

# Assessment of Thematic Mapper Imagery for Forestry Applications under Lake States Conditions

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**ABSTRACT:** Landsat Multispectral Scanner (MSS) data have only very general utility for forest type mapping and condition assessment under environmental conditions typical of the Lake States. Accurate classification is hindered by the considerable species and site variability of this region and the relatively coarse spatial, spectral, and radiometric resolution of the MSS. This paper presents a preliminary assessment of Landsat Thematic Mapper (TM) data for forestry applications under Lake States conditions. Two study sites in Wisconsin with distinctly different forest character were analyzed using both visual and computer-assisted interpretation techniques. Highly accurate hardwood versus softwood and upland versus lowland forest type separations were made, and further specification was shown possible. Distinction of jack pine budworm defoliation levels was also achieved. Approaches to digital data analysis which incorporate visual analysis techniques or spatial information appear needed to fully exploit the information value of the higher resolution data. This research indicates that TM data can provide better forest type mapping and condition assessment information than MSS data and may, therefore, be more widely used in forestry applications. However, additional analyses are needed to fully assess the capability of TM imagery for forestry applications in the Lake States region.

## INTRODUCTION

NUMEROUS FOREST CLASSIFICATION PROJECTS have experimented with Landsat Multispectral Scanner (MSS) imagery (see Heller *et al.*, 1983). The results have varied widely depending on the techniques used and the location and extent of the study regions. Heller *et al.*, (1983) and Williams and Nelson (1986) report that MSS data can be used to distinguish forest and other level I (Anderson *et al.*, 1976) land-cover classes with accuracies near 90 percent. Also, level II forest classes (hardwood versus softwood) can generally be classified with accuracies ranging from about 70 percent to just over 80 percent. However, specification of level III forest type classes (species groupings) cannot be performed consistently. These classification abilities are useful only for large regional projects, very general investigations, or forest stratification purposes. The spatial, spectral, and radiometric limitations of MSS imagery prevent species and site specific information extraction. Hence, the higher resolution data from the Landsat Thematic Mapper (TM) needs to be evaluated for forestry applications.

The difficulties of using MSS data in forest classification are especially evident in Lake States and northeastern United States forest environments. Classification is hindered in these regions by extreme variability in species, forest type, and other land cover. The spatial, spectral, and radiometric limitations of MSS data have further compounded the problem. Consequently, in these regions, MSS image classification has generally been found adequate only for level I forest mapping (Bryant *et al.*, 1980; Mead and Meyer, 1977; Roller and Visser, 1980). The hypothesis for this research is that the improved spectral, radiometric, and spatial characteristics of TM data might lead to forest classification improvements (relative to MSS) for Lake States and northeastern forest conditions. This paper provides an initial assessment of TM data for classifying forests in the Great Lakes region.

## BACKGROUND

Most reports on forestry applications of TM imagery have used Thematic Mapper Simulator (TMS) data (e.g., Blanchard and Frick,

1982; Franklin, 1986; Spanner *et al.*, 1984; Vogelmann and Rock, 1986). In general, TM-type data have been found superior to MSS imagery (Horler and Ahern, 1986; Williams and Nelson, 1986). Latty and Hoffer (1981a) studied the utility of TM spectral bands for a site in South Carolina using TMS data. They analyzed the statistical separability (transformed divergence) of spectral classes using various TMS spectral band combinations. Their results showed high separability between a number of forest classes (pine, pine-hardwood, old age hardwood, second growth hardwood, water tupelo, sycamore, and clearcuts). However, they emphasized the need for follow-up studies involving actual classification using spectral pattern recognition.

Nelson *et al.* (1984) reported preliminary supervised pattern recognition results using TMS data acquired for a site in Maine. While their results were generally disappointing (overall accuracy of 58 percent), they indicated better distinction of forest types than usually attributed to MSS. The forest classes analyzed were clearcut, old clearcut, conifer, hardwood, mixed wood, strip cut, severe conifer defoliation, heavy conifer defoliation, and severe mixed wood defoliation (defoliation was by the spruce budworm, *Choristoneura fumifera*, Clem.). These TMS data were collected at a suboptimal time (October) and the study site was in the boreal forest region<sup>†</sup> (rather than the central or northern forest regions of interest in this paper).

Williams and Nelson (1986) report the results of a North Carolina study where substantial classification improvements were obtained with TMS data (relative to MSS data) for seven level III forest classes (clearcut, four age classes of pine, pine-hardwood, and hardwood). The overall performance of the TMS classification was 60 percent as compared to 39 percent for MSS data. With four aggregated classes (clearcut, young pine, mature pine, hardwood), TMS data were still superior but the results were more comparable (77 percent for TMS versus 71 percent for MSS). The authors attribute the improvements associated with the TMS data to the better spectral and radiometric characteristics of TM-type data.

Fewer researchers present results from the use of actual TM data in forestry applications. Benson and DeGloria (1985) report on the application of TM data to forest surveys in California. The best TM band combination was better than the MSS data and the best results indicated that TM data will provide higher classification accuracies. The additional spectral information of

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<sup>†</sup>For the purposes of this paper, hardwood refers to deciduous, broadleaf species and softwood refers to coniferous species.

