen and most likely depends on the degree to which other interacting stress factors play a contributing role.

Table 4. Classification of stress factors in forest decline<sup>a</sup>

Types of Factors		
Predisposing	Inciting	Accelerators
Climate	Insect defoliation <sup>b</sup>	Bark beetles
Soil moisture	Frost	Canker fungi
Host genotype	Drought	Viruses
Soil nutrients	Salt	Root-decay fungi <sup>b</sup>
Air pollutants <sup>b</sup>	Air pollutants	Competition
Competition	Mechanical injury	

<sup>a</sup> Modified after Manion (1981).

<sup>b</sup> Associated with maple decline.

A slightly different approach to the problem is to consider how acid rain or ozone might influence insect survivorship or reproduction. For example, acid rain effects on soil fertility or ozone effects on maple physiology may have altered the leaf chemistry or nutrient balance of

sugar maples in such a way as to increase insect fecundity and/or survival rate. Specific hypotheses that have been formulated by other researchers (most notably by Patrick Hughes from Boyce Thompson Institute, Ithaca, N.Y.) suggest that many plants respond to moderate levels of air pollutants by manifesting higher levels of free amino acids and lower levels of plant defensive compounds such as phenolics. Both of these processes would raise the effective level of nitrogen in the insect diet and as a consequence raise its fertility.

A summary of possible direct and indirect effects of air pollutants on insect success is presented in Table 5. I would also suggest that, given the length of time pear thrips spend in the soil that it is appropriate to consider whether or not pollution loading of the soil environment has created a more favorable habitat for pear thrips survival.

Table 5. How air pollutants can affect insect success<sup>a</sup>

Direct effects	Indirect effects
Toxicity	Effect on predators, parasites or pathogens
Stimulation of metabolism	Altering the microclimate or microhabitat
Alteration of behavior	Inducing changes in the host plant chemistry/morphology
	Altering plant abundance or distribution

<sup>a</sup> Taken from Hughes (1988).

There are a number of examples where air pollutants have been shown to affect insect populations on plants (Table 6). These references can be found in the recent publication by Hughes (1988). These examples emphasize that there does exist a body of evidence that air pollutants, including acid rain and ozone, affect the success of leaf feeding insects (e.g., pear thrips). My hope is that this information will provide an impetus for investigation into the influence of air pollutants on the pear thrips/sugar maple interaction.

Table 6. Experimental studies concerning effects of air pollutants on the success of leaf feeding insects<sup>a</sup>

Pollutants	Insect	Plant
Hydrogen fluoride	Mexican bean beetle	Bean
SO <sub>2</sub>	Mexican bean beetle	Bean, soybean
Ozone	Mexican bean beetle Gypsy moth	Bean, soybean White oak
Ambient air	Green apple aphid Rose aphid	Hawthorn Rose
Acid rain	Mites/springtails	Humus
SO <sub>2</sub> , O <sub>3</sub> and acid rain	Elm leaf beetle	Elm

Many additional studies show a correlation between insect populations and the presence of air pollution in non-forest areas.

<sup>a</sup> Taken from Hughes (1988).

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## **DETECTION OF PEAR THRIPS DAMAGE USING SATELLITE IMAGERY DATA**

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### **Abstract**

This study evaluates the potential of measuring, mapping and monitoring sugar maple damage caused by pear thrips in southern Vermont and northwestern Massachusetts using satellite imagery data. Landsat Thematic Mapper (TM) data were obtained during a major thrips infestation in June 1988, and were compared with satellite data acquired during June 1984 (before pear thrips were a major problem in the area). Two different types of images were produced--damage assessment images and change detection images. Damage assessment images enable assessment of forest damage at any one particular moment in time, whereas change detection images enable assessment of the degree of forest change that has occurred between two different dates (in this case between 1984 and 1988). In this study, both types of images were found to accurately and effectively portray forest damage related to pear thrips activity. Both types of imagery indicated that damage was especially severe in low and medium elevation areas to the west and east of the Green Mountains, but that damage was not severe in the Green Mountains. Satellite data were used to assess the number of hectares seriously affected by the insect. Of approximately 202,000 hectares (0.5 million acres) of deciduous forest in southern Vermont covered by the TM scenes used, 24.7% was classified as medium damage, and 10.3% was classified as high damage. Of 95,500 hectares (236,000 acres) of deciduous forest covered in northwest Massachusetts, 30.9% was classified as medium damage, and 18.3% was classified as high damage.

## Introduction

During the spring of 1988, a major outbreak of thrips occurred throughout the northeastern United States. It was estimated that in the state of Vermont alone, approximately 202,000 hectares (0.5 million acres) of deciduous forest were affected by the insect (Parker et al. 1988). Damage was also extensive in Massachusetts, Pennsylvania and New York, and was noted in Connecticut and New Hampshire (Parker et al. 1988). Few cases of tree mortality have been attributed to pear thrips-induced defoliations. However, productivity may decrease following such an event, which can weakened trees, ultimately making them more susceptible to attack by other insects and pathogens. This is of special concern to the many maple sugar/syrup producers throughout New England. Any event that damages and weakens sugar maple trees has direct economic implications for these individuals.

Remote sensing provides a useful perspective for studying the Earth's vegetation. Several investigations (Leckie & Ostaff 1988, Mukai et al. 1987, Nelson 1983) have successfully used remote sensing for mapping and measuring forest damage caused by other insects. The overall objective of this study was to determine the feasibility of using Landsat Thematic Mapper (TM) data to map, measure and monitor deciduous forest damage caused by the pear thrips during the spring of 1988.

## Materials and Methods

### Study Area

The region selected for study is located in southern Vermont and northwestern Massachusetts (Fig. 1). Counties included are Bennington and Windham Counties in Vermont, and portions of Berkshire and Franklin Counties in Massachusetts. The Green Mountain chain runs north and south through the center of this region, and thus there is much topographic relief in the study area. Deciduous forest dominates the region, with some agriculture in the lowland areas to the east and west of the mountains. Dominant forest species include sugar maple

(*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britt.).

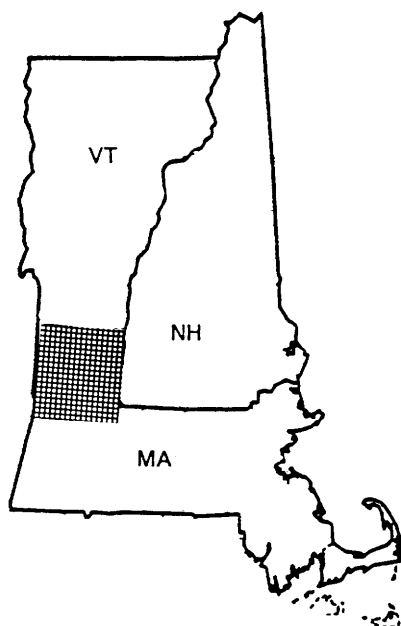


Figure 1. Map showing location of study area assessed for pear thrips damage using satellite imagery data.

Sugar maples of this area showed extensive foliar damage and defoliation due to pear thrips in the spring of 1988. During the infestation, extensive data were collected regarding the status of the sugar maple stands by personnel from the Vermont Department of Forests, Parks and Recreation. These data were used in this study as ground truth with which to compare the satellite data.

## Remote Sensing Data Acquisition

The Landsat Thematic Mapper (TM) acquires data from an altitude of 705 km, thus providing a synoptic view of the Earth not available with standard aerial photography. Data are gathered for an area of ground measuring 185 km on a side. The spectral coverage of TM extends from the visible out into the reflected infrared region (0.4-2.4 micrometers) of the electromagnetic spectrum, far beyond the spectral region covered by infrared-sensitive films (0.5-0.9 micrometers). Spatial resolution (or pixel size) of the TM is 30 meters on a side. For any one region, TM data are acquired every 16 days.

Two Landsat-5 TM quarter scenes covering the region described above were obtained from the Earth Observation Satellite Corporation (EOSAT). These were acquired on 10 June 1984, and 5 June 1988. The 1984 data set represents a condition before pear thrips were a major problem in the area, whereas the 1988 data set was acquired during a major thrips-induced defoliation event, and prior to refoliation.

## Data Processing

Thematic Mapper data were computer-processed using an Erdas image processing system with a Prime 4050 computer. Thematic Mapper bands used in the study included bands 3 (0.63-0.69 micrometers), 4 (0.76-0.90 micrometers) and 5 (1.55-1.75 micrometers). Using a series of ground control points, the 1988 data set was coregistered to the 1984 data set such that the two could be geometrically overlaid.

Two types of images were produced. The first was a false color composite using a ratio of TM bands 5/4 in the red plane, and bands 5 and 3 in the green and blue planes, respectively. This image, termed hereafter a "damage assessment image," has been found to be effective in measuring and mapping forest damage in high elevation spruce-fir forests (Vogelmann & Rock 1986, 1988; Rock et al. 1986, 1987).



The second type of image produced was a change detection image, providing information on locations and amounts of change that had occurred between 1984 and 1988. This image was produced using a TM band 4 difference data set (which indicates where the forest changes occurred) in the red plane, and 1988 TM bands 5 and 3 in the green and blue planes, respectively. Imagery was processed to indicate locations of areas where TM band 4 reflectance was lower in 1988 than in 1984. Decreases in TM band 4 reflectance imply lower levels of green leaf biomass in forested areas, and it is inferred that areas showing lower band 4 reflectance were less healthy in 1988 as compared to 1984. (See Vogelmann & Rock (1989) for more details regarding this procedure.)

Mean 1984-1988 TM band 4 difference digital number (DN) values and mean 1988 TM band 5/4 ratio values were extracted from the imagery for a series of defoliated and non-defoliated sites. The digital values obtained from defoliated versus non-defoliated sites were then used as guides for producing images.

Differences between high versus low levels of defoliation for the TM band 4 difference data set were used to estimate amounts of the area impacted by pear thrips within the region covered by the data sets. (See Vogelmann & Rock (1989) for details regarding this procedure.)

## **Ground Data**

During late May and early June 1988, personnel from the Vermont Department of Forests, Parks and Recreation obtained extensive information regarding the condition of sugar maple stands during the 1988 thrips infestation in Windham and Bennington Counties (Vermont). This included sketch maps (from aerial damage surveys), showing location of zones of defoliation, and aerial color photographs (with locations marked on topographic maps) of defoliated and non-defoliated areas for specific sites, both made from light aircraft. Many sites were ground checked to verify that the damage and defoliation seen from the air was caused by pear thrips. Both sketch maps and

photographs were provided for the purposes of comparison with the remote sensing data. Additionally, Vermont State personnel most familiar with the individual stand conditions of sugar maples in the region were consulted on several occasions regarding the accuracy of the imagery in depicting locations and levels of thrips damage. Input was provided such that imagery could be "fine-tuned" to more accurately represent actual maple stand conditions. Sketch maps showing location of thrips damage in northwestern Massachusetts provided by Massachusetts Department of Environmental Management personnel (C. M. Burnham) were also used in the study as a form of ground truth.

## Results

Mean TM band 5/4 ratios extracted from a series of defoliated and non-defoliated deciduous sites (Table I) indicated that high ratios characterized heavily defoliated areas whereas low ratios characterized non-defoliated areas. Mean digital differences between 1984 and 1988 for TM band 4 from these same sites (Table 1) indicated that small digital number (DN) value decreases, or increases in DN values between 1984 and 1988, characterized non-defoliated areas, whereas large DN value decreases characterized the defoliated sites.

True color aerial photographs taken in early June 1988 were compared with damage assessment images produced from the 1988 TM data. Regions that were characterized by severe defoliation in the photographs were orange in the damage assessment imagery, whereas the regions in the photographs that were non-defoliated were green in the imagery.

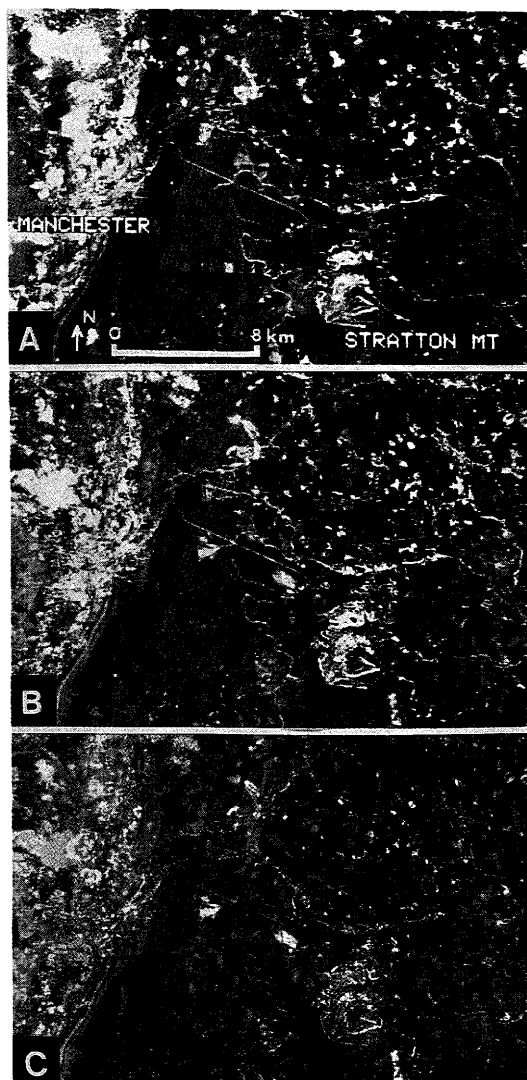
Table 1. Mean 1988 TM 5/4 band ratio values and mean TM band 4 differences between 1984 and 1988 from nine non-defoliated and ten defoliated sites in southern Vermont. Values are  $\pm 1$  standard deviation

Site	No. Pixels Used	Mean 1988 TM 5/4 Ratio Values	Mean 1984 - 1988 TM Band 4 Difference Values
Non-defoliated Canopy			
1	140	$0.676 \pm 0.025$	$-0.7 \pm 12.8$
2	34	$0.680 \pm 0.028$	$-2.6 \pm 9.4$
3	348	$0.702 \pm 0.021$	$-1.4 \pm 9.9$
4	120	$0.662 \pm 0.022$	$+13.2 \pm 5.0$
5	25	$0.724 \pm 0.035$	$-6.1 \pm 5.8$
6	9	$0.759 \pm 0.085$	$-12.0 \pm 4.5$
7	16	$0.674 \pm 0.024$	$-0.8 \pm 3.6$
8	21	$0.714 \pm 0.040$	$+0.9 \pm 5.6$
9	15	$0.703 \pm 0.050$	$+17.1 \pm 6.2$
10	21	$0.765 \pm 0.035$	$+0.4 \pm 5.5$
Defoliated Canopy			
11	12	$0.938 \pm 0.090$	$-46.3 \pm 2.9$
12	126	$0.760 \pm 0.044$	$-18.0 \pm 7.8$
13	39	$0.858 \pm 0.079$	$-29.6 \pm 6.6$
14	31	$0.893 \pm 0.058$	$-37.6 \pm 7.2$
15	19	$0.975 \pm 0.118$	$-44.7 \pm 7.5$
16	9	$0.998 \pm 0.066$	$-48.9 \pm 6.3$
17	21	$1.317 \pm 0.134$	$-42.5 \pm 7.5$
18	9	$1.279 \pm 0.134$	$-43.2 \pm 9.0$
19	14	$0.858 \pm 0.048$	$-39.2 \pm 7.3$
20	21	$0.926 \pm 0.089$	$-58.4 \pm 10.8$

Figure 2. (A) Damage assessment image of a portion of the TM scene acquired on 10 June 1984 from southern Vermont before pear thrips was a major problem in the area. Red or orange indicates areas of forest damage. The red that occurs at Stratton Mountain likely represents damage in the high elevation spruce-fir forest. Few areas of deciduous forest show high levels of damage.

(B) Damage assessment image acquired on 5 June 1988 for the same region as covered in Figure 2A. Red or orange indicates forest damage. Many orange areas are present in this image that are not present in the 1984 image. Most of these are inferred to be related to pear thrips damage.

(C) Change detection (difference) image for the same area covered in Figure 2A and B. Orange areas indicate where TM band 4 reflectance decreased markedly between 1984 and 1988. Although a few orange areas are artifacts related to clouds (upper left corner), most are believed to be related to pear thrips damage.



A damage assessment image (Fig. 2A) using the 1984 data set shows a portion of southern Vermont prior to major thrips infestation. In this image, green to blue-green areas represent healthy deciduous forest, orange indicates deciduous forest damage, dark areas are healthy conifers, as well as water or shadows, pink represents agricultural land or other human use areas, and red indicates locations of damaged conifers.

Few deciduous areas appear damaged in the 1984 damage assessment image (Fig. 2A), and most of these are associated with logging operations or other human-use activities. It is noteworthy that a significant portion of the high elevation spruce-fir forests at Stratton Mountain is red. In previous work (Vogelmann & Rock 1986, 1988; Rock et al. 1986, 1987) red in damage assessment images of high-elevation conifer forests has been shown to be related to high levels of conifer damage (e.g., fir wave damage, forest decline damage).

A damage assessment image (Fig. 2B) using the 1988 data set shows the same portion of southern Vermont seen in Figure 2A. In this image, many orange areas are present that are not present in the 1984 image. Based on ground surveys and consultation with Vermont Department of Forests, Parks and Recreation personnel, it is felt that these orange areas accurately depict the location of extensive damage in sugar maple caused by pear thrips. Most of the damaged deciduous areas are located to the east and west of the Green Mountains, which run north and south through the image on the left-center portion of the image. The few deciduous areas within the Green Mountains that have high levels of damage are known to be attributable to logging. High-elevation conifer damage on Stratton Mountain appears similar to that seen in the 1984 damage assessment image.

A change detection image using the 1984-1988 TM band 4 difference data set in the red plane, the TM 1988 band 5 data set in the green plane, and the 1988 band 3 data set in the blue plane is shown in Figure 2C. On this image, orange indicates where TM band 4 reflectance decreased markedly between 1988 and 1984 data sets. Most of the decreases in TM band 4 reflectance values (DN values) are

located in the deciduous forest, and most of these decreases are interpreted to represent thrips-induced loss of foliage that occurred in 1988. The pattern of inferred forest damage seen in this image is very similar to that seen in the damage assessment image (Fig. 2B), with most of the damage located in regions to the east and west of, but not within, the Green Mountains. The high elevation conifers on Stratton Mountain did not show decreases in TM band 4 reflectance between 1984 and 1988 (and is not shown in orange or red in Figure 2C). This region showed high levels of inferred forest damage in both 1984 and 1988 damage assessment images (Fig. 2A and B), but did not undergo decline that was detectable using TM band 4 between the two data sets.

Damage assessment and change detection images using the same procedures as for Figure 2B and C were produced for an area in northwestern Massachusetts. These images had more orange and red areas than did the images from southern Vermont, which implies that forest damage caused by the pear thrips was more severe in northwestern Massachusetts than in southern Vermont.

Remote sensing damage assessment images and change detection images were visually compared with sketch mapping data. There was general agreement between imagery and sketch maps, although it should be noted that there were some discrepancies. In addition, it was recognized that one series of sketch maps differed markedly in amounts of damage mapped from another series of sketch maps from an adjacent region. These two series were done by different individuals, and differences were attributed to differing individual interpretations of forest damage.

A total of 296,895 hectares (733,617 acres) of cloud-free deciduous forest were common to both 1984 and 1988 data sets. Approximately 202,000 deciduous hectares (0.5 million acres) were located in southern Vermont, and 101,000 deciduous hectares (0.25 million acres) were in northwestern Massachusetts (Table 2). In Vermont, approximately 10 and 25% of the deciduous area was classified as high and medium damage, respectively. In Massachusetts,

approximately 18 and 31% of the deciduous area was classified as high and medium damage, respectively.

Table 2. Estimate of hectares in study area affected by pear thrips in 1988 as inferred from 1984-1988 TM band 4 difference data

Damage Level	Vermont		Massachusetts	
	Hectares	Percent	Hectares	Percent
None or Low	131,092	65.0	48,522	50.8
Medium	49,705	24.7	29,438	30.9
High	20,685	10.3	17,452	18.3
<b>Total Hectares</b>	<b>201,482</b>		<b>95,412</b>	

### Discussion

Our results show that Landsat Thematic Mapper data may be used to accurately map and measure deciduous forest damage caused by pear thrips infestations. Imagery employing a ratio of TM bands 5/4 indicates the state of deciduous forest defoliation; areas of high damage caused by pear thrips are characterized by high ratios, and low or no damage areas are characterized by low ratios. In other studies employing Landsat and aircraft TM data (Vogelmann & Rock 1986, 1988; Rock et al. 1986, 1987) it has been found that high-elevation high-damage conifer sites are also characterized by high TM band 5/4 ratio values, and that conifer forest damage can be measured and mapped accurately using this ratio. Thus, the TM band 5/4 ratio appears to be a generic index effective in measuring forest damage in both deciduous and coniferous forests in the eastern United States. It is expected that the ratio will also work well for mapping and monitoring deciduous forest damage caused by other insects, such as gypsy moth defoliation.



Using change detection images employing a 1984-1988 TM band 4 difference data set, it was found that regions that had high levels of thrips damage in 1988 also showed large decreases in TM band 4 reflectance between 1984 and 1988. Regions with low levels of thrips damage showed little change between the two dates. Major TM band 4 reflectance decreases occurred throughout much of the deciduous forest in the low to medium elevation areas to the east and west of the Green Mountains, with slight to no changes noted throughout the deciduous forests within the Green Mountains. A decrease in reflectance for deciduous forests implies a decrease in leaf area index (Wiegand et al. 1979), which is related to a loss of green leaf biomass. In this study, it is inferred that the decrease in TM band 4 reflectance between 1984 and 1988 that occurred throughout much of the region is related to defoliation and loss of green leaf biomass caused by the pear thrips infestation during the spring of 1988.

