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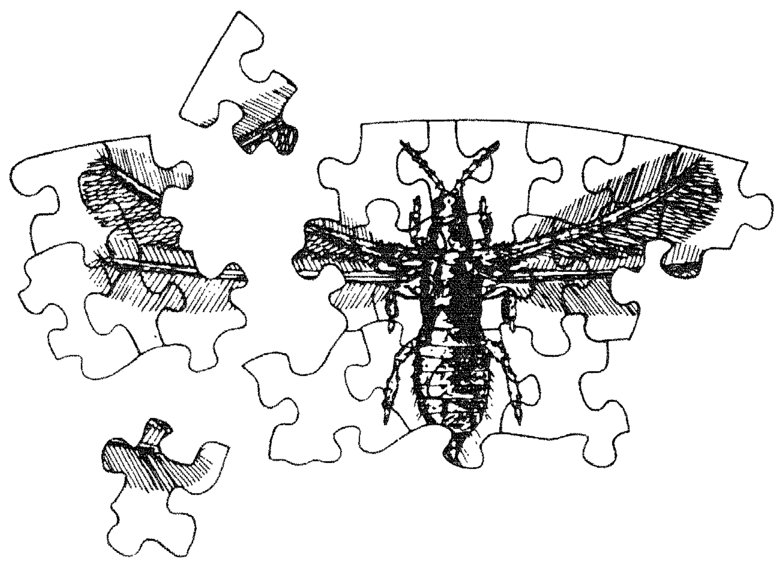
Towards Understanding Thysanoptera



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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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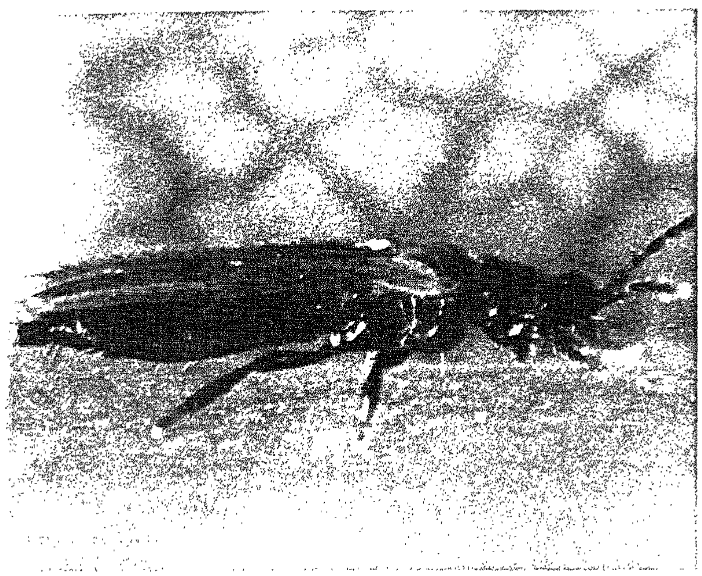
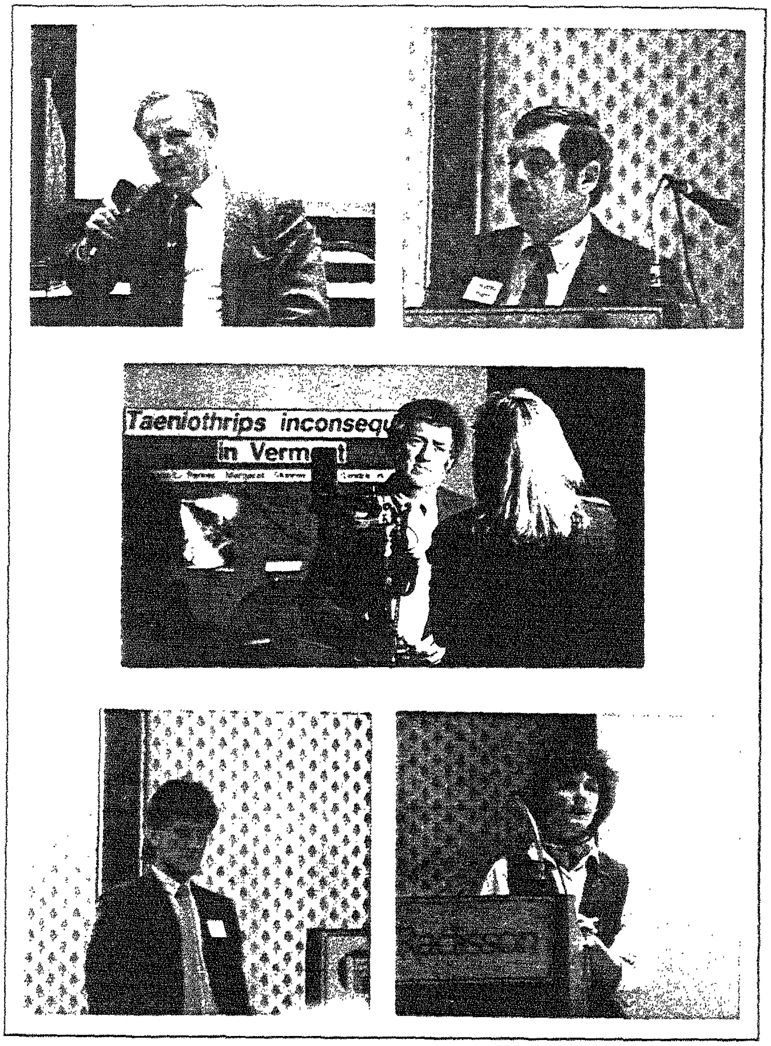


