A Comparison of the SPOT and Landsat Thematic Mapper Satellite Systems for Detecting Gypsy Moth Defoliation in Michigan

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ABSTRACT: The task of monitoring gypsy moth defoliation is becoming more difficult as the area of defoliation increases. The gypsy moth is now established throughout much of the northeastern U.S. and in Michigan, the site of this study. Defoliation in Michigan occurred on over 120,000 hectares in 1989, with a larger area anticipated for 1990. It is imperative that a monitoring system be able to collect information over these increasingly larger areas in a short time period and at relatively frequent intervals. In this paper we examine and compare two satellite systems—SPOT and the Landsat Thematic Mapper—for their efficacy in discriminating two levels of defoliation, moderate and severe, and non-defoliation. This comparison is done with the aid of a forest/non-forest mask to reduce the confusion between defoliated areas and non-forested areas. An interpretation of optical bar photography and limited ground data were used as reference. Comparisons were made by calculating the probable overlap among the three classes (severe, moderate, and non-defoliated) using Mahalanobis distance, and with supervised and unsupervised classifications. Results indicated that Landsat TM provided greater separability of the three classes. The Landsat TM classification had an 82 percent agreement with the reference data used in the study.

INTRODUCTION

THE GYPSY MOTH (*Lymantria dispar* L.) is the most significant defoliator of hardwood trees in the northeastern U.S. Since its introduction to Massachusetts from Europe in 1869, the insect has been spreading at an increasing rate, and is just now reaching the more susceptible oak-pine and oak-hickory forests of the eastern United States (Cameron, 1986). Populations now exist in several northwestern states, but the insect is well established throughout the northeastern U.S. and in Michigan, the site of this study.

Defoliation in Michigan has increased dramatically during the past decade. In the last several years alone, aerial surveys indicate an increase in defoliation from 16,000 hectares in 1987 to nearly 120,000 hectares in the summer of 1989. With close to 5 million hectares in Michigan considered susceptible to the gypsy moth, it is likely that defoliation will reach several hundred thousand hectares annually (Montgomery, 1988).

As the extent of annual damage increases, so will the demands placed on monitoring systems. These systems should be able to (1) provide a synoptic view over a large area; (2) provide several opportunities for data acquisition within a brief biological window (to avoid problems with cloud cover or haze); and (3) provide suitable accuracy at a reasonable cost. High altitude photography and satellite images are possible solutions in that they are able to gather data quickly over large areas at minimal cost. Digital satellite images offer the added benefit of compatibility with Geographic Information Systems (GIS), facilitating analysis and revision.

This study compares two satellite systems, SPOT and the Landsat Thematic Mapper (TM), for monitoring forest defoliation caused by the gypsy moth over a 200 km² area in central Michigan. The comparison is based on the satellite sensors' ability to accurately identify areas of defoliation and separate these according to the severity of the damage.

High-altitude, optical bar camera (OBC) photography was included in the study as a reference source. Interpretation of the OBC photography was first compared to ground plots in order to judge its reliability. It was then used as a more extensive "ground truth" for a second-level comparison between the two satellite images.

DEFOLIATION MONITORING TECHNIQUES

Sketch mapping is perhaps the most common method used for monitoring extensive forest damage. Results from this technique are often subjective due to differences among interpreters in experience and ability to quickly identify (and locate on maps) defoliation of varying intensity on the ground (Talerico *et al.*, 1978; Turner, 1984). In addition, the utility of low-altitude monitoring techniques may be limited by the changes that occur in the forest canopy during the time required for surveillance over increasingly larger areas (Williams, 1975). Detection of damage caused by the gypsy moth is best performed when defoliation has reached its peak in most areas and before severely defoliated trees start to re-leaf. This may be an interval of perhaps two or three weeks, while the ground coverage required may exceed several million hectares.

Satellites have been used to detect forest damage since the early 1970s. Rohde and Moore (1974) analyzed single and multidate Landsat-1 composites for a gypsy moth defoliation study in Pennsylvania. Confusion of areas of defoliation with agricultural fields or mining areas, due to the extensive loss of green biomass in severely defoliated stands, was resolved using change detection (multi-date composites). Williams *et al.* (1979) used a forest/non-forest mask, derived from an earlier Landsat image depicting healthy forest conditions, to remove non-forested areas from consideration. The workers still reported confusion of moderate defoliation with healthy forests on northwest slopes, despite the use of band ratios to minimize aspect effects. Nelson (1981) reported moderate defoliation to be indistinguishable from healthy forests (at a classification resolution of 320 by 220 m), while heavy defoliation was distinct throughout a five-week temporal window.