<sup>†</sup>Forest regions used in this paper correspond to the descriptions given by Eyre (1980).



TM band 5 appeared largely responsible for the improved performance. However, the study utilized visual interpretation methods and emphasized the information content of the different TM bands rather than their classification performance. In another recent paper, Horler and Ahern (1986) emphasized feature selection (the determination of optimal bands or band transforms) for visual enhancements of imagery of boreal forests. This paper reports that TM data contain more spectral information on forest classes than MSS imagery. However this project emphasized image enhancement and no classification was performed.

More information is needed in order to assess the performance of actual TM data for applications in central and northern forests. Information is especially needed on computer classification results. Consequently, two forest classification case studies were conducted in Wisconsin using actual TM data.

## OBJECTIVES

The primary objective of this research was to assess the accuracy and specificity to which computerized forest classification could be accomplished using actual TM imagery. Additional objectives were to investigate the utility of individual TM digital data bands for forestry application and to assess the visual interpretability of the imagery. In the process, the capability of TM data for delineating different levels of insect defoliation and for locating clearcut areas was also investigated.

## GENERAL PROCEDURES

Computer-assisted classification based on spectral pattern recognition was emphasized, but some visual interpretation was also performed. The two case studies examined distinct sites in Wisconsin (Figure 1). Study Site 1 represents the complex mixture of forest and other land-cover types which is typical of the southern Great Lakes region. Study Site 2 exemplifies the predominantly forested and commercially managed areas of the northern Great Lakes region. Together these two complementary sites represent a wide range of the forest conditions present in the Great Lakes region. There are some differences in the methods

applied to each study site because each site was analyzed independently by different authors. As a result, direct comparison between sites is sometimes difficult. The methods employed, and the results obtained, in each study are presented below. This paper emphasizes general findings, because exhaustive analysis of TM for the many conditions and situations found in Lakes States forests will require additional research.

## TM CASE STUDY: SITE 1

### STUDY SITE DESCRIPTION

Study Site 1 is part of the northern unit of the Kettle Moraine State Forest in Fond du Lac and Sheboygan Counties in east-central Wisconsin (Figure 1). This site provides a rigorous test due to the complex variety of land-cover types present. The nonforest types include water, nonforested wetlands, many agricultural types, and developed areas. The forest types consist of both upland and lowland types of hardwood and softwood species (Table 1a).

### IMAGE DATA

The TM data covering Site 1 were acquired by the Landsat 5 spacecraft on 18 July 1984. The 512- by 360-pixel subscene is of excellent quality and has only a few very small clouds (Figure 2).

### GROUND REFERENCE DATA

Reference data for Study Site 1 were derived from compartment and stand maps provided by the Wisconsin Department of Natural Resources. On these maps, upland hardwoods were typed into oak, northern hardwoods (maple-beech-birch and many other species), central hardwoods (walnut, cherry, elm in association with oaks and hickory), or aspen categories. Lowland hardwoods were typed as swamp hardwoods (ash and red maple) or lowland brush (willow, alder). The upland conifers were typed by species and the lowland conifers as swamp conifer (balsam fir, cedar, spruce in association with various lowland hardwoods), tamarack, or cedar.

Field visits showed the reference maps to be reliable. However, upland hardwood types in the Great Lakes region commonly contain different proportions of the same species. This confusing situation was evident in Study Site 1. Oak was common in all upland hardwood types, and stand typing was much less precise than indicated on the stand maps. Even the aspen stands included oak, sugar maple, and hickory; and contained pockets where these other species together composed a majority.

### ANALYSIS TECHNIQUES

A supervised maximum-likelihood classification was conducted using all seven TM bands. Two iterations of a "majority rule" smoothing algorithm using a 3 by 3 window were applied to the final classification prior to accuracy assessment. This smoothing was conducted to eliminate the "salt and pepper" effect resulting from small, isolated areas of different classes commonly produced during supervised statistical pattern recognition.

A reference data set of 6003 pixels was derived by outlining 229 reference polygons on the subscene. The sample data were examined statistically to determine if the cover types represented by the various polygons were separable and/or contained multiple "spectral classes." In this way, 26 spectrally discernable categories were identified.

Eight categories corresponded to agricultural cover types and seven described water, developed land, marsh, cloud, and cloud shadow. Because the emphasis of the study was forest-cover mapping, minimal attention was given to optimizing the classification results within these nonforest categories. The only concern was obtaining their adequate distinction from the forest types present in the subscene.



FIG. 1. Study site location map.