The locations of the 1984-1988 decreases in TM band 4 reflectance correlate with those areas characterized by high 1988 TM band 5/4 ratio values. This implies that regions with high levels of damage, as measured by the TM band 5/4 ratio, are also the regions that have undergone high levels of reflectance change (decreases in reflectance for TM band 4) between 1984 and 1988. Whereas the ratio is good for measuring forest condition at any one particular time, the difference image provides information regarding the changes in condition that the forests are undergoing, thus allowing for monitoring of forests on a regional scale.

Our results show that Thematic Mapper data can be used to effectively monitor deciduous forest damage by pear thrips. By comparing data from the past and future, the TM will enable study of the expansion of thrips throughout the northeastern United States, allowing for calculation of rates of thrips population migration. The TM will also enable evaluation of the health status of sugar maple communities (recovery or further defoliation, depending on thrips activity in the future) on a regional scale. Currently, the only other way in which aerial extent and level of defoliation data are routinely obtained is by aerial sketch mapping. In the current study, there was a general

agreement between sketch maps of defoliation damage and remote sensing imagery. However, it should be noted that there were a number of discrepancies between the imagery and the sketch maps. In this study, we feel that remote sensing provided for more precise location of damaged areas as well as a more objective means of comparing among adjacent regions, thus providing a better regional perspective on thrips damage than sketch mapping. However, the one major disadvantage of using the TM is that it obtains data for a given area only once every 16 days. Following a thrips infestation, there may be only one or two times during which TM data are acquired when trees are still defoliated. Study sites may be cloud-covered during these critical times of data acquisition, resulting in limited or no usable TM data for a given year. Thus, one advantage to sketch mapping is that data can be obtained on a day by day basis whenever the weather is appropriate. It may be preferable to use both sketch mapping and remote sensing when evaluating forest damage caused by pear thrips.

### **Acknowledgment**

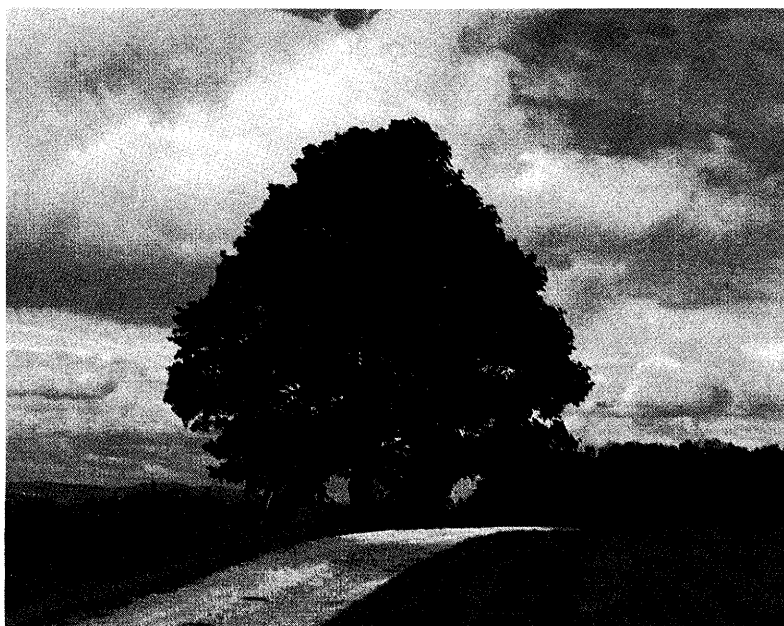
The work described in this paper was possible because of a grant from the State of Vermont and USDA Forest Service Forest Pest Management Program, and a grant from the EOSAT Corporation for the TM quarter scenes used. We wish to acknowledge the contributions of the following people: Governor Madeleine Kunin, Imants Millers, H. Brenton Teillon, Barbara Burns, James White, Sandra H. Wilmot, Ronald Kelley, Allan Sands, Charles Burnham, David Skole, Walter Chomentowski and Ted Sickley.

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## **INTEGRATED PEST MANAGEMENT**



Sugar Maple, *Acer saccharum* Marsh.  
(photo by D. Lockhart)

## INTEGRATED PEST MANAGEMENT AND THE PEAR THRIPS

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Although it is a pleasure to be here, our primary reason for being here is far from pleasant. During the last ten years, we have had serious problems with the gypsy moth, western spruce budworm, southern pine beetle, mountain pine beetle, fusiform rust and root diseases and the worst spruce budworm epidemic ever recorded. Just when these outbreaks have largely subsided, a new pest rears its ugly head in our Nation's forests.

These outbreaks, coupled with publicity about acid rain, air pollution, and global warming have influenced many Americans to perceive that there has been a rather dramatic decline in the health of our Nation's forests.

Has there been a precipitous decline in the health of our forests? Are our forests unhealthy? Recently, a task force within the Forest Service looked at the rate of tree mortality on commercial forest land as one indicator of forest health. Here in the North, growing stock mortality as a percentage of growing stock inventory in northern softwood and hardwood forests has remained stable except for a slight increase during the years 1952 to 1976 (due primarily to the spruce budworm outbreak), returning to approximately the 1952 rates after 1976. Nationally, modest decreases in softwood and hardwood growing stock mortality as a percentage of growing stock inventory have actually occurred between 1952 and 1987. The data show that, in general, mortality is increasing, but that annual growth is increasing even faster.

These figures do not indicate that a nationwide forest health crisis is at hand. However, serious local and regional problems exist. For example, in the South, softwood growing stock mortality as a percentage of growing stock inventory jumped significantly after 1976, primarily as a result of southern pine beetle outbreaks that occurred during the period.

In addition to some serious local and regional pest problems, we know that our forest land base is shrinking. In 1977, forests covered over 31 percent of the 1 billion hectares (2.4 billion acres) of land and water area in the United States. By the year 2030, the amount of land classified as forest is expected to decrease by about 9.7 million hectares (24 million acres) as other land uses take precedence. Most losses of forest land are expected to occur on the more productive sites at lower elevations where accessible land will be acquired for agricultural, industrial and urban development. The remaining forests will have to supply a greater proportion of goods and services.

To protect our forests from pests, we must use all the tools we have available. Managers must move from reactive to proactive strategies. This will mean greater emphasis on prevention and less dependency on suppression to reduce the impact of forest pests.

Integrated pest management, or IPM, is the best tool that we, as land managers, have available to assist in managing the forest. Integrated pest management is a much used and poorly understood concept in forest protection. IPM is defined in a Forest Service Handbook as: "a decision-making and action process incorporating biological, economic and environmental evaluation of pest-host systems to manage pest populations." There are other definitions of IPM and each of you probably has your own working definition. Nevertheless, certain components seem to be common to most definitions of IPM.

In forestry, IPM is a strategy for long-term management of forest pest-host interactions. Situations potentially capable of causing pest problems are anticipated and avoided or changed before outbreaks occur. IPM includes intensive surveys that provide early pest detection



and delineation information. IPM includes introduction, augmentation and/or conservation of predators, parasites or pathogens that help keep pest populations at low levels. And IPM includes intervention with appropriate techniques to prevent or disrupt damage-causing behavior or successful pest reproduction. IPM also considers the condition of trees and forests, their tolerance to pest effects, and their resilience in being able to recover from pest outbreaks.

Unfortunately, IPM is often erroneously promoted as an alternative to chemical insecticides. All too frequently, interest in IPM occurs only after pest populations have reached damaging levels. As land managers we understandably look for quick, efficient and cost-effective solutions. We may consider a series of options among which is an IPM approach that includes the use of a pesticide to control outbreak populations. The IPM option is selected, pesticide is applied and the pest outbreak subsides. But other components of the IPM option are often abandoned. Long-term benefits are not achieved because of the failure to implement all components of the IPM option.

Silviculture is, in the long run, the most powerful component of IPM that we, as forest managers, have to mitigate the impact of forest pests and atmospheric pollution on the condition of the forest. Silvicultural practices, such as site preparation, planting, prescribed fire, thinning, control of competing vegetation, and various harvesting practices, including regeneration cutting, commercial thinning and salvage, can have highly beneficial effects on forest vegetation, if applied properly and in a timely fashion. Other practices, such as the use of genetically-improved seedlings, also offer opportunities to grow forests that are more resistant to insects, diseases and pollution.

In my mind, truly integrated pest management must be accomplished through forest management prescriptions which accomplish the long-term goal of minimizing pest impacts. This means including the technical pest management information needed in the resource management decision-making process. And this technical

information must be in a form that is compatible with and meets the needs of the planning and decision-making process and is ecologically sound.

Many of the people in this room have worked together in the past. The Vermont Hardwood Tree Health Survey, the North American Sugar Maple Decline Project and the Vermont IPM Spruce Budworm Demonstration Project are just a few examples of successful cooperative efforts that we have undertaken together.

I feel confident that this conference will be a great help in developing an integrated pest management system for pear thrips that will meet short-term needs for protection as well as long-term goals for prevention. It is this kind of team approach that will most effectively address the problems posed by a new pest like the pear thrips.

## HERBIVORY BY *Thrips tabaci*

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Herbivory by *Thrips tabaci* (Lindeman) affects both the bulb yield and phytohormone balance in its major host plant, the onion (*Allium cepa* L.). Seasonal changes in the susceptibility of onion yield to *T. tabaci* feeding were examined during the three growth stages of onion; prebulbing, bulbing and sizing (Kendall & Capinera 1987). The prebulbing stage is characterized by rapid leaf initiation. Increased bulb size and decreased leaf initiation occurs during bulbing. Further bulb growth and collapse of the leaf bundle characterizes the sizing stage.

Thrips feeding also stimulates increased production of the phytohormone ethylene which affects the physiology of the plant. Ethylene is responsible for a wide variety of effects including fruit ripening and leaf senescence (Abeles 1973). On the biochemical level, ethylene is a secondary messenger responsible for the production of defensive compounds in plants (Yang & Pratt 1978). Our objective was to distinguish mechanical induction of ethylene evolution from enhanced production associated with thrips feeding (Kendall & Bjostad 1989).

### Materials and Methods

#### Susceptibility of Onion Growth Stages

Two field studies (1982 and 1983) and one greenhouse study (1984) were conducted. In order to assess seasonal changes in the susceptibility of the onion to herbivory, thrips populations were allowed

to build up to specific densities only within each growth period. Onions were sprayed with diazinon during the remaining growth stages. Weekly estimation of thrips densities per plot was determined by visual examination. Yield measurements were conducted 30-60 days after harvest. Bulb weights (50 onions per plot) were measured to the nearest 0.1 g on an electronic balance (Fisher 250). BMDP was used to analyze the regression analyses. For further detail see Kendall & Capinera (1987).

### **Ethylene Production**

**One-time mechanical damage (Experiment 1).** Glass tubes (23 ml) fitted with rubber septa were placed over onion plants, and weather-stripping putty (Mortite) was secured to the bottoms to prevent contact with the soil. The onions were treated in one of two ways: twenty second-instar thrips larvae were introduced or twenty 2 mm incisions were made with a sterile 00 insect pin. Control plants were left undamaged and empty control tubes were included to check for the presence of ethylene in the collection system. Tubes were stoppered with rubber septa and allowed to incubate for 48 hours. Sample size consisted of four plants per treatment. After 24 and 48 hours, ethylene analysis was performed, yielding eight ethylene readings each for uninfested, infested, and mechanically damaged tissues. After the 48-hour reading, plants were weighed to the nearest hundredth of a milligram. After 24 hours a 1-ml gas sample was withdrawn from the headspace of each vial using a pressure-lok syringe, and analyzed for ethylene. A model 5890 Hewlett-Packard gas chromatograph equipped with a flame-ionization detector, and a Hewlett-Packard model 3390A integrator recorder were used in the analysis.

**Semi-continuous mechanical damage (Experiment 2).** To more closely approximate the continuous feeding damage exhibited by thrips, intact plants were wounded every 12 hours with a sterile 00 insect pin attached to a wire entering the septum. In this manner, damage could be inflicted without opening the tubes. A piece of wire was also inserted into the septa of the remaining tubes. Experimental design was identical to the previous experiment. Sample size consisted of four

plants per treatment. Readings were taken after 14, 16, 19, 36, 39, 42, 60, 72, 84, and 94 hour incubation times. After 96 hours, the plants were dried and weighed to the nearest hundredth of a milligram. The wounds were measured to the nearest hundredth of a millimeter.

**Thrips extract (Experiment 3).** Thrips were placed in a sterile saline solution and macerated into a thick paste. An extract of ten thrips was placed in each of ten 5 mm wounds made with a sterile 00 insect pin. Mechanically damaged plants were treated in an identical manner to those with the thrips extract, except only sterile saline solution was placed in the wounds. A third of the plants remained unwounded. Sample size consisted of four plants per treatment. Readings were taken every 12 hours for 96 hours. After 96 hours, the plants were dried and weighed and the wounds were measured as described previously.

### **Statistical Analyses**

All data were analyzed by one-way analysis of variance using BMDP. For further detail see Kendall & Bjostad (1989).

## **Results**

### **Susceptibility of Onion Growth Stages**

A significant relationship between thrips numbers and yield was not found during the pre-bulbing or sizing stages. During the bulbing stage, a significant negative relationship between thrips numbers and bulb size was observed (Fig. 1). Similar results were obtained for the 1983 field season and the 1984 greenhouse study (Kendall & Capinera 1987).

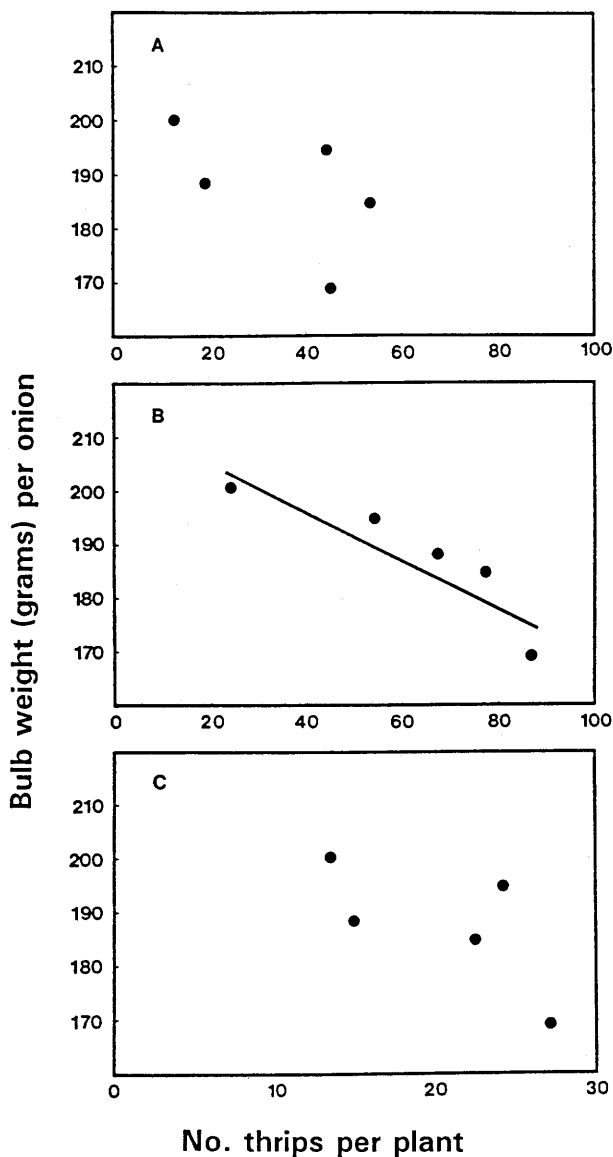


Figure 1. Effect of thrips herbivory on bulb size in 1982: (A) prebulbing ( $P > 0.05$ ), (B) bulbing,  $r^2=0.81$  ( $P < 0.05$ ), (C) sizing ( $P > 0.05$ ) (Kendall & Capinera 1987).

## Ethylene Production

In the first experiment, thrips-infested tissue produced significantly greater ethylene compared to uninfested plants and to foliage that was mechanically damaged at the beginning of the experiment (Table 1). Ethylene evolution from mechanically damaged and unwounded plants was not significantly different ( $P < 0.05$ ) (Table 1). In Experiment 2 significant differences existed between thrips-infested and semi-continuous mechanically-wounded plants and to unwounded foliage from 19 to 96 hours incubation time (Fig. 2).

Table 1. Ethylene production from infested, uninfested and mechanically wounded intact onion plants

Incubation  Hours	Ethylene production (pmole/g)*		
	Infested	Mechanically wounded	Unwounded
24	14.87 $\pm$ 3.33a	4.59 $\pm$ 0.96b	4.50 $\pm$ 0.69b
48	21.27 $\pm$ 5.10a	5.23 $\pm$ 1.00b	3.64 $\pm$ 1.23b

\* Mean and standard errors.

Means followed by the same letter in one row are not significantly different (Duncan's Multiple Range Test,  $P \leq 0.05$ ).

Mechanically-wounded and unwounded plants did not produce significantly different levels of ethylene (Fig. 2). The third experiment produced similar results. Plants inoculated with thrips extract produced significantly greater levels of ethylene than mechanically-wounded and unwounded foliage from 60 to 96 hours incubation time (Fig. 3). Ethylene evolution from mechanically damaged and unwounded plants was not significantly different ( $P < 0.05$ ) (Fig. 3).

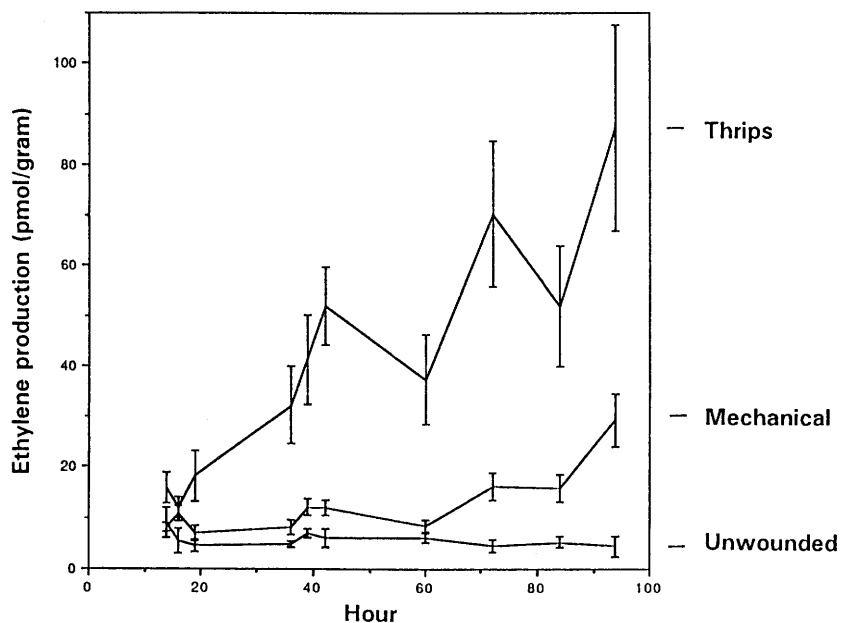


Figure 2. Ethylene production from thrips infested, semi-continuously mechanically-wounded, and unwounded intact onion plants. Vertical lines depict standard errors for the mean (Kendall & Bjostad 1989).



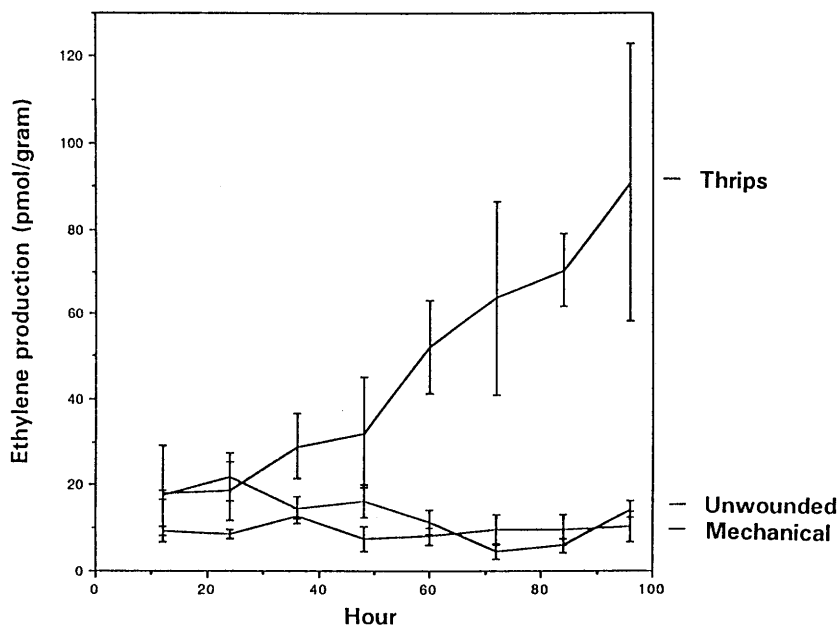


Figure 3. Ethylene production from plants inoculated with thrips extract, mechanically-wounded plants, and unwounded foliage. Vertical lines depict standard errors for the mean (Kendall & Bjostad 1989).

## Discussion

### Susceptibility of Onion Growth Stages

Growth stages of the onion exhibit differential responses to feeding by *T. tabaci*. The prebulbing and sizing stages are relatively insensitive to herbivory, but the bulbing stage is highly susceptible. During bulbing, nutrients from the foliage are shunted into the bulb which acts as a resource sink. If nutrients are removed from the foliage at this time, bulb weight will be reduced (Kendall & Capinera 1987). Management practices should concentrate on protection of this highly susceptible growth stage. The growth stages of many plant species exhibit similar responses to herbivore pressure (Bardner & Fletcher 1974). The maple may also exhibit seasonal changes in susceptibility to pear thrips.