By 1983, a three-year joint project between NASA's Goddard Space Flight Center and the Pennsylvania Bureau of Forestry,

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Division of Forest Pest Management, had resulted in an automated defoliation assessment system (Dottavio and Williams, 1983; Williams and Stauffer, 1978). A total of four georeferenced database layers were combined in a GIS: (1) a Landsat mosaic of Pennsylvania depicting healthy forest conditions; (2) a forest/non-forest binary mask developed from layer (1); (3) a Landsat mosaic depicting defoliation for the current year; and (4) county and forest pest management boundaries. If cloud cover were to eliminate Landsat coverage for a particular year, aerial sketch mapping would serve as a backup, with the results later digitized and entered into the database.

Some limitations of the Landsat technology commonly cited in these early studies were its poor spatial resolution (79 m) and infrequent overpasses (an 18-day cycle). With the successful launchings of Landsats-4 and -5 in the early 1980s and SPOT-1in 1986, researchers had access to images with higher resolution, better spectral characteristics (including mid-IR bands), and shorter repeat cycles.

Vogelmann and Rock (1988) found the Landsat TM mid-IR bands, which are sensitive to leaf moisture content, to be useful in assessing conifer forest decline in Vermont and New Hampshire. Results from 30-m resolution TM data were similar to those obtained with Thematic Mapper Simulator (TMS) data at 16- to 17-m resolution.

Ciesla et al. (1989) manually interpreted SPOT-1 color composites for a study of gypsy moth defoliation in southcentral Pennsylvania and western Maryland. Confusion of fallow fields and talus slopes with heavy defoliation again indicated the value of a preliminary forest/non-forest mask. Conifer plantations, shaded slopes, and a large degree of mortality in some stands were sources of confusion with moderate defoliation. The researchers concluded that SPOT color composites provdied adequate results at a regional or statewide scale, but were unacceptable for more specific assessments such as effectiveness of spray programs.

Lessons learned from this earlier research were incorporated into our comparison of the latest generation Earth resources satellites. These included development of a binary (forest/non-forest) mask to eliminate some potential sources of confusion, and digital analysis of the SPOT and TM satellite images to take full advantage of the spectral and radiometric data, while minimizing subjectivity in the classifications.

METHODS

DATA ACQUISITION

A 6000 km², four-county area in Michigan was initially chosen for study, but a cloud-free subset (200 km²) of this area was ultimately used in the comparison (Figure 1). Second- and third-growth forests cover slightly more than half of the subset area. Oak species dominate most of the upland and sandier soils in the area, with maple and aspen as stronger components on the more mesic sites.

Data were from four different sources: a full SPOT scene (60 by 60 km); a Landsat Thematic Mapper "moveable" scene (100 by 100 km); OBC photography for all four counties; and 17 ground plots. All data were acquired between the last week of June and the second week of July, 1988, at the peak of defoliation for the study area.

A 27 June 1988 SPOT scene (ID# 16032618806271640512X), centered at 43°47'N 84°38'W, was used, though cloud cover and haze ranged from 10 to 25 percent for two quadrants of the scene. No clearer scenes were available for the period of 20 June– 20 July 1988. The Thematic Mapper scene (ID# 5158115523), centered at 43°50'N 84°35'W, was acquired on 29 June 1988. Cloud cover in the scene was less than 10 percent.

Optical bar photography was taken at mid-day on 5 July 1988.

MICHIGAN

1 - Clare County
2 - Gladwin County

FIG. 1. Study area in northeast Clare and northwest Gladwin Counties.

Flight lines were approximately 29 km apart, with 60 percent overlap at nadir. Cloud cover was less than 10 percent within 18 km of the fight path. The camera (ITEK IRIS II) was mounted in an ER-2 reconnaissance aircraft flying at an altitude of approximately 20 km AMSL. Photo scale was 1:32,500 at nadir. The photography was acquired as part of a continuing gypsy moth project, begun in 1984, involving NASA and the USDA Forest Service, State and Private Forestry, for the Northeastern Area.

Ground plots were established between 5 and 12 July 1988. Each consisted of three variable-radius subplots. Subplot measurements were (1) DBH of all trees greater than 2 inches, (2) species, (3) canopy layer, and (4) percent of crown defoliated. Stands were considered severely defoliated if 75 percent or more of the measured trees were 75 percent or more defoliated, while moderate defoliation was indicated by 50 percent or more defoliation on 50 percent or more of the trees. Defoliation below these levels was categorized as non-defoliated. These definitions were chosen in order to remain consistent with classifications by the Michigan Department of Natural Resources (DNR). Collection of ground data came to an end when increasing occurrences of re-leafing among severely defoliated trees made it too difficult to discriminate between these secondary leaves and the primary leaves of non-defoliated trees.

IMAGE ANALYSIS

The SPOT and TM scenes were delivered in a computer-compatible tape (CCT) format and were digitally analyzed. The OBC photography was manually interpreted, with the interpretation transferred onto USGS maps before being converted to a digital format.