PEAR THRIPS, *Taeniothrips inconsequens* (Uzel)
(photo by T. E. Downer)



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 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^2 while refoliated leaves are only 35-40 cm^2. 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_2 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 aerially. 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 refoliate. 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 refoliated 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 refoliation, 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.

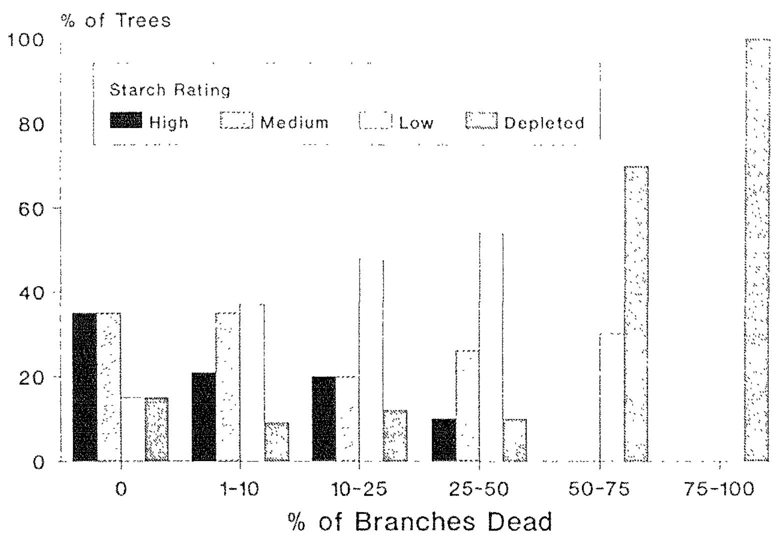

Figure 1. Percentage of trees in each starch rating category, in the fall of 1988 by crown dieback rating the previous summer.

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.

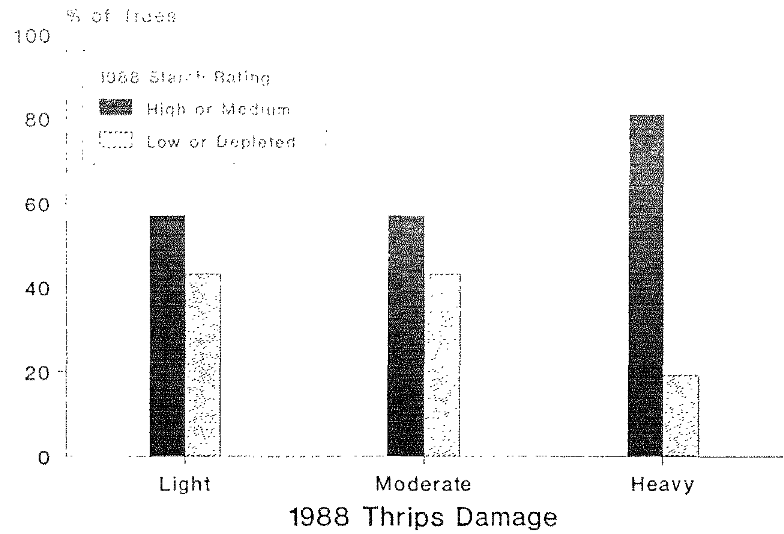

Figure 2. Percentage of trees in each starch rating group evaluated in the fall of 1988, by thrips damage the previous spring. Starch ratings are significantly different for heavily damaged trees ($P = 0.01$).

