R. F. Nelson
Earth Resources Branch
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
R. S. Latty
Remote Sensing Hydrology Laboratory
University of Maryland
College Park, MD 20742
G. Mott
Northeastern Forest Experiment Station
USDA Building, University of Maine
Orono, ME 04473

Classifying Northern Forests Using Thematic Mapper Simulator Data

Linear discriminant analyses were conducted to determine those wavebands most useful for delineating boreal forest cover types in Maine.

Introduction

Thematic Mapper Simulator (TMS) data were analyzed to determine how well boreal forest cover types could be identified. The study, which uses aircraft simulator data, is a precursor to one which will use Thematic Mapper (TM) data obtained over the same area. The observations made and problems encountered using the simulator data may improve approaches taken with the Landsat-4 Thematic Mapper data.

Abstract: *Thematic Mapper Simulator data were collected over a 23,200 hectare forested area near Baxter State Park in north-central Maine. Photointerpreted ground reference information was used to drive a stratified random sampling procedure for waveband discriminant analyses and to generate training statistics and test pixel accuracies. Stepwise discriminant analyses indicated that the following bands best differentiated the thirteen level II - III cover types (in order of entry): near infrared (0.77 to 0.90 μm), blue (0.46 to 0.52 μm), first middle infrared (1.53 to 1.73 μm), second middle infrared (2.06 to 2.33 μm), red (0.63 to 0.69 μm), thermal (10.32 to 12.33 μm). Classification accuracies peaked at 58 percent for thirteen level II-III land-cover classes and at 65 percent for ten level II classes.*

The objectives of this study were to use Thematic Mapper Simulator data (1) to determine those TM wavebands most useful for differentiating boreal forest cover types; (2) to determine those TM wavebands most useful for differentiating insect damaged forest from healthy forest; (3) to obtain a baseline assessment of classification accuracy due to waveband combination; and (4) to identify those land-cover types subject to confusion (misclassification) and suggest ways to alleviate that confusion.

From a remote sensing standpoint, classifications of the predominantly coniferous forests of the northeastern U.S. and eastern Canada are difficult and the results are highly variable (Beaubien, 1979). The boundaries between and within forested and non-forested land cover are often indistinct; cover changes tend to be gradual. Accurate classification of such an area is difficult regardless of the remote sensing technique used.

Researchers have explored the possibility of using Landsat MSS data to assess the northern forests. Harris *et al.* (1978) used Landsat-1 and -2 multispectral data to detect forest pest damage in British Columbia. They concluded that

> "The inadequacy of Landsat imagery or computer assisted classification for mapping forest pest damage

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relates ultimately to the spatial resolution of the current satellites. Some of the proposed satellites with improved resolution may overcome the present limitations."

Bryant *et al.* (1980) used MSS data to estimate hardwood, softwood, and mixedwood stand areas on a 200,000 hectare forest district in north central Maine. Districtwide MSS and airphoto-ground estimates agreed within five percent. Specific township evaluations, however, were not acceptable. They suggested that the higher spatial resolution of the Thematic Mapper may improve results.

Spatial detail, however, does not necessarily improve classification accuracy, all other factors being equal. The results of investigations by Kan and Ball (1974), Sadowski *et al.* (1977), Markham and Townshend (1981), and Latty and Hoffer (1981) show that an analysis of 30 metre data may result in classifications *less* accurate than the comparable 80-metre products. Because MSS classification accuracies in areas similar to this study site have been typically low (Bryant *et al.* (1980), 63 percent overall agreement; Mead and Meyer (1977), 43 percent overall agreement), serious classification problems were expected using TMS data. One purpose of this research was to document the problems and to suggest alternate methods or approaches which might increase classification accuracy.

Classification problems encountered using TMS data were investigated in the context of the waveband combinations employed. The utility of the different spectral regions vary with the land cover considered. Coggeshall and Hoffer (1973) demonstrated that at least one band in the near infrared or middle infrared is necessary to accurately discriminate deciduous and coniferous forest. Thermal data appeared most useful for identifying specific agricultural cover types and did little to separate forest types on a rural area in Indiana. Latty and Hoffer (1980) defined optimal TMS band combinations for a forested site in South Carolina on the basis of maximum spectral separability. Noting that little is gained in terms of spectral separibility when using more than four TMS channels, they found the blue, red, near infrared, and first middle infrared channels constituted the best four-band combination. Latty and Hoffer (1980) note that such waveband selection results are "highly data and applications dependent." Teillet *et al.* (1981) conducted TM band selection tests using aircraft scanner data to differentiate forest species and forest insect damage in British Columbia. They found that the blue band was most useful for discriminating the western forest types. The red and near infrared bands were also highly ranked, the near infrared for discrimintation of all cover types, the red for forest insect damage delineation. In the work reported here, linear discriminant analyses were conducted to determine those wavebands most useful for delineating boreal forest cover types in Maine.