TABLE 1. PREDOMINANT TREE SPECIES OCCURRING AT THE STUDY SITES.

a. Study Site 1	
UPLAND HARDWOOD SPECIES	
oaks ( <i>Quercus</i> spp.)	American basswood ( <i>Tilia americana</i> )
shagbark hickory ( <i>Carva ovata</i> )	American beech ( <i>Fagus grandifolia</i> )
sugar maple ( <i>Acer saccharum</i> )	birch ( <i>Betula</i> spp.)
black walnut ( <i>Juglans nigra</i> )	bigtooth aspen ( <i>Populus grandidentata</i> )
white ash ( <i>Fraxinus americana</i> )	black cherry ( <i>Prunus serotina</i> )
American elm ( <i>Ulmus americana</i> )	
LOWLAND HARDWOOD SPECIES	
black ash ( <i>Fraxinus nigra</i> )	red maple ( <i>Acer rubrum</i> )
green ash ( <i>Fraxinus pennsylvanica</i> )	willows ( <i>Salix</i> spp.)
alders ( <i>Alnus</i> spp.)	
UPLAND CONIFER SPECIES	
red pine ( <i>Pinus resinosa</i> )	Norway spruce ( <i>Picea abies</i> )
eastern white pine ( <i>Pinus strobus</i> )	
LOWLAND CONIFER SPECIES	
tamarack ( <i>Larix laricina</i> )	black spruce ( <i>Picea mariana</i> )
n. white cedar ( <i>Thuja occidentalis</i> )	balsam fir ( <i>Abies balsamea</i> )
b. Study Site 2	
UPLAND HARDWOOD SPECIES	
sugar maple ( <i>Acer saccharum</i> )	yellow birch ( <i>Betula alleghaniensis</i> )
northern red oak ( <i>Quercus rubra</i> )	bigtooth aspen ( <i>Populus grandidentata</i> )
white birch ( <i>Betula papyrifera</i> )	trembling aspen ( <i>Populus tremuloides</i> )
UPLAND CONIFER SPECIES	
jack pine ( <i>Pinus banksiana</i> )	red pine ( <i>Pinus resinosa</i> )
LOWLAND CONIFER SPECIES	
tamarack ( <i>Larix laricina</i> )	black spruce ( <i>Picea mariana</i> )
n. white cedar ( <i>Thuja occidentalis</i> )	

Nine forest information classes (white pine, red pine, Norway spruce, lowland conifer, oak/northern hardwood, central hardwood, lowland hardwood, aspen, and alder/tamarack) were represented by the 11 remaining reference data categories. The white pine and oak/northern hardwood classes each had two constituent categories. The two categories evident for oak/northern hardwood were unrelated to species. The oak and northern hardwood forest types were combined into a single information class after statistical analysis showed practically no separability and field visits confirmed the presence of oak in the northern hardwood stands.

Three reference subgroups were then created, each containing data combined from multiple scattered polygons from each category. Alternately, two reference subgroups were combined to form the training data and the third was reserved as an independent test sample. Three classifications were performed in this manner, each using a different combination of two subgroups as training data with the third subgroup reserved for testing. The results of the three classifications were then pooled to reduce any bias possibly resulting from the specific partitioning of the polygons into reference subgroups. In this way, all sample pixels were used for both training and testing but the test data were still independent of the training data during each separate classification.

#### CLASSIFICATION RESULTS

The results of the computer-assisted classification are reported in Tables 2 and 3 and shown in Plate 1. Table 2 provides accuracy statistics on the original detailed forest and nonforest cover types while Table 3 aggregates these cover types into five more-general forest categories and one nonforest category. In both tables, the alder/tamarack category contained scattered tamarack, making it very similar to a hardwood category. The average forest/nonforest accuracy was 98 percent, the average hardwood/softwood accuracy was 94 percent, and the average accuracy for the five aggregated forest classes was 90 percent. The average accuracy for the nine most detailed forest classes was 69 percent. Overall or pooled estimates of classification accuracy for the

various aggregations of interest were also computed and are reported in the tables. These estimates, which report the simple percentage correct for all pixels of all the classes of interest, were higher than the average results.

#### DISCUSSION

The excellent accuracy for distinction of forest from nonforest was expected. However, high classification accuracies are also evident for the majority of the forest information classes. The nine most detailed forest classes even show promise, if the disappointing results for central hardwoods are discounted. The poor result for central hardwoods is understandable given the extreme similarity in species composition between the oak/northern hardwood, central hardwood, and aspen cover types. At the same time, this similarity makes the results for classifying aspen seem encouraging. Many of the oak/northern hardwood omission errors went to the aspen class but most of these omission errors occurred in the vicinity of the known aspen stands. These nearby oak/northern hardwood stands may contain a larger component of aspen. At any rate, when the three upland hardwoods classes are aggregated into an upland hardwood category (Table 3), classification accuracy becomes excellent (99 percent).

The results obtained for red and white pine are encouraging, but the results for Norway spruce are disappointing. Most of these conifers occur in small plantations and there are only a few spruce stands, all of which are quite young. The use of larger, older, and more numerous stands of upland conifers to derive a better sample (especially for spruce) may have yielded better results. As with the upland hardwoods, when red pine, white pine, and Norway spruce are aggregated into an upland conifer category, excellent classification accuracy (94 percent) results.