Supervised and unsupervised classifications were performed on both satellite images. A spatial clustering approach was used, based on a modified SEARCH algorithm, for input into a Bayesian maximum-likelihood classifier (Ahearn and Lillesand, 1986; NASA/ERL, 1981). Unsupervised classifications used pixel counts for each cluster, divided by the total number of pixels sampled during the cluster building stage, as estimates (prior probabilities) of that class in the entire subset. Further processing, including majority and boundary filters, overlays, and accuracy assessments, were performed using ERDAS, a raster-based GIS and image processing package.

Manual interpretation of the optical bar photography was performed by the USDA Forest Service, State and Private Forestry, for the Northeastern Area. The film was viewed monoscopically on a light table, and areas of moderate or severe defoliation were outlined. The resulting polygons were visually transferred onto 7.5 minute maps (1:24,000 or 1:25,000 scale). These maps were then digitized using pcARC/INFO. Portions of this coverage were converted into raster formats compatible with the satellite imagery (i.e., 30- by 30- or 20- by 20-m pixels).

Extensive cloud cover, combined with the small number of ground plots, made it impossible to use the ground plots for both training and testing purposes. Instead, we decided upon a two-tiered approach to reference data: (1) accuracy of the OBC interpretation would be assessed by comparison with the 17 ground plots; and (2) the OBC interpretation would serve as a reference layer for a relative comparison of the SPOT and TM images, using a cloud-free subset from each. The area chosen encompasses approximately 200 km² in northern Clare and Gladwin counties, and contains extensive examples of each defolation category.

High altitude photography has been used as reference data in other studies of satellite imagery, though the practice is far from ideal (Ciesla et al., 1989; Dottavio and Williams, 1983; Nelson, 1981; Williams et al., 1979). The comparison with ground plots provides some indication of the reliability of the OBC interpretation and allows use of all 17 plots for testing purposes alone (Table 1).

The SPOT and TM subscenes were geometrically corrected and transformed to the Universal Transverse Mercator (UTM) coordinate system using a nearest-neighbor resampling scheme and an RMS error of less than one pixel.

A forest/non-forest mask for the subset area was developed to eliminate non-forested areas from consideration. Because the OBC interpretation only included moderately or severely defoliated forests, we needed an additional source for healthy forests. Forested areas delineated on USGS maps (1:100,000 scale) were digitized and transformed into 20-m and 30-m resolution raster files. The OBC file was then overlaid on this file to produce a three-class "reference" file that identified "severe," "moderate," and "non-defoliated" areas within the study subset (Plate

1a). The reference file was then applied as a mask to each of the original multi-band images, producing "forest only" images (Plate 1b).

Prior to classification, we determined whether the defoliation classes, as interpreted in the reference file, were in fact spectrally separable. We then estimated the confusion, or overlap, between these classes. This was accomplished by first cross-referencing the image files with the reference files to generate statistics (total number of pixels, mean vector, and covariance matrix) for each class. Hotelling T² tests for each possible pairing of defoliation categories indicated all were statistically separable ($\alpha = 0.01$). The Mahalanobis distance, a measure of separability between probability density functions, was then used to estimate the probability of error, or overlap, for each pairing.

The Mahalanobis distance between two classes (r_{ij}) represents the squared distance between the means of their probability density functions and is given by the formula:

$$r_{ij} = (m_i - m_j)^T C^{-1} (m_i - m_j)$$

where m_i and m_j are the mean vectors for classes i and j, respectively, and C is the pooled covariance matrix. Probability of error, $p(e)$, between classes is given by integration of the area under a standard normal curve: i.e.,

$$p(e) = \int_{(1/2\sqrt{r_{ij}})}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-y^2/2)dy$$

and is illustrated as the shaded area in Figure 2. Both the Hotelling T² test and the Mahalanobis distance assume normal distribution of the digital numbers (DN) for each band and equivalent covariance matrices for the classes being compared (Tou and Gonzalez, 1974). Comparisons were made for the three-band SPOT and six-band (non-thermal) TM images (Table 2).

RESULTS AND DISCUSSION

The estimates of overlap indicated that TM showed greater discrimination between the defoliation levels than did SPOT,

TABLE 1. GROUND PLOTS VERSUS OPTICAL BAR INTERPRETATION.

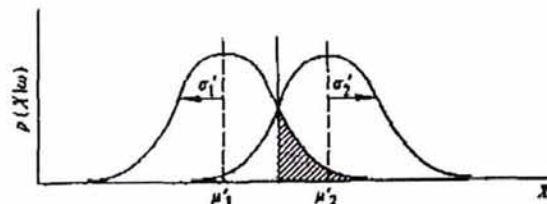| Optical Bar	Ground Plots			
	Severe	Moderate	Non-Defol	Totals
Severe	2	0	0	0
Moderate	3	5	1	9
Non-Defol	0	1	5	6
Totals	5	6	6	17
		Overall Accuracy: 70.59%*		

*Diagonal values/total.