Study Area

Thematic Mapper Simulator data and coincident aerial photography were acquired over a 23,200 hectare study area located approximately 50 kilometres northwest of Millinocket, Maine. The lands included a portion of Baxter State Park (Township 4-Range 10, T4-R10) and territory owned by the Great Northern Paper Company (GNP, T4-R11 and T4-R12). Figure 1 details the location of the study area and the TMS flightline.

The two western townships have been heavily cut by GNP. The areas logged prior to the mid-1970s are typically strip cut with both cut and leave swaths approximately 20 metres (66 feet, one chain) wide. Recently, GNP abandoned this silvicultural practice in favor of clearcutting due to the susceptibility of the leave strips to windthrow. In general, the soils are very shallow and windthrow is a significant problem not restricted to the strip cut areas. In the spring of 1981, a windstorm leveled approximately one-third of T4-R11. An estimated 100,000 cords of wood were blown down, and at the time of the TMS overpass, substantial amounts remained to be salvaged.

A serious spruce budworm epidemic (*Choristoneura fumiferana*, Clem.) has been plaguing the northern counties of Maine since the early 1970's. The larvae feed on the current year's growth of balsam fir (*Abies balsamea*, (L.)Mill.), red spruce (*Picea rubens*, Sarg.), and white spruce (*Picea glauca*, (Moench)Voss). The GNP townships have been periodically sprayed with varying degrees of suppression success. In general, the softwoods still standing on T4-R11 and T4-R12 are relatively healthy. Coniferous stands in Baxter State Park, a wilderness area, have not been sprayed since 1973 and are heavily damaged; black spruce stands (*Picea mariana*, (Mill.)B.S.P.) are an exception.

The study area is relatively flat in the western section, becoming rolling to mountainous as one moves east into the foothills near Mt. Katahdin. With the exception of Soubunge Mountain, a relatively small sentinel in T4-R11, relief varies only 150 to 200 metres across the study area. Topographic variability, then, was not considered a major factor in terms of the spectral variability of the forest cover types.

Data Acquisition

Thematic Mapper Simulator data were obtained over the study area between 10:30 and 10:45 a.m. EST on 12 October 1981. Flight specifications had called for a June/July overflight; however, weather conditions and aircraft schedule conflicts prevented such an acquisition. Weather conditions were excellent; the sky was clear and cloudless. The scanner employed was a modified Texas Instruments RS-18MS mounted aboard a Gates-Learjet model 23. The scanner, with a 2.5 milliradian instantaneous