### Ethylene Production

Thrips feeding induced significantly greater ethylene evolution that would be expected from mechanical damage alone, presumably because thrips introduce cues during feeding that induce ethylene production by the plant. Because mechanical damage is directly proportional to ethylene production, measurement of ethylene evolution from maple trees may represent a novel, relatively simple and inexpensive technique to quantitatively assess defoliation injury in maples.

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## **AERIAL SPRAY TECHNOLOGY: POSSIBILITIES AND LIMITATIONS FOR CONTROL OF PEAR THRIPS**

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### **Abstract**

The feasibility of using aerial application as a means of managing a pear thrips infestation in maple forest stands is examined, based on existing knowledge of forest aerial application acquired from theoretical and empirical studies. Specific strategies by which aerial application should be performed and potential problem areas are discussed. Two new tools, aircraft characterization equipment and an aerial spray program mission planning computer software package are briefly described as examples of technology transfer which have been used to improve aerial applications in forests.

### **Introduction**

This paper examines the feasibility of using aerial application as a means of dealing with the infestation of pear thrips in maple forest stands. It approaches the problem from theoretical and empirical standpoints based on knowledge that has been acquired on aerial application and suggests specific ways in which aerial application should be performed. No presumption is made that this is necessarily the correct approach, nor that it should be done in isolation, without integrated pest management considerations. Aerial application spray trials of specific insecticides for pear thrips management have been performed by others, and will be reported during this conference (H. B. Teillon & B. L. Parker, this publication).

To use an insecticide effectively for controlling a pest, the following facts should be known: (1) the distribution and behavior of the susceptible stage of the pest in space and time, (2) the approximate lethal dose required, (3) an efficient way of ensuring that an adequate number of toxic doses are deposited on the biological target with minimum contamination of non-target biomass.

Little is known about the behavior of pear thrips, *Taeniothrips inconsequens* (Uzel). However it would appear that the most vulnerable stage of the insect is the adult female, which emerges from the ground at the time of bud break, and flies to the bud. The timing of an application of pesticide would need to be exact to assure that the presence of a lethal concentration of insecticide coincides with the entry of the adult into the bud. Control of later larval stages that feed on newly expanded leaves would give a longer time frame. Once the biological target has been defined, in terms of its location, growth stage and timing, it is necessary to examine ways by which the insecticide can be applied with minimum drift outside the area of treatment. It is the definition of the methods that are used to optimize this process which are the subject of this paper.

### Objectives

- To examine and define possibilities and limitations of aerial application for controlling pear thrips.
- To approach the above question by extrapolating from existing knowledge of aerial application in broad-leaved and coniferous forests, and from theoretical considerations.
- To review available tools that provide aerial application projects with aircraft spray pattern assessment and computer planning and operation costs.

## Insecticide Application Considerations

**Target definition.** When the adult pear thrips emerges from the ground, she is thought to fly to the tree buds directly, probably settling on several twig sites before reaching her final destination. The insect then squeezes her way into the bud, where feeding takes place. It is thought that the female exhibits considerable exploratory behavior, moving around the bud before she commences her entry. The most likely ideal target therefore would be the bud and adjacent twig. The bud would have to be sprayed before the adult female enters it; the adult would have effective protection from the insecticide after entering the bud, unless a systemic pesticide was used. To enable reasonable planning for a spray project and unexpected changes in weather, the areas would have to be sprayed up to a week before the known likely emergence date. Therefore an insecticide with some degree of residual action would have to be used.

**Toxic dose.** Carbaryl (Sevin) is one of the few insecticides approved for spraying in maple forests. The  $LC_{95}$  of carbaryl is not known for pear thrips, but for the purpose of this paper has been conservatively assumed to be between 10 and 100 ppm. This figure can be used to calculate the number of  $LD_{95}$  doses in a range of droplet sizes typically produced by commercial spray equipment. These estimated numbers of toxic doses can then be used in guidance of the selection of spray parameters, namely the application rate and droplet size to be used in the control.

**Delivery of pesticide.** The accurate delivery of pesticide to broad leaves or pine needles in forest stands is one of the most challenging problems facing the forest pest manager. The factors limiting such accurate application have been summarized (Ekblad & Barry 1983).

Although a few studies of foliage deposition have been made on broad-leaved forests (Yendol et al. 1990), and a larger number on pine forests, no comprehensive studies exist on aerial application projects made on broad-leaved trees before leaf expansion. Orchard spraying is commonly done on leafless trees, but the technique used involves very

high application rates on short trees with ground sprayers, and bears little relevance to the situation being considered here.

It is therefore necessary to systematically examine the process of capture of droplets by targets the size of maple tree buds in order to get an indication of how to approach the aerial application problem.

**Droplet size considerations.** When sprays are aerially applied 15 m (50 ft) above a forest canopy, two kinds of off-target deposition may occur. Large droplets may fall through the canopy, at angles close to the vertical and impact on the forest floor or small droplets may drift away from the immediate target site, at angles close to horizontal without impacting on the buds and twigs. In the former situation unwanted contamination of the forest floor and understory foliage can take place, whereas with the latter situation, the contamination of an area outside the spray site may result.

Work on Douglas fir and other coniferous foliage in the control of spruce budworm, *Choristoneura occidentalis* (Freeman), established that pine needles most efficiently catch droplets below 50  $\mu\text{m}$ , even at low wind speeds (Himel & Moore 1967, Barry et al. 1977). The mean diameter of such a pine needle is around 1.6 mm. Because maple buds and twigs are larger than pine needles (4-5 mm in diameter), the pine tree studies can only be used as broad indicators of application strategy.

Droplets are collected on plant surfaces by sedimentation and impaction. Smaller droplets (less than 100  $\mu\text{m}$ ), because of their near horizontal path in winds greater than 2.5 m/sec (5 mph), are always caught by impaction. Studies on impaction of droplets have shown a complex interaction between the size of the droplet, its relative velocity and the obstacle in its path (May & Clifford 1967). Briefly, the collection efficiency of a target (the percentage of drops caught by a target expressed as a proportion of droplets which could be caught) placed in an airstream increases with droplet size and velocity, and decreases as the target increases with size.

These factors can be brought together in one parameter, the impaction parameter ( $P$ ). This parameter is a measure of the likelihood of a droplet striking a target assuming it is being transported towards the target with a windspeed  $V_o$ .

$$P = \frac{V_s V_o}{gD}$$

$V_o$  = Windspeed  
 $g$  = Acceleration due to gravity  
 $D$  = Diameter of target  
 $V_s$  = Sedimentation velocity of droplet of diameter  $D$

Empirical work has been done to measure catch efficiency ( $E$ ) for various values of the impaction parameter ( $P$ ) for various shapes of targets by May & Clifford (1967). This work has been recently added to by Spillman & Tongpuy (1987) to take into account variations in turbulence around a target as target size increases. What this means is that if the target dimension and wind speed are known, it is possible to determine what size range of droplets would be able to be caught by the forest canopy.

Of course the airflow inside a canopy is never constant, and the above discussion can only be used as a guideline. Nevertheless, use of such aerodynamic calculations is a good starting point. Table 1 shows calculated droplet sizes which give a high catch efficiency (70%) for different cylinder (twig) diameters at three different wind speeds. It is apparent that even in light winds, small droplets can be caught by twigs. The theoretical data presented in the table would indicate that droplets of 80 - 100  $\mu\text{m}$  would be suitable.

But what about drift? An 80  $\mu\text{m}$  droplet sediments at 16 cm/sec. During the time it takes a droplet to fall from the spray height (typically 15 meters (50 ft) above the canopy) to the top of the forest canopy, one might think it would not have drifted very far. In fact, this is often not the case under commonly occurring weather conditions.



Table 1. Droplet sizes corresponding to capture efficiencies of 70% on different sized cylinders for three different wind speeds

Cylinder diameter (mm)	Windspeed (m/sec)	Minimum drop size ( $\mu\text{m}$ )
2.5	1.0	51
2.5	2.5	10
2.5	5.0	7
5.0	1.0	96
5.0	2.5	45
5.0	5.0	10
10.0	1.0	148
10.0	2.5	85
10.0	5.0	56

Droplets sprayed over forests are dispersed by two main mechanisms, sedimentation and turbulent dispersal. Large droplets (greater than  $300\ \mu\text{m}$ ) have a high sedimentation velocity ( $V_s$ ), and can be deflected by the turbulent air found within forest canopies. Although moving rapidly, such air behavior would not markedly affect the position of the droplet in relation to its point of release. Smaller droplets have much lower sedimentation velocities, and can be entrained in any turbulent air created by the roughness of the canopy. In other words, the droplet goes where the wind blows. As wind speed increases, the turbulent velocity increases also, and the size of the droplet that is dispersed by the turbulent mechanism (instead of sedimentation) increases. For example, at wind speeds of 1 m/sec, a  $100\ \mu\text{m}$  droplet may behave like a large droplet in a forest canopy, essentially reaching the ground through sedimentation. The same droplet dispersed in a 5 m/sec wind however will behave as a small droplet, through entrainment in the turbulent eddies. Such droplet behavior has direct implications on determining which kind of weather conditions should be used for application.

**Toxicity of pesticide droplets.** The total number of droplets required to provide a high probability that each bud has several toxic doses which would either be ingested or transferred to the insect through physical contact can be broadly estimated. From the previous studies on crops and forests, it is apparent that it is not possible to get an even distribution of droplets on all targets. Instead the pesticide is distributed across a range of targets in a log normal manner, whereby some targets receive no dose or a minute dose, a large proportion receive a small dose, and increasingly smaller groups of targets receive still higher doses (Yendol et al. 1990, Uk & Courshee 1982).

Assuming that the pattern of distribution of droplets on buds and/or twigs is the same as that obtained by Yendol et al. (1990) on foliage, to ensure that 90% of the buds get at least a certain threshold dose, the mean dose rate has to be about five times the threshold value, assuming that the overall catch efficiency of spray is 70%.

In our present example, taking the tree surface area index (the surface area of the trees growing on 1 ha as 1, and 1 liter of spray material evenly atomized into 90  $\mu\text{m}$  droplets ( $2.62 \times 10$  drops), this would mean that 90% of the tree area, including buds would get  $26.2/5 = 5.2$  drops/cm. Admittedly, there are many assumptions and approximations made in this calculation, but accurate models which could be used do not yet exist in forest spray technology. In practice, atomization would be imperfect, resulting in the under production of ideal sized droplets. Application rates would therefore have to be higher than 1 liter/ha to ensure adequate coverage. A further advantage in increasing the application rate and at the same time decreasing the active ingredient concentration would be improved coverage because of the production of greater numbers of droplets. Such lower concentration material would have the added advantage of being less harmful to non-target organisms.

**Droplet toxic dose considerations.** Because of the very low weight of a pear thrips adult, 25  $\mu\text{g}$  (Foster & Jones 1915), the amount of pesticide in a lethal dose would be very small. Assuming a LC in the range of 10 - 100 ppm, a 90  $\mu\text{m}$  droplet would have between 600 and

60 toxic doses. During the process of bud entry, as well as movement on the bud surface, a thrips would almost certainly receive a toxic dose through ingestion or contact with the pesticide deposit. It has been noted that pear thrips perform considerable exploratory movement on the bud surface before selecting a location for entry into the bud. Therefore, although much of the bud surface might not be covered with pesticide, the acquisition of a lethal dose would still be highly probable if there were some deposits on the bud. An additional increase of pesticide coverage would take place as carbaryl in an oil formulation (Sevin 4-Oil), which would produce a pronounced spread of the insecticide after impactation on a waxy bud surface. These observations must be confirmed experimentally in the laboratory and in field trials before planning a spray program.

The practice in fruit orchards of spraying very high volumes (up to 5000 liters/ha) against thrips ensures that the whole tree is covered with a very low dose of pesticide, and minimizes undosed areas of the bud. Clearly such a strategy is not possible with aerial application.

**Atomizer selection.** Atomizers used in aerial application fall into two broad categories; rotary, and boom and nozzle. Rotary atomizers enable the droplet size to be controlled independently of the flow rate and spray boom pressure. They therefore have a considerable advantage over conventional nozzle equipment in that adjustments to the droplet spectrum can be made very quickly from the aircraft cockpit during flight with electrically driven units. With such a system the droplet size can be adjusted as required by circumstances. For example, a larger droplet size would be used in a small plot surrounded by sensitive areas to limit potential drift out of the area. A conventional boom and nozzle system would not have this flexibility.

One of the two main types of rotary atomizers used in aerial application is the air-driven Micronair series. Although excellent atomizers for fixed wing work, they would not be suitable on helicopters making short runs; these units require a finite period of time

to get up to speed after a turn. Electrically driven Beecomist units, although not capable of handling large flow rates would be the atomizer of choice in helicopters.

**Weather considerations.** Wind can be used to increase the capture of droplets in the forest canopy. However spraying in a strong wind will result in an overall drift of the swath of spray in a down wind direction. Although, as stated before, under most conditions it will not result in a large long distance drift of off-target spray. Application under such conditions is difficult, however, and can be dangerous because of the turbulence experienced by the aircraft. It is therefore usual to place an upper limit on wind speed of around 5 m/sec (10 mph).

Clear nights during spring in the mountains of New England can produce a strong temperature inversion, where radiational cooling reduces the temperature of the ground and the air immediately in contact with it. Such conditions cause this layer of air to be very stable which tends to dampen down turbulence, whether caused by the wind or by the wake disturbance of an aircraft performing an application. This resistance to allowing mixing of air is potentially dangerous if small droplets (less than 70  $\mu\text{m}$ ) are sprayed. Because no turbulent dispersal and impaction occurs, and lateral dispersion is also dampened, such that slowly sedimenting droplets have the potential of drifting long distances out of the target area without much lateral dispersal before they reach the ground. This condition should be watched for, especially if the material to be applied has a potentially serious effect on non-target organisms.

**Spatial and temporal dimensions.** Given the likely behavior of the adult thrips entering the bud, the spray window open for an aerial application control program appears to be small, lasting over a period of several days. The implications of such a short window would be that the pesticide to be used for control must have a half life which would give it a residual effect 1 to 2 weeks after spraying. This would allow the spray campaign to be performed over a period of about 10 days.

The use of aqueous sprays applied at high volume rates, although still widely used in agricultural aviation, is becoming a rarity in forestry. The work output of spray aircraft is largely inversely proportional to the volume rate being applied. The application of low volume rates therefore enhances the productivity of the aircraft, resulting in the need for a small number of aircraft to perform the control operation. Selection of aircraft and measuring their potential productivity is covered below.

Sugar maple stands in the forests of Vermont are small, typically averaging 4 ha (10 ac) in size. As shown above, a small (80-100  $\mu\text{m}$ ) droplet will be the most effective at reaching the selected target (the tree buds). However it would be difficult to confine a spray with such a droplet spectrum within a narrow area. Larger droplets would limit the amount of off-target drift, but would also increase the contamination on the forest floor. Under such conditions a compromise between size and driftability must be made. It is difficult to say exactly how large the Volume Median Diameter (VMD) of the droplet spectrum would have to be; this is an area that should be investigated empirically with field trials. However, based on droplet sedimentation speeds and the excess number of toxic doses in large droplets, it seems unlikely that the droplet VMD should be larger than 150  $\mu\text{m}$ .

**Aircraft type.** A square area of 4 ha would have dimensions of 200 X 200 meters. A typical single engine agricultural spray aircraft flying at 160 km/h (100 mph) would cover this distance in 4 seconds. A helicopter would be able to fly slower, and more accurately control its application. In addition, at speeds of 80 km/h (50 mph) the helicopter's rotor wash would contribute to the droplet cloud's penetration of the forest canopy. Helicopters also have the advantage of being able to operate closer to the forest areas needing to be sprayed, and not requiring airstrips that may be located some distance away.

## Recent Technological Advances In Aerial Application

In recent years technological advances have become available to users involved in aerial application. Two are described here, aircraft characterization equipment and an aerial spray program mission planning computer software package.

**The Swath Kit.** One of the most difficult jobs in aerial pesticide application for agriculture or forestry is the characterization of aircraft. The Swath Kit was developed for the USDA Forest Service to make weather and deposit measurements on-site and to display results promptly. It allows the user to quickly pinpoint problem deposit patterns and enables quick adjustments to the spray system configuration to be made. The Forest Service recognized a need for such a tool, as existing equipment was not able to quantify spray deposit, nor provide data on droplet spectra.

Before being used operationally, an aircraft needs to be calibrated. However, the aircraft should not be flown until the shape of the deposit pattern beneath the aircraft has been inspected. This second characterization task is a much more difficult problem if more than a visual inspection of the deposit shape is to be made. It is at this stage that the Swath Kit is employed.

The Swath Kit consists of a portable DOS personal computer fitted with proprietary image analysis and weather sensor equipment which is used as a multipurpose data recorder and analyzer. Operationally it can be divided into three parts according to the three broad tasks which comprise the characterization of aircraft.

1) Weather and Information Recording: The weather is monitored during a spray application to ensure suitable conditions exist for the characterization test. The following parameters are measured: wind speed, wind direction, temperature and relative humidity. These are presented graphically on the computer screen to help the user make quick go/no-go judgments on the suitability of the weather.

2) Deposit measurement: After spraying a card-line, the Swath Kit is used in its image analysis mode to measure the deposit on the cards. Deposit is presented in terms of volume of spray per unit area, number of droplets per unit area and percentage of the surface area covered with spray. In addition, size parameters of the droplet spectrum received by each card are presented.

3) Pattern Assessment: Following card measurement, the Swath Kit is used to assess the pattern of the deposit obtained beneath the aircraft. This is done by modelling the swath and presenting visual and statistical data on overlapped swath patterns. Problems in the pattern, such as the presence of peaks or valleys, and assessment of the effective width of the pattern, can be studied at this stage.

**CASPR (Computer Assisted Spray Productivity Routine).** CASPR was developed and written by the USDA Forest Service Equipment Development Center to automate a method of comparing productivity and costs. This work has been published as a report entitled "A Method for Comparing Cost & Productivity of Aerial Spray Delivery" by Robert Banaugh, Report 84342807, November, 1984. The program is available from Robert Ekblad, at the USDA Forest Service Equipment Development Center, Missoula, Mont.

The computerized method enables "what-if" scenarios to be run for a series of known spray sites. Different aircraft operating from a variety of airports or airstrips can be modelled to maximize productivity and minimize cost. Large airplanes operating from distant airfields can be compared with smaller airplanes operating from nearby airstrips. The cost of using helicopters can be compared with the cost of using fixed wing aircraft. The program is easy to operate, and has context sensitive help available.

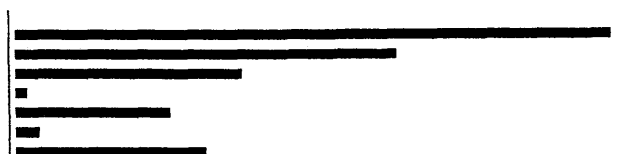
Examples of inputs and outputs are presented in Tables 1 and 2 and Figure 1 to demonstrate the rationale of the model. The modelling data are input into worksheets, dealing with application parameters and spray block dimensions, as well as additional ferrying information between spray blocks.

Table 1. Sample information provided by the Computer Assisted Spray Productivity Routine in the data worksheet

Factor	Data/unit
Application Rate	0.77 liters/acre
Tank Capacity	662 liters
Swath Width	22.5 meters
Spray Speed	185 km/h
Ferry Speed	209 km/h
Turning Time	35 seconds
Auxiliary Ferry Distance	7.2 kilometers
Number Auxiliary Turns	2
Touchup Constant	0.1
Spraying Cost Rate	275 \$/hour
Ferrying Cost Rate	275 \$/hour
Turning Cost Rate	275 \$/hour
Touchup Cost Rate	275 \$/hour
Loading Cost Rate	0 \$/hour
Loading Time/Cycle	7 minutes

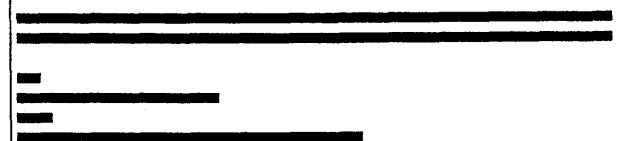
#### TIME NEEDED

Total  
Flying  
Loading  
Spraying  
Ferrying  
Touching up  
Turning



#### COST FACTOR

Total  
Flying  
Loading  
Spraying  
Ferrying  
Touching up  
Turning



PERCENT OF TOTAL

Figure 1. Sample graphic data output provided by the Computer Assisted Spray Productivity Routine from a 0.16 X 0.16 km (0.1<sup>2</sup> mile) block sprayed with a typical single engine fixed wing airplane.



