Interpretation of Landsat-4 Thematic Mapper and Multispectral Scanner Data for Forest Surveys

*Andrew S. Benson** and *Stephen D. DeGloria**
Remote Sensing Research Program, University of California, Berkeley, CA 94720

ABSTRACT: Landsat-4 Thematic Mapper (TM) and Multispectral Scanner (MSS) data were evaluated by interpreting film and digital products and statistical data for selected forest cover types in California. Significant results were: (1) TM color image products should contain a spectral band in the visible (bands 1, 2, or 3), near infrared (band 4), and middle infrared (band 5) regions for maximizing the interpretability of vegetation types; (2) TM color composites should contain band 4 in all cases even at the expense of excluding band 5; and (3) MSS color composites were more interpretable than all TM color composites for certain cover types and for all cover types when we excluded band 4 from the TM composite.

INTRODUCTION

LANDSAT MSS FILM AND DIGITAL products have represented an important part of vegetation surveys by serving as a basis for land cover stratification. Areas of similar cover types and management practices are delimited on photographic images based on their spectral and spatial characteristics in a single-date or multi-date mode. Because the detection and identification of different land cover conditions is a critical step in an effective stratification procedure, the high quality Thematic Mapper (TM) image products from the Landsat-4 and Landsat-5 systems should play an even more valuable role in this regard.

The spectral quality of TM data can be evaluated for survey purposes by determining the extent to which natural targets in vegetated environments can be discriminated using specially generated and commercially available image products. An approach for this type of investigation is: (1) extract spectral statistics for specific land cover types, (2) compare these data to selected photographic reproductions of the same area representing various spectral band combinations, and (3) qualitatively determine which color composite provides the most information for stratification purposes. Using image products and statistical summaries of individual agricultural and forest cover types, DeGloria (1984) found the TM data quality to be quite useful for discriminating land cover conditions for certain land management and planning activities.

A second approach to assessing spectral quality of image data is to conduct quantitative image interpretation tests in which selected land cover types are annotated and subjected to an identification process by a set of independent interpreters. Our objective at the Remote Sensing Research Program (RSRP) in support of the LIDQA Program was to determine the relative value of composite TM and Multispectral Scanner (MSS) images based on the identification of major forest cover types using established interpretation techniques (Colwell, 1978; Benson and Dummer, 1983). The interpretation process, as conducted by human analysts, requires that the image products allow both the detection and correct identification of features of interest. Detection requires, at a minimum, the simple recognition or awareness that a feature is present. Identification of a detected feature requires a further synthesis of spectral, spatial, textural, and associative characteristics (Hay, 1982). By conducting these interpretation tests some quantitative measure of interpretability can be generated to compare with the previous results achieved by these and other investigators (Williams *et al.*, 1984; Anuta *et al.*, 1984).

* Both authors are now with the Resource Survey Institute, P.O. 423, Benicia, CA 94510.

METHODS

STUDY SITE SELECTION

The Plumas Forest study site is located in Plumas County, CA, approximately 265 km northeast of San Francisco. The area has been defined as part of the Sierra Nevada Mixed Conifer forest cover type by the Society of American Foresters (1980). The area contains a diversity of forest cover types ranging from stands of red and white fir (*Abies magnifica* and *A. concolor*, respectively), to stands of mixed conifer dominated by ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), and/or sugar pine (*P. lambertiana*). Several other cover

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cover types are also prevalent and include low density Jeffrey pine (*P. jeffreyi*) stands on soils derived from ultramafic parent material; hardwood stands on wet and dry sites; dense shrub fields; wet and dry meadows; bare soil; granitic rock outcrops; and large water bodies.

Cover Type Selection

Based on over 40 years of experience using remote sensing imagery for forest cover type mapping in this study area, eight forest resource categories were defined as important for stratification purposes and for which selective photointerpretation keys were developed: high density conifer, low density conifer, hardwood-conifer mix, brush, wet and dry site hardwood, wet and dry meadow, bare ground, and rock (Table 1).

Table 1. Forest Resource Categories Used to Develop Selective Image Interpretation Keys for One Multispectral Scanner and Three Thematic Mapper Images for the Plumas Forest Study Site, California

High Density Conifer—Mixed and pure conifer stands. Stands dense to moderately open: dense stands most often present on moist north and west slopes, and more open stands present on the other aspects. Rough image texture.

