COMPUTER ANALYSIS AND MAPPING OF GYPSY MOTH DEFOLIATION LEVELS IN PENNSYLVANIA USING LANDSAT-1 DIGITAL DATA*

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ABSTRACT

The purpose of this study was to investigate the effectiveness of using LANDSAT-1 multispectral digital data and imagery, supplemented by ground truth and aerial photography, as a new method of surveying gypsy moth (Porthetria dispar (L.)) (Lepidoptera; Lymantriidae) defoliation, which has greatly increased in Pennsylvania in recent years. Since the acreage and severity of gypsy moth defoliation reaches a peak from mid-June through the first few days of July, the July 8, 1973, LANDSAT-1 scene was chosen for analysis. Results indicate that LANDSAT-1 data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that digital processing methods can be used to map the extent and degree of defoliation.

INTRODUCTION

Endemic populations of defoliating insects are common in forests, but seldom cause noticeable damage. Although there are many defoliating insects from various orders, insects of the order Lepidoptera generally account for most defoliations.[1, 2] If these insect populations explode, serious damage may result. For instance, heavy defoliatior affects stream flow, reduces wildlife habitat, increases fire and erosion hazards, increases the susceptibility of forest vegetation to other insects or disease, reduces tree growth, and increases tree mortality. In addition, defoliation, and the presence of the insects, create an aesthetically unattractive appearance at a time of the year when tourism is at its peak, resulting in significant reductions in the value of public and private recreational lands and financial loss to the tourist industries. Where heavy mortality on commercial forest land occurs, large-scale salvage operations seem to offer the best means of reducing financial loss. However, substantial losses are incurred, and plans for maintaining a continuous flow of timber products are disrupted, whenever immature stands are harvested.

One such insect, the gypsy moth (Porthetria dispar (L.)) (Lepidoptera: Lymantriidae), has increased and spread in epidemic proportions throughout much of the mixed woodlands of eastern and central Pennsylvania in recent years. The alarming rate of increase may best be expressed by noting that the defoliated acreage in Pennsylvania increased by 113 percent over that in 1972, for a total of about 348,000 hectares (860,000 acres) in 1973.[3] In the entire northeastern United States, the gypsy moth partially defoliated at least 688,000 hectares (1.7 million acres) of forest in 1973.[4] In 1974, approximately 162,000 hectares (400,000 acres) were defoliated in Pennsylvania. The noticeable reduction in defoliation was mainly due to population collapses in the northeastern counties, but the areal extent of defoliation in central Pennsylvania greatly increased.

Considerable research has been done in an attempt to eradicate the gypsy moth, but the task of eradication is an economic, if not physical, impossibility. Therefore, in recent years, there has been an increased emphasis directed toward the development of an effective suppression program. To initiate and sustain such a program, the agencies responsible for control must have early, accurate, and efficient methods of detection and mapping. In the past, many survey techniques have been applied to the problem of detection, including ground surveys, aerial surveys, and photographic or remote sensing surveys with subsequent photointerpretation and mapping.

The oldest technique, the ground survey, is used to obtain such information as the extent of defoliation, refoliation, and mortality. Its only advantage over the other types of surveys is that by

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close observation on the ground one can quickly and accurately identify the tree species attacked. Major disadvantages include the great amount of time, and consequent cost, required to cover large areas, and the many changes which can occur in the forest canopy during the time required to carry out the survey.

One commonly used aerial survey method, known as sketch mapping, relies on the extensive use of light aircraft with an observer directly mapping the extent of defoliation onto topographic maps. This method has the potential of providing timely and accurate data related to areal extent of defoliation, but the precision of mapping is inherently affected by the observer's knowledge of the local geography and his ability to relate this to what he sees from the air. In addition, inaccuracies may occur due to fatigue and air discomfort, changes in the forest canopy during the time required to complete the survey over vast areas, and differences between observers' interpretations of the various defoliation categories.

Photographic surveys have been widely used in recent years for assessing forest defoliation or mortality. Croxton[5] reported successful detection and classification of ash dieback using color aerial photography. Wert and Roettgering[6] described the use of aerial color photography for inventorying mortality in Douglas-fir (Pseudotsuga taxifolia) resulting from attacks by the Douglas-fir beetle (Dendroctonus pseudotsugae Hopk.) (Coleoptera: Scolytidae), while Bousfield[7] used aerial photography to estimate the volume of timber losses in northern Idaho caused by the same insect. Rohde and Moore[8] tested the utility of large-scale aerial photography for detecting and evaluating gypsy moth defoliation, and results revealed that defoliation was easily detected. Furthermore, they stated that