Table 2. Tabular data provided by the Computer Assisted Spray Productivity Routine from a 0.1 X 0.1 mile block sprayed with a typical single engine fixed wing airplane

Factor	Data/unit
Total Spray Area	2.59 hectares
Material Flow Rate	68.81 liters/min
Spray Cycle Distance	17.70 kilometers
Number of Spray Cycles	1
Total Spray Distance	1.13 kilometers
Number of Spray Turns	8
Number of Ferry Turns	2
Number Auxiliary Turns	2
Total Number of Turns	12
Spraying Time	0.35 minutes
Ferrying Time	5.77 minutes
Turning Time	7.00 minutes
Touchup Time	0.74 minutes
Total Flying Time	13.86 minutes

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## BIOLOGY AND IMPACT OF *Thrips calcaratus* Uzel IN THE GREAT LAKES REGION

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### Introduction

Basswood (*Tilia americana* L.) stands in the Lake States have been experiencing defoliation since around 1979. These symptoms were originally attributed to frost damage because they occur in early spring. However, the pattern of damaged trees was atypical of frost injury. Only basswood trees were affected, and there was no relationship to sites known to be frost pockets. By 1980 it was recognized that a thrips was associated with defoliation. The pest was originally identified as the basswood thrips, *Neohydatothrips* (then *Sericothrips*) *tiliae* (Hood) (Thripidae), a native species. Because this insect has no history of causing damage, the judgement was to let natural forces suppress the population. Outbreaks continued to expand, however, casting doubt on the role of a heretofore innocuous species as the causal agent. Further examination led to the identification of an introduced species, *Thrips calcaratus* Uzel (Thripidae) as the primary pest (Raffa & Hall 1988). This species was first recorded in North America in New York in 1925 (Hood 1927), and is now distributed throughout the Middle Atlantic States, Ontario, and Quebec, in addition to the Lake States.

The outbreak originated in northeastern Wisconsin, near the border with the upper peninsula of Michigan. The progression of infestation and the current outbreak area are shown in Figures 1 and 2. Defoliation shows no signs of abating. Currently, around 81,000 hectares (200,000 acres) are affected each year in Wisconsin (Table 1). There are about 40,470 hectares (100,000 acres) defoliated in Minnesota each year, and additional losses occur in Michigan (Wisconsin Department of Natural Resources 1980 - 1988, Minnesota Department of Natural Resources 1983 - 1987).

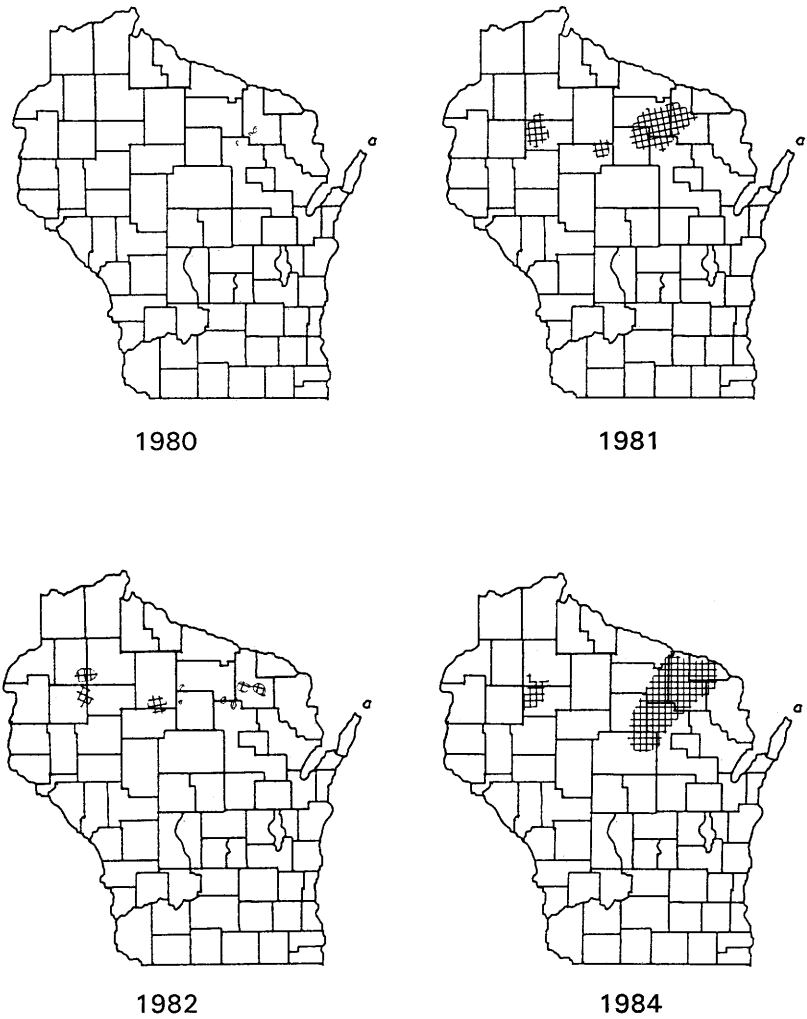


Figure 1. Areas (shaded) of moderate to severe defoliation by basswood thrips in Wisconsin from 1980 - 1984.

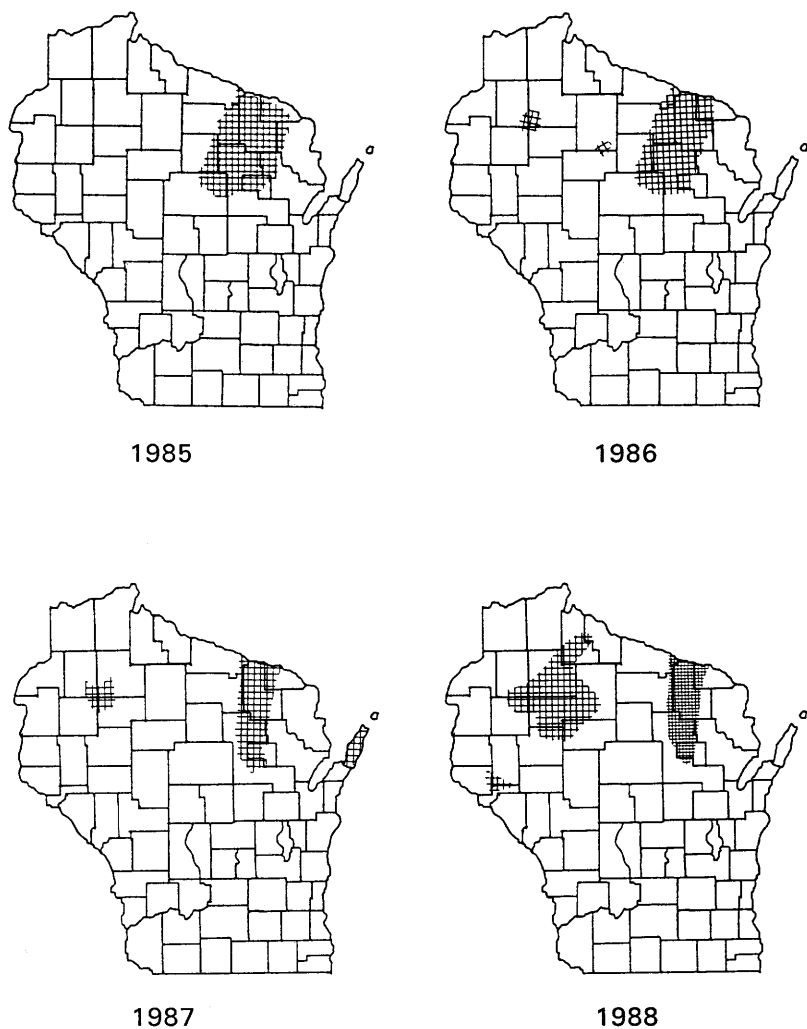


Figure 2. Areas (shaded) of severe defoliation by basswood thrips in Wisconsin from 1985 - 1988. Area shaded with small cross-hatching in the 1988 map represents regions of light to moderate thrips defoliation.

Table 1. Defoliation of *Tilia americana* by *Thrips calcaratus* in Wisconsin from 1980 - 1987<sup>a</sup>

Year	Hectares with moderate to severe defoliation
1980	809
1981	2,307
1982	20,000
1983	40,470
1984	105,222 <sup>b</sup>
1985	101,175
1986	101,175
1987	80,940

<sup>a</sup> Data from Forest Pest Conditions in Wisconsin, WI Dep. of Natural Resources.

<sup>b</sup> Includes light defoliation.

Basswood is the third most common tree in the Lake States northern hardwood forest. This region has a large tourism economy, which could be adversely affected by thrips defoliation of this tree species. Basswood also has important commercial uses such as veneer, furniture, and particle board. This tree is also an important soil-improvement and wildlife habitat species (Fowells 1965, Panshin & de Zeeuw 1980, Beier 1985).

#### Basswood Thrips Bioecology

Very little is known about *T. calcaratus* biology. Because this species is not a pest in its native European range, it has not been studied beyond the taxonomic level (Gentile & Bailey 1968, Jacot-Guillarmod 1975). It has been recorded on nine tree genera, including some which occur in association with basswood in the North American range of *T. calcaratus*. The latter include maple, hickory, beech, ash, and oak. However, there are no rearing data available, and so these may be just casual associations. The European data suggest that *Tilia*

species are the only suitable breeding hosts (Jacot-Guillarmod 1975). The European hosts are *Tilia europa*, *T. platyphyllos*, and *T. vulgaris*. There are no data on developmental rates, fecundity, or behavior. The species is believed to consist entirely of females, as no males have been collected.

*Thrips calcaratus* appears to tolerate a wide range of climatic conditions. It is distributed throughout almost all of Europe, north to Denmark, south to Italy, west to Great Britain, and east to the Ukraine (Jacot-Guillarmod 1975). Thus, it seems that this species will ultimately colonize the entire range of basswood in North America.

In 1988 we initiated a two-year study on the life history and impact of *T. calcaratus*. Twelve permanent 0.10 hectare (0.25 acre) plots were established in April. Thirty basswood trees were randomly selected per plot. Tree data on each tree, including defoliation estimates in 1988 and 1989 and increment cores in 1989 were taken at scheduled times. Insect data were collected on eight plots, and include collections from two emergence traps and six soil/litter samples per plot per week. Soil samples were extracted using Berlese funnels. Direct observations of thrips adults and larvae in the field were also made.

*T. calcaratus* overwinters in the soil as an adult. Emergence begins during the first week of May in southern Wisconsin, and about a week later in the northern counties. Emergence is highly synchronous, being nearly complete by the end of the second week of May in the south, and late May in the north. Adult emergence coincides with basswood bud swelling. They feed in the opening buds, just as the leaves are starting to expand. The opening leaves show a shotgun effect, in which small feeding holes shred and further tissue degradation occurs. The leaves become chlorotic, and eventually drop off if feeding is extensive. Oviposition appears to occur in the main veins of the lower leaf surface. Larvae appear in early June, by which time very few adults can be found. Because a high degree of defoliation has already occurred by this time, adult feeding is probably the main source

of injury. Larvae complete development in June, drop to the ground, and burrow into the soil. Soil populations are much higher than litter populations. Development to the adult stage for most *T. calcaratus* is complete by mid-July, although some immatures are present into September. There is one generation per year.

### Impact of Basswood Thrips

The impact of thrips feeding on basswood trees is largely unknown. We subsampled 77 trees in 1988, and based on these preliminary data, defoliation above 30% appears to reduce radial growth (Table 2). Branch dieback has also been observed. Defoliated trees do refoliate, but the new leaves appear small, chlorotic, and sometimes scorched at the edges. The actual source of injury remains a mystery. The amount of damage surely exceeds the actual consumption rates by these tiny insects. Feeding appears to induce necrosis around the site of puncture, but whether this is due entirely to mechanical damage is unknown. The chlorosis suggests that phytotoxic secretions may be involved, but we have no evidence for this.

Table 2. Effect of defoliation by *Thrips calcaratus* on radial growth of *Tilia americana* in northwestern Wisconsin in 1988

Defoliation (%)	<i>n</i>	Annual Radial Growth (% Increase)
0 - 30	10	0.81
40 - 60	20	0.49
70 - 100	47	0.42

Before we can develop intelligent management strategies, we need to answer some very basic questions about why this insect is so damaging here, but so innocuous in Europe. At least two biological features need to be considered. The first is natural enemies. Whenever an introduced species undergoes outbreak behavior in its new zone, the



possibility of escape from predators, parasites, and pathogens that regulate population densities in the native range must be considered. This may provide an opportunity for classical biological control through the introduction of natural enemies from Europe. In addition, the North American natural enemy complex should be characterized so that any control strategies against *T. calcaratus* do not negatively impact beneficial species.

A second consideration is that American basswood may be more sensitive to *T. calcaratus* feeding than European *Tilia* species. In Wisconsin, thrips injury has not been observed on ornamental linden, which is almost entirely of European stock. For example, 60% of ornamental *Tilia* are of the Greenspire cultivar, derived from European littleleaf linden, *T. cordata*, and in the Lake States most of the remainder are Redmond linden, a cross of the European *T. euchlora* with *T. americana*. Perhaps these species can support thrips populations, but are either less favorable for development or more tolerant to thrips feeding. However, an alternate explanation of why ornamental trees have not suffered damage is that site conditions may be unsuitable. Native basswood stands normally occur on relatively rich soils, with thick litter layers, certainly different conditions from most lawn trees. The host range, both of suspected suitable genera and other potential hosts within *Tilia* needs to be critically examined.

### Acknowledgment

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### Discussion Period

Question: Do you think the black plastic on your emergence cage effects your results? Do you have any data that suggests a change in soil temperature that might alter thrips phenology?

Raffa: Probably the black plastic warms up the soil to a certain amount. Our goal this spring was to get an indication about when to concentrate our research efforts. We now know there is about a 3-week period when they emerge. In the future, we are going to try different sampling methods within that time.

Question: You mentioned that thrips damage could result in growth loss. Have you had any examples of mortality or subsequent decline in those trees?

Raffa: The only examples we have of mortality has been landowner testimony. Based on these sources there does appear to be some mortality due to thrips damage. However, we have no direct evidence of this. I don't expect mortality to be very high considering the amount of damage that has occurred.

Question: Have you done any work on chemical control for basswood thrips?

Raffa: No control methods have yet been tried. At this point we wouldn't know how to go about doing it. There are also economic issues to consider. I have described to you the virtues of basswood, but not everybody would agree with me. The softwood industry predominates in the Lake States and many people do not consider the basswood to be of high value. In our state the Mongamy Indians are the principle hardwood managers and the impact of basswood thrips damage will probably be greatest on them. However, we don't have good data on the economic value of this tree.

Question: You mentioned that you plan to look at the predacious insects that attack basswood thrips. Have you found promising predators?

Raffa: No, not yet. All our specimens are in vials. We have finished the extractions and have separated the thrips, but the rest must still be analyzed. It is a very important question though. I disagree with the Governor, who said yesterday that it is better to act and make a mistake than to do nothing at all. Certainly our history and biological experience doesn't support that. It is critical to know how our control strategies may effect beneficial organisms and the overall environmental balance before they are implemented.

Question: Once you identify the predators in your samples, how are you going to make associations with basswood thrips?

Raffa: We're not. That would require elaborate biological studies. Our work on basswood thrips is a boot-leg effort; we have no formal research program in this area so any work on predators will have to be on a small scale.

Question: What do the thrips do in the ground?

Raffa: I think they are in an overwintering stage by that time, based on the population profiles we've seen in the emergence data and the soil data. We've found adults in the soil from early June to early July, and prior to that only larvae in the soil and after that no larvae in the soil. One thing we wondered about was could basswood thrips have alternate hosts that support it but don't show the same level of sensitivity to feeding. It is possible that there is an allergic reaction or something like that in basswood.

## WESTERN FLOWER THRIPS, A SERIOUS PEST OF FLORICULTURAL CROPS

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The western flower thrips, *Frankliniella occidentalis* (Pergande), has recently become one of the most serious pest problems facing the ornamental industry (Robb & Parrella 1988). It is polyphagous and has been collected from plants of almost every order of the Spermatophyta in California (Watson 1923, Bailey 1933, Bryan & Smith 1956). However, western flower thrips probably has a greater impact on ornamental crops than any other crop. It attacks essentially all floricultural crops and also transmits the tomato spotted wilt virus to numerous ornamental plants (Best 1968).

Tomato spotted wilt virus, like western flower thrips, has a very broad host range, which includes numerous field crops, vegetables, weeds and ornamental crops (Best 1968). Tomato spotted wilt virus is only transmitted by a few thrips species; no other vectors have been identified. Western flower thrips is one species known to vector this virus and it is currently the primary vector associated with this disease in United States; on the East Coast (Da Graca et al. 1985), in the southern states (Barnes & Halliwell 1985, Greenhough et al. 1985), the western states and Hawaii (Allen et. al. 1983, Cho et al. 1987, Robb et al. 1988), as well as in Canada (Allen & Broadbent 1986, Broadbent et al. 1987).

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Damage thresholds for floricultural crops are very low or non-existent. This is especially true for pests such as the western flower thrips which attack the flower, the most important part of these aesthetic crops (Parrella & Jones 1987). Flower losses caused by thrips damage, because of reduced crop yields and market values, as well as increased costs for additional pesticide applications, have been staggering for many ornamental crop producers (Robb & Parrella 1988). Despite its broad host range, vector capabilities and the economic importance of this pest, there have been surprisingly few studies on its biology.

### Development of Western Flower Thrips

Although this insect is occasionally found on the foliage of some plants, it is primarily anthophilous. Eggs are deposited within plant tissue and first instars begin feeding upon egg eclosion. Second instars are also active feeders. Both larval instars are thigmotactic and are generally found in the protection of the perianth of the flower or within developing terminal foliage. Second instars become whitish in color just prior to the next molt and usually move down the plant to pupate in the soil or plant litter. Prepupae and pupae are quiescent non-feeding stages whereas the adult resumes feeding. Females are larger than males and can vary in coloration from yellow to dark brown while males are always pale yellow. Females arise only from fertilized eggs, but they are facultatively arrhenotokous and can produce male offspring from unfertilized eggs.

Under field conditions in California, Bailey (1933) reported a life cycle length of 15-20 days for the western flower thrips. Bryan & Smith (1956) determined the developmental times of western flower thrips at 15°, 20°, and 26.7°C on wild radish leaves and Lublinkhof & Foster (1977) evaluated development times and fecundity at 15°, 20° and 30°C on green bean sections. However, since there had been no evaluations of western flower thrips development on an ornamental crop, a trial was conducted to determine their development on the ornamental host, chrysanthemum, at selected constant temperatures.

Western flower thrips were confined to chrysanthemum, cv. Hurricane, leaves using a modified Munger cell design (Munger 1942, Morse et al. 1986, Robb 1989). Pollen was provided to the thrips. Leaf petioles were suspended in water, and the leaves were changed at least every three days.

Adult female thrips were exposed to chrysanthemum leaves for oviposition for four hours at a constant temperature of 25°C. The adults were removed and the leaves were held in temperature cabinets at 15°, 20°, 25°, 27.2°, 30° or 35°C. The development of each thrips was monitored every four hours until it became an adult.

The highest rate for total development from egg to adult was 30°C (Table 1). Plotting the development rates against temperature revealed a sigmoidal curve. The development rates determined by this experiment were fit by the biophysical model of Wagner et al. (1984) (Fig. 1). A four-parameter model, with high temperature inhibition, best fit the developmental data with 50% high temperature inhibition at 33.26°C.

Table 1. Egg to adult development times of *Frankliniella occidentalis* (Pergande) at selected constant temperatures

Temperature Regime (°C)	n*	Mean hours	(±SE)	Development Rate (Time <sup>-1</sup> )
15	44	939.16	(14.191)	0.001065
20	33	625.85	(20.436)	0.001598
25	51	309.95	(9.161)	0.003226
27.2	25	245.57	(4.275)	0.004035
30	36	223.33	(4.444)	0.004478
35	33	257.79	(5.183)	0.003879

\* Total number of individuals evaluated, trials replicated at least three times for each temperature regime.

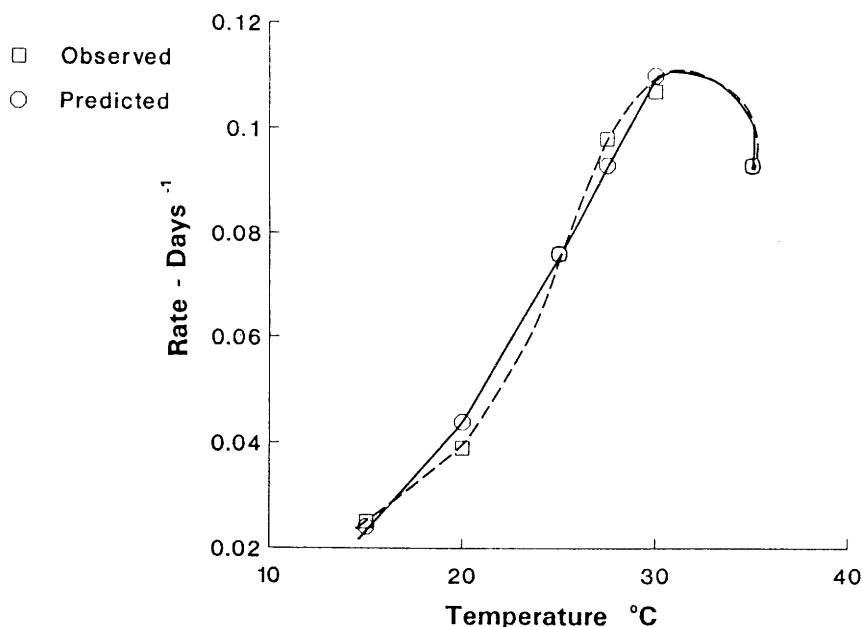


Figure 1. Development rates of *Frankliniella occidentalis* (Pergande) at selected temperatures and nonlinear regression fit by biophysical model.

The development rates observed in this study differ from those reported by Bryan & Smith (1956) on wild radish and by Lublinkhof & Foster (1977) on green bean sections. These differences probably reflect responses of this thrips species to the different host plants utilized in each trial. Dintenfass et al. (1987) observed an exponential increase in western flower thrips populations in onion fields up to temperatures of 35°C whereas above 35°C, development was considerably reduced. Their results were based on ambient field temperatures, however the temperature in the microenvironment of the thrips was probably lower, being modified by the crop canopy. Thus, the results of Dintenfass et al. (1987) generally agree with the findings of this study.