FIG. 2. Center decision boundary and probability of error (shaded area) for two probability density functions.

TABLE 2. CLASSIFICATION ERROR VERSUS ESTIMATE DERIVED FROM MAHALANOBIS DISTANCE.

Image	"M"-Distance	% Overlap Expected	% Confusion in Unsupervised Classification
(TM 6 Bands)			
Severe-Moderate	3.98	15.96	11.34/24.35
Severe-Nondefol	7.64	8.35	1.50/ 9/70
Moderate-Nondefol	1.64	26.12	21.91/26.28
(SPOT)			
Severe-Moderate	2.88	19.78	13.11/25.75
Severe-Nondefol	4.31	14.96	1.32/ 7.66
Moderate-Nondefol	0.51	35.99	26.38/34.06

with the greatest spectral overlap occuring between moderate and non-defoliated information classes.

While there are slight differences in placement of the green, red, and near-IR bands, the primary spectral difference between TM and SPOT images is TM's additional blue and mid-IR bands. The contribution these bands make to separability is more apparent when shown graphically. Figures 3 and 4 show the mean digital numbers ($\pm$ 1 s.d.) for each band in the image subsets, separated by class. The graphs demonstrate that, with increasing severity of defoliation, reflectance increases in the visible bands, decreases in the near-IR, and increases in the mid-IR region. These results agree with observations by other workers (Leckie *et al.*, 1988). Separability in the blue (0.45 to 0.52 μm) is slight except for severe defoliation, though others have found the band somewhat useful in discriminating basal area or foliage biomass (Franklin, 1986). Separability in the mid-IR region is much more obvious, particularly between severe defoliation and the other two categories. The middle-IR bands are primarily influenced by water absorption, so these differences probably reflect the loss of high water content leaves in defoliated areas.

Because these results indicated that the three defoliation classes were indeed spectrally separable, an unsupervised classification was performed on both subsets using only three clusters. This approach assumed that degree of defoliation, not another attribute such as species composition, would be most important in separating the three clusters. Previous attempts with more clusters resulted in considerable mixing of spectral classes within and between defoliated areas, though some severely defoliated stands showed greater uniformity. The clustering algorithm may have divided these categories too finely, identifying several spectral clusters within and between information classes. These clusters could not be confidently labeled without similar detail in the reference file.

Supervised classifications were also performed. Coordinates of the training areas were recorded so that nearly identical areas from the SPOT and TM subsets could be used.

Contingency tables for the unsupervised and the supervised are shown as Tables 3 through 6. Kappa statistics are included as indicators of agreement beyond that which could be expected from chance alone (Bishop *et al.*, 1975; Rosenfield and Fitzpatrick-Lins, 1986). TM classifications showed 4 to 8 percent greater overall agreement with the reference file than did the SPOT classifications, with the greatest agreement (67.4 percent) resulting from an unsupervised TM classification (Table 6).

Results are compared with estimates in Table 2. The unsupervised SPOT classification resulted in better than expected separation of defoliated from non-defoliated areas, though all other overlaps were similar to estimates derived from Mahalanobis distances. The two values given in the last column of Table 2 differ according to the order in which the comparison was made (e.g., the percent of severe classified as moderate versus the percent of moderate classified as severe). Differences between the two values may be due to covariance matrices that were not identical as assumed, so that overlap may be greater on one side of the center line (shown in Figure 3) than the other.

Because the TM unsupervised classification showed the closest agreement with the reference file, subsequent processing was performed on it alone. Our objective was to identify some of the discrepancies between the two files in order to make them more comparable, not necessarily to improve accuracy in relation to known ground conditions.

The reference file was derived from two sources (the OBC interpretation and a USGS map), each with its own inherent errors. Discrepancies related to the OBC classification are considered first.