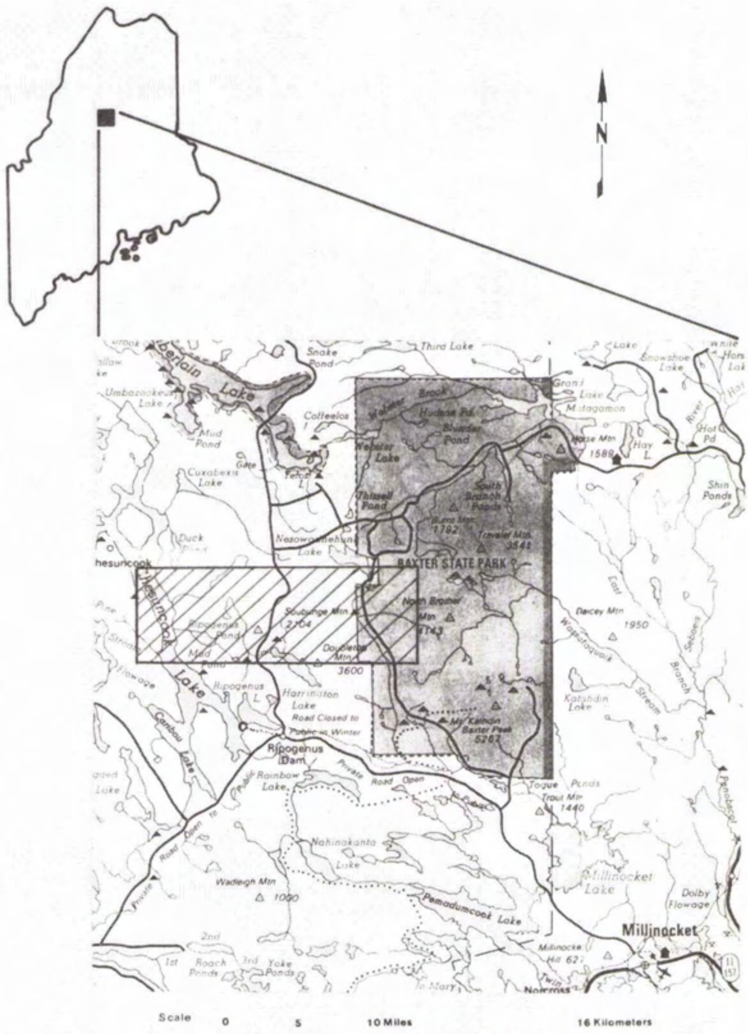

FIG. 1. Thematic Mapper Simulator study site, including sections of Baxter State Park and Great Northern Paper Company lands, 50 kilometres northwest of Millinocket, Maine.

field of view (IFOV), was flown approximately 12,000 metres (40,000 feet) above mean ground level, resulting in a nominal spatial resolution at nadir of 30 metres for all spectral bands. The modified T1 RS-18MS has a channel configuration nearly identical to that of the Thematic Mapper (see Table 1).

Coincident color infrared aerial photographs (Kodak 2443 film) at a scale of 1:80,000 were obtained simultaneously with the scanner data. The camera used was a Zeiss RMK 15/23 with a 152 mm (6 inch) lens and an AV-12 filter. Ancillary data acquired to facilitate development of a ground reference data base included 1:7200 scale color infrared photographs over the Baxter State Park portion of the scanner flightline. This imagery was acquired by the U.S. Forest Service on 24 July 1981.

PROCEDURE

The 1:7200 and 1:80,000 scale photographs were used to create a digital ground reference data set. The 1:7200 scale photos were used to differentiate various levels of defoliation in the Baxter State Park area. Thirteen land-cover classes were identified on the photographs; the results of the photointerpretation were digitized. These classes, and the number of ground reference pixels found in these

Table 1. Spectral and Spatial Resolutions of the Thematic Mapper Simulator Scanner (ORI, 1982) and the Landsat-4 Thematic Mapper (Salomonson, 1978)

Wavelength Region	Thematic Mapper Simulator[1]			Thematic Mapper		
	Band	Wavelength (μm)	Nominal Pixel Size (m)	Band	Wavelength (μm)	Nominal[2] Pixel Size (m)
Blue	1	0.46–0.52	30	1	0.45–0.52	30
Green	2	0.53–0.60	30	2	0.52–0.60	30
Red	3	0.63–0.69	30	3	0.63–0.69	30
Near Infrared	4	0.77–0.90	30	4	0.76–0.90	30
Middle Infrared 1	5	1.53–1.73	30	5	1.55–1.75	30
Middle Infrared 2	6	2.06–2.33	30	7	2.08–2.35	30
Thermal Infrared	7	10.32–12.33	30	6	10.40–12.50	120

[1] TMS band nomenclature is used throughout this paper. Band 6 refers to the second middle infrared band, band 7 to the thermal channel.
[2] The instantaneous field of view of the Thematic Mapper is 30 metres. The data are resampled to 28.5 metres (114 metre thermal) to permit overlaying TM and MSS (57 metre) data.

classes, are listed in Table 2. A wall-to-wall photointerpretation assessment was not done due to the complexity of the site. Approximately 45 percent of the area was photointerpreted and digitized to produce the ground reference image. Ground control points were located on the photos and in the TMS data for registration purposes. The ground reference data were registered to the TMS data to avoid resampling the TMS data. The average line and sample residuals were 0.79 and 0.94 pixels, respectively. The Geographic Entry System, IDIMS utility functions, IDIMS image processing software (ESL, 1978), and programs written in-house implemented on an HP-3000 minicomputer were used to process the data.

The TMS data were examined to identify scanner-dependent sources of spectral variation. Data quality checks were run to determine the presence and magnitude of the following anomalies: bit dropout, along-track detector drift, band-to-band misregistration, and scan-angle-dependent grey level variations.