### Longevity and Fecundity of Adult Female Western Flower Thrips

Adult male and female pairs were confined to chrysanthemum leaves at the temperature regimes described previously. Adult mortality was assessed daily to determine age specific survival ( $l_x$ ). Leaves were changed every other day and subsequently held for seven days at 25°C to ensure emergence of all larvae. Emerging larvae were transferred to fresh leaves and maintained until adult emergence to determine sex ratio and age specific fecundity ( $m_x$ ). The  $l_x$  and  $m_x$  data were used to compile life tables for each temperature regime (Carey 1982).

The greatest numbers of progeny per female and progeny per female per day were produced at 27.2°C (Table 2). In addition, mean longevity of females maintained at 27.2°C was almost three times as long as the mean longevity of females at 30°C. Net reproductive rate,  $R_0$ , was greatest at 27.2°C and dropped sharply as temperature increased. Intrinsic rate of increase,  $r_m$ , was lowest at the temperature extremes and mean generation time decreased with increasing temperature. It is clear from this short generation time and high reproductive rate how quickly large populations of western flower thrips can build up in greenhouses. Other factors, such as migration, also influence the numbers of thrips in greenhouses.

### Western Flower Thrips Movement Into and Within Greenhouses

Numerous crops and weeds serve as hosts of western flower thrips outside greenhouses. Adults, after their original host plants senesce or are harvested, search for and move to new hosts. Adult dispersal is initiated with the adults launching themselves into the wind (Lewis 1973). Thrips are not strong fliers, and airspeed is negligible in relation to the speeds of circulating winds (Johnson 1969). Even in relatively calm weather, wind speed is greater than thrips' flight speed (Lewis 1973). Consequently, thrips can be dispersed great distances and can be carried into greenhouses through openings such as open doors and vents.

Table 2. Longevity, fertility and life table parameters of *Frankliniella occidentalis* (Pergande) at selected temperatures

Temperature Regime (°C)	$n^a$	Longevity Days ( $\pm$ SE)	Mean No. Progeny/ Female ( $\pm$ SE)	$R_0^b$	$r_m^c$	T (days)	$t_2$ (days)
15	9	46.33 ( 9.735)	50.51 (18.771)	42.25	0.0563	66.523	12.311
20	9	75.17 (10.131)	125.88 (34.676)	86.49	0.0941	47.186	7.366
25	10	31.40 ( 3.776)	135.60 (46.550)	99.51	0.1713	26.856	4.046
27.2	9	34.00 ( 4.120)	228.60 (34.502)	124.92	0.2545	18.969	2.724
30	11	12.67 ( 2.833)	42.00 (14.292)	35.39	0.2054	17.366	3.381
35	10	9.50 ( 2.604)	5.10 ( 3.567)	2.69	0.0563	17.565	12.312

<sup>a</sup> Total number of individuals evaluated, trials replicated at least three times for each temperature regime.

<sup>b</sup> Net reproductive rate.

<sup>c</sup> Intrinsic rate of increase.

Colored sticky traps were used to evaluate thrips movement within greenhouses. Yellow sticky traps are attractive to many pests of ornamental crops, including whiteflies, aphids and leafminers (Roach & Agee 1972, Parrella & Jones 1985, Jones & Parrella 1986). White and blue traps have been reported to be as attractive, or more, to western flower thrips than to other common ornamental pests (Moffitt 1964, Beavers et al. 1971, Yudin et al. 1987, Brødsgaard 1989).

The attractancy of white, yellow, blue and green traps to western flower thrips was determined in a chrysanthemum greenhouse. Colored acrylic panels (12.8 X 17.8 cm) were used for traps. The panels were placed inside a polyacetate envelope which was covered with a very thin layer of Tanglefoot<sup>®</sup>, which traps insects as they alight without affecting the attractancy of the trap (Prokopy 1968, Gregory 1985). Traps were suspended over benches of chrysanthemums. Four traps, one of each color, were placed over four benches in a Latin square design. The traps were left in place for 48 hours and then the thrips were counted. Traps were rearranged and the trial was repeated four times. Data were analyzed using analysis of variance procedures. Treatment means were separated using Duncan's multiple range test.

Blue and yellow were the most attractive colors to western flower thrips (Table 3). Yellow traps were chosen for all subsequent trials since yellow is attractive to other pests of ornamental crops (Roach & Agee 1972, Parrella & Jones 1985, Jones & Parrella 1986).

Evaluations in rose, carnation, chrysanthemum and poinsettia greenhouses indicated that several factors affected western flower thrips movement. These factors include movement into greenhouses, crop type and cultivar composition. Mark-recapture studies demonstrated that adult thrips were trapped at greater distances from the release point in greenhouses containing poinsettias, a non-preferred host, than in greenhouses with roses, a preferred host. In the rose greenhouse, 72.2% of the thrips were recaptured within 20 m of the release point. No thrips were captured near the release point in the poinsettia greenhouse and more than half were caught 96 m from the release point (Robb 1989).

Table 3. Effects of trap colors on attractancy to *Frankliniella occidentalis* (Pergande)

Trap Color	<i>n</i> <sup>a</sup>	Mean No. ( $\pm$ SE) thrips/trap <sup>b</sup>
Green	16	40.00 ( 5.038)a
White	16	86.88 (10.396)b
Yellow	16	125.50 (14.609)c
Blue	16	150.50 (19.519)c

<sup>a</sup> Total number of traps evaluated per color. Traps were changed and rearranged every 48 hours. Trial was replicated four times.

<sup>b</sup> Means followed by the same letter do not differ significantly ( $P > 0.05$ ) Duncan's multiple range test.

Significant differences were also observed in the attractancy of different cultivars of carnations and roses to western flower thrips. The spectral reflectance of different cultivars probably accounted for some of the differences observed with cultivar composition (Robb 1989). Other factors are also important, however. In roses, for example, flower development and time of sepal splitting also affected the number of thrips in the flowers. Early splitting cultivars had a longer exposure time to adult females and a greater percentage of larvae were present at harvest (Robb 1989). It is clear from these results that an understanding thrips biology and behavior is crucial to the development of integrated control strategies for this pest.

### Western Flower Thrips Control Strategies

Chemical control of western flower thrips can be extremely difficult for many reasons. Good contact of thrips with pesticides is hard to achieve due to the thigmotactic behavior of this insect. Its propensity to develop insecticide resistance is another factor which complicates control. Reinfesting populations through migration of thrips into greenhouses further complicates the problem.

Based on our knowledge of the biology and behavior of this pest, several management strategies have been developed. An integrated approach incorporates strategies for the reduction/prevention of western flower thrips in the greenhouse, without relying solely on insecticides for control. While all these strategies may not be appropriate for every situation, many can be used by almost every grower.

### **Physical Controls**

**Thrips exclusion.** The most effective strategy for thrips control is prevention (Robb 1990). Many greenhouse structures have open sides or vents for increased ventilation. However, this offers no impediment to thrips movement into these greenhouses. Therefore, screening over vents and doorways can greatly reduce this movement into greenhouses and reduce or eliminate the need for insecticides.

**Isolation of propagation areas.** One of the most important factors in managing thrips populations is to start with clean plant material. However, this is virtually impossible if thrips move from production areas to stock and rooting areas.

Therefore, isolation of stock and propagation areas is crucial. Physical barriers, such as screening or distance from production areas can serve to isolate propagation areas.

### **Cultural Controls**

**Weed control around greenhouse.** As mentioned previously, western flower thrips have a broad host range, including weeds as well as flowering plants. Weeds, however, are not usually targeted for pesticide applications and can serve as a refuge during pesticide applications. Moreover, weeds can act as a reservoir for tomato spotted wilt virus.

**Avoidance of continuous cropping.** Many flower crops are grown in very large, contiguous greenhouses. All stages of production may be present under one roof. As crops are harvested, mobile adult

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## THRIPS ON STONE FRUITS: FORMATIVE STAGE OF PEST MANAGEMENT

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### Abstract

Thrips populations and injury attributed to their feeding on nectarine and peach fruit surfaces were monitored in sprayed and unsprayed orchards in central Georgia from 1983-1988. *Frankliniella tritici* (Fitch), the eastern flower thrips; *F. occidentalis* (Pergande), the western flower thrips; and *Neohydatothrips* (= *Sericothrips*) *variabilis* (Beach), the soybean thrips; were the most abundant of the 31 thrips species recovered from the orchards. Their relative abundance changed each year. The western flower thrips appears to be most damaging in causing russetting on nectarine surfaces. Silvering injury to peaches and nectarines was caused by either or both of the flower thrips and coincided with peak populations of adults at or near final fruit swell on early ripening cultivars. Soybean thrips caused little or no injury to fruit. None of the above mentioned flower thrips species were recovered from various weed and grass species in and near the nectarine orchard during two years of overwintering studies. Control strategies are based on sampling for thrips adults and larvae.

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## Introduction

Peaches are a valued fresh fruit crop in the southeastern United States. Georgia and South Carolina produced and shipped 217.4 million kg (480 million pounds) with a gross value in excess of \$80.1 million in 1988 (Ga. Agric. State Service 1989).

Although peaches are by far the major stone fruit in the Southeast, nectarines appear to have potential for future markets in this area. Recently there has been new interest in developing nectarine cultivars adapted to the Southeast (Okie et al. 1985). Insect control strategies for peaches have been relatively static for several years with no major emphasis on thrips control, simply because thrips injury has been a minor problem. However, this strategy may change due to the recent introduction of the western flower thrips, *Frankliniella occidentalis* (Pergande). At present, we have no spray guide specifically for nectarines. Comments are made in the peach spray guide advising those growers (limited number) who produce nectarines as to modifications in the peach pest practices which are necessary or appropriate for nectarines (Bertrand et al. 1988). Reports from California have noted that thrips injury due to *F. occidentalis* is a problem in certain California nectarine producing areas (LaRue et al. 1972) and to a lesser degree on peaches (Weldon 1921). Indications are that southeastern nectarine producers will face similar problems.

## Thrips Threat to Nectarines and Peaches

In 1980, the western flower thrips was first reported to be damaging cotton in the Southeast and in 1981 it was reported as a new pest on peanuts in Georgia (Beshear 1983). Also, the species has been shown to be a vector of tomato spotted wilt virus on tomatoes and peanuts (McRitchie 1986, Hagan et al. 1987). Until 1983, very little information was available on thrips and their association with peaches and nectarines in the Southeast. During 1983 and 1984, we regularly surveyed for thrips in non-sprayed peaches and sporadically sampled in sprayed peach orchards in 1984 and 1986. In 1986-88 we concentrated on non-sprayed nectarines in order to gather basic life

history data on damaging thrips species (Yonce et al. 1988). In 1988 we further expanded our studies to sprayed peaches (Horton et al. 1988). We needed to determine which thrips species were important, their seasonal distribution patterns, and if the western flower thrips was becoming established on nectarines and peaches in the Southeast.

### **Thrips Sampling Procedure**

Sampling was done with a modification of a unique sampling device designed and originally built for sampling pecan arthropods (Teddars 1983). Two aluminum trays (117 x 76 cm) were placed under the canopy of a tree designated for sampling, and the limbs above were then sprayed with a short residue, knockdown insecticide (6% pyrethrin plus 60% piperonyl butoxide). Application was made with a small battery powered Porta-Jet<sup>®</sup> sprayer (Fig. 1). After 30 min. trays were picked up and placed on a supporting framework, and arthropods were washed with water into a trough through a funnel into sheer cloth bags after which they were removed and placed in 70% ethanol. Thrips were later separated and identified by methods described by Allen & Broadbent (1986), Sakimura (1986), Stannard (1968) and Moulton (1948). Voucher specimens were sent to S. Nakahara (USDA-Insect Identification Lab., Beltsville, Md. 20705) for verification. Sampling was begun at bud swell and continued at weekly intervals until harvest, then every two weeks until 1 September.

### **Fruit Injury Damage Types**

There are two types of injury to fruit. Russetting is a rough textured, tan-colored blemish that may result in cullage (Fig. 2). At bloom time, adult flower thrips enter the flower and lay eggs in tender flower parts near the ovary. Subsequently, eggs hatch and the young larvae remain inside the flower. Oviposition wounds and feeding by small larvae on the young embryonic fruit produce injury that is greatly magnified on the mature fruit at harvest time. The appearance is often referred to as "buckskin." Silvering, the other type of injury, is less severe and results in a benign, light-colored blemish (Fig. 3). It seldom produces cullage of fruit in the commercial market. It is caused by adult

and immature thrips feeding on outer layers of pigment-containing cells and results in bleaching and speckling of the red blush when fruit begins final swell. Silvering seems to be more common on cultivars that ripen when adult flower thrips populations are peaking.



Figure 1. Handgun application of pyrethrin-piperonyl butoxide insecticide mix to sample thrips populations in peaches. Thrips are collected in white trays placed on the ground.

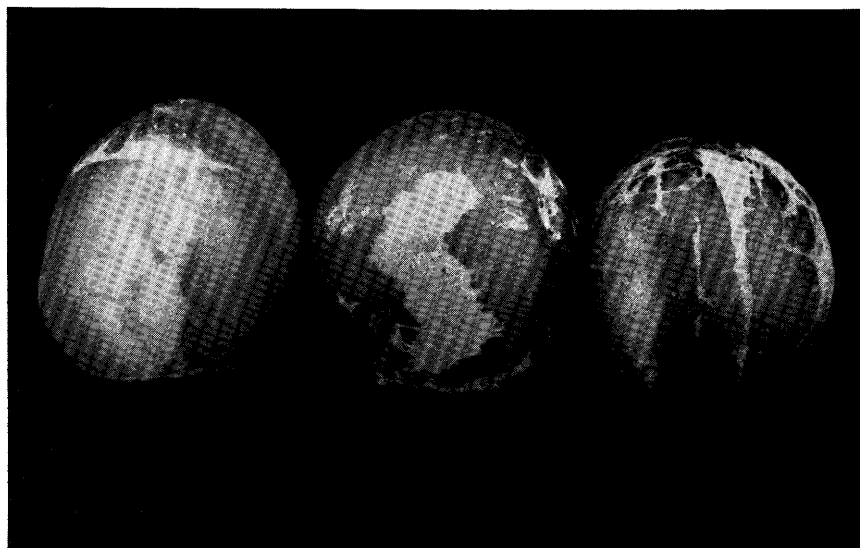


Figure 2. Nectarines with moderate and severe russeting from thrips feeding.

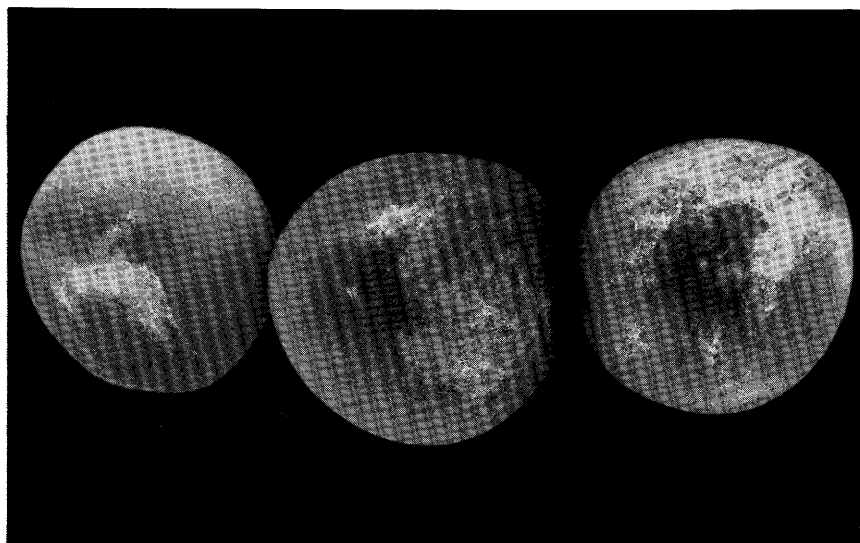


Figure 3. Peaches with light and moderate silvering injury from thrips feeding.

## Results and Discussion

### Orchard Experiments

In 1983 and 1984, our sampling in non-sprayed peach orchards at Byron, Ga. revealed the presence of 31 species of thrips (Table 1). The majority of captures were the eastern flower thrips, *Frankliniella tritici* and the soybean thrips, *Neohydatothrips* (= *Sericothrips*) *variabilis*. Captures of other species were much less common; half of the species were incidentals and a few were captured only once or twice during the entire two-year period.

Limited sampling was done concurrently in commercial sprayed peach orchards in 1984. Thrips captures in these orchards were not different from captures in non-sprayed orchards. This was the first circumstantial evidence that thrips populations were virtually unaffected by standard insecticidal control strategies that rely almost exclusively on ethyl parathion. During a three-year study (1986-88) of intense sampling for thrips in non-sprayed nectarine plantings, the western flower thrips, *F. occidentalis*, became noticeably more abundant. In 1986 western flower thrips were considerably more common than they had been in the two previous years' sampling in peaches. In 1987 this trend reversed; western flower thrips was almost nonexistent, the eastern flower thrips, *F. tritici*, captures were very few, while the soybean thrips were quite prevalent. Conversely, in 1988 the western flower thrips were more abundant than all the other species.

Sampling in commercial peach orchards during 1988 revealed a high incidence of silvering on some peach cultivars that ripened during the time when western flower thrips populations were peaking. However, the soybean thrips appeared to contribute very little to russetting or silvering injury. Damage to fruit was low during 1987 when the soybean thrips population was dominant over flower thrips. In one experiment, the number of soybean thrips recovered from nectarine trees without fruit was equal to the number of soybean thrips recovered from trees with fruit. This was further evidence confirming that soybean thrips are unimportant in causing fruit injury to nectarines.

Table 1. Thrips species captured in unsprayed "Redskin" and "Redglobe" peach orchards in 1983 and 1984. USDA Fruit and Tree Nut Research Laboratory, Byron, Ga.

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SUBORDER TEREBRANTIA

**Aeolothripidae Uzel (1895)**

*Aeolthrips bicolor* Hinds

*Aeolothrips melaleucus* Haliday

**Heterothripidae Bagnall (1912)**

*Heterothrips quercicola* Crawford, J.C.

**Thripidae Stephens (1829)**

*Bregmatothrips gracilis* Hood & Williams

*Bregmatothrips venustus* Hood

*Caliothrips nr. phaseoli* (Hood)

*Chirothrips mexicanus* Crawford, D. L.

*Frankliniella bispinosa* (Morgan)

*Frankliniella fusca* (Hinds)

*Frankliniella occidentalis* (Pergande)

*Frankliniella tritici* (Fitch)

*Limothrips cerealium* (Haliday)

*Microcephalothrips abdominalis* (Crawford, D. L.)

*Neohydatothrips variabilis* (Beach)

*Plesiothrips perplexus* (Beach)

*Pseudothrips inequalis* (Beach)

*Salpingothrips aimotofus* Kudo

*Scolothrips pallidus* (Beach)

*Sericothrips cinqualatus* Hinds

*Thrips hawaiiensis* (Morgan)

*Thrips trehernei* Priesner

SUBORDER TUBULIFERA

**Phaeothripidae Uzel (1895)**

*Elaphrothrips armatus* (Hood)

*Elaphrothrips coniferarum* (Pergande)

*Haplothrips* (K.) *graminis* Hood

*Haplothrips* (K.) *harti* (Hood)

*Hoplandrothrips microps* Hood

*Hoplandrothrips japonicus* Karny

*Leptothrips mali* (Fitch)

*Megalothrips spinosus* Hood

*Neurothrips magnafemoralis* (Hinds)

*Plectothrips antennatus* Hood

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## Control Status

At present, our efforts to control thrips injury on nectarines and peaches in the Southeast are less than satisfactory, particularly with respect to russetting injury on nectarines. Although we have managed to suppress russetting in some of our control experiments, it appears that timing of insecticide applications is most important. There is also a need to screen chemicals to find something better than those presently recommended. Early season migration of flower thrips into the orchards needs to be studied more thoroughly. Possibly, pre-bloom spraying or some type of orchard management to destroy overwintering hosts might intercept or disrupt thrips movement into the flowers before they oviposit. Silvering, on the other hand, can be controlled more easily with chemicals since we now have predictable seasonal distribution patterns that allow us to look for thrips and injury on cultivars that ripen when our flower thrips populations peak (15 May-1 June).

## Pest Management

Thrips pest management in southeastern stone fruits is, as our title implies, in infancy. The recently established presence of western flower thrips seems to have heightened the pest potential of this group. Nectarines and probably plums are more at risk for thrips injury than peaches.

We lack adequate early season sampling techniques that might help in timing insecticide applications. Berlese funnels are currently in use to refine our knowledge of when flower thrips move to stone fruit to lay eggs and feed. Detailed chemical exclusion studies aimed at refining our excessively broad early-season control windows are to be conducted this season. White sticky traps may be used after more detailed information on thrips movement into orchards is obtained. Preliminary trials with white traps were discouraging, as heavy early-season orchard traffic tends to litter the traps with debris and limit their usefulness. Current recommendations for nectarines suggest preventive application of formetanate hydrochloride (Carzol) at pink bud and petal

fall. This is a provisional recommendation based on materials and timing recommended in California, France, Italy, and Greece (Rice, personal communication, University of California; Bournier 1973; Cravedi et al. 1983; Kourmadas et al. 1982; Cravedi & Molinari 1984). Further refinements are obviously needed in these russet prevention sprays. Silvering as previously noted is much less damaging. Current recommendations simply require careful observation. Spraying may be necessary if abundant thrips and/or injury are detected during final fruit swell. Correlation of thrips numbers to injury in susceptible cultivars is a future research goal.