> . . . remote sensing techniques, when properly used, can provide . . .: (1) timely data with respect to time of defoliation and subsequent refoliation and mortality, (2) synoptic data providing accurate delineation of areal extent of damage, (3) permanent records of forest composition and damage for more detailed studies at a later date to evaluate recovery rates, species composition, tree condition, tree size, stocking, density, number of trees killed, etc., and (4) direct management information with respect to planning effective suppression operations. (p. 13)

Many researchers have found remote sensing techniques to be considerably cheaper than previous survey methods. Wert and Wickman[9] reported that the use of color photography for obtaining estimates of mortality caused by the Douglas-fir tussock moth (Hemerocampa pseudotsugata McD.) (Lepidoptera: Lymantriidae), resulted in a 67 percent savings in man-hours when compared to obtaining comparable data by ground cruises. Ciesla et al.[10] reported the cost of aerial photographic surveys of southern pine beetle (D. frontalis (Zimm.)) to range from \$0.0023 to \$0.0077 per hectare (\$0.0055 to \$0.019 per acre), depending upon the size of the area surveyed.

This last qualifying statement, that cost depends upon the size of the area surveyed, initiated considerable interest in very small-scale (high-altitude) aerial photography. Heller et al.[11] stated that in general, as photographic scale decreases and infestation spot size decreases, photointerpretation accuracy decays accordingly. However, improved methods of multispectral image processing, both analog and digital, have been devised to aid the interpreter and improve accuracy. According to Heller et al.,[11]

> the potential for improved processing results will be achieved when multispectral scanners are available which provide for a common field stop for all channels, or at least a common instantaneous field of view, in the visible, near infrared and thermal infrared regime. . . . The availability of simultaneously registered data covering this entire bandwidth in narrowband increments should yield large improvements in accuracy. (p. 48)

On July 23, 1972, the first dedicated earth resources land-use satellite (LANDSAT-1) was launched. The spacecraft carries television cameras as well as radiometric scanners to obtain image data similar to that suggested as necessary by Heller et al.[11] The satellite circles the globe 14 times a day, 915 kilometers (494 miles) above earth, and is capable of sensing the same spot anywhere in the world at the same time of day, local time, every 18 days. The resulting photographs cover an area on the earth's surface approximately 189 kilometers (115 statute miles) square, with a resolution of about 80 meters (260 feet).[12] Therefore, the satellite affords the researcher the opportunity to analyze a sequence of both photographic and multispectral scanner data taken under uniform lighting conditions over a given area.

To analyze and test the utility of this new remote sensing data source, the National Aeronautics and Space Administration (NASA) has contracted with hundreds of investigators from other government agencies, industry, universities, and foreign governments. After just 7 months, the first "Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1" was held to give the users of LANDSAT data the opportunity to present the significant accomplishments of their investigations. Using LANDSAT-1 imagery and NASA underflights to detect damage by the mountain pine beetle (D. ponderosa Hopk.), Hall[13] reported that he could differentiate areas of heavy damage from those with little or no damage in the lodgepole pine type. Anderson et al.[14] reported that techniques have been implemented using LANDSAT-1 imagery of the Cook Inlet Basin to stratify damage to white spruce (Picea glauca), by the spruce beetle (D. obesus (Mann.)), into three levels—healthy, newly killed, and old killed. Rohde and Moore[8] used LANDSAT-1 imagery for the detection of fall cankerworm (Alsophila pomentaria (Harr)) (Lepidoptera: Geometridae) damage in a small forested area in Frederick County, Maryland. Using later LANDSAT-1 imagery, at or near the peak of gypsy moth defoliation, they found it possible consistently to identify areas of heavy defoliation and areas with no apparent defoliation. However, consistent detection of light and moderate defoliation classes in areas with no heavy defoliation was not demonstrated, and areas of defoliation were often confused with areas associated with mining activity and certain agricultural practices.

All of these investigators used photointerpretation of LANDSAT-1 images to detect damage, and therefore did not fully utilize the vast amount of data collected by the four-channel multispectral scanner. Since trees suffering varying degrees of defoliation will have different spectral signatures due to changes in the percentage of green vegetation present, LANDSAT-1 multispectral data and imagery, supplemented by good ground truth or aerial photography, should allow the detection of the various categories of defoliation: light (0-30%), moderate (30-60%), and heavy (60-100%). It was the intent of this project to test the effectiveness of using an integrated system, consisting of computer analysis and mapping, photointerpretation of LANDSAT-1 images, as well as underflight photography and ground truth, to detect more consistently and accurately gypsy moth defoliation in an efficient manner.