Bit dropout and detector drift were not apparent. Scan-angle-dependent variations were minimized by truncating the data at plus or minus 20 degrees (i.e., plus or minus 140 pixels from nadir). The band-to-band registration analysis suggested that the blue band may be misregistered on the order of 0.7 pixels relative to the other six bands. Billingsley (1982) and Swain (1980) suggest that small displacements on the order of 0.1 to 0.3 pixels may significantly affect pixel assignments. However, the band-to-band misregistration error was smaller than the ground reference-TMS misregistration error. Hence, no attempt was made to register the first band with the remaining six bands.

WAVEBAND SELECTION

The ground reference image (registered to the TMS spectral data) was used to direct a stratified (by cover class) random sample of pixels. The pixels were sampled without replacement. The sample size for each ground reference class was proportional to the relative abundance of that class. Sample sizes were calculated using the following formula:

$$n = \frac{t^2 PQ/d^2}{1 + (1/N)\,[t^2PQ/d^2]}$$

where n = class sample size;
t = Student's t Statistic, 1.96 for alpha level of 0.05, infinite degrees of freedom;
P = proportion (relative frequency) of a cover type determined from ground reference;
$Q = 1 - P$;
d = allowable error (in this study, 0.05, i.e., 5 percent); and

TABLE 2. A LISTING AND DESCRIPTION OF THE LAND COVER CLASSES FOUND IN THE GROUND REFERENCE DATA SET AND NUMBER OF PIXELS.

Class	Number of Ground Reference Pixels	Description
1. Clearcut	3349	Predominantly slash on ground
2. Old Clearcut	10447	Some shrub-hardwood regeneration
3. Conifer*	19832	>70% of tree crown area is coniferous
4. Hardwood*	7336	>70% of tree crown area is hardwood
5. Mixed wood*	13228	<70% hardwood and <70% softwood
6. Bog	6102	Alder and spruce bogs
7. Blowdown	6176	<30% of trees standing, remainder blown down
8. Water	17806	
9. Strip cut	11050	
10 Meadow	301	Short shrub or grassland
11. Severe Conifer Defoliation	2691	80–100% of canopy removed
12. Heavy conifer Defoliation	2664	60–80% of canopy removed
13. Mixed wood Defoliation	2298	60–100% of conifer canopy removed

* An area is considered forested if >30% of area is covered by tree crown.

N = population size (number of identified pixels in ground reference data)

Those classes whose sample sizes, based on this formula, were less than 30 pixels (i.e., the rare classes) were assigned sample sizes of 30 pixels. The sampling program produced a file of 7-band spectral data by cover type.

Descriptive statistics (skewness and kurtosis) were calculated for each band and cover type to characterize the sampled data. The sampled data were to be used in a discriminant analysis procedure which involved the calculation and comparison of F statistics. Such calculations assume normality, though the statistic is fairly robust. Based on significance tests of skewness and kurtosis values (see BMDP2D program, Dixon and Brown (1979)), those cover types which were significantly nonnormal were dropped from consideration in the following analyses.

Linear discriminant analyses were run on the sampled spectral data using the BMD program P7M (Dixon and Brown, 1979). The spectral bands which best differentiated between cover types were selected in a stepwise fashion. The band which best discriminated the cover classes of interest was entered first (forward selection). Subsequent band entries were those which resulted in the greatest increase in the discriminant function in the context of previously selected bands. The band order suggested by the discriminant analysis involving all cover types was used in the classification section to determine the effects of additional bands on classification accuracy.*

CLASSIFICATION ACCURACY ASSESSMENT

A second stratified random sample was obtained by using the ground reference image to select 250 randomly sampled pixels (without replacement) from each cover class. Of the 250 pixels selected, 125 were used to produce the training statistics. The remainder served as test pixels.

Training statistics were generated for each cover class (13 classes) for the waveband combinations (seven combinations) indicated by the rankings of the discriminant analysis. Guided clustering was used to generate these statistics. To avoid confounding a "training approach" or "analyst" effect with waveband combination, the ISOCLS parameters remained the same regardless of the cover type/band combination being clustered. The ISOCLS parameters were set such that each cover type was described by one or two spectral classes, depending on the variability in the bands considered.

