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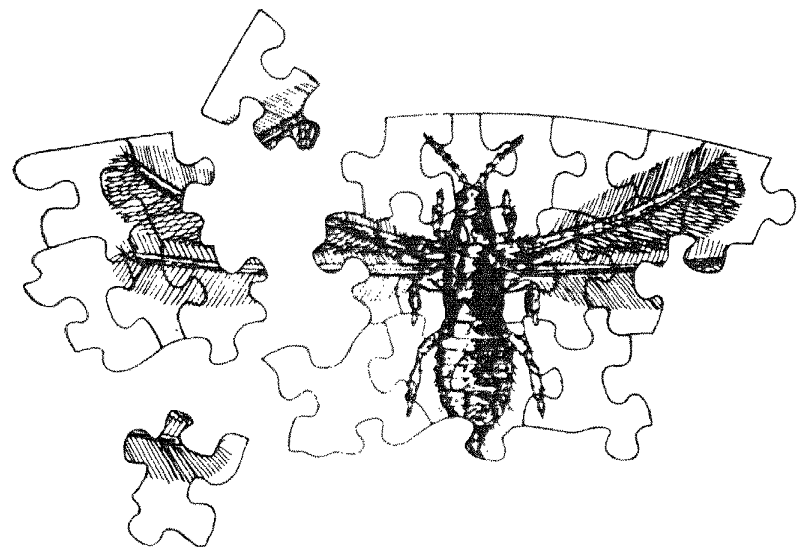
General Technical Report NE-147

Towards Understanding Thysanoptera



Editors:

Bruce L. Parker
Margaret Skinner
Trevor Lewis

ACKNOWLEDGMENTS

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

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TOWARDS UNDERSTANDING THYSANOPTERA

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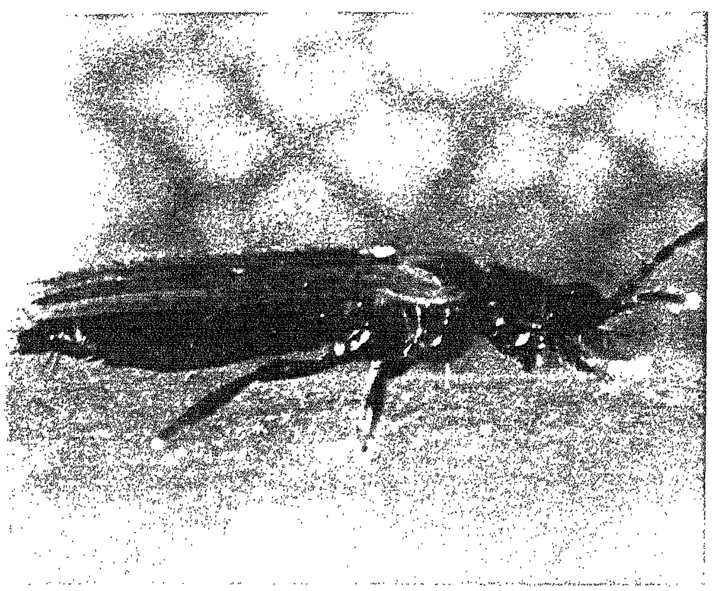
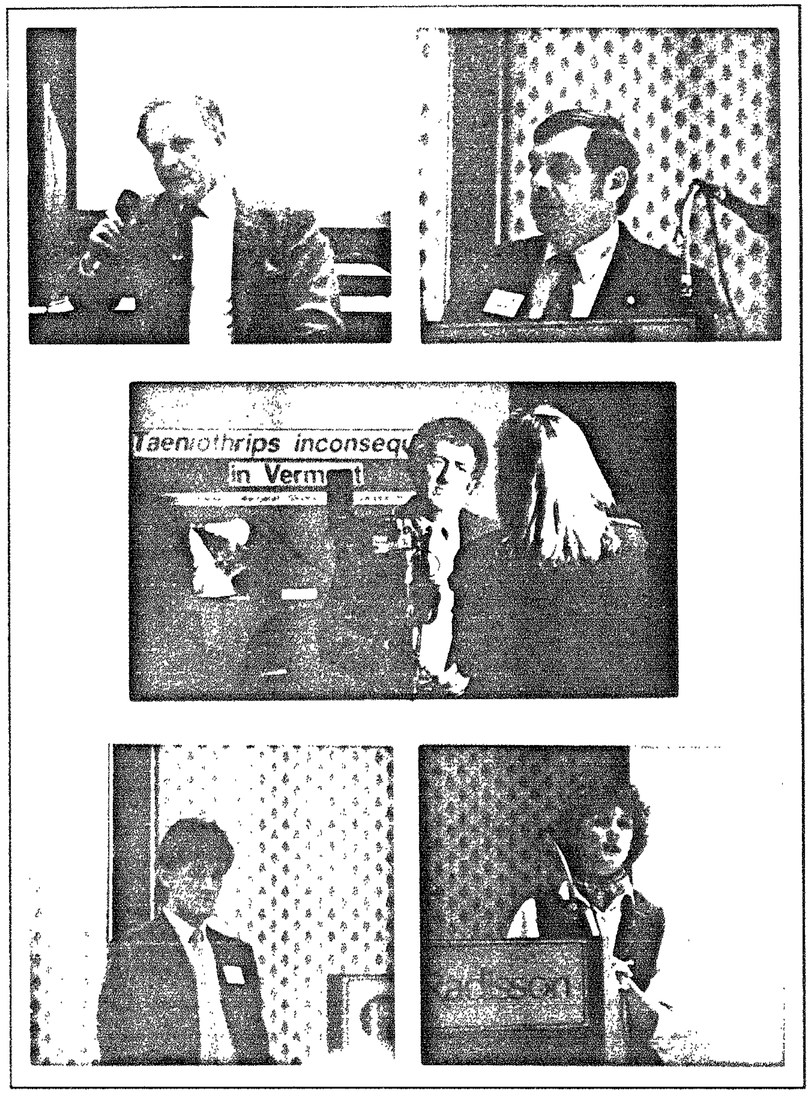


PEAR THRIPS, *Taeniothrips inconsequens* (Uzel)
(photo by T. E. Downer)



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

PREFACE

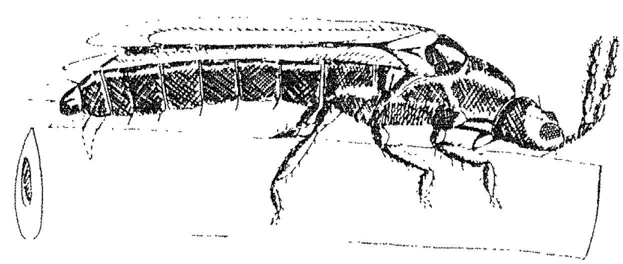
Pear thrips, *Taeniothrips inconsequens (Uzel)*, first surfaced as a pest of sugar maple, *Acer saccharum* Marsh, in Pennsylvania in the late 1970s. Though similar damage was observed in Vermont in the early 1980s, it was probably misdiagnosed as frost damage until 1985, when finally thrips were positively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

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

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

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

PEAR THRIPS IN VERMONT



Taeniothrips inconsequens (Uzel)

THE PEAR THRIPS PROBLEM

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As entomologists, we sometimes like to think of an ir problem as simply a problem with an insect and its host. would be much easier if that were the case, but of course, i that simple. There are many other factors besides the insect, one must be fully considered to understand the problem an effective management solutions. In this case I see many fact us besides the pear thrips and the sugar maple tree. (Fig. 1