THE GYPSY MOTH

Since its introduction into the United States over 100 years ago, there has developed a considerable volume of literature on the gypsy moth. Perhaps the best overall and most up to date documentation of the gypsy moth appears in an annual volume published by the United States Department of Agriculture. The "Final Environmental Statement of the Cooperative Gypsy Moth Suppression and Regulatory Program—1974 Activities"[15] is the result of the combined efforts of several experts, and it was used as the main source of information in this section on the gypsy moth, except where otherwise noted.

The impact of gypsy moth on trees is well documented. Information is available on tree mortality, lost growth in trees, changes in forest stand composition, and, more recently, estimates of economic loss.

Gypsy moth caterpillars cause tree damage by devouring foliage. This feeding begins shortly after the caterpillars hatch from their eggs, generally in early May in Pennsylvania. Except where gypsy moth populations are unusually large, defoliation is not noticeable until early to mid-June. In late June and early July the heaviest defoliation takes place as the caterpillars reach full size. Where defoliation is complete, trees may remain bare as late as early August, but in general, by mid-July hardwood trees that had about 60 percent or more of their foliage removed begin to refoliate. Studies indicate that hardwoods suffering less than 60 percent loss of foliage do not refoliate, and evergreens are not capable of refoliation.

The process of refoliation requires the use of stored energy, and after 2 years of defoliation these food reserves in the tree become critical. The result may be the outright death of the tree, or a gradual decline in vigor, possibly resulting in death, due to an increase in the tree's susceptibility to attack by organisms or other environmental extremes that ordinarily do not harm trees.

In a study on oak mortality in Pennsylvania, Nichols[16] found that a year of moderate defoliation reduced radial growth by 20 to 30 percent. But 1 year of heavy spring defoliation resulted in a 40 to 70 percent growth reduction. Later studies by Nichols[17] indicated that 2 consecutive years of 60 to 100 percent spring defoliation may kill about 30 percent of the oaks, and after 3 years of heavy defoliation the oak mortality may be 60 percent or more. Mortality of hardwood trees other than oak is expected to be less than 10 percent of their total number, while hemlocks and many pines and spruces completely stripped of their foliage will die in 1 year.

The rather obvious differences in tree mortality between the oaks and other hardwoods, and between hardwoods and conifers, is mainly due to the differences among varying tree species to withstand attack, and the differences in the food preferences of the gypsy moth larvae, both young and old. For example, aspen, basswood, larch, and all species of oak are among the tree species favored by all larval stages, while ash, black locust, poison ivy, sycamore, tulip poplar, and walnut are not favored by any larval stages. Other commonly encountered tree species in the eastern United States fall somewhere in between these two extremes as preferred food of the gypsy moth. Nichols[17] compiled a more complete list of the food preferences of the gypsy moth.

Information on the effect of gypsy moth defoliation on future stand composition is not abundant, but the larvae's preference for oaks seems to indicate a future reduction in the oak component in most stands. Some investigators feel that the defoliation benefits the red maple in the understory due to decreased competition for light and space, and an increase in available nutrients from frass manufactured at the expense of the oak. Whatever the long-term effect of the gypsy moth on forest stand composition may be, its immediate effect is a marked reduction in forest management options—often the only option is to salvage by clearcutting.

In an attempt to forecast expected timber losses, McCay and White[18] made an economic analysis of the gypsy moth problem in commercial forest stands in the northeast. They presented methods for calculating immediate and future losses in both pulpwood and sawtimber stands, as well as an average expected loss for each. For example, on the average the forest manager can expect a $1.88 loss per hectare ($4.65 loss per acre) in a pulpwood stand by the third year after 1 year of heavy defoliation. In a sawtimber stand, the immediate loss per hectare that may be expected from 1 year of heavy defoliation is $30.50 ($75.40 per acre), while total discounted future losses may exceed $46.58 per hectare ($115.10 per acre). Considering the number of acres infested by the gypsy moth, and the fact that much of this area is commercial forest land, financial losses will be sizable.

Payne et al.[19] did a similar type of economic analysis but applied to residential property. Guidelines were presented for determining dollar losses in residential property values from tree mortality caused by the gypsy moth. However, the effects on value from reduced tree vigor or the unsightly appearance of defoliated trees were not included. Their estimates of the value of residential trees were considerably higher than corresponding timber values. This fact led to an overall conclusion that more expensive and more selective control measures are justified for gypsy moth control in residential areas than in timber-producing areas.