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 refoliation, 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.

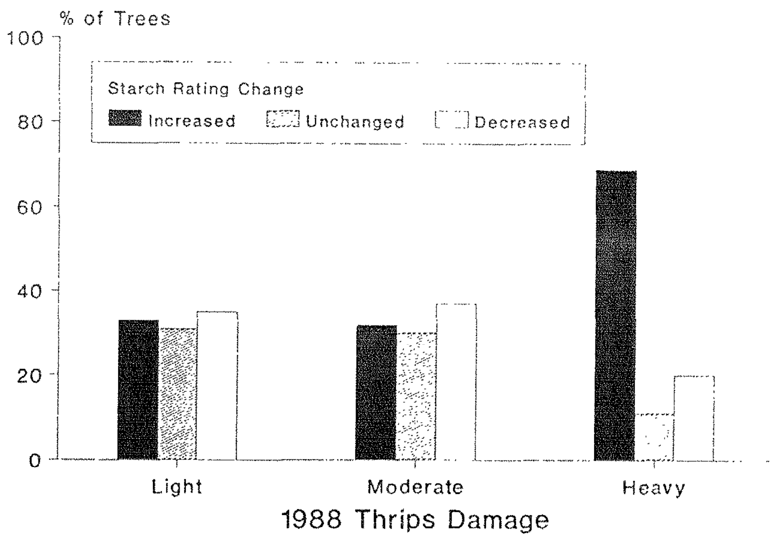

Figure 3. Percentage of trees with root starch levels that increased, stayed the same, or decreased between fall, 1987 and fall, 1988, by thrips damage in the spring of 1988. Change in starch rating is significantly different for heavily damaged trees ($P = 0.01$).

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 refoliation 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

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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 loses 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 loses, 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.

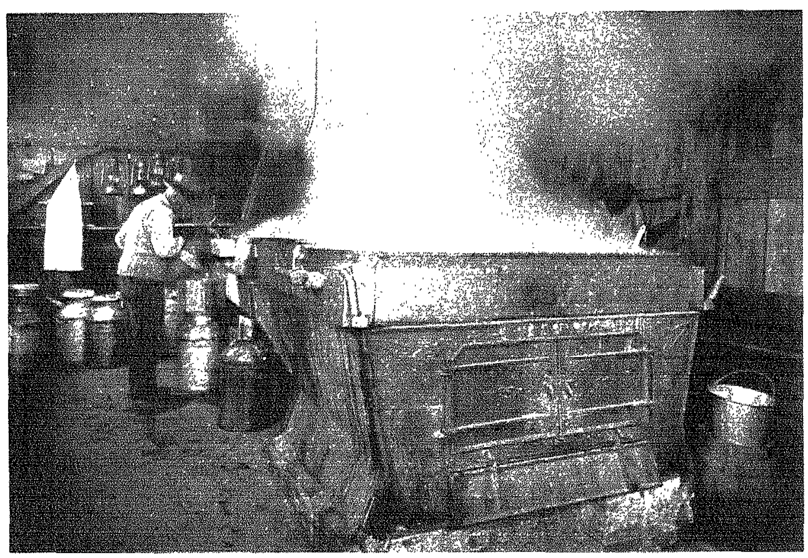
I certainly don't mean to sound like an alarmist. As I mentioned before, I'm not an economist, and therefore not qualified to frighten people. At this point, from everything I understand, there are just too many variables in the thrips situation to even begin suggesting an imminent economic crisis. Besides, 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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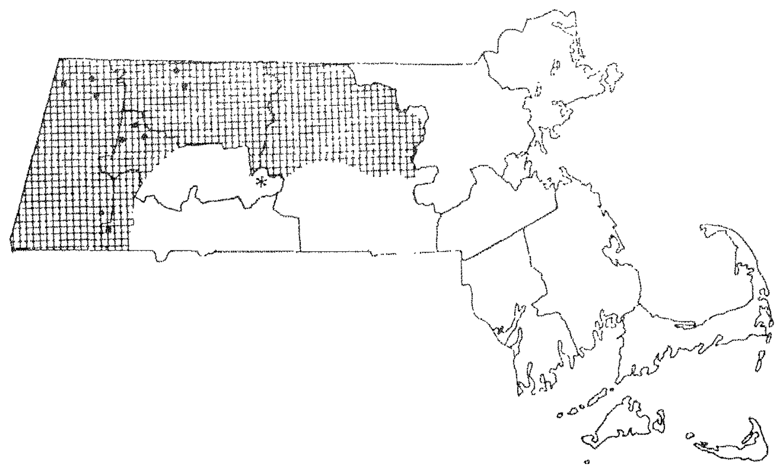

Figure 1. Map of Massachusetts with shaded portion showing area predominating in sugar maple where pear thrips damage has been most severe. Root starch analyses were conducted in permanent forest health monitoring sites (indicated by dots) and a control plot (indicated by asterisk).