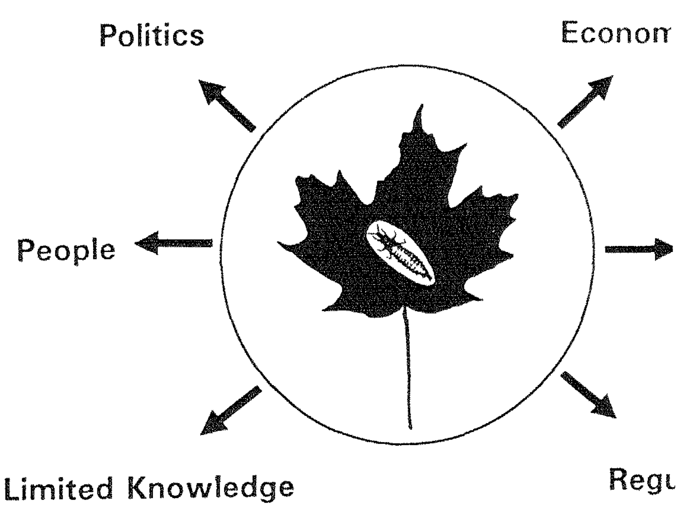


Figure 1. Key factors associated with the pear thrips

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.

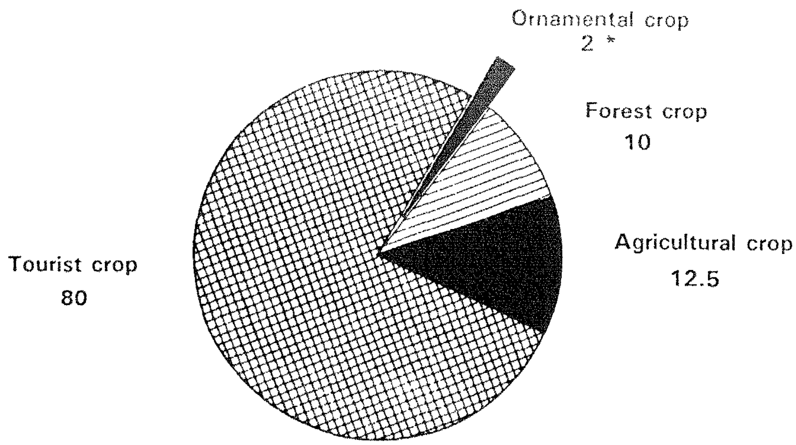
Time plays a crucial role in the problem of pear thrips in two respects. First, consider the life cycle of this insect; it is active above ground for such a short period, about two and one-half months. That gives us very little time to carry out the essential research to find the answers needed to develop 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).

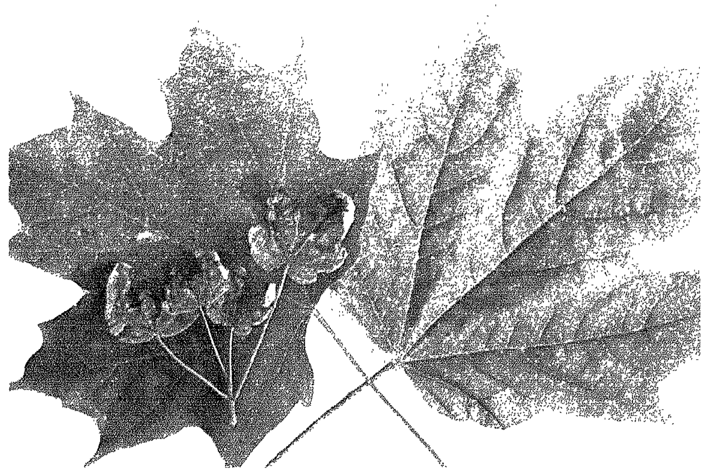


Figure 3. Healthy and pear thrips-damaged maple leaves.

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

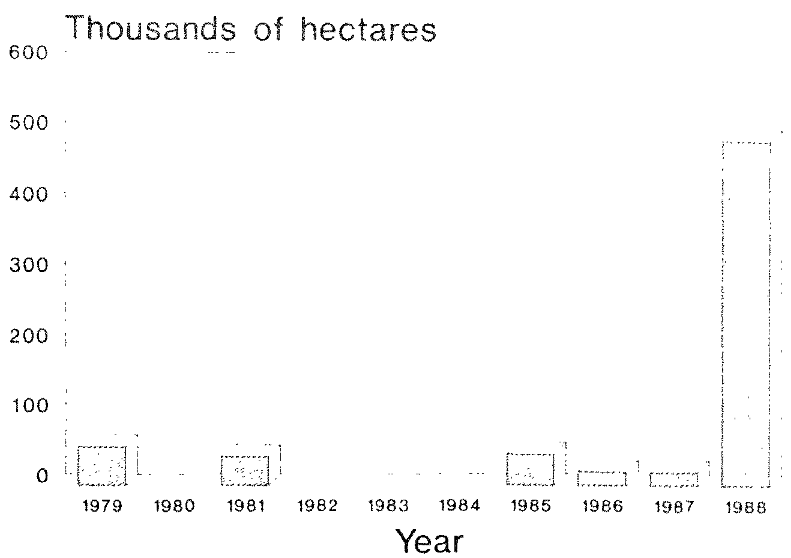


Figure 5. Pear thrips damage in Pennsylvania, based on aerial sketch mapping.

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.

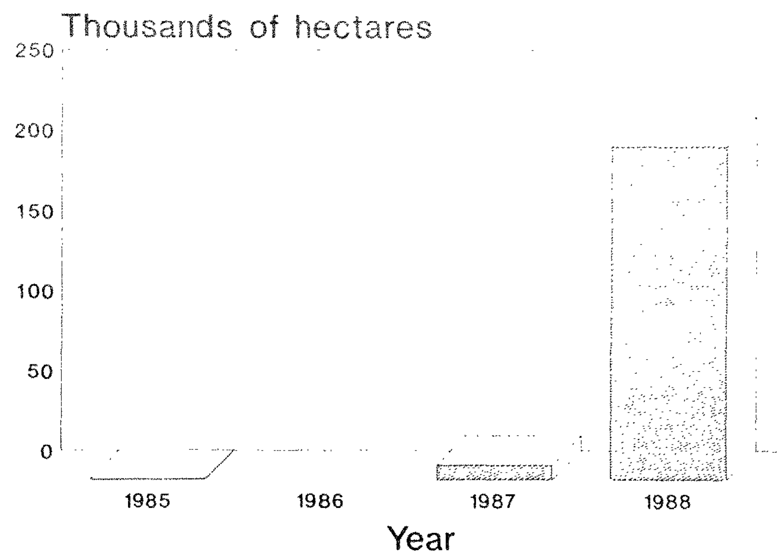


Figure 6. Pear thrips damage in Vermont, based on aerial sketch mapping.

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.

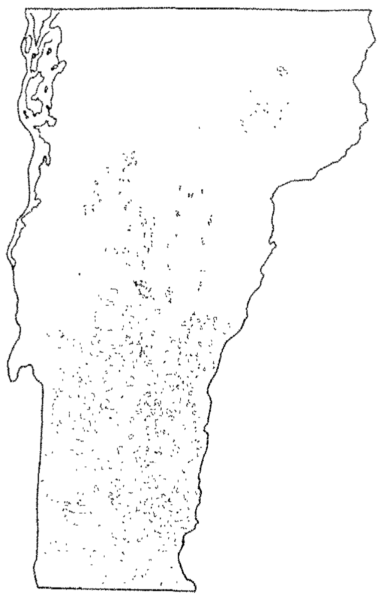


Figure 7. Areas of severe pear thrips damage in Vermont determined from aerial sketch mapping in 1988 (Teillon et al. 1988).