### Summary

After 5 years of seasonal thrips sampling in both peach and nectarine orchards, the following points are noteworthy:

1. The western flower thrips is well established in central Georgia and appears to be more damaging to fruit than the eastern flower thrips.
2. Russetting injury occurs very early in fruit development and could require an insecticide as early as pink bud. Lack of sampling techniques prevents spraying as needed. We hope to narrow the treatment window as our knowledge of thrips biology on southeastern stone fruit improves.
3. Silvering occurs near final swell of fruit when peaches and nectarines begin to show a substantial amount of red blush before ripening. Silvering is more prominent on peach cultivars such as "Sunbrite" and "Empress" and nectarine cultivars such as "Sunfre" and "Armking" that ripen when adult populations of flower thrips are peaking. In central Georgia, this occurrence is obvious from 15 May to 1 June. Cultivars ripening mid- and late season are unlikely to have silvering problems. Thresholds are desired that would allow spraying of nectarines as needed to prevent excessive silvering injury.
4. Soybean thrips, *N. variabilis*, contribute very little, if any, feeding injury to peach and nectarine fruit.

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**THRIPS BIOCONTROL: OPPORTUNITIES FOR USE OF  
NATURAL ENEMIES AGAINST THE PEAR THRIPS**

## **THRIPS BIOCONTROL: OPPORTUNITIES FOR USE OF NATURAL ENEMIES AGAINST THE PEAR THRIPS**

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### **Abstract**

Thrips have been considered as both target pests and control agents in biological control. The main emphasis of this paper concerns the natural enemies of thrips and an appraisal of the potential for biological control of the pear thrips on sugar maple in the northeastern United States. Previous attempts at biological control of thrips pests have been confined to the Caribbean and Hawaii and have made use of eulophid larval parasitoids and anthocorid predators as control agents. A review of the literature indicates that while these two groups often figure most strongly in natural enemy complexes of thrips, fungal pathogens are an important, if neglected, group. For biological control of pear thrips it is considered that synchronized univoltine parasitoids and fungal pathogens from Europe, the region of origin of the pest, show most promise as potential biological control agents.

### **Introduction**

Biological control has been widely practiced worldwide as an effective means of controlling accidentally introduced pests by the importation and release of specific natural enemies from their region of origin (Clausen 1977, Julien 1987). This approach led to the successful

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control of the cottony cushion scale, *Icerya purchasi* Maskell in California one hundred years ago through the importation of the Vedalia beetle, *Rodolia cardinalis* (Mulsant) (Caltagirone & Douth 1989). While chemical treatments dominated pest management in the post-war years, environmental concerns have brought biological control back to the forefront of current integrated pest management practices.

Biological control of forest insects (Pschorn-Walcher 1977, Waters et al. 1976, Turnock et al. 1976) has enjoyed a long and successful history of natural enemy importations. The Commonwealth Institute of Biological Control (CIBC) database of classical biological control importation, BIOCAT, records 360 natural enemies released against 42 forest pests. From these importations, 29% have become established in the target area and 34% of these have provided at least some degree, if not lasting, of control. A recent review of the suitability of forest environments for biological control and the success or failure of key case histories is provided by Dahlsten & Mills (in press).

Thrips have figured in biological control both as target pests and as natural enemies of weeds. Four thrips have been targets for biological control (Table 1) and the natural enemy agents selected for importation have included both predators and parasitoids. The results of importations have not been so successful, with only the anthocorid, *Montandoniola moraguesi*, being credited with providing at least partial control of the ornamental laurel thrips, *Gynaikothrips ficorum* (Marchal) (Cock 1985). As biological control agents of weeds, thrips have had greater success (Table 2). Of two earlier projects one is a complete success and the other is uncertain due to confounding effects of other simultaneously imported and released agents.

Table 1. Classical biological control projects against thrips, data from Clausen (1977), Cock (1985) and McMurtry (this publication)

Target	Region (Date)	Agent (Origin)	Result
<i>Thrips tabaci</i>	Bermuda (1938) Hawaii (1930-32)	<i>Ceraninus brui</i> (Japan) <i>C. russelli</i> (USA) <i>C. vinctus</i> (Philippines) <i>Goetheana parvipennis</i> (Ghana)	- Established
<i>Selenothrips rubrocinctus</i>	Caribbean (1936-37) Hawaii (1936)	<i>Goetheana parvipennis</i> (Ghana)	- Established
<i>Gynaikothrips ficorum</i>	Hawaii (1964-65)	<i>Macrotrachelia thripiformis</i> (Mexico) <i>Montandoniola moraguesi</i> (Philippines) <i>Orius tristicolor</i> (USA) <i>Chrysopa</i> sp. (Mexico)	- Established
	Bermuda (1960-63, 1973)	<i>Montandoniola moraguesi</i> (Philippines) <i>Goetheana parvipennis</i> (Ghana) <i>Thripastichus gentilei</i> (Brazil)	- Provides partial control
<i>Heliothrips haemorrhoidalis</i>	California (1987?)	<i>Thripobius semiluteus</i> (Japan/Argentina)	- Probably established



Table 2. Weed biocontrol projects using thrips as natural enemies, data from Julien (1987) and Greenwood & Mills (1989)

Target	Region (Date)	Agent (Origin)	Result
<i>Clidemia hirta</i>	Fiji (1930)	<i>Liothrips urichi</i> (Trinidad)	Good lasting control
<i>Alternanthera philoxeroides</i>	Florida (1967)	<i>Amynothrips andersoni</i> (Brazil)	Uncertain
<i>Mikania micrantha</i>	Solomon Islands (1988) Malaysia (1989)	<i>Liothrips mikaniae</i> (Trinidad)	Not yet known

## The Pear Thrips as a Target for Biological Control

The pear thrips, *Taeniothrips inconsequens* (Uzel), is an infrequent European thrips that was accidentally introduced into North America around the turn of the century. It initially caused some concern in pear and plum orchards in California but since the early 1980s has been responsible for severe defoliation of sugar maple in Vermont, Pennsylvania and Connecticut (see Parker, this publication).

The biology, life cycle and natural enemies of the pear thrips have not been studied in detail either in Europe or the United States. General observations from the United States (Foster & Jones 1915; Skinner et al., poster presentation, this publication) indicate that adults emerge from the soil in spring to feed on the expanding buds of the host tree. Adults oviposit on the leaves and the two larval stages then feed on the foliage for 4-6 weeks before dropping to the soil to produce earthen cells for overwintering.

Observations from Europe (Priesner 1924, Blunck & Neu 1949) indicate that the pear thrips is widespread in northern and central Europe and differs from the United States populations by the occurrence of males (Bournier 1956). Food plants include trees of the genera *Aesculus*, *Acer*, *Crataegus*, *Juglans*, *Malus*, *Pirus*, *Prunus*, *Populus* and *Salix*. Adult fecundity is estimated as approximately 100-200 eggs and adult feeding and larval development tend to occur between mid-March and the end of May.

Since no specific studies of the natural enemies of the pear thrips have been made, it is necessary to take a look at natural enemies of thrips in general to get an appreciation of the types of organisms likely to be associated with the pear thrips in Europe.

## Thrips Natural Enemies

### Predators

The slow moving larval thrips are easy prey for a wide range of general arthropod predators (Table 3). The majority of these accept a wide range of prey and thrips may not represent their preferred host in many cases. Some of the more specific thrips predators are the Aeolothripidae, the anthocorid genera *Orius* and *Montandoniola*, the cecidomyiid genus *Thripsobremia* and the sphecid genus *Microstigmus*.

Anthocorids have an important impact on thrips populations in cotton (Stoltz & Stern 1978), in soybean (Irwin & Kuhlman 1979), in ornamental fig (Cock 1985) and in Glyricidia flowers (Viswanathan & Ananthakrishnan 1974). In addition, the coccinellid, *Scymnus thoracicus*, is suggested to be able to regulate populations of *Chaetanaphothrips orchidii* (Moulton) on banana (Delattre & Torregrossa 1978). Most other predators will contribute to the control of their prey populations but are unlikely to be useful as biological control agents. In the context of glasshouse crops, the phytoseiid mites, *Amblyseius cucumeris* and *A. mackenziei* are mass reared for the control of *Thrips tabaci* (Ramakers 1983). Again, these mite predators are not so specific in their diet and can only be effective in confined situations.

### Parasitoids

Thrips are attacked by both egg and larval parasitoids (Table 4). Egg parasitoids of the genus *Megaphragma* are some of the smallest known insects and have been recorded from a variety of thrips species (Lewis 1973). They have been little studied (McMurtry 1961), and do not appear to contribute significantly to thrips mortality. In contrast, the eulophid larval parasitoids play a more dominant role with 70-80% parasitism being recorded for *Ceraninus* species on bean thrips (Russell 1912), pea thrips (Kuetter 1936), onion thrips (Sakimura 1937); for *Goetheana parvipennis* on cocoa thrips (Cotterell 1927) and *Thripastichus gentilei* on olive thrips (Melis 1934).

Table 3. The range of arthropod predators known to attack thrips

Order	Family	Species	Reference
Thysanoptera	Aeolothripidae	<i>Aeolothrips</i> spp. <i>Franklinothrips</i> spp.	Bournier et al. 1978 Callan 1943
Hemiptera	Anthocoridae	<i>Orius</i> spp. <i>Montandoniola moraguesi</i>	Irwin & Kuhlman 1979 Muraleedharan & Ananthakrishnan 1978
	Lygaeidae	<i>Geocoris tricolor</i>	Ananthakrishnan 1984
	Miridae	<i>Teratophylidea</i> spp.	Doesberg 1964
Neuroptera	Chrysopidae	<i>Chrysopa</i> spp.	Callan 1943
Coleoptera	Coccinellidae	<i>Adalia</i> spp. <i>Coccinella</i> spp. <i>Scymnus</i> spp.	Priesner 1964 Ghabn 1948 Dyadechko 1977
	Malachiidae	<i>Malachius viridis</i>	Tansky 1958
Diptera	Syrphidae	<i>Metasyrphus corollae</i>	Ghabn 1948
	Cecidomyiidae	<i>Thripsobremia liothrips</i>	Barnes 1930
Hymenoptera	Sphecidae	<i>Microstigmus thripictenus</i>	Matthews 1970
Acari	Pyemotidae	<i>Adactylidium nicolae</i>	El Badry & Tawfik 1966
	Phytoseiidae	<i>Amblyseius cucumeris</i> <i>A. mackenziei</i>	Ramakers 1983

Table 4. Egg and larval parasitoids of thrips

Family/ Genera/species	Host stage attacked	Distribution
<b>Trichogrammatidae</b>		
<i>Megaphragma</i> spp.	Egg	Tropical & sub - tropical
<b>Eulophidae</b>		
<i>Ceraninus</i> (= <i>Thripoctenus</i> )	Larval	Temperate - tropical
<i>Goetheana parvipennis</i>	Larval	Tropical & sub - tropical
<i>Thripastichus</i> (= <i>Tetrastichus</i> ) spp.	Larval	Temperate - tropical
<i>Thripobius</i> spp.	Larval	Tropical & sub-tropical
<i>Thripoctenoides gaussi</i>	Larval	Temperate

The biologies of the larval parasitoids are similar (Russell 1912, Sakimura 1937, Dohanian 1937, Bournier 1967). Adults live approximately 3 weeks and oviposit into young thrips larvae. The solitary endoparasitoid larvae kill and pupate within the host pre-pupae and the life cycle is completed in about one month. The parasitoids are generally multivoltine, although there is some evidence that, at least in the case of *Thripastichus gentilei*, diapause may be controlled by that of its host. In association with the laurel thrips both host and parasitoid have continuous generations (Bournier 1967) but in association with the olive thrips, which has an overwintering adult diapause, the parasitoid remains in host pre-pupae from October through to April (Melis 1934).

## Pathogens

Allantonematid nematodes have occasionally been found infesting thrips but records are few (Ananthakrishnan 1984). While these nematodes are internal parasites, they do not cause the death of their host and their impact is confined to a reduction of adult fecundity. It is probable that arboreal thrips, such as the pear thrips, are not attacked by nematodes on the foliage of their hosts but may well be attacked during the long period spent in the soil.

Raizada (1976a) notes the occurrence of heavy microsporidial infection of *Scirtothrips oligochaetus* on cotton but this is the only known record. In addition, there are no known viral (Martignoni & Iwai 1981) or bacterial diseases of thrips.

Thrips are attacked by fungi of many genera including *Beauveria*, *Neozygites* (*Entomophthora*), *Verticillium*, *Paecilomyces* and *Hirsutella* (Raizada 1976b). *Beauveria bassiana* infected up to 20% of larvae of *Haplothrips tritici* in Bulgaria (Lyubenov 1961) and probably attacks all thrips that pupate or overwinter in the soil. Two species of Entomophthorales have been described (MacLeod et al. 1976, Samson et al. 1979) that infest larval hosts while feeding on foliage and a *Hirsutella* sp. nov. has recently been isolated by CIBC from foliage feeding larvae of *Liothrips mikaniae* (Greenwood & Mills 1989). *Verticillium lecanii* gives good control of *Thrips tabaci* in glasshouses (Gillespie et al. 1983) and a water-miscible formulation reached an advanced stage of commercial development in England. While there are no records of fungal pathogens of the pear thrips it is probable that such natural enemies do exist, at least in their region of origin.

## Appraisal and Discussion of the Potential of Natural Enemies for Biological Control of Pear Thrips

It is clear from the literature that pear thrips has not been a pest of concern in Europe in recent years and that it has never been considered a pest of broadleaf forest trees. The host range of the pear

thrips in its native Europe is not well known but it appears to be more of an orchard than a forest species. No study of the natural enemies of the pear thrips has been made in Europe and it is not possible, therefore, to assess their role in maintaining this species at endemic densities in its area of origin.

Nutritional factors may affect the abundance of thrips populations and may be one of the factors involved in the recent outbreak of the pear thrips on sugar maple in the United States. Fennah (1955, 1965), in some classic studies of the cocoa thrips in Trinidad, found that the establishment of thrips on particular trees or parts of the trees was related to the extent of derangement of normal host tree physiology. Adverse factors affecting normal leaf metabolism lead to increased nitrogen availability and higher thrips populations. Similar interactions could occur between pear thrips and sugar maple trees, brought about by the action of recent years of lower than average rainfall or increased levels of acid rain. Fertilization to improve general tree health could be experimentally investigated as a means to reduce levels of thrips infestation.

Of the natural enemies that are known to attack thrips, predators are the least specific and of least interest in terms of potential for biocontrol. While some success has been achieved in Bermuda with the anthocorid *Montandoniola moraguesi* (Cock 1985), temperate predators appear less promising. These are represented by congeneric species in both the Nearctic and Palearctic faunas and the importation of European predators does not seem warranted.

Egg parasitoids appear to be infrequent and to have little impact on their host populations. Larval parasitoids, such as *Ceraninus* spp., have a very significant impact on their hosts but little is known of their host range or habitat preferences. The majority of host records for *Ceraninus* species are from the Thripidae (family including the pear thrips) but most records are from hosts feeding on crops and other low growing plants. This probably reflects the greater attention that has been paid to thrips pests of agricultural and horticultural importance, rather than a distinct habitat preference of the parasitoids. The most

frequent species, *C. russelli*, is Holarctic but a number of other species are known from the Palearctic region. In contrast, *Thripastichus* species appear to be more associated with the Phlaeothripidae, and most of the records are from arboreal hosts. *T. gentilei* is an important parasitoid in Europe and there is some evidence that diapause in this species may be controlled by the host (Melis 1934).

The univoltinism and restricted time period in which the pear thrips is active above ground poses difficulties for biocontrol by parasitoids. To be able to use parasitoids effectively, a species must be found that can be induced into diapause by the host to provide the necessary synchronization and independence from alternative hosts. The currently known parasitoids are multivoltine and are better known from multivoltine thrips hosts. However, the limited knowledge of these parasitoids suggests that parasitoid diapause may well be controlled by that of the host. Thus the diapause of the pear thrips may induce univoltinism in some of the parasitoids. If not, then it is unlikely that parasitoids would be able to inflict significant levels of parasitism on this host, particularly at the early stage of the season when the pear thrips is active.

Of the known or probably occurring pathogens, the allantonematid nematodes have little potential for use in biocontrol. Nematodes of the genera *Heterorhabditis* and *Neoaplectana* have far greater potential for control of the pear thrips in the soil and local Vermont strains of these entomopathogenic genera, isolated from the soil in sugar maple forests would be the most appropriate to use in experimental trials.

Very little is known of the fungal and other pathogens of thrips and there are no records from the pear thrips. Rather than indicating an absence of important pathogens this is likely to reflect a lack of investigations on these rather small and often insignificant hosts. In recent years species of Entomophthorales have been discovered attacking thrips and it is probable that a range of other thrips-specific fungi have yet to be discovered. Members of the Entomophthorales and other specialized fungal pathogens infesting the pear thrips could



be considered for classical biocontrol introductions. A precedent for this exists in the recent establishment in Australia of an introduced strain of *Erynia radicans* for control of the alfalfa aphid, an exotic pest (Milner et al. 1982).

Other fungi, such as *Beauveria*, *Metarhizium* and *Verticillium* species, can be more readily mass produced and formulated for application as myco-pesticides. The most appropriate fungal strains to use in either case would probably be those isolated from the pear thrips in its region of origin.

Several precedents exist for the application of formulated pathogens to perennial crops and forests. *Beauveria brongniartii* has been sprayed on swarming adults of the European cockchafer *Melolontha melolontha* (Coleoptera: Scarabaeidae) with subsequent contamination and suppression of larval populations in the soil for several years (Keller 1986). This success is encouraging for pear thrips control because here too, application of the pathogen to the insect on the trees could lead to an increase in the soil population of the pathogen and consequent long-term suppression of the pest.

Very large areas can be treated with myco-pesticides. In Brazil, 6000 ha are treated with the fungus *Metarhizium anisopliae* to control the spittlebug, *Mahanarva posticata* (Hemiptera: Cercopidae) (e.g., Ferron 1981). Even larger areas of Canadian forests are aerially sprayed with commercial formulations of *Bacillus thuringiensis* to control the spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae) (Morris et al. 1986). In this last case it was public concern about environmental damage from chemical control measures that led to the adoption of *B. thuringiensis* by the Canadian authorities. The environmental safety of biological pesticides is of particular relevance where large areas of land such as forests must be treated.

The conidia of dry-spored fungi such as *Beauveria* and *Metarhizium* are hydrophobic and are miscible in oil. Such oil formulations are much more infective than water suspensions because the oil adheres to the insects' cuticle (Prior et al. 1988). Oil formulations would be suitable for ultra-low volume aerial spraying, where the use of water sprays is precluded by their rapid evaporation and the large volumes of water required. The prospects for developing an oil-based, ultra-low volume myco-pesticide against pear thrips are good.

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**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, Entwistle 1972). Subtropical southern California

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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 Entwistle (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, Entwistle 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.

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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).

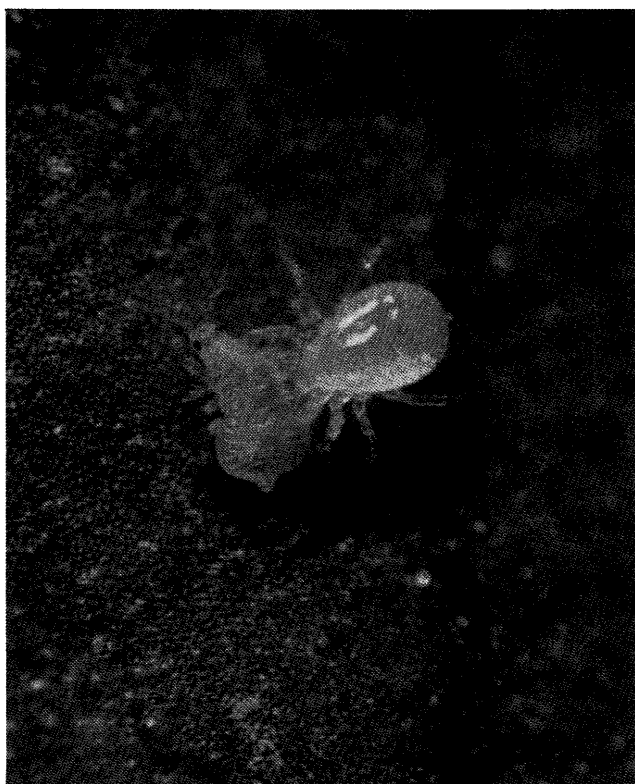


Figure 1. *Euseius tularensis* sucking the body contents of a second instar citrus thrips (photo by J. K. Clark).

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*	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

\* *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).



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).

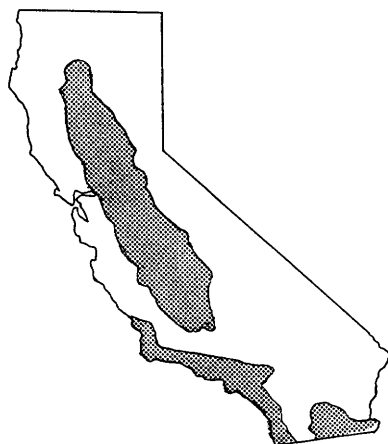


Figure 4. Distribution of *Scirtothrips citri* (shaded area) in California (from Tanigoshi 1981, Tanigoshi & Nishio-Wong 1982).