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[a]

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

[a] 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[a] 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

[a] 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.

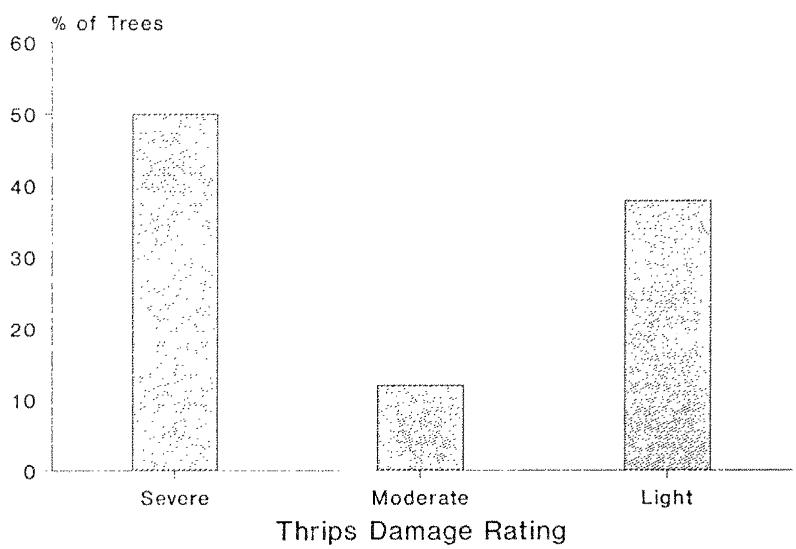

Figure 2. Rate of thrips damage in the summer, 1988 for sugar maple trees in ten permanent plots of the North American Sugar Maple Decline Project. Damage is a de/refoliation percentage: 1 = greater than 60%, 2 = 30 - 60%, 3 = less than 30%.

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).

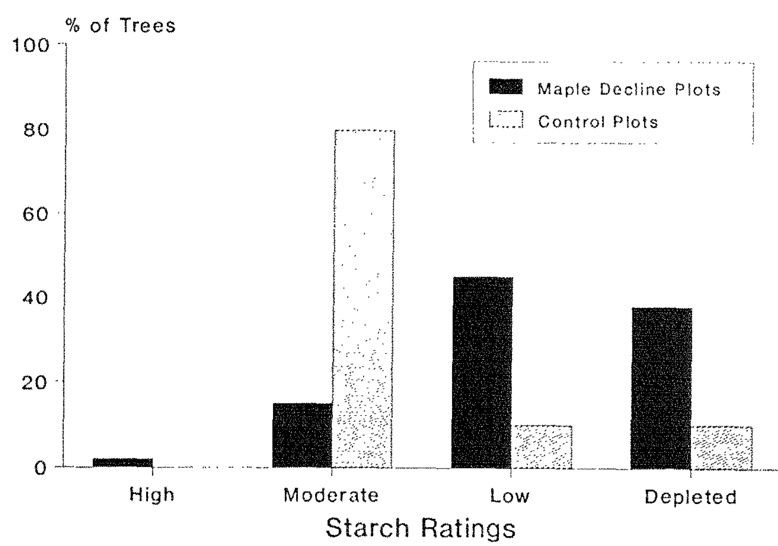

Figure 3. Mean root starch levels of sugar maple trees in 10 plots (within the area of thrips damage in 1988 [n = 334]) of the North American Sugar Maple Decline Project and one control plot (outside the thrips-damaged area [n = 20]) sampled in 1988 in Massachusetts.

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[a] in Massachusetts

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

[a] Supported in part by the Massachusetts Dep. of Environ. Management.

[b] Based on foliar and branch characteristics using a system developed by the Ontario Ministry of the Environment.

[c] 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[a]

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

[a] Modified after Manion (1981).
[b] 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[a]

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

[a] 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[a]

Pollutants	Insect	Plant
Hydrogen fluoride	Mexican bean beetle	Bean
SO_2	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_2, O_3 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.		