References Cited

Bailey, S. F. 1944. The pear thrips in California. Univ. Calif. Bull. 687. 55 pp.

Department of Forests, Parks and Recreation. 1988. Vermont forest facts. VT Department of Forests, Parks and Recreation. Agency of Natural Resources, Waterbury, VT.

Houston, D, D. Allen & L. Abrahamson. 1988. Expected impact to trees in sugarbushes and forest stands, pp.80-94. *In* B. L. Parker, M. Skinner & H. B. Teillon [eds.], Proceedings Regional meeting: "The 1988 thrips infestation of sugar maple". Bennington, VT June 23. Vt. Agr. Exp. Sta. Bull. 696 Univ. Vt., Burlington.

Laudermilch, G. 1988. Thrips in Pennsylvania, pp. 36-62. *In* B. L. Parker, M. Skinner & H. B. Teillon [eds.], Proceedings Regional meeting: "The 1988 thrips infestation of sugar maple". Bennington, VT June 23. Vt. Agr. Exp. Sta. Bull. 696 Univ. Vt., Burlington. 113 pp.

Parker, B. L., R. S. Walters, H. B. Teillon & C. M. Boulanger. 1977. Carbaryl residues in sugar maple sap. J. Econ. Entomol. 70:785-788.

Teillon, H. B., B. S. Burns & R. S. Kelley. 1985 - 1988. Forest insect and disease conditions in Vermont, calendar years 1985 - 1988. Vt. Agency of Natural Resources, Dept. of Forests, Parks and Recreation, Waterbury, Vt.

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[1] 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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[1] 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.

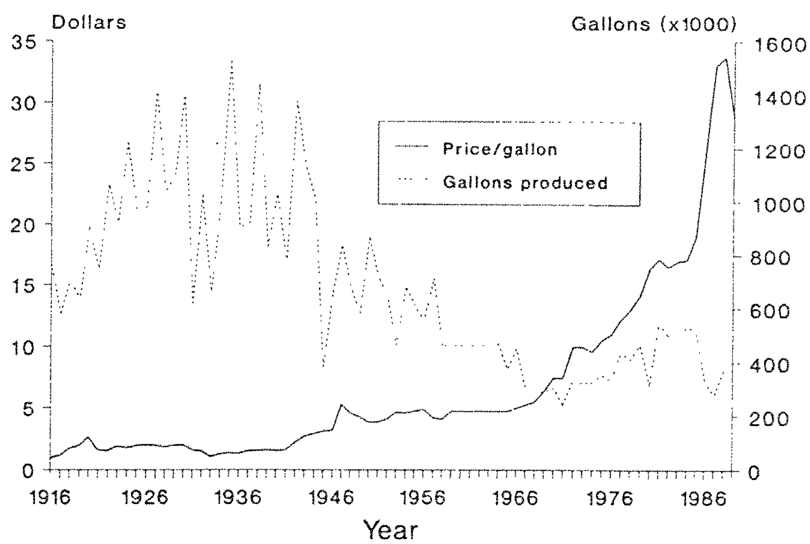

Figure 1. Average price per gallon of maple syrup and the number of gallons produced in Vermont from 1916 - 1989 (from VT Department of Agriculture).

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.

References Cited

Department of Agriculture. 1989. New England Agricultural Statistics. USDA.

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[1]?" 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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[1] 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^2) 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^2 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.

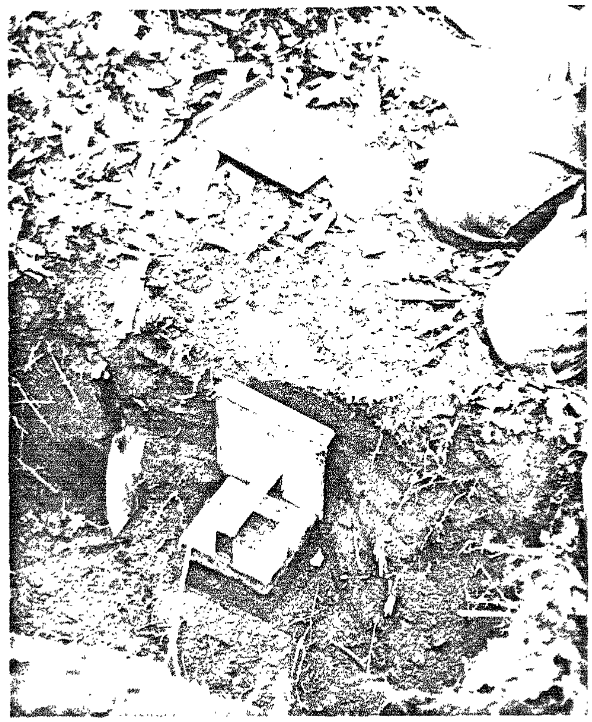

Figure 1. Pit sampling to determine vertical distribution of pear thrips in forest soil.

Prior to extraction, samples were stored in a refrigerator at 4°C. Thrips were extracted in the laboratory, using the magnesium sulfate flotation method[2] 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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[2] 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^3 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.

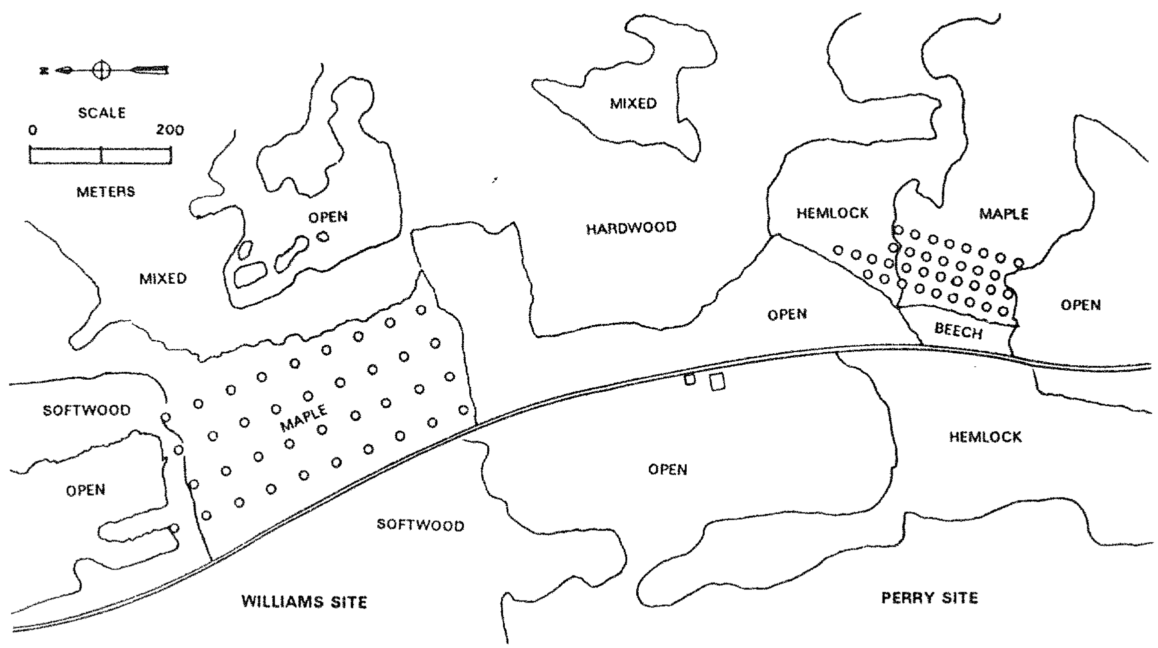

Figure 2. Sampling grid system in pear thrips research sites to determine thrips distribution in forest soil; open circles indicate location of sample tree. Predominant vegetation type within and adjacent to sites are indicated, Mixed = mixture of softwoods and hardwoods, open = pasture land (drawn by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

[a] 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^3) 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^3), 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.