Besides the potential error of misclassification by the OBC interpreter, there is a "clumping" error related to the minimum
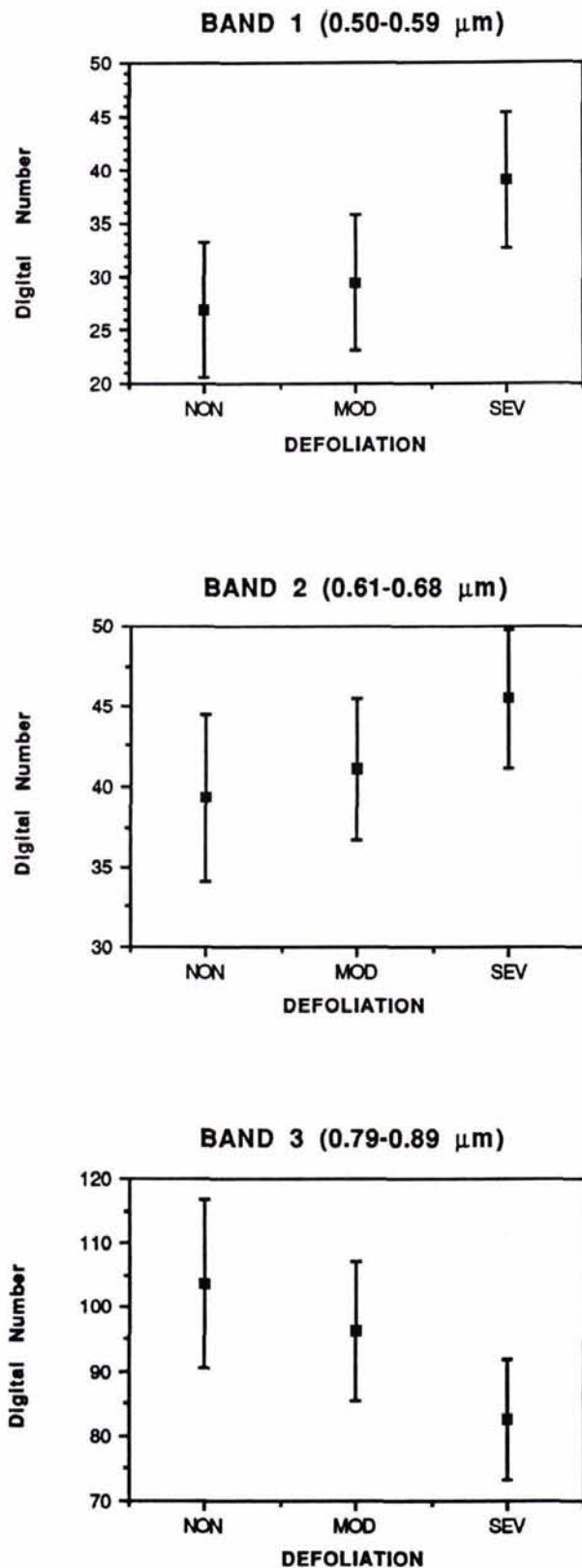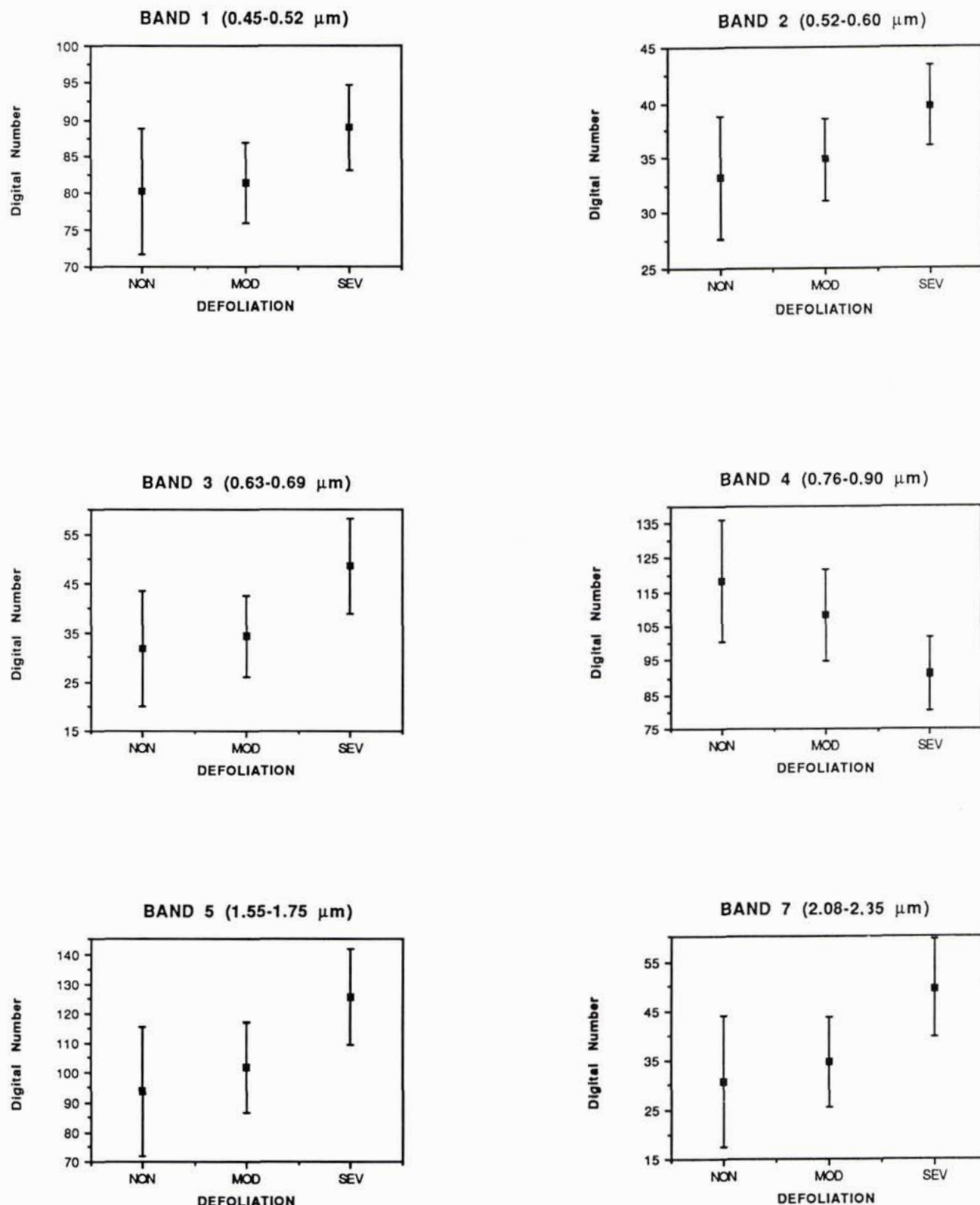