The lowland conifers also classified reasonably well, the only major confusion being with lowland hardwoods. This confusion is explained by the tendency of lowland conifer areas to contain numerous pockets of lowland hardwoods which were not delineated on the reference maps. The lowland hardwood category classified very well. The most notable confusion occurred





Fig. 2. Thematic Mapper band 5 subimage of Study Site 1.

with the alder/tamarack category which is similar to many of the areas labeled as lowland hardwood. The consistent separability and high accuracy (95 percent) for the alder/tamarack cover type is especially noteworthy.

All seven TM bands were included in the analysis, but the thermal infrared (band 6) digital data exhibited very little range in brightness for all cover types. Visual inspection of the thermal data verified the general lack of contrast. Consequently, the utility of band 6 was tested by performing a second classification using only the six non-thermal channels. The six-band results were slightly better overall. Curiously, the six-band classification (no thermal data) yielded accuracy improvements of 5 to 9 percent in the lowland hardwoods, marsh, and cloud categories while the seven-band results were better by 1 to 5 percent in the lowland conifer, alder/tamarack, central hardwoods, water, and developed categories. The practical significance of these changes is doubtful, so the statistical significance was not evaluated. On balance, for this case study and application, the thermal infrared data added no classification information to the other six channels.

Several other observations about the TM bands were made while analyzing the digital reference data during the training and classification phases of the project. First, band 5 contains at least as much forest type discrimination information as band 4. In addition, these two bands appear to complement one another by providing for distinction between different forest categories. Bands 1, 2, and 3 exhibited little contrast among the forest categories but were important for distinguishing forest from nonforest. Finally, band 7 data seemed to contribute to the discrimination of forest classes as well as the separation of forest from nonforest.

These results show that the "intrinsic dimensionality" of TM

data for forest and land-cover typing may be higher than the often reported bidimensionality of MSS data (Kauth and Thomas, 1976; Landgrebe, 1978; Jensen and Waltz, 1979). In other words, the high correlation often found between the green and red MSS bands and the two near-infrared MSS bands has limited the effective channels of MSS data to two. At least three effective discrimination channels seemed evident in the TM imagery during this project (see also Sadowski *et al.* (1985), Horler and Ahern (1986), and Williams and Nelson (1986)). The actual dimensionality of TM data or the degree of correlation between any TM channels was not determined quantitatively. However, analysis of reference pixels during training and preliminary classification showed that at least one band from the visible, near-infrared, and middle infrared wavelength regions should be included.

Visual analysis of the TM image data produced additional results. First, the finer spatial resolution of TM (compared to MSS) greatly facilitated the location and delineation of sample areas. Correspondence between stand maps and the imagery was aided by the improved evidence of rural roads, rights-of-ways, and other distinguishing features in the TM data. Second, visual contrast in bands 1, 2, 3, and 7 was limited, and contrast enhancement (by linear histogram stretching) improved the visual detail in these bands substantially. Finally, visual (qualitative) inspections were performed on three color composites: a normal color composite (NCC) derived from bands 1, 2, and 3; a standard false color composite (FCC) created using bands 2, 3, and 4; and an FCC composed of bands, 3, 4, and 5. This last combination was designed to include a visible, near-IR, and mid-IR band in the composite. Band 3 was selected as the visible band because it corresponds to a region of vegetative absorption of light.

All composites allowed visual separation of forest and other level I cover types. Little forest refinement was possible using the NCC but, as expected, substantially more forest type information was provided by the standard FCC. With the standard FCC, level II cover classes of hardwood and softwood were readily distinguished while upland/lowland forest classes were just separable. Even more distinct forest specification was evident using the band 3, 4, 5 FCC. Not only were upland and lowland classes of both hardwood and softwood very distinct, but variability within these categories was also evident. However, the improved variability of forest in this third color composite came at the expense of decreased ability to separate forest from agriculture or other vegetated categories. There was also a marked decrease in cultural detail (e.g., roads, developed areas, and field boundaries), making visual registration of the image with the maps more difficult. These problems may have been alleviated by using band 2 as the visible band because cultural features were more pronounced in that band. Our visual results further support the desirability of including at least one band from each of the three wavelength regions. Benson and DeGloria (1985) and Horler and Ahern (1986) report similar results of visual interpretation.

#### TM CASE STUDY: SITE 2

In order to expand the representativeness of this test of TM capability, computer classification was also performed for a second study site. Site 2 was selected to test the capability of TM data in a predominantly forested area actively managed for commercial forestry. In addition, the site contains areas subject to jack pine budworm (*Choristoneura pinus pinus*) defoliation and timber harvesting. Therefore, a preliminary assessment of TM for such disturbed forest classes could be made. The procedures applied to Study Site 2 varied from those applied at Site 1 because the two sites were worked on independently and in parallel. While the different techniques complicate direct comparison of the results from the two sites, they also extend the range of procedures and results reported in this paper.

#### STUDY SITE DESCRIPTION

Study Site 2 is a 15 km<sup>2</sup> area in Douglas and Bayfield counties in northwest Wisconsin (Figure 1). Upland forest cover types predominate, though small areas of wetlands and lowland



TABLE 2. CLASSIFICATION RESULTS FOR TM CASE STUDY 1.