PROCEDURE

Programs provided by the Office for Remote Sensing of Earth Resources (ORSER) of the Space Science and Engineering Laboratory (SSEL) and processed by an IBM System 370 Model 168 computer, both located at The Pennsylvania State University, were used in analyzing the LANDSAT computer compatible tapes (CCTs). The programs are fully described in a users' manual.[20]

Digital processing of remote sensed data requires the use of an iterative procedure. A test area, generally selected because of the availability of ground truth data, is processed and the results are compared with ground truth. Successive refinements in classification techniques are then followed until a satisfactory match between the computer-produced maps and ground truth is obtained. A much larger area is then processed to test the generality of the technique. Due to the iterative nature of this process, there is no clear differentiation between procedure and results, so that the distinction which is made in this, and the following section is largely arbitrary.

The woodlands of Pennsylvania offer the unique situation of widespread similarity of tree species at differing degrees of gypsy moth infestation. Initially, however, it was decided to concentrate on the forests of the northeastern portion of Pennsylvania for two main reasons: (1) the existence of vast acreages of varying degrees of gypsy moth defoliation in this region, and (2) the availability of ground truth information in the form of color infrared (IR) aerial photography at a scale of 1:6000 (taken July 18, 1973) and data gathered in the field by the Pennsylvania Bureau of Forestry (BOF) and the U.S. Forest Service (USFS).

The acreage and severity of gypsy moth defoliation reaches a peak from mid-June through the first few days of July. If the defoliation has only been light to moderate in past years, the deciduous trees will respond with a new canopy of leaves by mid- to late-July.[15] For this reason, the timing of aerial coverage and ground support data is extremely important. LANDSAT-1 coverage of northeastern Pennsylvania on July 8, 1973, fell on a cloud-free day, and LANDSAT-1 scenes 1350-15183 and 1350-15190 proved very satisfactory for visual and computer analysis.

The first step in computer processing was to develop work tapes containing the digital data from those portions of the scenes where gypsy moth damage was known to have occurred. Two aids were used in deciding which scene portions would make good study areas: the "Forest Pest Report,"[3] which gave a county-by-county summary of total defoliation for both 1972 and 1973; and the LANDSAT-1 images themselves. Image reproductions of MSS band 7 showed defoliation as dark gray. Healthy vegetation appeared as lighter shades of gray, while black represented water bodies (Figure 1). The SUBSET program was used to transfer the desired data from the original NASA LANDSAT tapes to a work tape. This program also converts the tape format to a standard ORSER format.

Once the desired portions were subsetted, proper location and orientation on the tape, pertaining to the areas of interest on the ground, had to be achieved. The NMAP program was used for this purpose. This program uses all four channels of the LANDSAT data to map element brightness averaged over these channels. Output from the program consisted of a brightness map. Certain symbols were assigned to various percentage intervals of brightness and the patterns of symbols were helpful in interpretation. Water bodies were extremely helpful for orientation purposes due to their low brightness, uniformity, and distinctive spectral signature. Northeastern Pennsylvania has numerous lakes and swamps large enough in size to show up on LANDSAT-1 images. A complete supply of U.S. Geological Survey (USGS) 7.5 minute topographic maps of the study areas proved to be invaluable in substantiating accurate identification of water bodies.

After the proper areas had been subsetted and orientation within these areas achieved, the combined tasks of classification and character mapping were undertaken. Two different paths were available at this point—the supervised or unsupervised classification procedures. The unsupervised classification, or cluster analysis, procedures were chosen, with the intent of using the supervised procedures at a later date to check for uniformity as well as variability in the spectral signatures obtained from cluster analysis.

The majority of spectral signatures used throughout the project were developed using the DCLUS program. In using this program, one specifies the corner coordinates of the target area(s) to be processed, the number of sample points to be chosen initially, and the initial critical clustering distance. Output consists of a list of spectral signatures corresponding to the mean vector length and standard deviation. A character is assigned to each cluster spectral signature and a character map of the specified target area(s) is output.

RESULTS*

The discussed method of developing spectral signatures was initially applied to two different study areas. A section of Blue Mountain, located near Auburn, Pennsylvania, on the Schuylkill-Berks County line, and represented on LANDSAT-1 scene 1350-15190, was chosen for analysis because the areal extent of defoliation was adequate, yet somewhat isolated from the extensive defoliation to the northeast. A second area, north of East Stroudsburg, Pennsylvania, in Pike County, encompassed three experimental plots aerially sprayed with the chemical insecticide Dylox. These plots were easily identifiable on LANDSAT-1 image 1350-15183 due to their peculiar shapes and orientation.