FIG. 3. SPOT mean DNS ($\pm$ 1 s.d.).

mapping unit recognized by the photo interpreter. For example, small pockets of severe or non-defoliation within a larger moderate stand may be clumped together as one moderate polygon.

BAND 1 (0.45-0.52 µm)

BAND 2 (0.52-0.60 µm)

BAND 3 (0.63-0.69 µm)

BAND 4 (0.76-0.90 µm)

BAND 5 (1.55-1.75 µm)

BAND 7 (2.08-2.35 µm)

FIG. 4. TM mean DNs (± 1 s.d.).

Less than 1 percent of the polygons outlined by the OBC interpreter were smaller than 8100 m², comparable to a 3 by 3 square of pixels at TM resolution. We used a 3 by 3-pixel window to "generalize" the TM classified image to the resolution of the OBC interpretation, with the central pixel in the window given a class value equal to that of the plurality of the surrounding pixels. Use of the filter resulted in a nearly 4 percent increase in overall agreement (71.0 percent).

TABLE 3. SPOT SUPERVISED CLASSIFICATION VERSUS REFERENCE FILE.

	Optical Bar Interpretation (Reference)				Comm. Err (%)
	Severe	Moderate	Non-Defol	Totals	
Severe	7406	6213	14099	27718	73.28
Moderate	3349	33610	58657	95616	64.85
Non-Defol	198	14471	122306	136975	10.71
Totals (Pixels)	10953	54294	195062	260309	
Omm. Error (%)	32.38	38.10	37.30		
Kappa (× 100):	63.76	39.79	21.28	28.98	
Overall Agreement (%): 62.74					

TABLE 4. SPOT UNSUPERVISED CLASSIFICATION VERSUS REFERENCE FILE.

	Optical Bar Interpretation (Reference)				Comm. Err (%)
	Severe	Moderate	Non-Defol	Totals	
Severe	7988	7118	14939	30045	73.41
Moderate	2820	32855	66439	102114	67.83
Non-Defol	145	14321	113684	128150	11.29
Totals (Pixels)	10953	54294	195062	260309	
Omm. Error (%)	27.07	39.49	41.72		
Kappa (× 100):	69.40	35.02	17.83	25.36	
Overall Agreement (%): 59.36					

TABLE 5. TM SUPERVISED CLASSIFICATION VERSUS REFERENCE FILE.

	Optical Bar Interpretation (Reference)				Comm. Err (%)
	Severe	Moderate	Non-Defol	Totals	
Severe	3095	2012	7178	12285	74.81
Moderate	1586	15736	20731	38053	58.65
Non-Defol	201	6335	59567	66103	9.89
Totals (Pixels)	4882	24083	87476	116441	
Omm. Error (%)	36.60	34.66	31.90		
Kappa (× 100):	59.08	48.52	26.20	34.85	
Overall Agreement (%): 67.33					

TABLE 6. TM UNSUPERVISED CLASSIFICATION VERSUS REFERENCE FILE.

	Optical Bar Interpretation (Reference)				Comm. Err (%)
	Severe	Moderate	Non-Defol	Totals	
Severe	3620	2732	8483	14835	75.60
Moderate	1189	15022	19164	35375	57.53
Non-Defol	73	6329	59829	66231	9.67
Totals (Pixels)	4882	24083	87476	116441	
Omm. Error (%)	25.85	37.62	31.61		
Kappa (× 100):	70.38	45.96	26.70	35.37	
Overall Agreement (%): 67.39					

TABLE 7. TM UNSUPERVISED CLASSIFICATION (FILTER AND BOUNDARIES) VERSUS REFERENCE FILE.