Clustering was regarded as being necessary to accommodate cover classes which had large spectral variances and/or were multimodal in the 125 pixel training sample set generated. The number of clus-

* The forward stepping procedure eliminates the possibility of dropping previously entered variables. Hence, the "best" combinations are a function of the bands initially entered. The final band sets, therefore, may not necessarily be the best if all possible waveband combinations are considered.

ters was limited to two due to the limited number of training pixels. The number of pixels was limited by the size of the rarest class, which contained only 301 pixels. The approach taken results in observations that may be more universally applied because the effects of analyst and study area are minimized. Study results provide valid estimates of the "value added" by the individual TMS bands in the context of classification accuracy. The classification accuracies provide a conservative estimate of the performance that may be expected in boreal forest regions using TM or TMS data.

Results

Waveband Discriminant Analysis

Two analyses were run to determine those bands which best discriminated between (1) all cover types, and (2) defoliated and healthy conifer cover types. Those cover types found to be significantly nonnormal—mixedwood, mixedwood defoliation, stripcut, and water—were not included in the discriminant analysis. Two rankings are given for each analysis. The first ranking is the band ordering based on the size of the F statistics at step 0 (i.e., before any bands have been entered). This listing (and associated F values) indicate the utility of the individual bands, assuming that only one band would be used to discriminate the cover types. The F values are useful for comparison purposes only within a cover type group (e.g., within "Defoliated and Healthy Conifer," within "All Cover" types), not between groups. The second ranking provides the order of entry of the bands into a forward stepping discriminant function. The first band entered is the same as that band which individually provides the most information for differentiating the cover types (band number 1 in the step 0 ranking). Subsequent bands entered are those that provide the most discriminatory information in the context of the bands previously entered. An F-to-enter level of 4.0 (the BMD default value) was employed to define those bands which afforded significant cover type discrimination information. Given a specific F value (4.0), the alpha level varies with the number of cover types considered, and the significance of the test varies for each of the analyses. In all cases, however, those bands entered provided significant discriminatory information at a confidence level greater than 95 percent. These figures were derived using values available in Table D, pages 316-321 of Hicks (1973).

Defoliated and Healthy Conifer Cover Types:

Cover types considered:
- healthy conifer
- severe conifer defoliation
- heavy conifer defoliation

Alpha level <0.05 (4.0 F to enter, three cover types)

Band Ranking at Step 0, most informative to least informative (F-to-enter in parentheses):

1. band 1 (57.3)
2. band 6 (45.2)
3. band 4 (27.7)
4. band 7 (23.9)
5. band 5 (22.0)
6. band 3 (8.6)
7. band 2 (6.5)

Forward Stepping Band Selection:

step 1 band 1	step 3 band 5
step 2 band 6	step 4 band 3

Bands 2, 4, and 7 were not entered.

All Cover Types:

Cover types considered: All cover types listed in Table 2 except mixedwood, mixedwood defoliation, stripcut, and water.

Alpha level <0.01 (4.0 F to enter, nine cover types)

Band Ranking at Step 0, most informative to least informative (F-to-enter in parentheses):

1. band 4 (178.0)	5. band 3 (89.8)
2. band 6 (176.8)	6. band 5 (66.6)
3. band 1 (175.1)	7. band 2 (50.4)
4. band 7 (146.7)	

Forward Stepping Band Selection:

step 1 band 4	step 4 band 6
step 2 band 1	step 5 band 3
step 3 band 5	step 6 band 7

Band 2 was not entered.

Based on the results of the discriminant analyses, the following observations were made.

Band 1. The blue band was most useful for discriminating various levels of coniferous defoliation. This band accentuated the contrast between the green canopy and the dead tops and branches of those trees repeatedly attacked by the spruce budworm. Similar results were noted by Leckie and Gougeon (1981) and Teillet *et al.* (1981). When considered alone or in conjunction with near and middle infrared bands, the blue band contained significant, unique spectral information for delineating northern forest cover types.

Band 2. In terms of assessing vegetation types in northern forests, this band contained little discriminant information. Previous work has shown that this band is of limited utility for vegetation monitoring (Tucker, 1978). The lack of utility may also be a function of the TMS 2 gain setting during the data collection mission. This band exhibited little contrast across the study area; the dynamic range was limited. Also, the signal-to-noise ratio was apparently low.