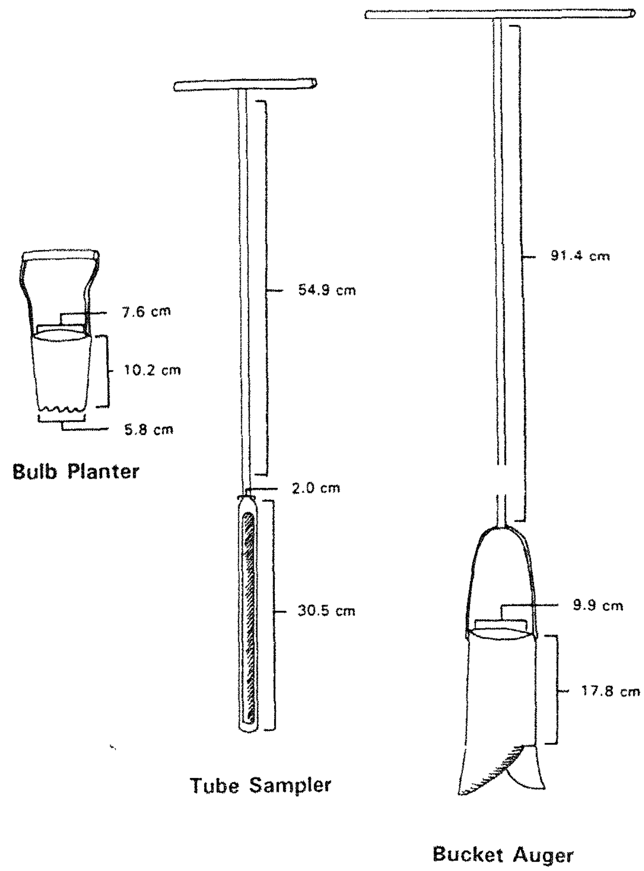

Figure 3. Soil sampling tools tested for sampling pear thrips in Vermont forest soils (drawn by L. Cravedi-Cheng).

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 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 ± 12 thrips per sample and 5 ± 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.

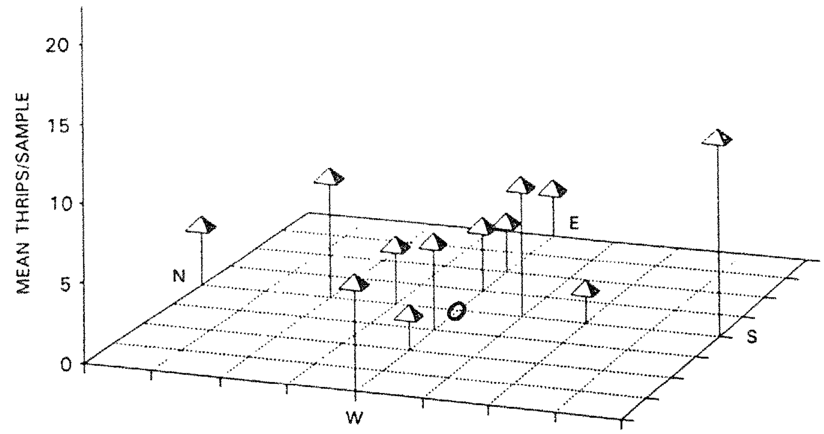

Figure 4. Mean number of pear thrips per sample at 1, 2 and 4 m from the bole of sugar maple trees at the four cardinal directions (mean derived from four sample trees). The center circle represents the bole of the sample tree and the pyramids indicate the mean number of thrips at each sample location.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

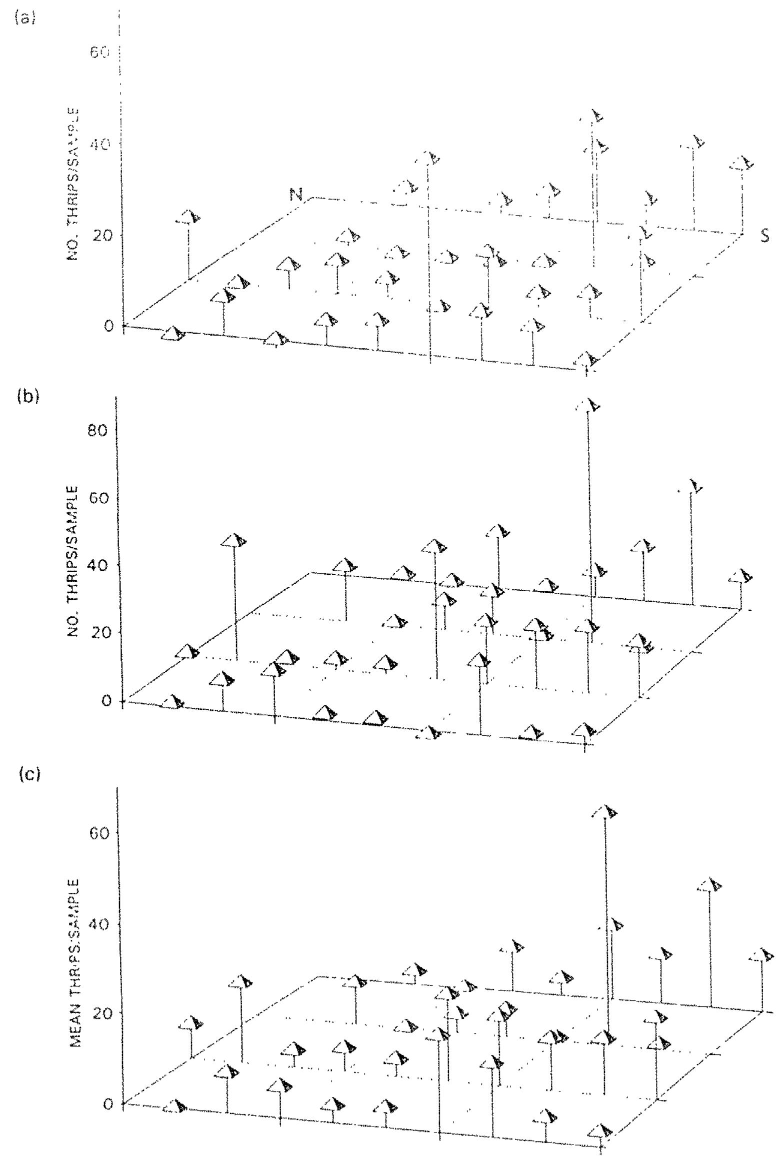

Figure 5. Number of pear thrips per sample in the Perry sampling grid (see Fig. 2) at (a) 2 m from the tree, (b) 4 m from the tree, and (c) the mean from samples at 2 and 4 m. All samples were taken on the south side of each tree and trees were located about 25 m apart.