	Optical Bar Interpretation (Reference)				Comm. Err (%)
	Severe	Moderate	Non-Defol	Totals	
Severe	2725	894	2851	6470	57.88
Moderate	479	10473	5222	16174	35.25
Non-Defol	19	3434	49368	52821	6.54
Totals (Pixels)	3223	14801	57441	75465	
Omm. Error (%)	15.45	29.24	14.05		
Kappa (× 100):	83.10	62.78	53.16	59.45	
Overall Agreement (%): 82.91					

There are a number of errors inherent in the digitized USGS layer, the most significant due to inaccuracies of the original map. Some of these are obvious when the layer is placed over the TM multi-band image (Plate 1c). The amount of forested area (red areas indicating high near-IR reflectance) not covered by the green mask is considerable, most likely due to growth in vegetation since the map was last updated. What can't be seen is the amount of forest removed since the map inventory, but still considered forested in the reference file. This may also be significant, resulting in confusion between areas classified as "defoliated" in the TM file and non-defoliated in the reference file. This is evident in all contingency tables, where a large number of "non-defoliated" reference pixels are classified as severe while few "severe" reference pixels are classified as non-defoliated.

Other potential errors in the USGS file relate to registration and digitization. Forest (green) polygons on the original USGS map were outlined using a 0.5-mm lead pencil before being digitized. At the scale of the maps (1:100,000), the effective border ("margin" of error) for these polygons amounts to 50 m on the ground, nearly two TM pixels wide. Conversion from vector to raster format probably added slightly to this error. Minor registration errors also likely resulted from geometric correction and resampling of the original image pixels. Many of the severe defoliation pixels in the classified images occur along the edges of the mask polygons. It is likely that these represent non-forested areas on the forest fringe that were included due to inaccuracies of the borders. Roads that were borders between forested areas were also included in the mask and likewise were classified as severe defoliation. In order to remove these from consideration, a one pixel border around each polygon was masked out.

Application of the border to the majority-filter file increased overall agreement to nearly 83 percent (Table 7). While the border reduced the total number of pixels considered by 35 percent, it decreased the number of non-defoliated pixels classified as severe by 62 percent, indicating that border "severe" pixels were indeed a primary source of error.

## CONCLUSION AND SUGGESTIONS FOR IMPROVEMENT

We examined the utility of two forms of satellite imagery (SPOT and the Landsat Thematic Mapper) for detecting defoliation by the gypsy moth in a 200 km^2 area in central Michigan. Post-classification processing of the TM data resulted in an overall agreement of 82.9 percent with a reference file. TM agreements were approximately 4 percent higher than for SPOT using a supervised approach and 8 percent better using an unsupervised approach.

Cloud cover during the SPOT acquisition date limited the size of the area that could be compared, while insufficient ground information required the use of high altitude photography (the Optical Bar Camera) for reference rather than inclusion in the comparison.
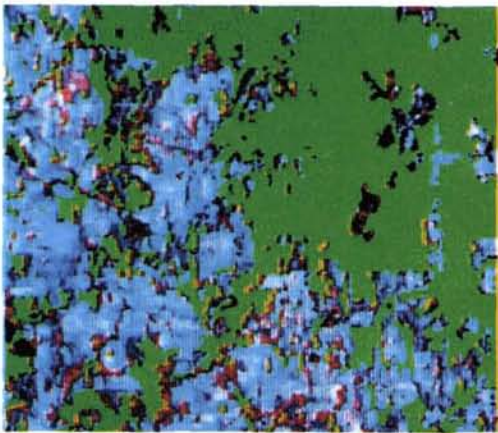
The statistical separability and percent overlap of defoliation classes were estimated prior to classification. This was accom-
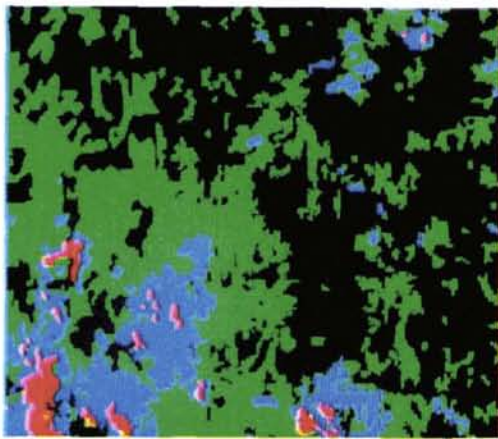
(a)
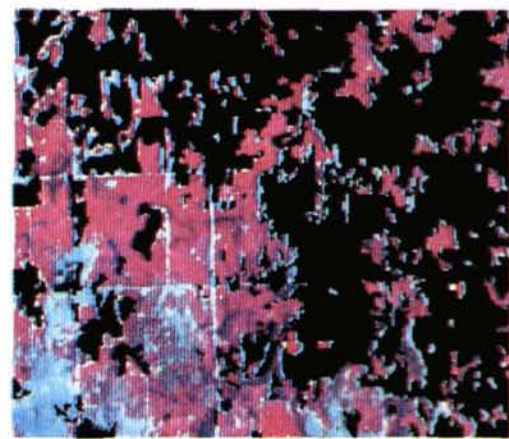
(b)