Band 3. The utility of the red band for differentiating defoliated coniferous forest or all northern cover types was limited. In terms of the visible wavebands available, the blue band was far more useful than the red. The red wavelengths do not accentuate cover type differences in the visible perhaps because of a slight reduction in solar irradiance in the red region, slightly increased chlorophyll absorption in the blue, and the specific spectral characteristics of the insect damage involved in this study.

Band 4. The near infrared response was most useful for separating among all forest cover types. However, the band did not contain enough unique spectral information concerning canopy density to warrant inclusion in the band selection process for defoliated and healthy coniferous cover types. Hence, the utility of the near infrared lies more with discriminating between forested cover types (for the most part hardwood/conifer separation) rather than within cover type canopy density discrimination. Typically, conifers have a spectral response markedly lower than broadleafed species in the near infrared. Losee (1951) and Gausman (1974) explain that conifer-hardwood spectral differences in the near infrared are due to differences in leaf morphology.

Bands 5 and 6. The two middle infrared bands provided significant discriminant information for the two cover type groups considered. On an individual basis, and in conjunction with other bands, at least one of the two middle infrared channels was consistently, highly ranked. TMS 6 proved more useful than TMS 5 for coniferous defoliation assessment (canopy density discrimination). The first middle infrared was more useful for differentiating all cover types. The results indicate that, for the northern forest cover types, the two middle infrared bands did not contain redundant information, even though both wavelength regions interact with total leaf water content in the field of view. Surprisingly, the near infrared and second middle infrared responses may be redundant. The inclusion of one precluded or postponed the inclusion of the other in the stepwise selection process.

Band 7. The thermal band proved to be of little utility, even at the 30 metre spatial resolution. This channel may have provided more useful information if data were acquired during the growing season on an afternoon overflight. A second factor which affected the thermal responses was (like the green band) gain setting. The dynamic range, hence scene contrast, was relatively low compared to the other bands.

The stepwise analyses for forest and all cover types indicated that the most informative band combinations included at least one band from each of the spectral regions—visible (0.4 to 0.7 μm), near infrared (0.7 to 1.3 μm), and middle infrared (1.3 to 3.0 μm). Hoffer and Staff (1975), using 13 channel S-192B Skylab scanner data, found that data from each of these electromagnetic spectrum regions was "vital" for effective computer classification of forested regions.

CLASSIFICATION ANALYSES

The band ranking of the stepwise analyses, which assessed nine of the 13 cover types, was used to define the best band (TMS 4), best two bands (TMS 4 and 1), best three (TMS4, 1, and 5), . . . , all seven bands. Training statistics were generated for each cover class and band combination. The statistics for each of the 13 cover classes for a particular band combination were used to classify the 125 training and 125 test pixels. The results are illustrated in Figure 2. Table 2 provides a list of the 13 cover classes. The 10 classes were produced by combining clearcut and old clearcut, conifer and mixedwood, and severe and heavy conifer defoliation.

Figure 2 is noteworthy in that (1) it highlights the amount of discriminatory information added by the individual bands as a function of bands previously entered, and (2) it illustrates the effects of limited dynamic range and/or limited sample size. The second point refers to the fact that training accuracies do not change and test accuracies decrease with the addition of the green band. The limited dynamic range (low signal/noise) was responsible for at least part of the accuracy decline. A second mechanism may also be operating. Swain and Davis (1978, page 345) explain that the decreasing accuracy may be a function of a fixed training sample size and increasing dimensionality. Given a fixed training sample size, classification accuracy will peak and slowly diminish as more and more dimensions (bands) are added. From Swain and Davis (1978):

> "Since we are endeavoring to derive a continually increasing amount of information from a fixed amount of data (the training samples), the accuracy of estimation must eventually begin to decrease. One could not expect a good classifier performance if ten-dimensional statistics were derived from five training samples. . . . the important point is that there is a maximum, i.e., there is a best measurement complexity."

A quantitatively rigorous treatment of the dimensionality problem may be found in Duda and Hart (1973, page 66). They explain that the number of samples required to converge on an estimate of a multivariate statistic increases exponentially as the number of dimensions increases linearly. It follows that the error of the estimate calculated from a fixed sample size increases exponentially with linear increases in the number of dimensions. In this case, with 124 training samples, the optimal number of dimensions seems to be five, and the lack of utility of the thermal and green bands may be a function of both sample size and signal/noise.