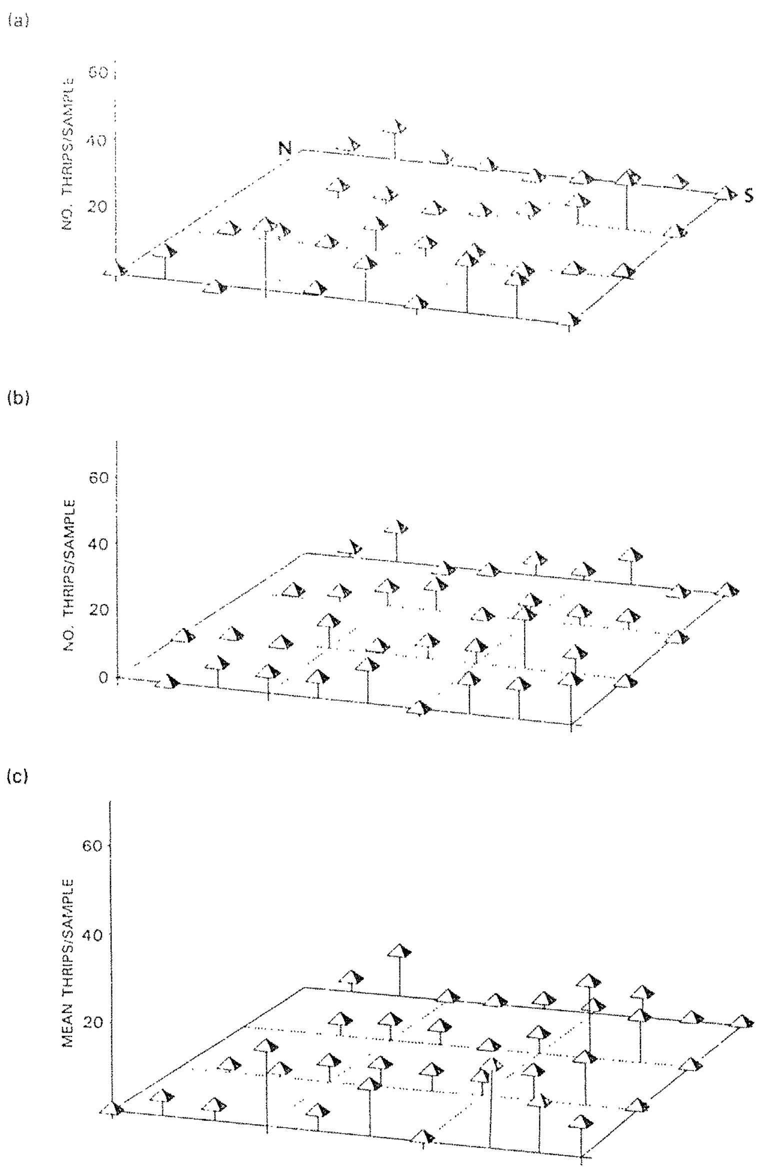

Figure 6. Number of pear thrips per sample in the Williams sampling grid (see Fig. 2) at (a) 2 m from the tree, (b) 4 m from the tree, and (c) the mean from samples at 2 and 4 m. All samples were taken from the south side of each tree and trees were located about 50 m apart.

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 ± 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.

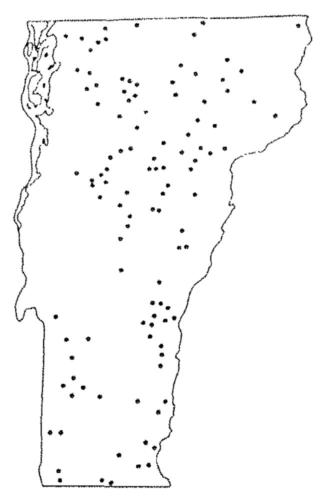

Figure 7. Map of Vermont showing the location of sites in which soil sampling was conducted for the Statewide Pear Thrips Soil Survey.

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.

References Cited

Bailey, S. F. 1944. The pear thrips in California. Univ. of Calif. Bull. 687. 55 pp.

Edwards, C. A. & K. E. Fletcher. 1970. The assessment of terrestrial invertebrate populations, pp. 57-66. *In* J. Phillipson [ed.], Methods of study in soil ecology. Proc. UNESCO and IBP Symposium, Paris.

Moulton, D. 1907. The pear thrips (*Euthrips pyri* Daniel). USDA Bur. Entomol. Bull. 68, Pt. 1. 16 pp.

Parker, B. L., M. Skinner & H. B. Teillon. 1988. Proceedings, Regional Meeting: "The 1988 thrips infestation of sugar maple". Bennington, VT June 23. Vt. Agr. Exp. Sta. Bull. 696. Univ. VT, Burlington. 113 pp.

Parker, B. L. M. Skinner & J. R. Grehan. 1989. A mechanized soil extraction system for determining population densities of pear thrips in sugarbushes. Final Res. Rep. to North American Maple Syrup Council. Entomology Research Laboratory, South Burlington, Vt.

Skinner, M. & B. L. Parker. 1989. Vermont soil survey for pear thrips, protocol for statewide sampling program. Research Report, January 20, 1989. Entomology Research Laboratory, South Burlington, Vt.

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 then 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

$$\mu(x) = E[v(x)] \tag{1}$$

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

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

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

and

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

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*:

$$\gamma(x,x') = \gamma(x-x') = \gamma(h) \tag{5}$$

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

For a particular time, let us sample thrips at locations $x_1,\ldots, x_n$. Let v_i be the mean number of thrips per sample at location x_i, and i = 1, ..., n. Given the data (x_i, v_i), i = 1, ..., 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 $\hat{v}(x) = \Sigma a_i v(x_i)$ and select a_i such that:

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

and

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

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

$$\hat{v}(x) = \Sigma a_i v(x_i) \qquad (8)$$

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 cov (x,x'). For the variogram we use the exponential model:

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

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, ..., n and j = 1, ... k. The data will be given in the form (x_i, t_j, v_{ij}), i = 1, ..., n and j = 1, ..., 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, ...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.

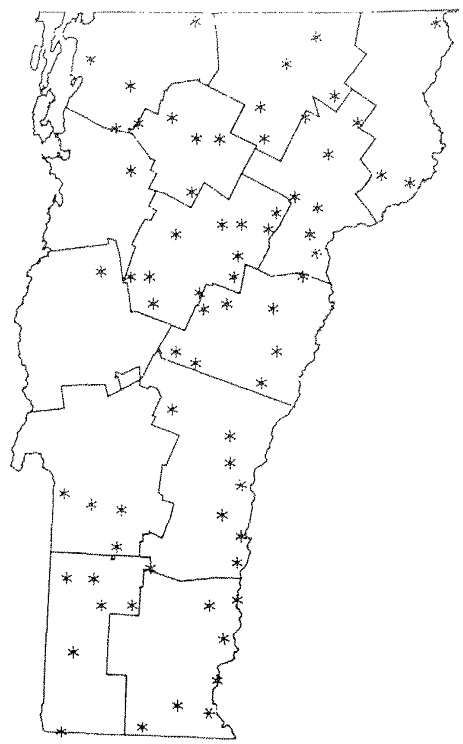

Figure 1. Townships (*) in which samples were taken for the Vermont Pear Thrips Soil Survey in 1988-89.

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.

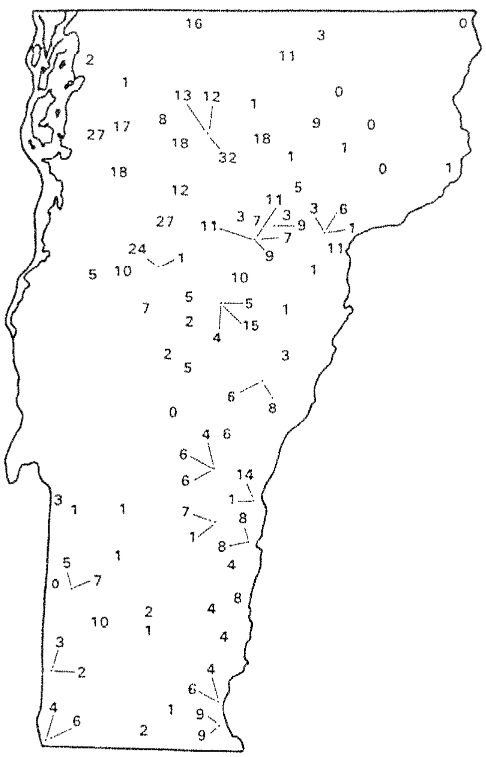

Figure 2. Scatter diagram of the mean number of thrips per sample in sites sampled for the Vermont Pear Thrips Soil Survey in 1988-89.