(c)

PLATE 1. (a) Three class reference file: red = severe and blue = moderate defoliation (both from OBC interpretation); green = non-defoliated (from USGS map). (b) Multi-band TM subset, masked to show only forested areas (red = healthy vegetation, blue-gray = defolation). (c) Forested areas (red) not included in the mask.

plished by cross-referencing the original image files with a combined OBC/forest mask reference file. Assuming complete accuracy of the reference data, these estimates represent the best results that could be expected from classification of the satellite data. Of course, any confusion of classes by the OBC interpreter, or errors in the forest mask file, would result in greater overlap being indicated than actually occurs. Estimates of error compared favorably with the classification results.

Development or acquisition of a forest/non-forest data layer would be a significant step towards making detection by satellite operational. Accuracy may also be increased if more specific information, such as basal area of preferred species, density of gypsy moth egg masses, or proximity to previous defoliation can be expressed as a weighting factor in classifications.

The Michigan DNR currently uses an airborne, color-IR video system for detection. Tapes from these flights are reviewed and interpreted on the ground, with interpretations digitized and entered into a GIS. Current plans in the ongoing satellite study call for a similar system for gathering reference data. Several transects would be flown at low altitude to sample the current year's hot spots, with a LORAN reading incorporated into the tape display. Reference data from a wide range of ground conditions could then be gathered quickly and related more extensively to image pixels. Cloud cover during satellite flyover dates could determine whether the video system is used for ground reference sampling or complete coverage in a given year.

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Forum

Modeling and Evaluating the Effects of Stream Mode Digitizing Errors on Map Variables

It was a pleasure to read "Modeling and Evaluating the Effects of Stream Mode Digitizing Errors on Map Variables" (*PE&RS*, July 1991, pp. 957–963) by Keefer *et al.* However, there could be a mistake in this paper. In the second paragraph of the second section, the paper states: "As the cursor is moved continuously along the map line, the operator never follows the line perfectly, but instead continually crosses form one side of the line to the other side." In the seventh paragraph of the second section, the paper defines positive and negative errors as: "Positive errors were defined as errors to the left of the line segment when viewed in the direction of digitizing. Those errors to the right of the line segment were considered negative errors." However, in the last paragraph of the second section, the paper states: "The serial correlation coefficient, ϕ, was also estimated for each of the 80 data sets. Most of the coefficients were in the 0.65 to 0.85 range which indicated a strong positive correlation process in digitizing error. The empirical distribution was used later in the simulation process to select values for ϕ.

The statement, "a strong positive correlation," could be wrong. According to the definition of correlation coefficient, the correlation coefficient is calculated by

$$\phi = E\left(\frac{\bar{x} - E(\bar{x})}{\delta_x} \times \frac{\bar{y} - E(\bar{y})}{\delta_y}\right)$$

Because "the operator continually crosses from one side of the line to the other side," the errors should continuously change from positive to negative or negative to positive according to the definition for positive error and negative error given in the paper. Therefore, the correlation coefficient should be negative instead of positive.

This mistake could have serious consequences. If a positive correlation coefficient were used to simulate the digitizing error

in terms of Equation 4, the conclusions and the four tables in the paper could be based on a false assumption.

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Response

We believe that Mr. Zhang has misinterpreted one of our statements, or we failed to make the point clearly enough. When we stated that ". . . the cursor is moved continuously along the map line. . . .," that did not mean that a crossing occurred between each and every sampled point. If that had occurred, then Mr. Zhang would be correct and the correlation would have been negative and would have approached unity. We think it is clear that this was not the case. Figure 2 on page 959 indicates that there tended to be several points on one side of the line before a crossing occurred, and that is why the correlation was positive. It may be true that, when we used the word "continuously," we presented an incorrect impression. However, to the operator, there is a continuous movement from side to side, but several points are sampled before the adjustment is made. That is, to the operator the movement is continuous from side to side, but to the software there is a time delay between crossings that results in more than one point being sampled on the same side of the line. That phenomenon produces the positive correlations.

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