DETECTION OF PEAR THRIPS DAMAGE USING SATELLITE IMAGERY DATA

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Abstract

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

Introduction

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

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

Materials and Methods

Study Area

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

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

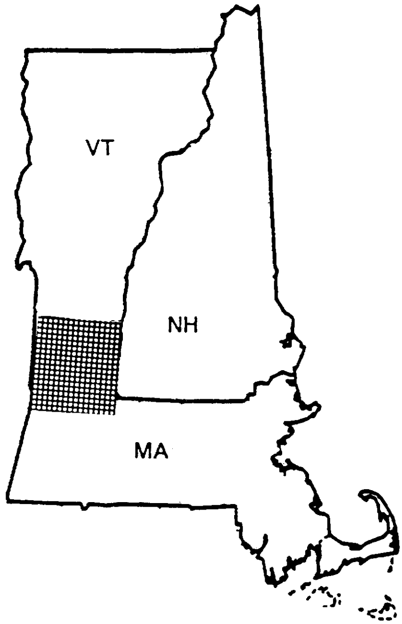


Figure 1. Map showing location of study area assessed for pear thrips damage using satellite imagery data.

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

Remote Sensing Data Acquisition

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

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

Data Processing

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

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

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

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

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

Ground Data

During late May and early June 1988, personnel from the Vermont Department of Forests, Parks and Recreation obtained extensive information regarding the condition of sugar maple stands during the 1988 thrips infestation in Windham and Bennington Counties (Vermont). This included sketch maps (from aerial damage surveys), showing location of zones of defoliation, and aerial color photographs (with locations marked on topographic maps) of defoliated and non-defoliated areas for specific sites, both made from light aircraft. Many sites were ground checked to verify that the damage and defoliation seen from the air was caused by pear thrips. Both sketch maps and photographs were provided for the purposes of comparison with the remote sensing data. Additionally, Vermont State personnel most familiar with the individual stand conditions of sugar maples in the region were consulted on several occasions regarding the accuracy of the imagery in depicting locations and levels of thrips damage. Input was provided such that imagery could be "fine-tuned" to more accurately represent actual maple stand conditions. Sketch maps showing location of thrips damage in northwestern Massachusetts provided by Massachusetts Department of Environmental Management personnel (C. M. Burnham) were also used in the study as a form of ground truth.

Results

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

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

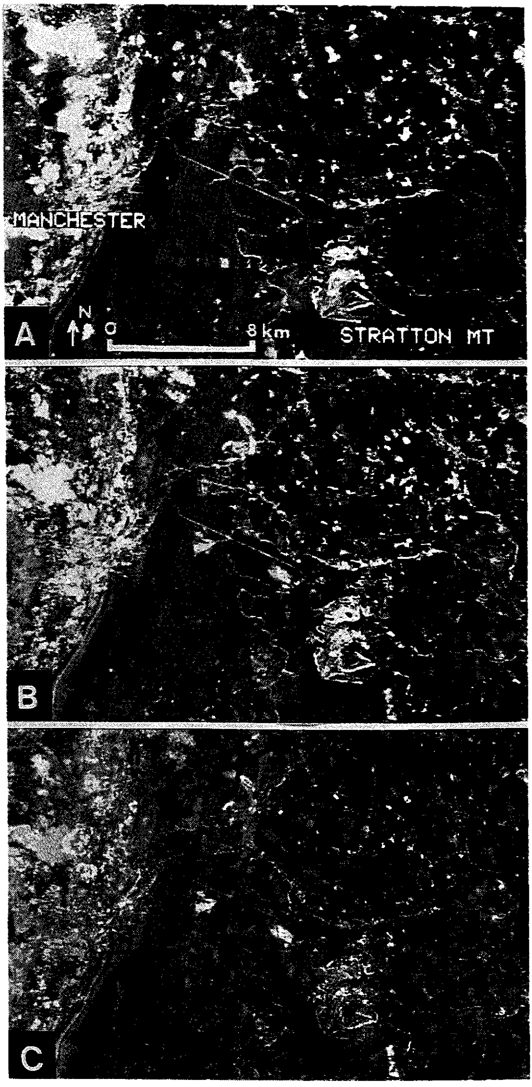
Table 1. Mean 1988 TM 5/4 band ratio values and mean TM band 4 differences between 1984 and 1988 from nine non-defoliated and ten defoliated sites in southern Vermont. Values are ±1 standard deviation

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
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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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