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.)

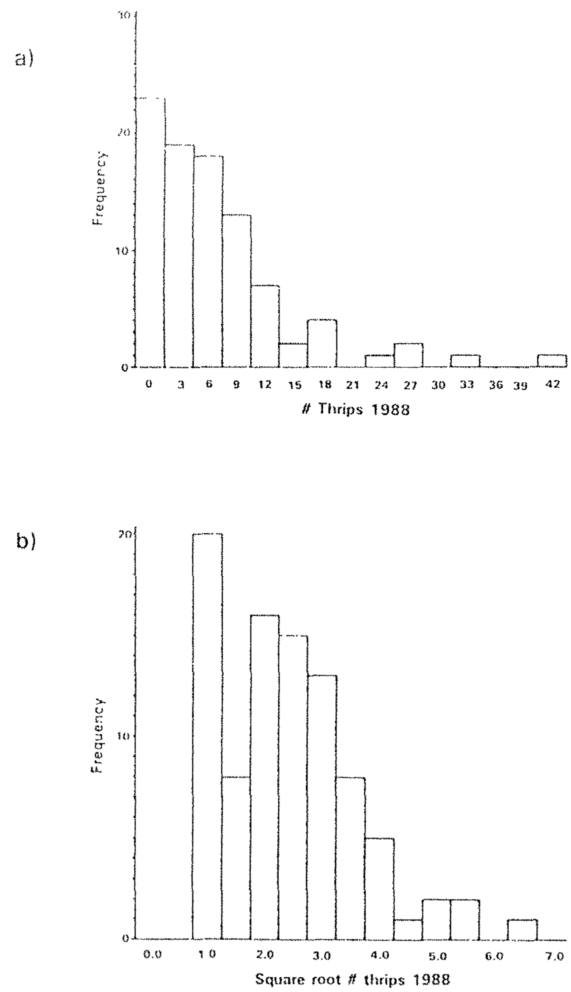

Figure 3. Histograms of the mean number of thrips per sample for each site sampled for the 1988-89 Vermont Pear Thrips Soil Survey, a) for the original data, b) for the transformed data, $\sqrt{v_i + 3/8}$.

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).

a)

b)

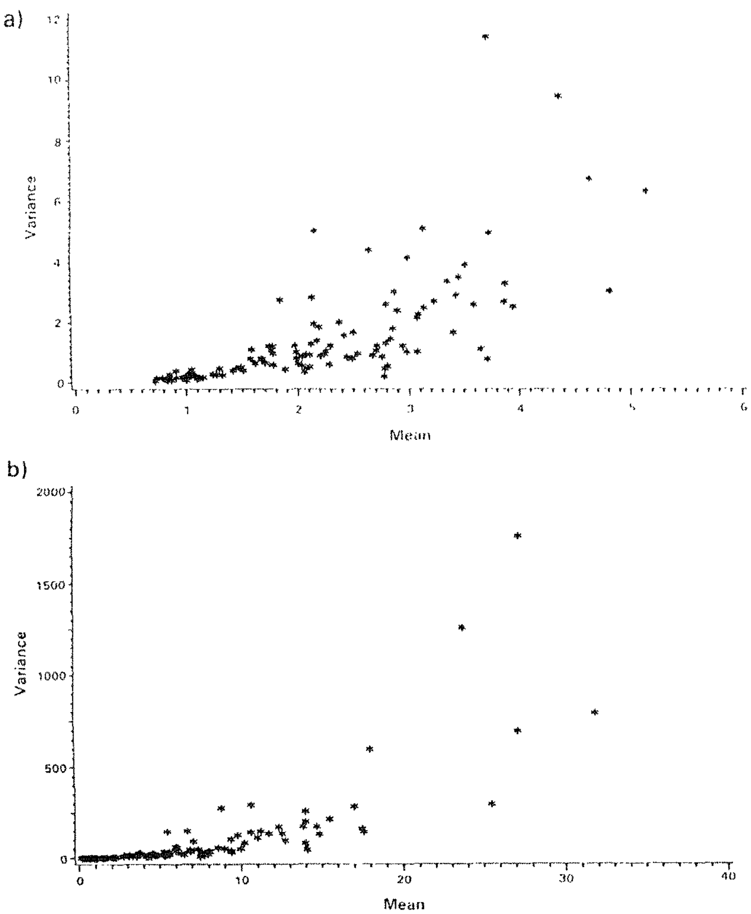

Figure 4. Plots of variance versus the mean number of thrips per sample from the Vermont Pear Thrips Soil Survey in 1988-89, a) for original data, b) for transformed data, $\sqrt{v_i + 3/8}$.

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, and x'. 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 ÷ 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 ± 0.4 to 3.6 ± 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.

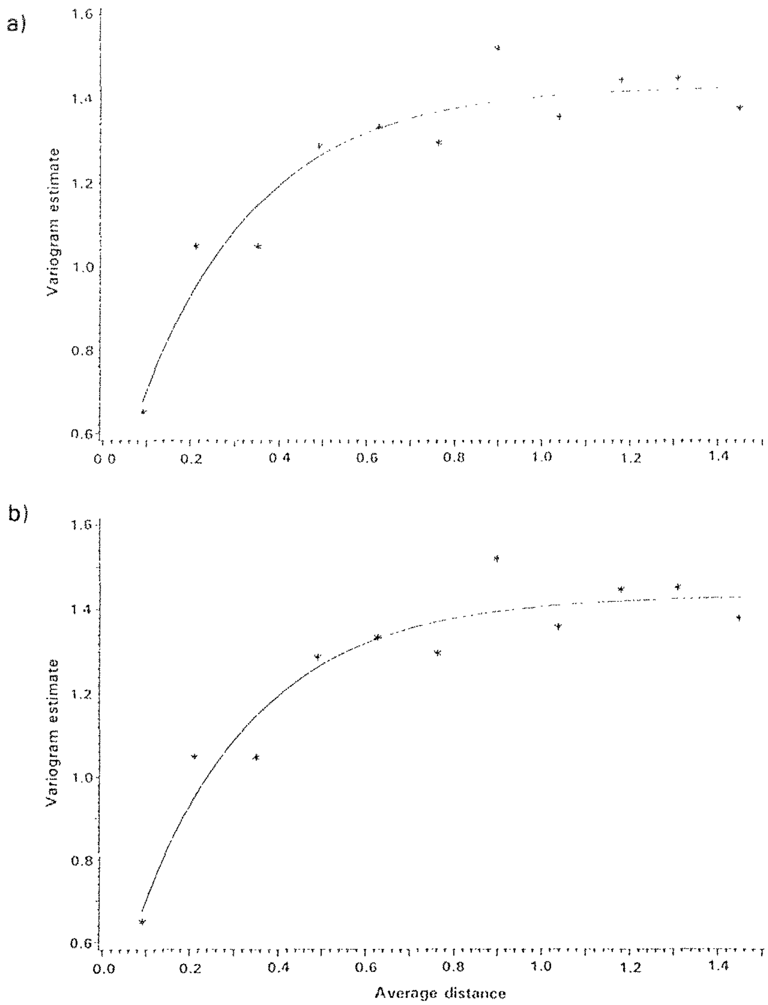

Figure 5. Variograms for data from the Vermont Pear Thrips Soil Survey in 1988-89, a) for original data, b) for transformed data, $\sqrt{v_i + 3/8}$.