One objective of the study was to note which cover types were consistently misclassified and suggest action which might alleviate the confusion. Table 3 presents the test pixel classification matrix for that band combination which produced the highest overall accuracy when 13 classes were considered. Bands 1, 3, 4, 5, and 6 were used to produce this matrix.

The poor classification of the hardwood forest points to factors which, in addition to small training sample size, increase the possibility of misclassification. Hardwoods were confused with mixedwood

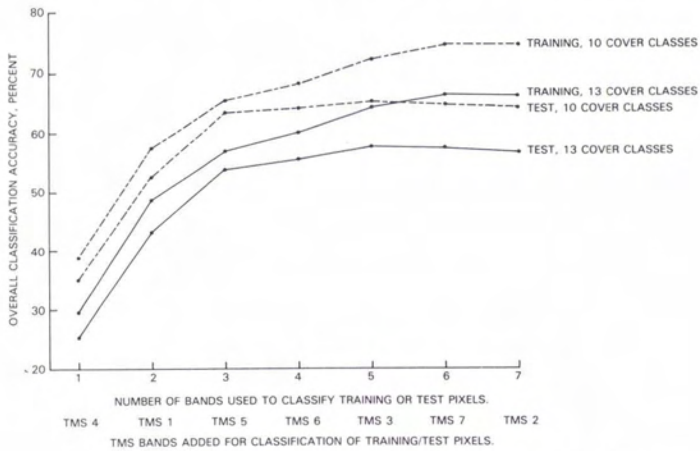

FIG. 2. Training and test pixel classification accuracies (in percent) as a function of bands used.

severe defoliation and conifer severe defoliation. That confusion may be reduced by analyzing growing season data (June, July, and August). The TMS data were obtained 12 October 1981, the hardwoods were past full color, and leaf drop was beginning. The confusion with defoliated forest is understandable because, in some areas, leaf fall had progressed to the point where contiguous patches of hardwoods were leafless. A change of acquisition date would not completely resolve the problem. Spruce budworm defoliation is a cumulative, destructive process. Heavily defoliated stands of balsam fir and white and red spruce have been repeatedly attacked over periods of 8 to 12 years. Commonly, as the canopy opens up, a dense understory of *Ribes* spp. (currants and gooseberries) develops. These shrubby hardwoods add to the hardwood-mixedwood-defoliation discrimination problem.

Meadow, the smallest class (number of pixels), was classified incorrectly 75 percent of the time, with strip cut and hardwood cover types accounting for 43 percent of the omission error. Subsequent analyses indicated that the small meadow areas were significantly affected by the misregistration offset between the TMS and ground reference data. Hence, training and test pixels may have been selected in land-cover classes other than that designated. Some level of classification inaccuracy due to misregistration error may be expected in all classes. However, the classes most affected by such offsets are those involving small areas or linear features.

The classification problems encountered assessing strip cuts are a function of the spatial resolution of the data. The cut and leave strips on T4-R11 and T4-R12 are typically one chain wide (66 feet, or 20 metres). Results indicate that the TMS data were classified into the component cover types. The contrast between the cut and leave strips offset the fact that the strips are smaller than the nominal sensor resolution. The high within-class variability which is characteristic of 30 metre data suggests the use of a spatial or per-field classifier. Such a classifier could make use of increased within-class variability, which tends to depress per-point classification accuracies. Latty and Hoffer (1981) have demonstrated the utility of a per-field classifier using 30 meter TMS data.

CONCLUSIONS

The objectives of this research were to assess TMS waveband utility for differentiating northern forest cover types, assess the effects of the wavebands on classification accuracy, identify classification problem areas, and suggest ways to alleviate these problems. The following observations and suggestions are made.

- The discriminant analyses suggested that useful waveband combinations include at least one band from the visible (0.4 to 0.7 μm), near infrared (0.7 to 1.3 μm), and middle infrared (1.3 to 3.0 μm) spectral regions.
- The blue band proved most useful for discriminating coniferous defoliation categories. The forward stepping selection process ranked the blue band second in overall utility for assessing all cover types. Classification accuracies increased approximately 17 percent with the addition of this band. An unknown portion of the 17 percent increase is a function of the position of band entry. The remainder is due to the unique spectral information afforded by TMS 1.
- The two middle infrared bands provided significant spectral information for differentiating all cover type groups considered. The second middle infrared proved most useful for coniferous defoliation assessment, the first proved most useful for differentiating all cover types. Though the two middle infrared bands do not appear to contain redundant information, the discriminant analyses indicate that the same cannot be said for the near infrared and the second middle infrared bands.