[a] 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.).

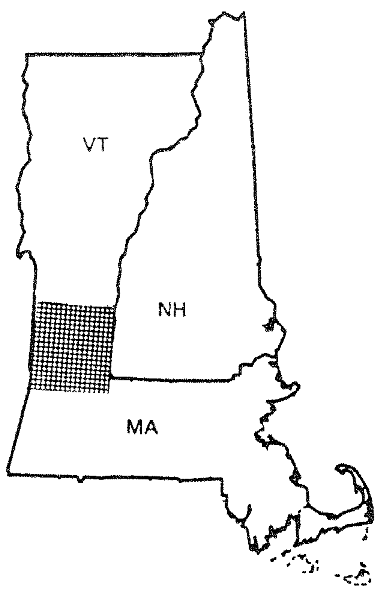


Figure 1. Map showing location of study area assessed for pear thrips damage using satellite imagery data.

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.

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.

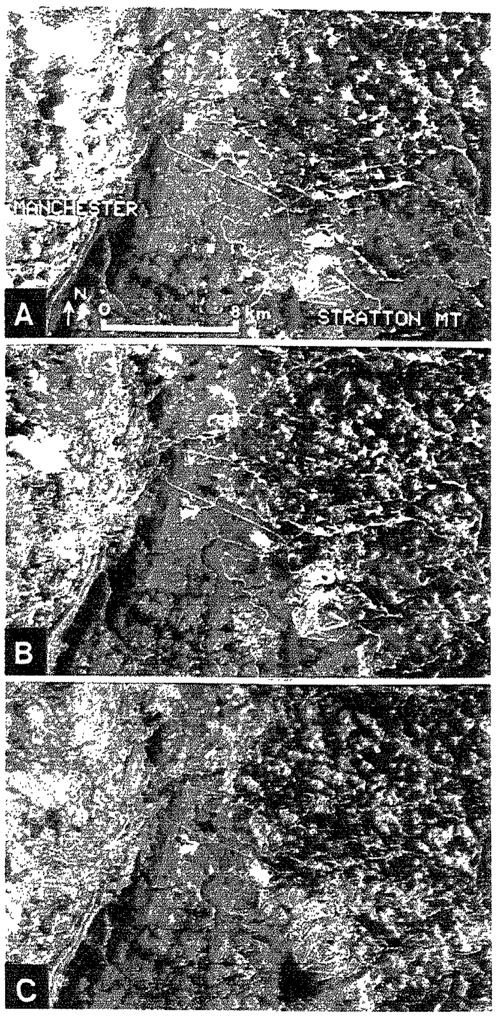
Table 1. Mean 1988 TM 5/4 band ratio values and mean TM band 4 differences between 1984 and 1988 from nine non-defoliated and ten defoliated sites in southern Vermont. Values are ±1 standard deviation

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 ± 0.025	-0.7 ± 12.8
2	34	0.680 ± 0.028	-2.6 ± 9.4
3	348	0.702 ± 0.021	-1.4 ± 9.9
4	120	0.662 ± 0.022	+13.2 ± 5.0
5	25	0.724 ± 0.035	-6.1 ± 5.8
6	9	0.759 ± 0.085	-12.0 ± 4.5
7	16	0.674 ± 0.024	-0.8 ± 3.6
8	21	0.714 ± 0.040	+0.9 ± 5.6
9	15	0.703 ± 0.050	+17.1 ± 6.2
10	21	0.765 ± 0.035	+0.4 ± 5.5
Defoliated Canopy			
11	12	0.938 ± 0.090	-46.3 ± 2.9
12	126	0.760 ± 0.044	-18.0 ± 7.8
13	39	0.858 ± 0.079	-29.6 ± 6.6
14	31	0.893 ± 0.058	-37.6 ± 7.2
15	19	0.975 ± 0.118	-44.7 ± 7.5
16	9	0.998 ± 0.066	-48.9 ± 6.3
17	21	1.317 ± 0.134	-42.5 ± 7.5
18	9	1.279 ± 0.134	-43.2 ± 9.0
19	14	0.858 ± 0.048	-39.2 ± 7.3
20	21	0.926 ± 0.089	-58.4 ± 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.


MANCHESTER
A
N
0
8 km
STRATTON MT
B
C

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

	Vermont		Massachusetts	
Damage Level	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
Total Hectares	201,482		95,412	

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.

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