MAP VERIFIED CLASS	LANDSAT TM CLASSIFICATION															PERCENT CORRECT
	pw	pr	sn	lc	at	oh	ch	as	lh	ag	wo	wm	dv	sh	cl	
pw	276	35	25	3	0	0	0	0	1	6	0	1	0	0	0	80
pr	45	256	16	0	0	0	0	0	0	12	0	3	3	0	0	76
sn	52	8	64	1	0	0	0	0	2	14	0	2	0	0	0	45
lc	1	0	0	145	0	0	0	0	45	4	0	6	0	0	0	72
at	0	0	0	0	139	0	0	0	7	0	0	0	0	0	0	95
oh	0	0	0	0	0	831	47	239	2	4	0	0	0	0	0	74
ch	0	0	0	0	0	56	13	1	1	2	0	0	0	0	0	18
as	0	0	0	0	0	14	12	69	0	0	0	0	0	0	0	73
lh	0	0	0	3	17	2	1	0	370	12	0	13	0	0	0	88
ag	0	0	0	0	0	0	0	0	7	2236	0	18	89	0	0	95
wo	0	0	0	0	0	0	0	0	0	0	378	3	0	0	0	99
wm	0	0	0	11	0	0	0	0	8	33	0	83	0	0	0	62
dv	0	0	0	0	0	0	0	0	0	0	0	0	125	0	0	100
sh	0	1	0	0	0	0	0	0	0	0	0	0	0	60	0	98
cl	0	0	0	0	0	0	0	0	0	0	0	0	6	0	64	91

Overall Accuracy: 85%

Average Class Accuracy: 78%

Classes: pw: white pine  
pr: red pine  
sn: Norway spruce  
lc: lowland conifers  
at: alder/tamarack

oh: oak/N. hardwood  
ch: central hardwoods  
as: aspen  
lh: lowland hardwoods  
ag: agriculture

wo: open water  
wm: marsh (emergent veg.)  
dv: developed  
sh: cloud shadow  
cl: cloud

TABLE 3. AGGREGATED CLASS RESULTS FOR TM CASE STUDY 1.

MAP VERIFIED CLASS	LANDSAT TM CLASSIFICATION						PERCENT CORRECT
	uc	lc	at	uh	lh	nf	
uc	777	4	0	0	3	41	94
lc	1	145	0	0	45	10	72
at	0	0	139	0	7	0	95
uh	0	0	0	1282	3	6	99
lh	0	3	17	3	370	25	88
nf	1	11	0	0	15	3095	99

Overall Accuracy: 97%

Average Class Accuracy: 91%

Classes: uc: upland conifers<sup>1</sup>  
lc: lowland conifers  
at: alder/tamarack

uh: upland hardwoods<sup>2</sup>  
lh: lowland hardwoods  
nf: nonforest<sup>3</sup>

Summary of Further Class Aggregations:

Average Hardwood/Softwood Accuracy: 94%

Pooled Hardwood/Softwood Accuracy: 95%

Average Forest/Nonforest Accuracy: 98%

Pooled Forest/Nonforest Accuracy: 98%

<sup>1</sup>Derived by combining the results for white pine, red pine, Norway spruce.<sup>2</sup>Derived by combining the results for oak/northern hardwood, central hardwood, aspen.<sup>3</sup>Derived by combining the results for all nonforest categories.

conifers also occur (Table 1b). Water is the only substantial nonforest cover type. However, some roads, a couple of gravel pits, and a few small fields also exist in the area.

**IMAGE DATA**

Imagery for the site was acquired on 21 June 1984 by Landsat 5. The 512- by 512-pixel subscene is of generally good quality, though thin clouds cover approximately 4 percent of the site and some haze occurs near the clouds (Figure 3).

**REFERENCE DATA**

Reference information for this site was derived from field visits, stand transects, and 70-mm color infrared (CIR) aerial

photography. The CIR photography was acquired at a scale of 1:15,440 on 25 July 1984. These data sources were used to identify hardwoods, lowland conifers, red pine, jack pine, clearcuts, and three levels of jack pine budworm defoliation. These three levels of defoliation were moderate (20 to 50 percent of foliage removed), severe (> 50 percent of foliage removed), and dead trees. Reference information about open water, roads, and gravel pits was also determined from the three data sources.

**ANALYSIS TECHNIQUES**

A supervised maximum likelihood classification algorithm was applied to bands 2, 3, and 4. Only bands 2, 3, and 4 were used so that results could be compared to those which might be obtained using CIR photography. Currently, CIR aerial