Table 3. Test Pixel Classification Matrix Using 5 TMS Bands to Discriminate 13 Land Cover Classes for a Boreal Forest Region in North-Central Maine. Table Accuracies are in Percent.

Landsat Classification	Ground Reference Data (Air photointerpretation) Clearcut	Old Clearcut	Conifer	Hard	Mixed	Bog	Blowdown	Water	Srip Cut	Meadow	Severe Con. Def.	Heavy Con. Def.	Mixed, Sev. Def.
Clearcut	65.6	12.8	1.6	12.8	0.8	0.8	7.2				2.4	4.0	0.8
Old Clearcut	12.0	71.2	3.2	2.4		3.2	2.4		4.8	1.6			
Conifer	0.8	0.8	50.4		25.6	10.4		0.8	11.2		1.6	3.2	
Hardwood	2.4	0.8		36.0	3.2	2.4	3.2	1.6	1.6	9.6	1.6	2.4	9.6
Mixed Wood		0.8	19.2	0.8	51.2	9.6		2.4	12.8	2.4			0.8
Bog		4.0	9.6	1.6	4.8	57.6	0.8	0.8	11.2	4.0	1.6	1.6	
Blowdown	6.4	3.2	0.8	0.8	1.6	1.6	61.6		5.6	8.0	6.4	15.2	3.2
Water			0.8		1.6			93.6	0.8	0.8			
Strip Cut		4.0	1.6	2.4	7.2	10.4	8.8	0.8	42.4	33.6	1.6	0.8	
Meadow	5.6	2.4	3.2	4.0	0.8		7.2		6.4	25.6	1.6	0.8	0.8
Severe Con. Def.	4.0		1.6	9.6	1.6		6.4		0.8	2.4	64.8	20.0	6.4
Heavy Can. Def.	2.4		7.2		1.6	2.4	2.4		2.4	8.0	13.6	52.0	0.8
Mixed Wd, Sev. Def.	0.8		0.8	29.6		1.6				4.0	4.8		77.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Number of Test Pixels	125	125	125	125	125	125	125	125	125	125	125	125	125

Total Number of Test Pixels: 1625 Overall Accuracy: 57.7%

- Three of the four most useful bands for discriminating northern forest cover types (bands 1, 5, and 6) are not available on the Landsat-1 to 5 MSSs. Hence, significant improvements may be expected in the ability to spectrally differentiate these level II and level III land cover categories using TM data.
- Test pixel classification accuracies were 58 percent for 13 level II-III cover types and 65 percent for ten level II classes. Training pixel accuracies were 5 to 10 percent higher.
- The decrease in test pixel classification performance with the addition of the thermal band may be a function of the effects of fixed sample size and increasing spectral dimensionality. The same arguement holds for decreases noted with the addition of the green band. In addition, a depressed signal-to-noise ratio limited the utility of both bands for cover class identification.
- The use of data acquired on 12 October presented problems in terms of adequately describing hardwood spectral variability. The New England fall coloration and subsequent leaf drop should be avoided, especially when dealing with multi-colored cover types such as bogs and coniferous stands which include tamarack (*Larix laricina*, (Du Roi) K.Koch), a deciduous conifer. Data should be obtained during the growing season (June, July, or August). To assess budworm damage, investigators have suggested that mid-July data would be optimal for current year budworm activity, and August data for overall tree condition (Ashley *et al.*, 1976).
- The spectral variability of the cover types and the ability of the 30-metre sensor to discriminate artifacts two-thirds that size on the ground suggest that a per-field classifier may be used to advantage.

The TMS data and this study serve to acquaint the user with problems which may be confronted when using Thematic Mapper satellite data. To this end, a number of problems have been encountered with the 30-metre, seven-band aircraft data, and a number of observations/solutions have been suggested. Future work will utilize Thematic Mapper data acquired over this same territory. Of primary concern will be (1) the utility of various satellite bands for discriminating land cover and (2) the utility of a per-field classifier.

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For further information please contact

Dr. J. R. Hardy
Remote Sensing Society
c/o Dept. of Geography
University of Reading
Reading RG6 2AU, U.K.

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For further information please contact

Dr. Leo W. Newland, Director
Environment Sciences Program
Texas Christian University
Fort Worth, TX 76129
Tele. (817) 921-7271