Low Density Conifer—Open stands of mixed and pure conifer stands. Brush or herbaceous understory may be present. Open stands may be the result of poor site quality (serpentinitic soils) or selective logging practices. Rough to smooth image texture.

Hardwood/Conifer—Mixed hardwood and conifer tree stands. Stands dense to moderately dense. Stands most often present on drier sites (south slopes) or may develop ten to twenty years after selective logging. Rough image texture.

Hardwood—Pure and mixed evergreen and deciduous hardwood stands. Stands may be on dry or wet sites: dry sites present on south aspects; wet sites located in water courses or interspersed throughout dense stands of conifer at the higher elevations. Based on area covered, this class is very small. Moderately rough image texture.

Brush—Dense stands of evergreen or deciduous shrubs. Usually present in large contiguous stands on dry sites. Evidence of vegetation modification may be present. Smooth image texture.

Grassland—Vegetative cover predominantly annual or perennial grasslands. Sites may include dry or wet habitats or improved pasture lands. Smooth image texture.

Bare Ground—Nonvegetated soil. Includes recently disturbed sites, logging roads (unpaved), and extremely poor habitat. Not to be confused with the rock category (below). Smooth image texture.

Rock—Areas of bare rock which are devoid of vegetation to include rock outcrops, talus slopes, and gravel bars. Smooth to moderately smooth image texture.

Image Data Acquisition and Processing

The Landsat-4 TM and MSS data used for our analysis were acquired on 12 August 1983 (#84039218143, WRS path 44, row 32). The TM data were transmitted to Goddard Space Flight Center (GSFC) via the Tracking and Data Relay Satellite System (TDRSS) and the TDRSS receiving station at White Sands, NM; they were processed by the Thematic Mapper Image Processing System at GSFC as a "P" tape (NASA, 1983). The MSS data were acquired in the usual manner from the EROS Data Center.

Large-scale (1:4300–1:13,000) color and color infrared oblique aerial photography was acquired within one hour of the overpass for the Plumas National Forest study site, California, using a dual 35 mm camera system operated from a light aircraft. This photography was used in conjunction with available ground data to document forest canopy, nonforest cover, and understory conditions as well as to document the environmental conditions prevalent at the time of the overpass.

Based on the available ground data and aerial photography for this study site, a 1200 × 1200 pixel block of TM data (1,440,000 pixels) and corresponding MSS digital data were extracted from the full scene CCTs.

Color glossy prints of four color image types, derived from the simultaneously acquired MSS and TM data were used to develop the photo interpretation keys for the following four composite image types: (1) MSS bands 4, 2, and 1; (2) TM bands 4, 3, and 2; (3) TM bands 5, 3, and 2; and (4) TM bands 5, 4, and 3. For each image type, the three bands were color coded with red, green, and blue color channels, respectively, on the RSRP color monitor using a linear mapping function to simulate color infrared imagery. Because the RSRP color monitor can only display a maximum area of 316 samples by 202 lines, each TM image was subdivided into six separate test images, and the MSS image was subdivided into four separate images. Each test image was copied to photographic film using a Matrix color graphic camera. The resulting TM and MSS copy products were enlarged to scales of 1:75,000 and 1:120,000, respectively. The image specifications are summarized in Table 2.

The linear mapping functions that were applied to the four Landsat-4 images tested in this study were computed in the following manner. For each of the three bands to be used to make an image, a histogram was made using all of the digital values of scene brightness. From this histogram, the arithmetic mean ($\bar{x}$) and standard deviation (s) were calculated. The mapping interval was calculated for the respective color gun intensity levels (eight intensity levels for each color gun on the RSRP color monitor) as follows:

$$\text{Mapping interval} = \frac{\text{Range of values} + 1}{\text{Number of intensity levels}} \quad (1)$$

where:

Range of values = Maximum step value − Minimum step value

Maximum step value = $\bar{x} + 3^*s$ or the maximum step value observed, whichever is less; and

Minimum step value = $\bar{x} - 3^*s$ or the minimum observed step value, whichever is greater.