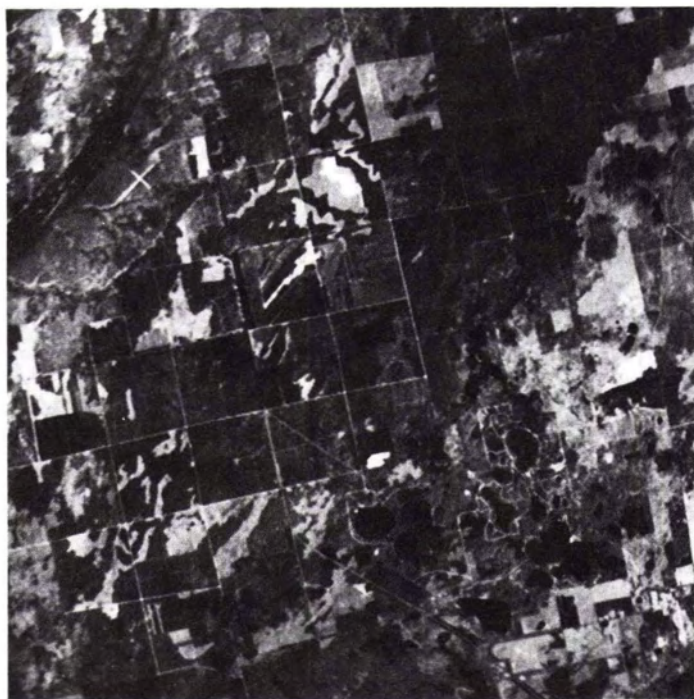


FIG. 3. Thematic Mapper Band 5 Subimage of Study Site 2.

photographs are widely used by foresters in the region. Also, use of these bands will subsequently allow an approximate comparison with the MSS bands. Two iterations of a majority rule smoothing algorithm using a 3 by 3 window were applied to the classified data prior to accuracy assessment. This smoothing was performed to eliminate small, isolated pockets of different class which commonly result during supervised classification.

A training data set was derived by outlining 30 reference polygons (4292 pixels) on the subscene. Evaluation of the classification was accomplished using a test sample of 33 polygons (1655 pixels). This test sample was collected after the classification and contained no training pixels. Some of the test polygons were derived from the same forest stands as the training data.

The information classes included hardwoods, red pine, jack

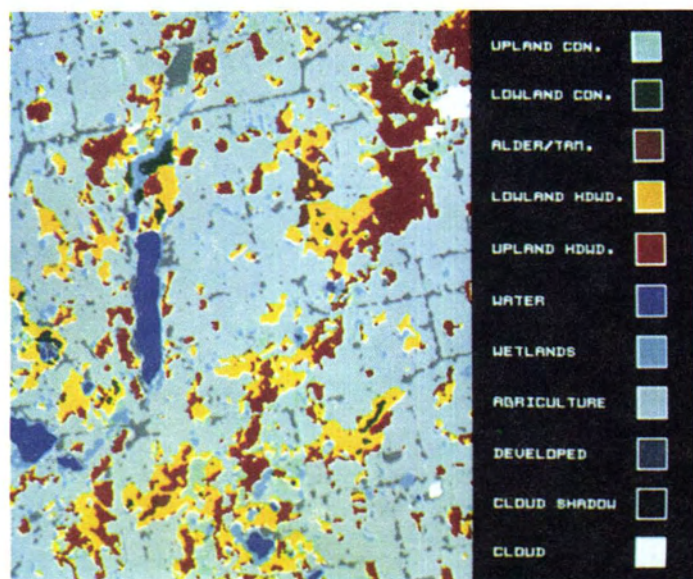


PLATE 1. Classification of Study Site 1 showing the aggregated forest classes.

pine, lowland conifers, clearcuts, the three defoliation levels, open water, roads, gravel pits, and clouds. Analysis of the digital data during preliminary training indicated some spectral confusion between the lowland and upland conifer categories. Most of the lowland conifers occur in one area along a river so they were outlined manually. This manual delineation formed a mask which was used to accomplish discrimination of this lowland forest region during classification.

#### CLASSIFICATION RESULTS

The classification results are presented in Table 4 and Plate 2. The classification accuracy statistics in Table 4 show the overall accuracy was 93 percent and the average accuracy for the various information classes was 90 percent. When the clearcut and defoliation categories were considered as softwood, the average forest/nonforest accuracy was 90 percent, the average hardwood/softwood accuracy was 95 percent, and the average accuracy for the forest classes was 92 percent. As in Study Site 1, the overall or pooled accuracy estimates were higher than the average results. Detail to Anderson Level III was obtained for the coniferous classes, with high classification accuracies for jack pine and red pine. The three levels of jack pine budworm defoliation were also separated accurately (96, 98, and 79 percent). Newly logged areas could not be distinguished from unpaved roads using the three bands analyzed.