## 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).

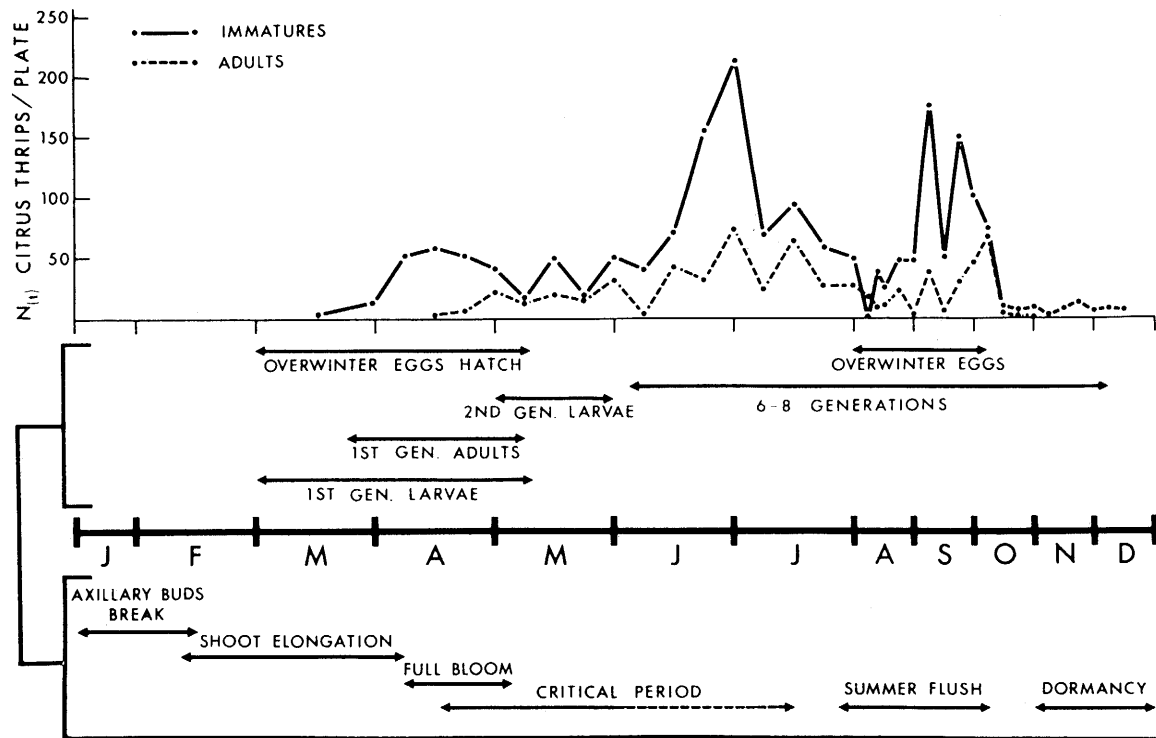


Figure 5. Phenograph of navel orange and *Scirtothrips citri* showing the critical injury period for developing fruitlets, Riverside, Calif., 1974.

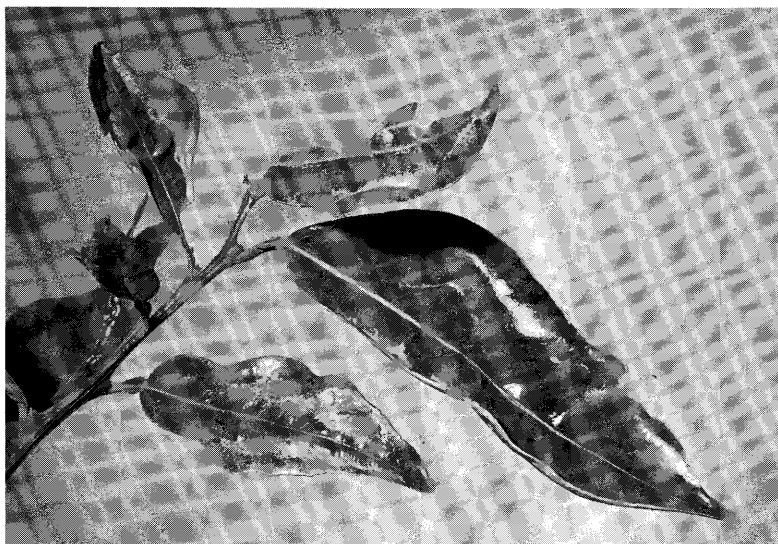


Figure 6. Leaves scarred by citrus thrips feeding (photo by M. E. Badgley).



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

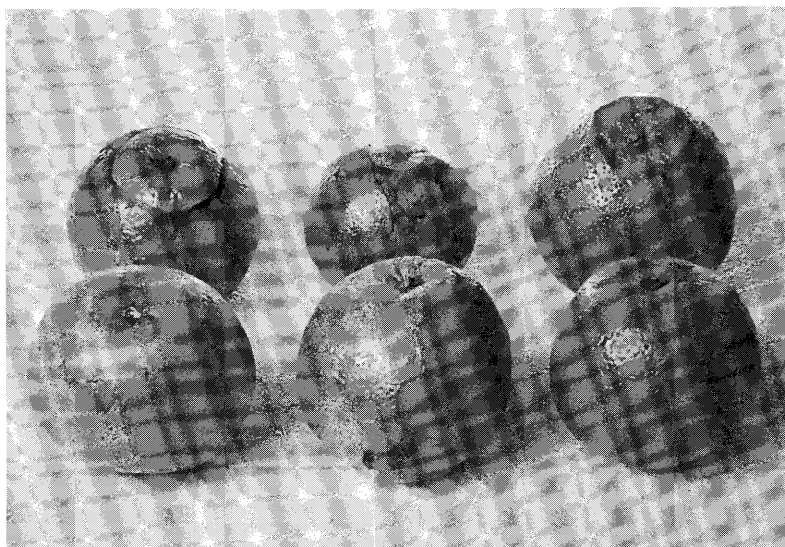


Figure 8. Stem-end navel orange injury (photo by M. E. Badgley).

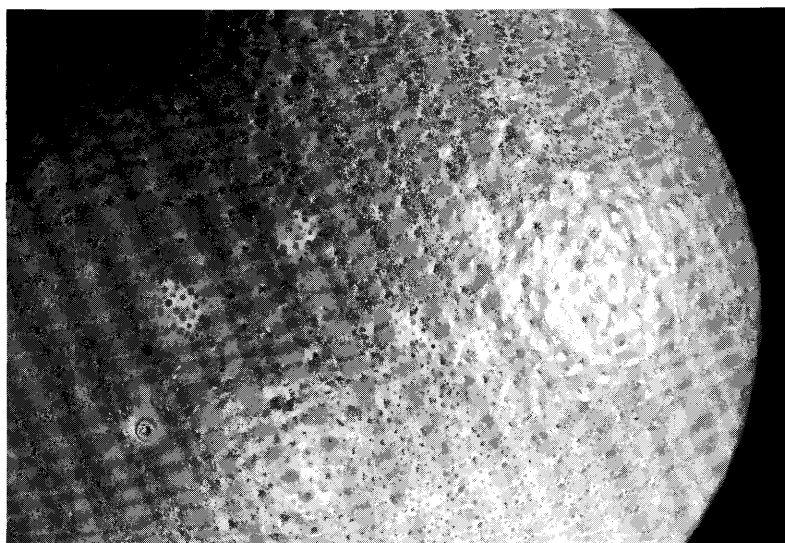


Figure 9. Citrus thrips ovipositional injury (photo by M. E. Badgley).

### 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<sup>2</sup> 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).

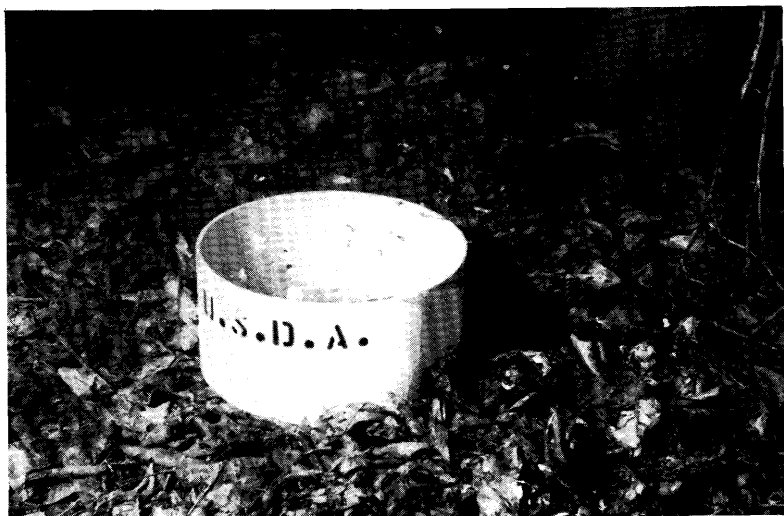


Figure 10. PVC-acetate dispersal-emergence trap for monitoring citrus thrips adult emergence from soil and larval descent into the litter (photo by M. E. Badgley).

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.

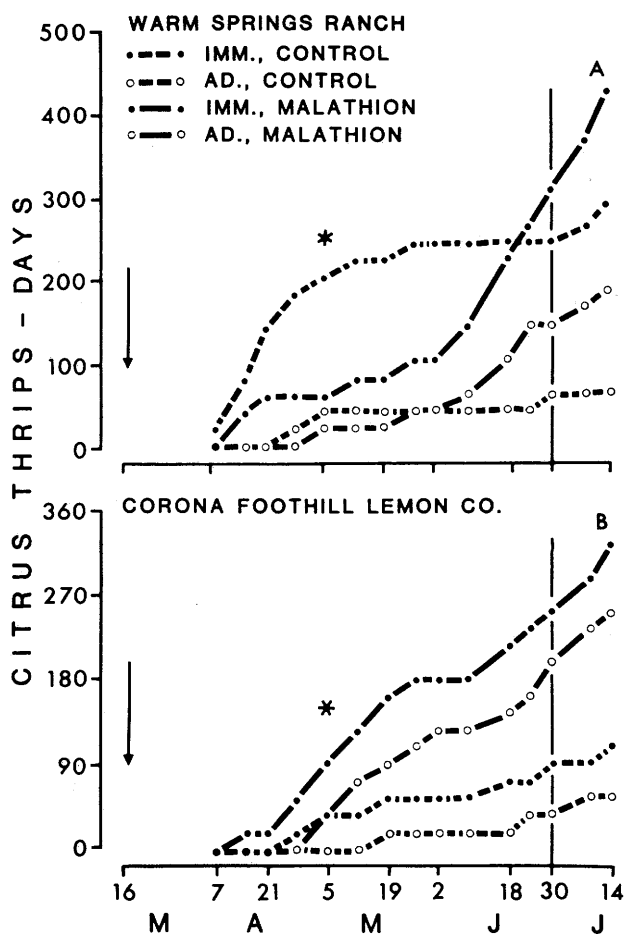


Figure 12. Accumulations of *Scirtothrips citri*-days on PVC-acetate traps placed under navel orange (A) and lemon (B) trees in 1981. Imm. = immatures, Ad. = adults, arrow = treatment date, \* = 100% petal fall, vertical line = end of critical injury period (from Tanigoshi et al. 1985).

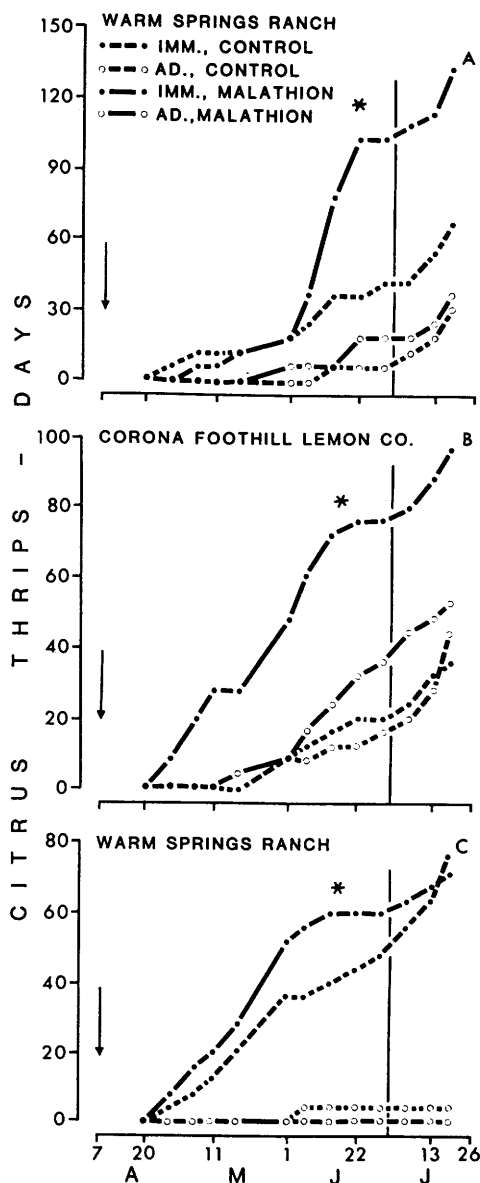


Figure 13. Accumulations of *Scirtothrips citri*-days on PVC-acetate traps placed under navel orange (A), lemon (B), and grapefruit (C) trees in 1982. Imm. = immatures, Ad. = adults, arrow = treatment date, \* = 100% petal fall, vertical line = end of critical injury period (from Tanigoshi et al. 1985).

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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## **POSTER PRESENTATIONS**

**A COMPUTER-COMPATIBLE KEY  
TO THE GENERA OF THE TUBULIFERA (THYSANOPTERA)**

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This poster is a representation of a key which could be adapted in a computer program for easy and quick identification of the genera of the Tubulifera (Fig. 1); (Chiasson 1985). The term "computer-compatible key" was given by Williams & Lauck (1982) to describe keys which have the following characteristics:

1. They have the capacity to be multidirectional.
2. They use multiple characters or multiple states of a character.
3. They are easier and faster to use than a dichotomous key and are accurate.
4. Characters can be randomly selected.

The computer compatible key offers several advantages over completely computerized keys since:

1. They can be used with or without a computer.
2. They can be written in a book format.
3. They are easier and faster to use than a dichotomous key and the computerized key. A bank of computer compatible keys can be developed quite easily.

The type of computer compatible key used here is the eliminator key, since it operates through the process of elimination. Here it uses characters that are considered to be diagnostic at the generic level, as well as other characters that show overlap or intergradation among the different genera. This key therefore does not group genera along an established taxonomic hierarchy.

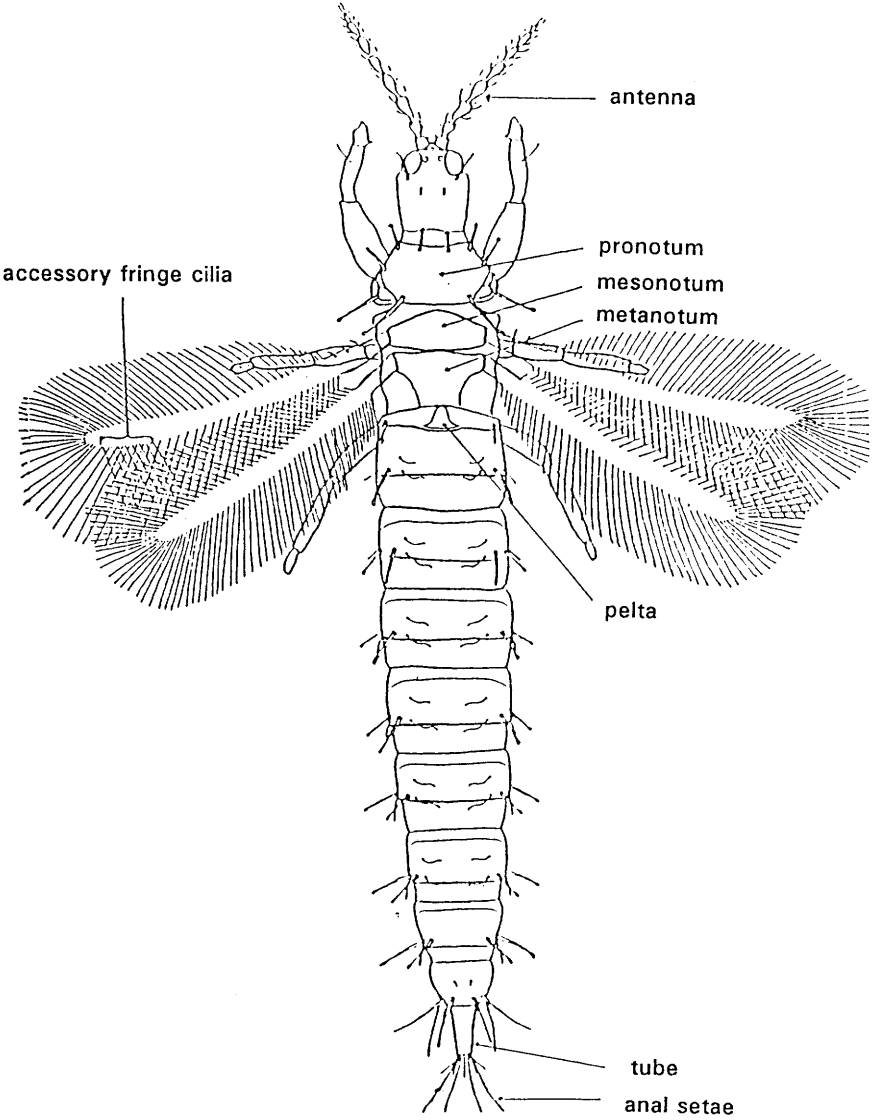


Figure 1. A Tubuliferan Thrips.



The key must start with a good description of the group to be identified. A letter is then assigned to each subgroup (in this case to each genus) (Table 1); these letters represent the genera in the key and all illustrations are identified by these letters. In this key, ten sets of characters or states of a character, are presented. These are followed by verification sheets, which are complete descriptions of the genera used in the key.

The descriptions of the genera of the Tubulifera are not given here but included are the characters used in the key for identification:

**Surface sculpturation:** from weak transverse striae to deep anastomosing striations, or strong hexagonal reticulation; restricted to a small area or extended over almost the entire body.

**Setae:** presence, form, length and position on body of the setae are all useful in classification at and below the generic level.

**Head:** the size of the eyes in relation to the head; the number of segments in the antennae; the presence and position of sensory trichomes on the antennae; the position and size of the postocular setae and setae or tubercles on the cheeks.

**Maxillary stylets:** the width, shape and position of the stylets are considered here in this key.

**Prothorax:** number, size and position of the pronotal setae.

**Wings:** wings may be fully, partially or not developed in the adults, i.e. macropterous, micropterous or apterous.

**Abdomen:** the sclerite on tergum I is reduced to a shield-like plate called the pelta. Although not usually considered as a diagnostic character, the pelta is given special consideration in this key.

Table 1. The genera of the Tubulifera in Canada

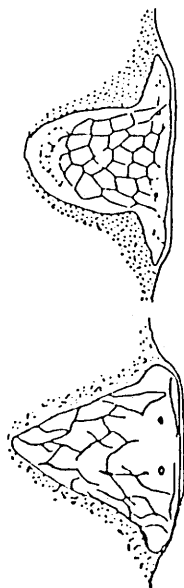
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A - Bolothrips	K - Hoplandothrips
B - Compsothrips	L - Poecilothrips
C - Cryptothrips	M - Stictothrips
D - Elaphrothrips	N - Lispothrips
E - Megalothrips	O - Cephalothrips
F - Megathrips	P - Lissothrips
G - Trachythrips	Q - Liothrips
H - Haplothrips	R - Gnophothrips
I - Leptothrips	S - Gynaikothrips
J - Acanthothrips	T - Hoplothrips

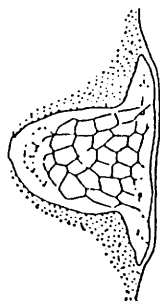
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a. Triangular



G H I L Q S

b. Bell-shaped



G K O

c. Rectangular



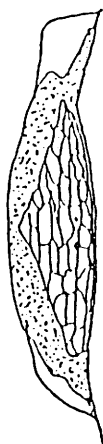
J

d. Broad with squared or flattened top



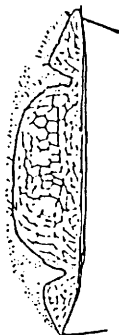
B N O P Q R T

e. Broad with tapered tip or pointed tip



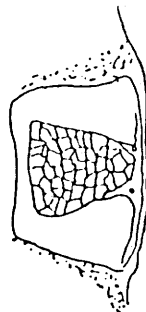
A C O

f. With lateral flanges



D E F

g. Square



M

Figure 2. Size and shape of pelta.

Figure 3. Wing shape and without wing.

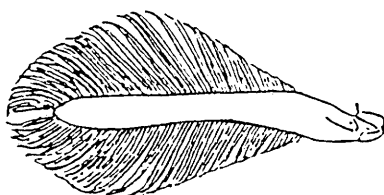
**Wing Length 5 Times Length of Head**

a - entire wing strap-like,  
membranous part parallel-sided  
throughout, with or without  
accessory fringe cilia



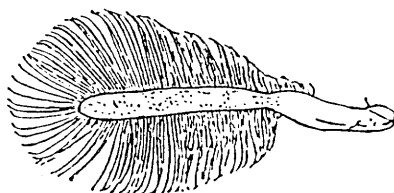
**A C D E F G L Q S T**

b - entire wing sole-shaped,  
membranous part medially  
basally enlarged, with or  
without accessory fringe  
cilia



**G H I K**

c - bent wing, membranous part medially constricted, basally  
enlarged, without accessory fringe cilia



**N**

**Wingless or Wing Length Less than 5 Times Length of Head**

d - forewing short,  
2 1/2 times length of head

e - brachypterous

f - apterous

**R**

**C D F K N P Q T**

**A B J P T**

### How To Use This Key

1. The first set in the key (Fig. 2) is first considered. After finding the correct shape of the pelta, the letters given for that particular pelta are recorded. (If the specimen has a pelta with a shape intermediate between two forms shown in the set, the letters shown under both forms need to be recorded.)