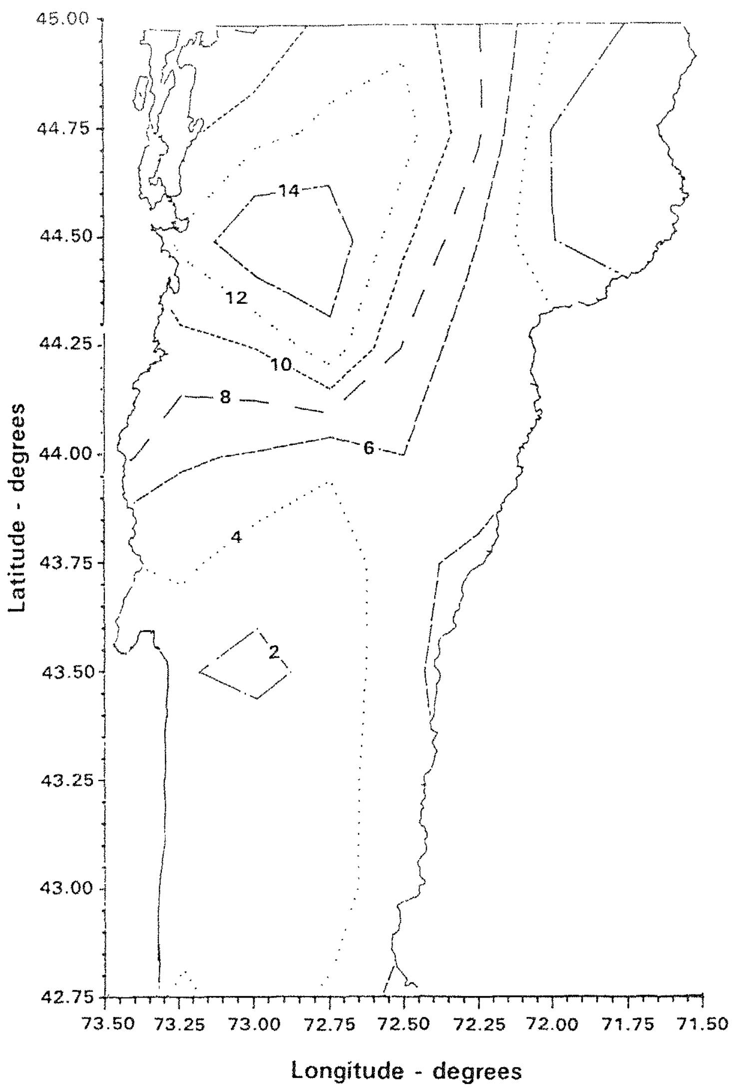

Figure 6. Map of Vermont showing contours for thrips density based on Kriging estimates from original data of the Vermont Pear Thrips Soil Survey in 1988-89.

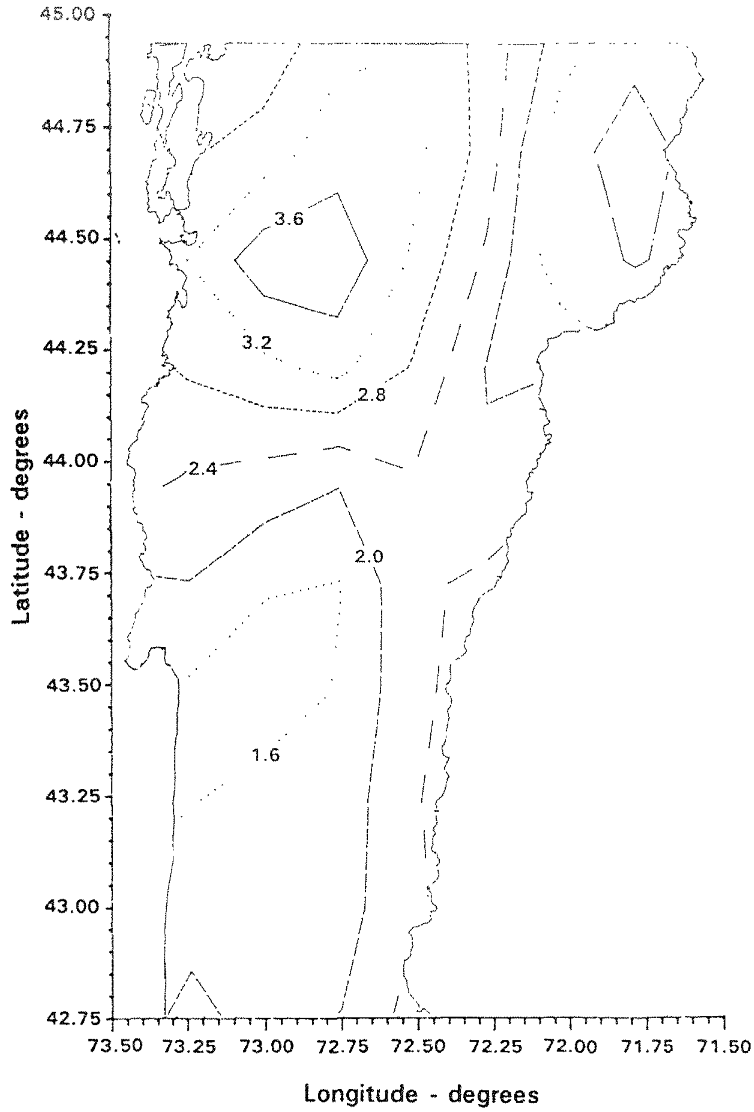

Figure 7. Map of Vermont showing contours for standard deviations of thrips density based on Kriging estimates from original data of the Vermont Pear Thrips Soil Survey in 1988-89.