#### DISCUSSION

Excellent classification accuracies were obtained for most forest-cover classes evaluated. The forest/nonforest accuracy is, however, lower than in Study Site 1. This drop in accuracy may result from the use of different bands or from the lack of nonforest cover in Study Site 2. The lack of nonforest seems the more probable reason because just one of the few nonforest categories (unpaved roads) accounted for most errors. These roads ("dv" in Table 4) were often confused with recent clearcuts in the area. Also, the sample for the road category was quite limited. When the confusion between roads and clearcuts is ignored, the average forest/nonforest accuracy becomes very high (99 percent) and is consistent with the results obtained for Study Site 1. The

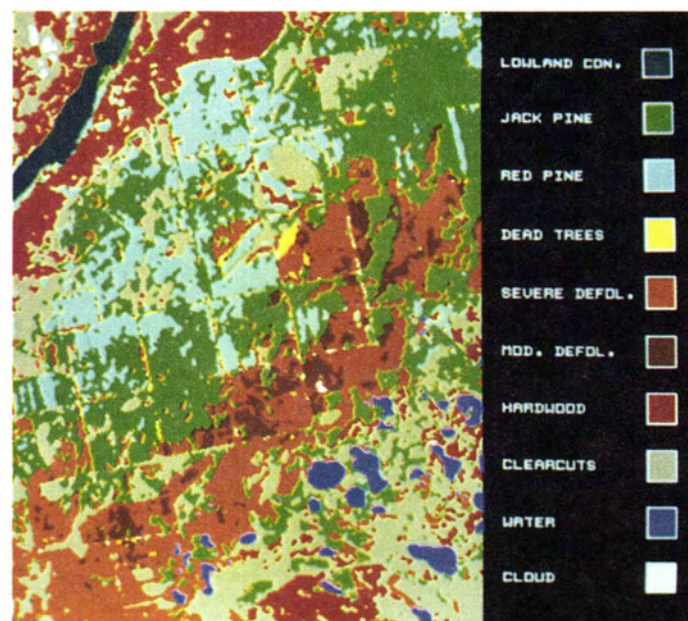


PLATE 2. Classification of Study Site 2. (Only a portion of Study Site 2 is shown to provide room for the legend.) The clearcut class also includes roads and developed land (cottages around the ponds in the lower right).



TABLE 4. CLASSIFICATION RESULTS FOR TM CASE STUDY 2.

FIELD VERIFIED CLASS	LANDSAT TM CLASSIFICATION											PERCENT CORRECT
	dv	uh	wo	lc	cc	gp	dm	ds	dd	pr	pj	
dv	32	0	0	0	28	0	0	0	0	0	0	53
uh	0	173	0	0	11	0	0	3	0	0	0	92
wo	0	0	89	0	0	0	0	3	0	0	0	97
lc	0	0	0	93	0	0	0	0	0	6	3	91
cc	29	0	0	0	173	0	0	0	5	0	0	84
gp	0	0	0	0	0	34	0	0	0	0	0	100
dm	0	0	0	0	0	0	206	8	0	0	0	96
ds	0	0	0	0	0	0	0	192	3	0	0	98
dd	0	0	0	0	0	0	8	3	42	0	0	79
pr	0	0	0	0	0	0	0	0	0	231	3	99
pj	0	0	0	0	0	0	0	0	0	8	269	97

Overall Accuracy: 93%

Average Class Accuracy: 90%

Classes: dv: roads/developed  
uh: upland hardwoods  
wo: open water  
lc: lowland conifers  
cc: clear cuts  
gp: gravel pits

dm: moderate defoliation  
ds: severe defoliation  
dd: dead trees  
pr: red pine  
pj: jack pine

Summary of Further Class Aggregations:<sup>1</sup>

Average Hardwood/Softwood Accuracy: 95%

Pooled Hardwood/Softwood Accuracy: 97%

Average Forest/Nonforest Accuracy: 90%

Pooled Forest/Nonforest Accuracy: 96%

<sup>1</sup>Clear cut and defoliation categories counted as softwood forest.

accuracies for hardwood/softwood distinction are consistent with those obtained in Study Site 1.

The accuracies with which red pine and jack pine were distinguished are especially notable. These exceptional classification accuracies are partially explained by the fact that these two pine species occur in extremely homogeneous plantations and are the only two upland conifer classes in the study area. Also, effective discrimination of these types from lowland conifers was assured by the manual delineation of the lowland conifers described earlier. Even so, the distinction of red and jack pine was excellent. The ability to separate different levels of defoliation was also notable, indicating high potential for monitoring insect infestations and damage conditions.

The only serious classification problem was distinguishing between recent clearcuts and unpaved roads. This confusion is understandable given that both classes are characterized by little living vegetative cover on a common soil base (a glacial outwash plain). Cottage development (around the ponds in the lower right portion of the scene) was also confused with the clearcut class. Quantitative estimates for this confusion are unavailable because the cottage development areas could not be sampled adequately. The dead tree defoliation damage class also has lower accuracy but almost all of its errors were associated with the other defoliation classes.

These classification problems might have been alleviated by using different and/or additional bands in the analysis. As shown by the analysis of Study Site 1 and by several other researchers (Spanner *et al.*, 1984; Horler and Ahern, 1986; Williams and Nelson, 1986), inclusion of a mid-IR band (i.e., band 5) may provide additional discrimination.

On the other hand, good results were still obtained using only the three bands. Consequently, the digital image reference data for Study Site 1 were reexamined using just bands 2, 3, and 4. This additional examination showed that forest/nonforest and hardwood/softwood discrimination levels at Site 1 would have remained high using just the three bands. However, further specification of the Study Site 1 forest classes would have been degraded by excluding the other bands (especially band 5). Feature selection (e.g., Latty and Hoffer, 1981a; Horler and Ahern,

1986; Williams and Nelson, 1986) and the use of three or four information channels will likely produce results which approach the maximum quality obtainable from single date TM imagery for forest type mapping.