**Example:** if the specimen observed has a triangular pelta the letters recorded are:

G H I L Q S

2. Any other set can be next selected and the correct state is chosen. The letters that do not appear in both sets are crossed out.

**Example:** (Fig. 3) the wings of the specimen correspond with state "b" of this set, i.e. wing sole-shaped with or without accessory cilia

= G H I K

G H I

3. Other sets are selected subsequently and the remaining letters are eliminated as outlined in 2, until only one letter remains. As an option the verification sheets can be used when only two or three letters remain and the characters of the remaining genera can be compared with the specimen.
4. Once an answer is obtained this answer can be verified by using additional sets.

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## THE LIFE CYCLE OF PEAR THRIPS, *Taeniothrips inconsequens* (Uzel) IN VERMONT

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Life history information has been collected for pear thrips in orchard habitats in California and British Columbia (Cameron & Treherne 1918, Bailey 1944). However such information is not available for this insect in a northern hardwood forest ecosystem in the eastern United States. Research is currently underway at the University of Vermont to determine the pear thrips life cycle in Vermont sugarbushes. These data are urgently needed to assist researchers and forest managers in their efforts to develop methods to effectively manage this pest. Results from 1988-89 are presented here to provide preliminary life cycle information. Research is continuing to determine annual trends and variations in the pear thrips life history and to correlate these variations with weather conditions.

### Adult Emergence

Based on observational information, adult pear thrips emerged from the soil around 15 April 1988 in southern Vermont (B. Burns, personal communication). When they first emerge, these adults are light brown in color, but soon after emergence they turn dark brown or black (Fig. 1).

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<sup>1</sup> Vt. Agency of Natural Resources, Dept. of Forests, Parks and Recreation, Waterbury, Vt.



Figure 1. Pear thrips adult female on leaf vein of sugar maple (photo by T. E. Downer).

### Feeding

Pear thrips ascend to the canopy after emerging from the soil to seek opening buds, into which they crawl and begin feeding. The most severe damage to maple leaves occurs as a result of thrips feeding for a prolonged period within the partially opened buds. Brown margins on developing leaves at the tip of opening buds are the characteristic early signs of thrips damage (Fig. 2).





Figure 2. Characteristic pear thrips damage on sugar maple buds as they begin to open.

### Oviposition

Soon after emergence pear thrips commence oviposition. Eggs are laid on the undersides of leaves primarily in the mid-veins, and less commonly in secondary veins. Oviposition also occurs on the leaf petiole. A brownish scar remains in the leaf tissue after the thrips larva hatches from the egg (Fig. 3).

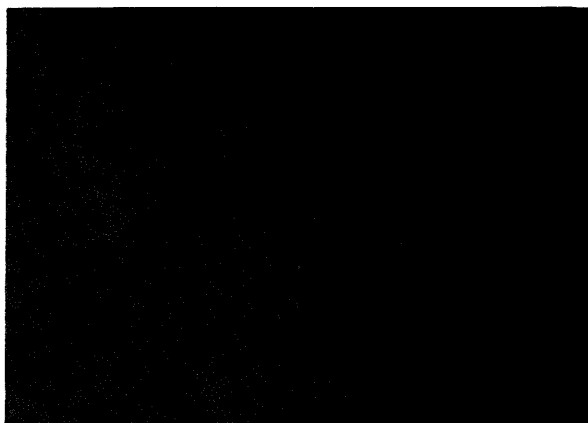


Figure 3. Pear thrips oviposition scars along the main vein on the underside of a sugar maple leaf.

### Larval Hatch

In California, larvae hatched from the egg in the leaf within 6 - 7 days, depending on temperature (Bailey 1944). It is likely that pear thrips in Vermont require a similar incubation period. Based on our observations, once hatch begins, the first instar emerges from the egg within 20 - 30 minutes. The larva, with the characteristic red eyes visible, wiggles vigorously to free itself from the egg (Fig. 4).

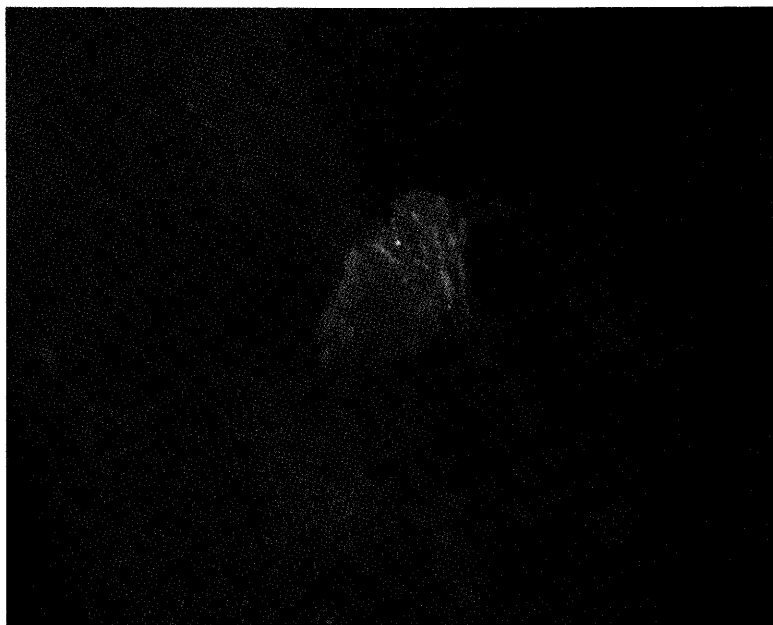


Figure 4. A pear thrips larva hatching from an egg within the leaf vein. The characteristic bright red eyes are clearly visible (photo by T. E. Downer).

## Larval Development

Pear thrips have two instars. First instars are slightly smaller than seconds, but it is difficult to differentiate the two (see Nakahara, this publication). The second instar is fairly distinctive, having a prominent ring of sclerotized spines at the base of the abdomen that are visible at 10x magnification (Fig. 5). Larvae can be found commonly congregating on the undersides of leaves at the base of the leaf veins.

Second instars drop from the foliage in early June. They can be found on a wide variety of ground vegetation. Significant damage to first- and second-year sugar maple seedlings can occur as a result of feeding by thrips larvae at this time of year. By the end of June most of the larvae have left the foliage to enter the soil. Once in the soil they construct an overwintering chamber by tamping down the sides of the cavity with their abdomen (Bailey 1944). Though basically inactive once in the soil, they will move about if disturbed.

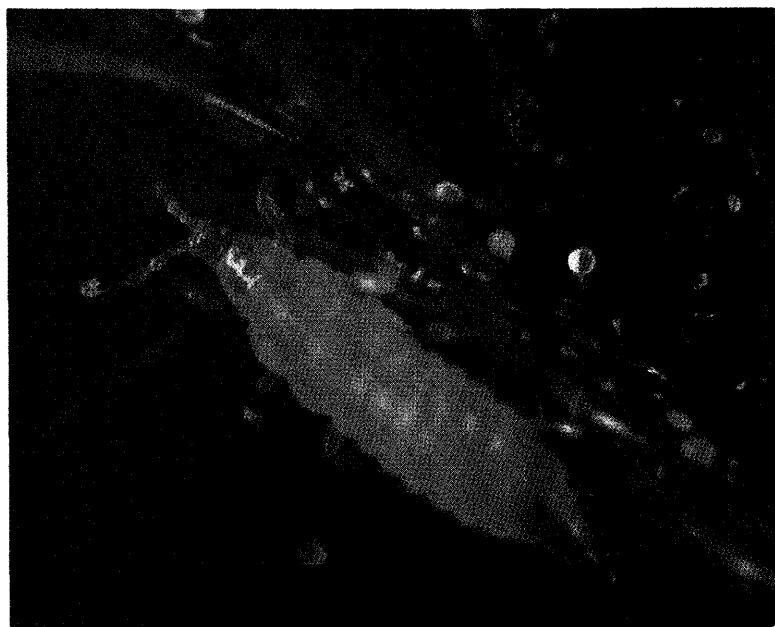


Figure 5. Second instar pear thrips (photo by T. E. Downer).

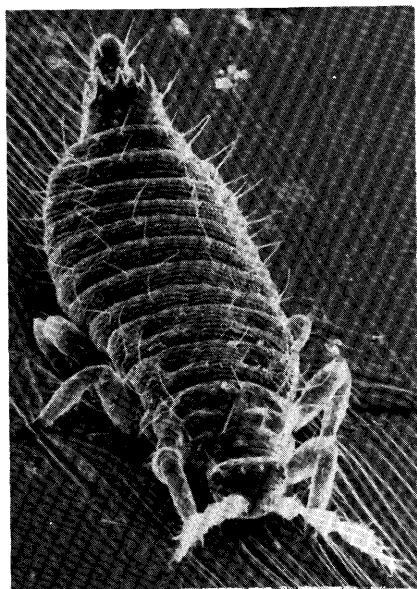


Figure 6. Second-instar pear thrips (SEM by G. M. Hendricks).

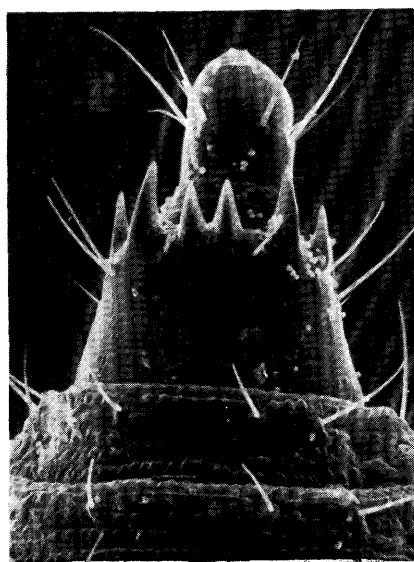


Figure 7. Abdominal spines on second-instar pear thrips (SEM by G. M. Hendricks).

In Vermont, pre-pupae and pupae (Fig. 8 and 9) were first found in soil samples taken on 15 September 1988. The fact that both life stages were found simultaneously suggests that the pre-pupal stage is relatively short. The differences between the two stages are difficult to distinguish because development is gradual. The wing pads slowly elongate, ultimately reaching beyond the base of the abdomen at which time it is considered a pupa.

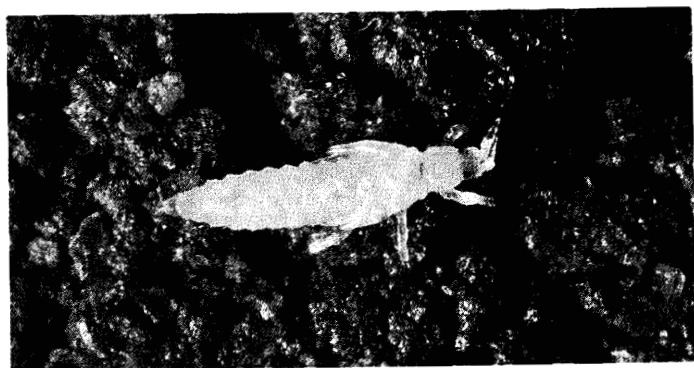


Figure 8. Pear thrips pre-pupa (photo by T. E. Downer).



Figure 9. Pear thrips pupa (photo by T. E. Downer).

### Adulthood

Pear thrips transformation to adulthood is gradual. Though they still resemble pupae, being fleshy, soft-bodied and whitish in color, fringes on the wings can be detected in the early stages (Fig. 10). Pear thrips finally complete adult development, but remain a light honey color (Fig. 11). Completion of the tanning process occurs after they emerge from the soil in spring.



Figure 10. Pear thrips collected from the soil during transformation from the pupal to adult stage. Note the soft-bodied appearance suggesting the pupal stage and fringes on the wings, an adult characteristic (photo by J. K. Clark).

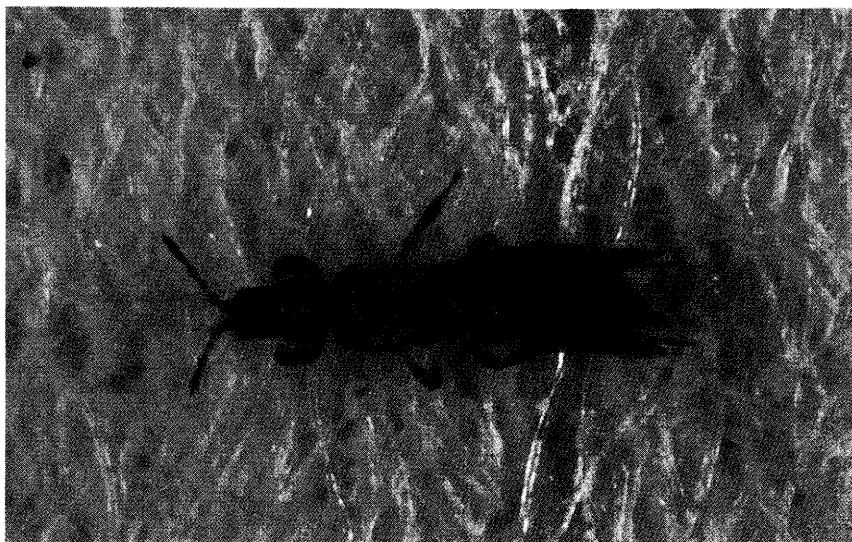


Figure 11. Teneral adult pear thrips collected from the soil (photo by T. E. Downer).

Table 1. Pear thrips, *Taeniothrips inconsequens* (Uzel), life cycle information. Central and southern Vermont sugarbushes, 1988

Event	Date
Emergence of adults from the soil	15 April
Second instar enters the soil	15 June
Prepupae and pupae found in the soil	15 September
First adults collected in the soil	26 October
Last pupa found in the soil	11 November

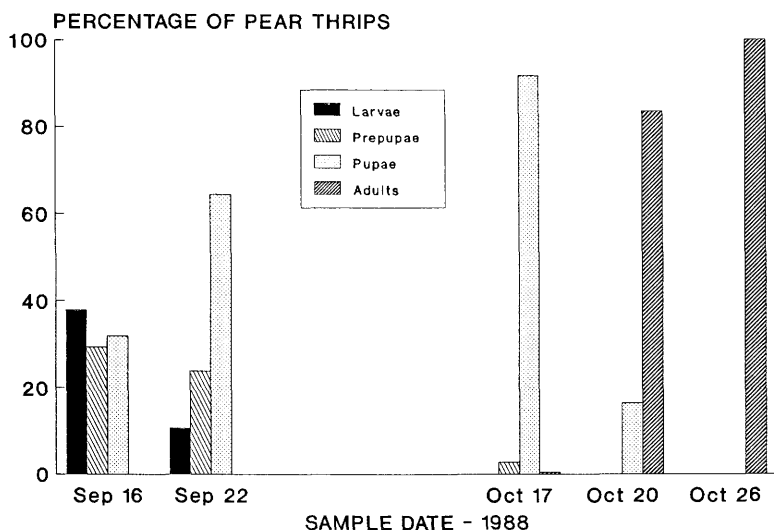


Figure 12. Percentages of life stages of pear thrips, *Taeniothrips inconsequens* (Uzel), found in soil samples taken in Randolph, Vt.

#### References Cited

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- Cameron, A. E. & R. C. Treherne. 1918. The pear thrips (*Taeniothrips inconsequens* (Uzel)) and its control in British Columbia. Can. Dep. Agric. Entomol. Branch Bull. 15.



## **A METHOD FOR EXTRACTING PEAR THRIPS FROM FOREST SOILS**

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### **Introduction**

A standardized method of extracting pear thrips from forest soils, modified from a procedure of Walter et al. (1987) was developed. Several factors were considered of prime importance when developing this extraction method:

1. Accuracy of determining number of thrips per sample,
2. Minimization of extraction processing time,
3. Simplicity of methodology,
4. Consistency of extraction efficiency,
5. Cost.

### **Soil Sampling**

Samples are taken with a hand-held tulip bulb planter (5.72 cm diameter, 10.16 cm length), giving a volume of about 261.09 cm<sup>3</sup> of soil and bagged individually (Fig. 1). The leaf litter is removed prior to taking soil samples. Our research has shown that thrips are not found in this litter layer in September and October, when soil samples are collected. Removal of this light organic matter increases the rate of extraction by reducing the amount of material that floats with the thrips.



Figure 1. Pear thrips soil sampling using a hand-held bulb planter.

### Sample Rinsing and Sieving

Thrips are separated from the homogenized soil using USA Standard full height testing sieves (ASTME-11 specification) arranged in three tiers with a top sieve (205-mm diam) with 2.0-mm mesh, a middle sieve (305-mm diam) with 850-micron mesh and a bottom sieve (305-mm diam) with a 250-micron mesh. The sample is placed in the top sieve and washed with water using a 100-cm wide water breaker fan attached to a hose (Fig. 2). Remaining clumps of soil are broken apart by hand. Disposable surgical gloves are worn to protect the hands. The top sieve is lifted to allow the underside to be lightly rinsed over the second sieve, thereby removing any thrips that may adhere to the bottom. This rinsing procedure is repeated with the middle sieve. The residues from the first two sieves are then discarded.



Figure 2. Rinsing of soil sample to remove large pieces of organic matter prior to flotation.

The residue from the bottom sieve is rinsed with cold water into a 1-litre Nalgene bottle, sealed with a tight-fitting screw cap and stored at about 5°C for 8-12 hours or processed immediately as described below. Samples containing a large amount of organic matter are generally stored for about 8 hours to allow some of the unwanted organic matter to become waterlogged and sink during the flotation process.

#### **Heptane Extraction/Flotation Process**

Protective goggles should be worn during the following procedures. The contents of the Nalgene bottle are poured through a short stem funnel into a 2000 ml separatory funnel which is positioned on a ring stand in a fume hood. The Nalgene bottle and sides of the funnel are rinsed with water from a plastic squeeze bottle to ensure all contents reach the separatory funnel.

Additional water is added until the total volume in the separatory funnel is 1,215 ml. To facilitate this a line is drawn on the separatory funnel indicating the approximate level desired. Next, using an automatic dispensing pipette, 50 ml of technical grade heptane is added (Fig. 3). This forms a 3-mm layer above the water and organic matter (Fig. 4).

The separatory funnel is removed from the ring stand and held in a horizontal position. The contents is gently shaken back and forth to remove the organic matter that might be lodged in the funnel stem or neck and then the funnel contents is rotated 10 times to mix the heptane with the water - organic matter layer (Fig. 5). Each rotation should be done in the same deliberate manner, pausing between each swirl to allow separation within and taking care not to use excessive vigor (force). To avoid organic matter becoming lodged in the neck, the funnel is tipped slightly during the rotation process. The contents is then shaken back and forth 10 times. This completes the mixing and the separatory funnel should be returned to the ring stand.



Figure 3. Addition of 50 ml of heptane to separatory funnel for flotation of thrips from soil residue.



Figure 4. Separatory funnel containing water, soil residue with thrips and a thin layer of heptane floating on the surface. Thrips float at the water-heptane interface.



Figure 5. Agitation of material in the funnel to stir heptane into the sample residue solution.

The glass stopper is removed to relieve internal pressure and the sides are rinsed into the funnel with a small amount of water from a squeeze bottle. The separatory funnel is returned to the ring stand and left to stand for a minimum of two minutes to allow the heptane to partition from the water, the organic matter to sink and the thrips to move to the water-heptane interface. The stop-cock is opened carefully and the water and debris are allowed to drain slowly until approximately 60 ml of water and the heptane remains in the funnel. Care is taken not to open the stop-cock to the point where a whirl-pool motion occurs during the draining. To remove fine debris if it adheres to the side of the separatory funnel, the drainage process is stopped and the funnel side is tapped or the funnel is shaken near the stem. Care is taken not to overly agitate the entire contents of the funnel as thrips may be forced down into the portion being drained.

The layer of heptane and remaining water is drained onto a disposable prefolded coffee filter over a Buchner funnel attached to a suction pump (Fig. 6). The sides of the separatory funnel are rinsed to

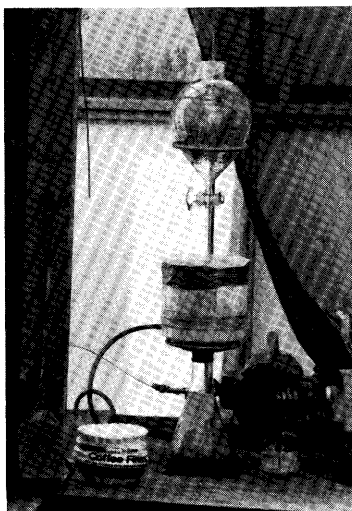


Figure 6. Drainage of thrips and light organic matter onto paper filter over Buchner funnel.

remove any organic material or thrips that may remain. More than one filter are used if a large amount of organic matter residue is obtained in the flotation process.

### Thrips Counting Procedure

The paper filter is spread smoothly onto a 20 x 20 cm glass plate marked with a 1-cm<sup>2</sup> grid. This is placed on a light table and thrips are counted using a binocular microscope with 8x magnification. For species identification, slide mounts are made for viewing under high power. Testing is underway at the Entomology Research Laboratory to test the efficiency of this extraction method for recovering pear thrips from the soil.



Figure 7. Inspection of filter containing organic matter and thrips over an illuminated light table.

### Acknowledgment

Funding for this research was provided by the North American Maple Syrup Council and the USDA, Forest Service. Particular thanks go to the technical staff from the Univ. of Vermont who have assisted in the development and testing of this extraction method.

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Thirty-one papers and three posters on the systematics, biology, behavior and management of Thysanoptera, with particular reference to *Taeniothrips inconsequens* (Uzel), pear thrips, presented at an international conference in Burlington, Vermont.

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