A lack of ground truth data resulted in the abandonment of the Blue Mountain study area. On the other hand, ample ground truth data were available as an aid in analyzing the area surrounding the Dylox spray plots. With the help of color IR aerial photography, and other supporting ground truth information, classification of the spectral signatures into categories was not difficult. It was apparent that defoliated trees had lower responses in MSS bands 6 and 7, with the degree of response depression corresponding to the severity of defoliation. Initially, 10 categories were delineated and used as input in the more sophisticated classification program DCLASS.

DCLASS allows the user to input spectral signatures obtained from DCLUS or certain other ORSER programs. The euclidean distance of separation between an element vector and each of the category vectors is used to assign the element to the category to which it is closest. If the element is distant from every category by more than the user-assigned critical distance, it is classified as "other."

The standard deviations, in distance units, from DCLUS were used as a guide for setting the critical distance in DCLASS. An initial critical classification distance of 8.0 was used. Mapping symbols were assigned to each category and character maps were generated. Further refinements in category specification were made possible as familiarity with the target areas increased. Eventually, a total of 31 categories were separated through continued use of DCLUS and DCLASS.

In addition to character maps, DCLASS outputs frequency distributions for all categories and distances of separation between all pairs of spectral signatures. Of the 31 signatures, there were 9 for lakes and swamps, 10 for healthy vegetation, 5 for defoliated forests, and 7 for miscellaneous categories. The frequency distribution table indicated that the signatures assigned category symbols to 98 percent of the study area, leaving only 2 percent unclassified.

The table of distances of separation revealed that the distance among spectral signatures within the set of 5 categories for heavy defoliation and within the set of 10 categories for healthy vegetation were much less than the distance between category sets. Within the 5 categories for heavy defoliation, the average distance of separation was 2.89, with a range of values from a low of 0.90 to a high of 4.20. Within the 10 categories for healthy vegetation, the average distance of separation was 4.10, with a range of values from 0.80 to 9.00. The higher average and greater range of values for healthy

*A portion of these results has been previously reported in Williams and Turner.[21] All analytical work was carried out by the senior author.

vegetation were not surprising, as one would expect greater heterogeneity in spectral signatures due to the number of different deciduous and coniferous species found in the mixed forests of Pennsylvania. On the other hand, one would expect better overall similarity among spectral signatures for denuded woodlands, as the forest floor and bare branches would reflect roughly the same amount of radiation regardless of tree species.

With this in mind, it was decided to average the 5 spectral signatures for heavy defoliation to get 1 overall signature for this category. The same was done with the 10 spectral signatures for healthy vegetation. Thus, the total number of categories was trimmed from 31 to 11. This cut the costs of generating character maps, while sacrificing little accuracy.

DCLASS, using 11 categories, generated a character map which closely resembled previous maps when all 31 categories were specified. The greatest change occurred in the percentage that was unclassified. It increased from 2 to 7 percent. However, the distance of separation between the category for heavy defoliation and that for healthy vegetation was 12.7. When the initial critical classification distance of 8.0 was increased to 10.0, the percentage unclassified was reduced from 7 to 3 percent.

As a first approximation to obtaining a category for moderate defoliation, a spectral signature midway between that for heavy defoliation and healthy vegetation was obtained by averaging their spectral signatures, thus differing from each by 6.3 units. This signature was refined after comparing character maps with estimates of defoliation on ground photos.

Table 1 is a list of the 12 categories delineated within the study area, including a summary of the symbols assigned to each category and their spectral signatures. It should be noted that channel numbers 1, 2, 3, and 4 correspond with MSS bands 4, 5, 6, and 7. The signatures of particular interest are those for heavy defoliation (10), healthy forest (11), and moderate defoliation (12). Although these 3 categories show similar responses in channels 1 and 2, substantial differences in response can be seen in channels 3 and 4, corresponding to the degree of defoliation. "Healthy forests" is considered to have approximately 0-30 percent defoliation; "moderate defoliation," 30-60 percent; and "heavy defoliation," 60-100 percent defoliation.

Figure 2 is a picture of the Dylox spray plots as derived from BOF maps and color IR aerial photography. These plots not only offered good reference points, but were most helpful in the development of spectral signatures as all defoliation levels were represented. Those areas receiving maximum spray application were relatively unharmed and healthy, while the surrounding unsprayed forest land was generally heavily defoliated. Inadequate application of the Dylox spray caused certain areas within and around these plots to show moderate degrees of defoliation.

A character map produced by the classification program DCLASS from the spectral signatures given above shows the three sprayed plots in the lower half of the figure (Figure 3). The total area represented in the figure is approximately 6,475 hectares (16,000 acres). Character maps such as these are useful as work maps for the user in his analysis of MSS data. However, they are inherently distorted in the length to width relation because of the fixed number of lines and characters per inch on line printers.