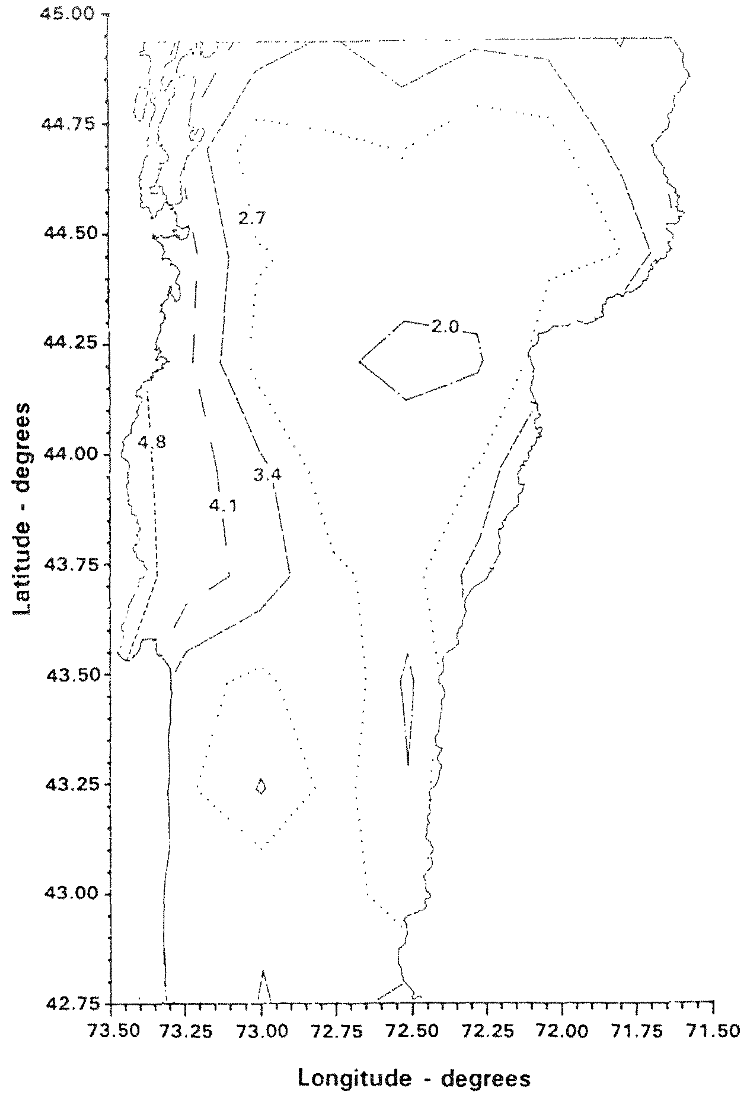

Figure 8. Map of Vermont showing contours for thrips density based on Kriging estimates from transformed data, $\sqrt{v_i + 3/8}$, of the Vermont Pear Thrips Soil Survey in 1988-89.

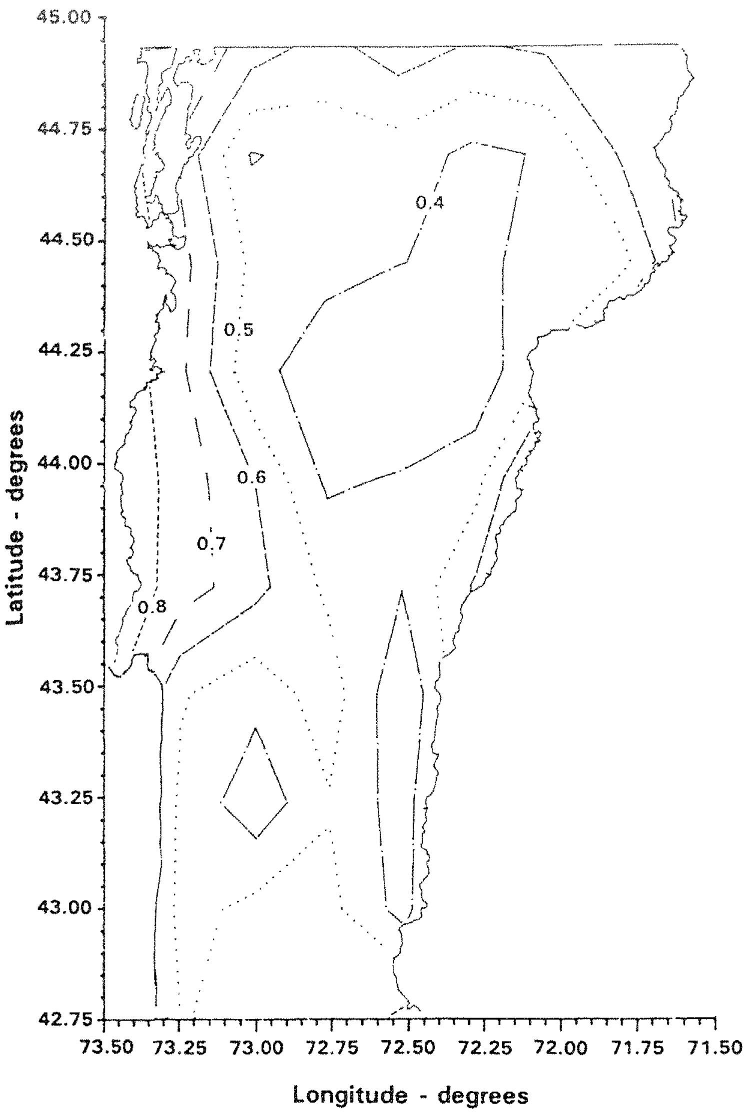

Figure 9. Map of Vermont showing contours for standard deviations of thrips density based on Kriging estimates from transformed data, $\sqrt{v_i + 3/8}$, of the Vermont Pear Thrips Soil Survey 1988-89.

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.

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References Cited

Burgess, T. M. & R. Webster. 1980. Optimal interpolation and isarithmetic mapping of soil properties, I: the semi-variogram and punctual Kriging. J. Soil Sci. 31: 315-331.

Cressie, N. A. C. 1986. Kriging nonstationary data. J. Am. Statistical Assoc. 81: 625-634.

Cressie, N. A. C. 1990. Spatial prediction from networks. Research Report, Dept. of Statistics, Iowa State Univ., Ames, Iowa.

Englund, E. & A. Sparks. 1988. Geostatistical environmental assessment software users guide. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S.E.P.A., Los Vegas, Nev.

Johnson, D. E. 1990. (unpublished). Introduction to spatial statistics and Kriging with some possible application to experimental designs. Paper presented at the Joint Statistical Meeting of the Am. Statistical Assoc. and the Biometric Soc., August 1990, Anaheim, Calif.

Krige, D. G. 1951. A statistical approach to some mine valuations and allied problems in Witwatersrand. Master's thesis. University of the Witwatersrand, Johannesburg, South Africa.

Matheron, G. 1971. The theory of regionalized variables and its applications. Cahiers du Centre de Morphologie Mathematique, No. 5, Fontainebleau, France.

Ord, J. K. & M. Rees. 1979. Spatial processes: recent developments with applications to hydrology, pp. 95-118. *In* E. H. Lloyd, T. O'Donnell & J. C. Wilkinson [eds.], The mathematics of hydrology and water resources. Academic Press, London.

Parker, B. L., M. Skinner & H. B. Teillon. 1988 Proceedings, regional meeting: "The 1988 thrips infestation of sugar maple". Bennington, VT June 23. Vt. Agr. Exp. Sta. Bull. 696. Univ. Vt., Burlington. 113 pp.

Skinner, M. & B. L. Parker. 1989. Vermont soil survey for pear thrips, protocol for statewide sampling program. Research report, Entomology Research Laboratory, South Burlington, Vt.

Yates, S. R & M. V. Yates. 1988. Disjunctive Kriging as an approach to management decision making. Soil Sci. Soc. Am. J. 52: 1554-1558.

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	*O,O*-Diethyl *O*-(3,5,6-trichloro-2-pyridinyl)-phosphorothioate
	Orthene	*O,S*-Dimethyl acetylphosphoramid-othioate
	Cythion	*O,O*-dimethyl phosphorodithioate
	Mavrik	(α-*RS*,2*R*)-fluvalinate[(*RS*)-α-cyano-3-phenoxybenzyl (*R*)-2-[2-chloro-4-(trifluromethyl)anilino]-3-methyl-butanoate]
Fruit	Lorsban	*O,O*-Diethyl *O*-(3,5,6-trichloro-2-pyridinyl)-phosphorothioate
Sugarbush	Carbaryl	1-Naphthyl *N*-methylcarbamate
Forest	Cythion	*O,O*-dimethylphosphorodithioate
	Carbaryl	1-Naphthyl *N*-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

		Number of Droplets[a]	
Plot	Canopy Level	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

[a] 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.

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References Cited

Parker, B. L., M. Skinner & H. B. Teillon. 1988. Proceedings, regional meeting: "The 1988 thrips infestation of sugar maple." Bennington, VT, June 23. Vt. Agr. Exp. Sta. Bull. 696. Univ. Vt., Burlington. 113 pp.

Rhone-Poulenc. 1989. Product Label Guide. Rhone-Poulenc Ag Co. Research Triangle Park, N.C.

Calibration of Aircraft for 1988 Spray Trials in Vermont