A few qualitative observations were made concerning the use of color composites for the visual interpretation of forest land cover. The color composites studied were an NCC constructed from bands 1, 2, and 3; a standard FCC derived using bands 2, 3, and 4; and a band 4, 5, 7 FCC. This last composite was designed to use only the infrared channels in order to assess the utility of this new combination of spectral information and to expand the visual analysis of bands started in Study Site 1. The few Anderson level I cover classes which were present in Study Site 2 were readily distinguished on all of the color composites. Hardwood/softwood (level II) interpretation was also possible with all of the composites. The improved results for the NCC (relative to Study Site 1) were probably due to the presence of only two upland conifer classes which were concentrated into a distinct area formed by a glacial outwash plain. As expected, the level II interpretations were accomplished more readily with the two FCCs. In addition, the band 4, 5, and 7 FCC provided distinct separation of the red pine and jack pine categories (a level III determination). After contrast enhancement, the red pine stands were distinctly dark blue while the jack pine stands were medium to light green. This example again shows that the middle infrared bands provide additional and unique information on vegetation variability. Interestingly, while the band 4, 5, and 7 FCC improved species separation for the upland conifers, the levels of jack pine budworm defoliation were not as evident. The band 2, 3, and 4 FCC appeared better suited for the interpretation of damage levels.

## CONCLUSIONS

Our findings must be regarded as preliminary due to the limited nature of the techniques employed. Even so, the results indicate the high utility of TM image data for forest resource assessments. This utility will undoubtedly vary depending upon the exact nature of the information required and the character-



istics of the area under study. Extensive generalizations would, therefore, be premature. However, our study of two different Wisconsin test sites suggests the following:

- TM data are superior to MSS data for forest resources applications under Lake States conditions. Relative to the accepted capability of MSS data under these conditions, TM imagery provided substantial improvements in both classification accuracy and specificity. Useful specification of forest classes beyond the hardwood/softwood level was possible for both study sites. Further classification into lowland and upland categories appears especially promising. Potential distinction of species or species groups was strongly indicated by the successful separation of red and jack pine in Study Site 2 and the classification performance for most of the detailed forest classes of Study Site 1. Furthermore, TM data showed high potential for differentiation of damage levels due to the jack pine budworm.
- Full exploitation of the information content inherent in TM data will require the development of analysis procedures which go beyond the "traditional" procedures currently utilized to process MSS data. The higher resolution imagery contains visually apparent spatial information which is poorly utilized in conventional (per-pixel) computer-assisted classification techniques. The higher spatial resolution and additional spectral bands of TM imagery permit much more effective visual interpretation than MSS imagery. Combining conventional computer processing of imagery with visual interpretation (by means of cursor delineation on a display monitor) is probably the best short-term approach to utilizing spatial information. Such methods can be used to stratify image data and separate cultural features from forested areas. Computer classification procedures might then discriminate forest variations more effectively. The separation of lowland conifers in Study Site 2 is an example of such a course of action. Spatially oriented computer processing techniques (e.g., Latty and Hoffer, 1981b) would also utilize more of the information present in TM data.
- At least one band from each of the non-thermal wavelength regions of the TM (visible, near-IR, and middle-IR) is desirable for forestry applications. Direct comparisons between different numbers and combinations of bands were not performed in this project. However, using three, or possibly four, TM bands during computer-assisted classification appeared to perform as well as using all bands. Analysis of the data during training and the results obtained from Study Site 2 (where only three bands were used) supports this conclusion. Also, the thermal IR band displayed little utility for the conditions studied in this project.

In this study, additional spectral information in TM data was a distinct advantage in computer-assisted classification. The high spatial resolution of TM had minimal impact on computer classification but did contribute substantially to visual analysis. Other researchers (e.g., Latty and Hoffer, 1981b; Spanner *et al.*, 1984) have reported degraded classification performance when using data with higher spatial resolution (which unveils greater spectral variability in many cover types, especially forest). The well developed, high canopy closure stands used in this study seem to have minimized spectral variability and, thus, alleviated the classification impact of the greater spatial resolution.

The improved spectral and spatial resolution of TM data (relative to MSS data) will clearly heighten the interest of the forest management community in satellite remote sensing. However, continued research and development will be required to provide definitive assessments of TM data for use in environments typical of the Lake States and northeastern United States. In particular, studies need to be conducted which involve more extensive study areas and other computer-assisted techniques and procedures.

#### ACKNOWLEDGMENTS

This research was supported by the College of Agricultural and Life Sciences, School of Natural Resources, University of Wisconsin-Madison, and by the UW-Madison Institute for Environmental Studies. Some of the reference data used in this research were supplied by the Wisconsin Department of Natural Resources. Martin P. Buchheim, Marcia M. Verhage, and

Witold Fraczek are acknowledged for their help in the preparation of the manuscript for this paper.

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(Received 10 April 1986; revised and accepted 7 October 1987)