These results indicated that LANDSAT-1 data could be used to discriminate between defoliated and healthy vegetation in northeastern Pennsylvania and that the digital processing methods developed by ORSER could be used to map the extent and degree of defoliation. Next, it was necessary to determine if the spectral signatures developed in northeastern Pennsylvania could be used to detect defoliation in other parts of the state.

Some 5,260 hectares (13,000 acres) of woodland near Aaronsburg and Woodward, in eastern Centre County, were defoliated in varying degrees by the gypsy moth in 1973. Since most of the defoliation was moderate and rather scattered in occurrence, it was not as easily detectable visually on LANDSAT-1 scene 1350-15190 as the vast amount of heavy defoliation that occurred in the eastern counties. In fact, a photointerpreter may have overlooked it entirely if he had no previous knowledge that defoliation had occurred there. It was decided to use the spectral signatures developed earlier from both LANDSAT-1 scenes as input into the DCLASS program to see if the Centre County defoliation would be detected.

The DCLASS map of the Centre County defoliation compared very well with a sketch map obtained via aerial reconnaissance, but certain discrepancies were noted in the classification of degrees of defoliation. For instance, the majority of the areas classified as heavy defoliation on the sketch map were classified as moderate defoliation on the computer-generated maps. There are two possible explanations of this discrepancy and both are related to the timing of the surveys. LANDSAT-1 coverage occurred on July 8, 1973, while the aerial reconnaissance for sketch mapping was done on July 23, 1973, roughly 2 weeks later. This seemingly small difference in time can be very important in the development of insect populations, or other biologically or climatically controlled phenomenon. For example, Hopkin's Bioclimatic Law states that for every 1° change in latitude north, every 5° change in longitude east, or every 400-foot increase in elevation, there is a 4-day delay in development.[22] Using this as a guideline, it can be estimated that biological development in Centre County, such as the leafing of trees and the hatching of insect eggs, etc., should occur approximately 10 days later than in eastern Pennsylvania. Therefore, heavy defoliation would be unlikely in Centre County on July 8, as the later and most damaging instars of the gypsy moth would not have developed at that time. By July 23, however, heavy defoliation would have occurred in the areas of dense insect populations.

A second possibility, one that must always be considered when using data based on human judgment, is the inherent variability in judgment decisions. As indicated previously, it is easily possible that what one observer calls heavy defoliation could be called moderate by another observer. That is why it is important to devise a system with an unbiased decision rule such as spectral characteristics interpreted by a computer program.

Another area of interest, and possible confusion, was briefly investigated. The ability to discriminate between defoliated trees and trees killed as a result of previous defoliation would greatly aid those responsible for preparing impact statements, or those interested in the early detection of salvageable stands. By comparing data obtained at the time of defoliation with data from a LANDSAT-1 pass later in the summer after refoliation, it was hoped that nonrefoliating or dead trees could be detected.

LANDSAT-1 scene 1404-15175 provided good coverage of eastern Pennsylvania on August 31, 1973. It covered the same area as the July 8, 1973, scene 1350-15183, and in particular, the area surrounding the Dylox spray plots. A thorough step-wise investigation of the digital data, similar to that described in earlier parts of this chapter, was performed, but no spectral signatures were obtained that would indicate dead trees (i.e., low responses in MSS channels 6 and 7). An attempt was also made to recalibrate the August digital data to the July standards, using the RECAL program, so that the July spectral signatures could be better utilized. However, the two scenes were so different spectrally due to the lack of foliage in July and the abundance of foliage in August, that the recalibration process was unsatisfactory.

Further investigation, including personal communication with people familiar with the gypsy moth problem in Pennsylvania, failed to result in the location of any large areas of forest totally killed by gypsy moth. Since the resolution of LANDSAT-1 is much greater than the crown area of individual trees, scattered tree mortality would not be detectable because dead trees could be obscured by surrounding foliage.

CONCLUSIONS

These results have indicated that LANDSAT-1 data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that the digital processing methods developed by ORSER can be used to map the extent and degree of defoliation. However, a critical factor in any defoliation detection and mapping scheme is timing. All data must be collected after the peak of feeding by the larvae and before refoliation begins. At most, this period is 2 or 3 weeks.

Present survey methods, which rely heavily upon aerial survey from light aircraft, have several limitations. Although they can provide timely data related to the extent of defoliation, the precision of mapping is inherently affected by the observer's knowledge of the local geography and his ability to relate this to what he sees from the air. In addition, the necessity of covering vast areas in a short time span requires the use of several observers, and differences between each observer's interpretations may be substantial.

On the other hand, LANDSAT-1 data, when analyzed by a computer, can result in the production of maps which are not subject to operator bias. The problem of changes in the forest canopy during the survey are negated since substantial areas, covering entire watersheds or states, can be monitored in one day. Computer-generated maps allow for a more precise location of boundaries, and area estimates are obtained as a by-product.

However, there are several problems associated with relying solely on LANDSAT-type satellites for detection programs. The most serious limitations are associated with the frequency of passes. The satellite covers a given area only every 18 days, which is roughly the length of the critical feeding stage in the life cycle of the gypsy moth. In addition, there is a greater than 50 percent probability in this part of the country that cloud cover will be present on a given overpass. There is therefore a high possibility that adequate coverage will not occur when defoliation is at its optimum detection stage. These timing problems could be alleviated in the future if more satellites were in orbit, thus allowing for more frequent coverage. Another limitation of LANDSAT-1 imagery is its resolution of 60 to 90 meters (200 feet to 300 feet), making it appropriate for detecting only widespread defoliation or mortality over large areas.

At present, the best use of LANDSAT-1 data seems to be the unbiased detection and mapping of the areal extent of the various defoliation categories. Continued research, supplemented by more frequent coverage and faster dissemination of monitored data, may result in a system which provides rapid and accurate means of detection and mapping of insect defoliation in forests.

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TABLE 1. - MEAN SPECTRAL SIGNATURES AND MAPPING SYMBOLS DERIVED FROM DCLASS OUTPUT

Category Name	Number	Symbol	Critical Distance	Unnormalized Category Specifications			
				Channels[1]			
				1	2	3	4
Water	1	=	10.0	27.83	19.00	17.25	5.21
Wetlands	2	-	10.0	33.60	24.00	31.00	14.00
Swamp1H20	3	=	10.0	32.51	22.77	24.67	9.90
Lake-edge	4	-	10.0	32.50	22.75	32.75	15.00
Siltwater	5	=	10.0	35.60	24.93	21.57	6.74
Swamp2H20	6	=	10.0	33.32	24.26	26.71	11.31
Swamp3H20	7	=	10.0	31.63	21.46	22.33	8.61
Swamp4H20	8	=	10.0	33.02	22.98	21.02	5.23
Swamp5H20	9	=	10.0	29.03	19.22	23.67	9.25
Heavy Defoliation	10	@	10.0	34.08	25.47	41.30	21.08
Healthy Forest	11	I	10.0	34.79	24.61	51.47	28.52
Moderate Defoliation	12	+	10.0	34.44	25.04	46.38	24.80

[1]Channels 1, 2, 3, and 4 correspond with MSS bands 4, 5, 6, and 7.

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Figure 1. - A blowup of a portion of MSS band 7 from LANDSAT-1 scene 1350-15183, July 8, 1973. (Water appears black, defoliation appears as darker shades of gray, and healthy vegetation appears as lighter shades of gray. The area inside the box includes Dylox spray plots represented in other illustrations.)

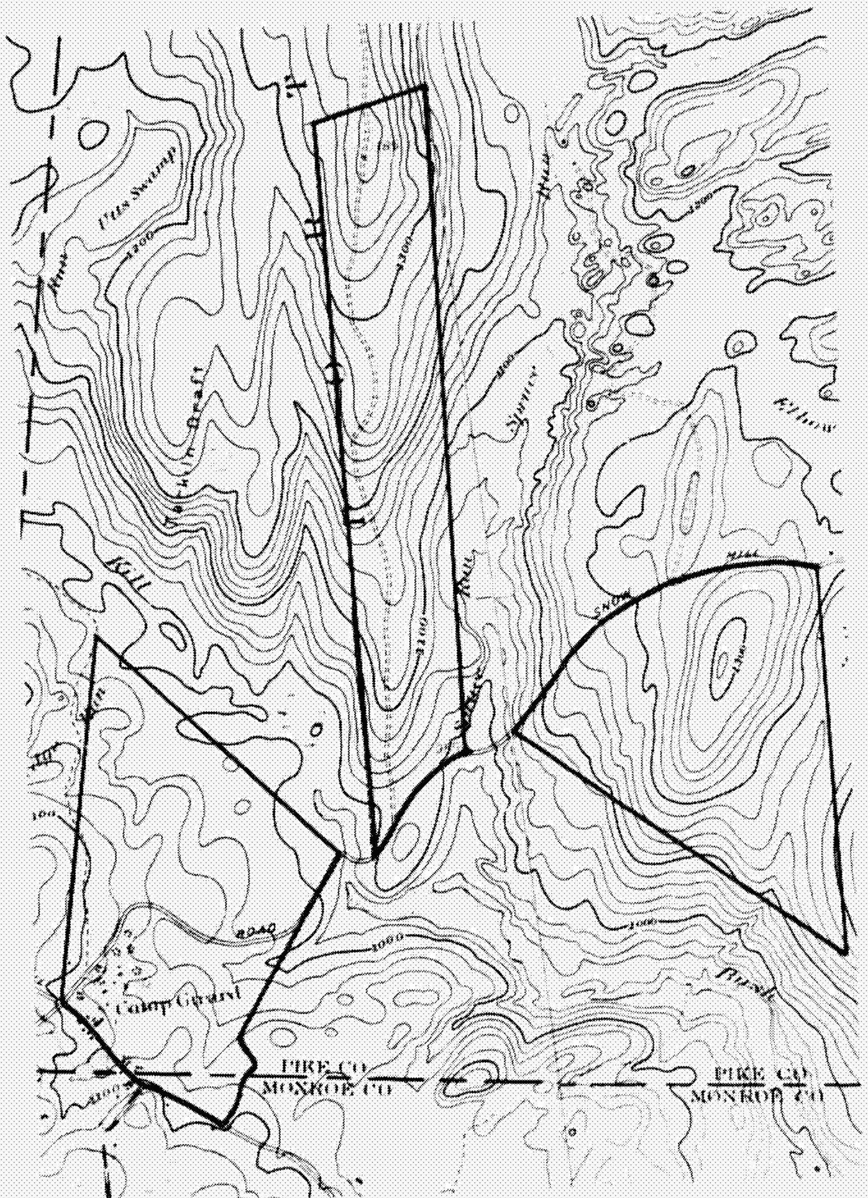
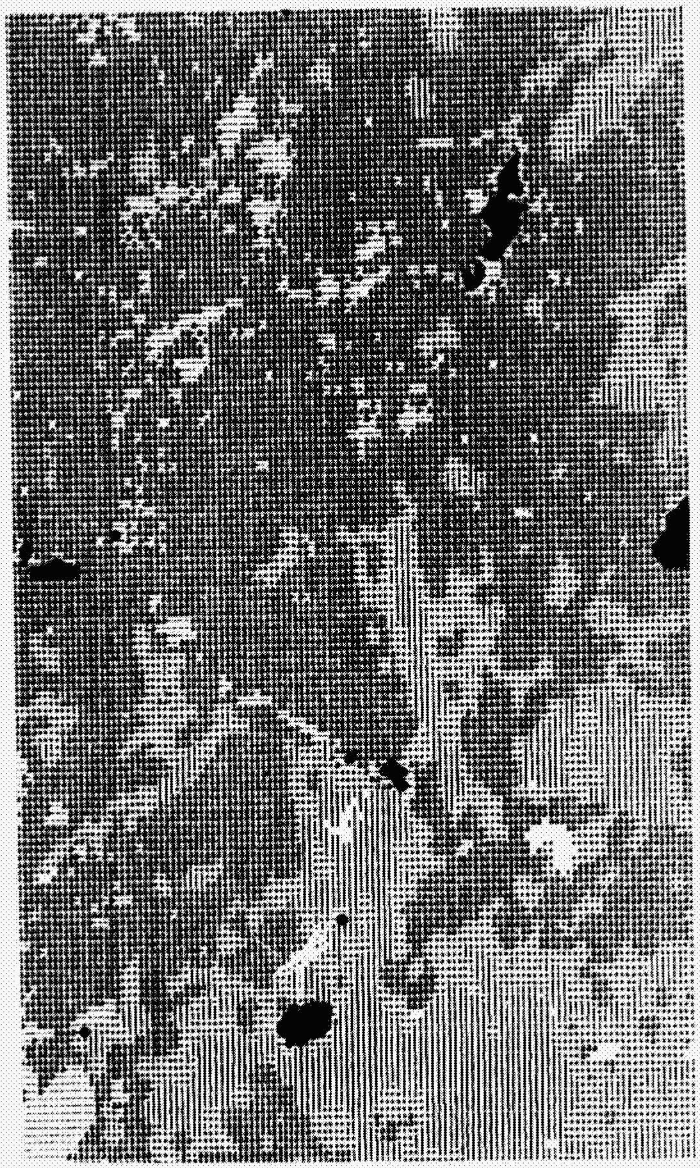


Figure 2.- Picture of Dylox spray plots showing shape and orientation.



LEGEND

Heavy Defoliation	@
Moderate Defoliation	+
Healthy Forest Land	I
Wetlands	-
Water	"dark"

Figure 3. - Character map derived from DCLASS using spectral signatures given in Table 1. (Dylox spray plots appear in lower half.)