Based on our interpretation experiences using both this enhancement procedure and other commonly used procedures, we prefer the linear mapping enhancement. This product uses the available color levels efficiently, provides an image that closely simulates color infrared photography if the appropriate TM and MSS bands are used, and preserves many of the subtleties which occur in transition zones between and within wildland vegetation types.

Selection of the four image types, shown in Plate 1 and used in our testing procedures, was based on the following reasons:

(1) MSS bands 4, 2, and 1 represented those images that have been available since the Landsat system was first launched in 1972. Through a comparison of the interpretability of this image to the following TM image types, we can make some inferences as to improvement in interpretability due to increased spatial and spectral resolution of the TM sensor.

Table 2. Summary of Landsat-4 Image Specifications for One MSS Image and Three TM Images for Which Photo-Interpretation Tests were Performed on the Plumas Forest Study Site

Sensor	Image Bands	Color Filter	Band Mean	Standard Deviation	Band Display Range	Image Scale
MSS	4	Red	40.93	10.08	10–71	
	2	Green	15.58	14.63	2–31	1:120,000
	1	Blue	13.42	15.87	7–26	
TM	4	Red	64.07	15.93	16–111	
	3	Green	23.14	8.21	7–47	1: 75,000
	2	Blue	23.69	5.22	11–39	
TM	5	Red	46.30	21.65	0–111	
	3	Green	23.14	8.21	7–47	1: 75,000
	2	Blue	23.69	5.22	11–39	
TM	5	Red	46.30	21.65	0–111	
	4	Green	64.07	15.93	16–111	1: 75,000
	3	Blue	23.14	8.21	7–47	

(2) TM bands 4, 3, and 2 had approximately the same spectral sensitivity of MSS bands 4, 2, and 1 but with more than twice the spatial resolution.

(3) TM bands 5, 3, and 2 allowed us to compare the contribution made to an image if the middle infrared band (band 5) is used in place of the more traditional photographic infrared band (band 4).

(4) TM bands 5, 4, and 3 appeared to contain more

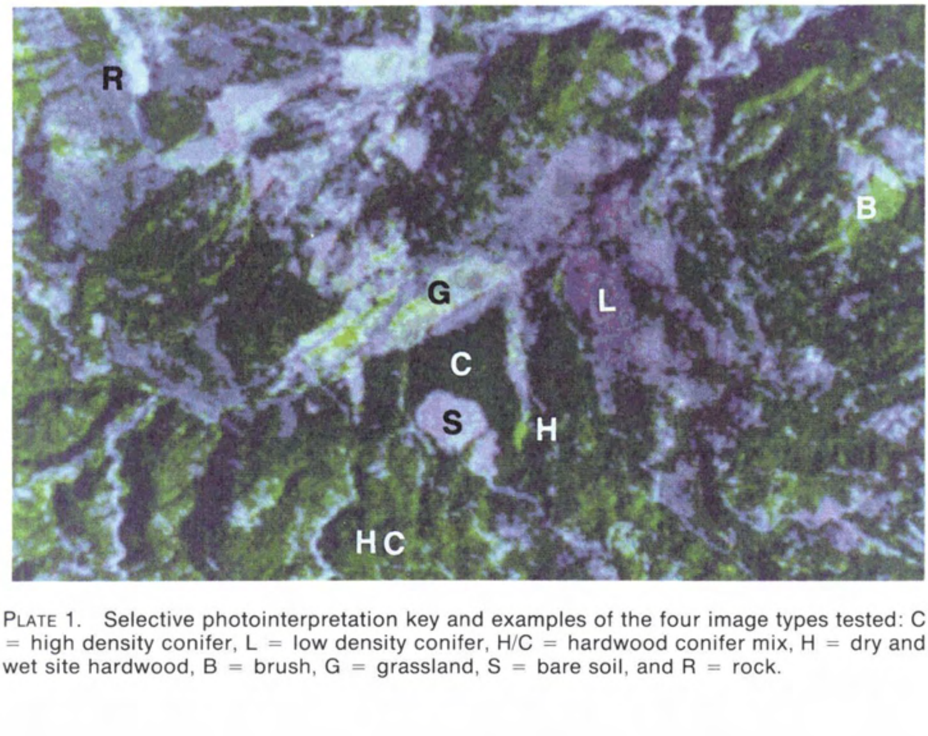
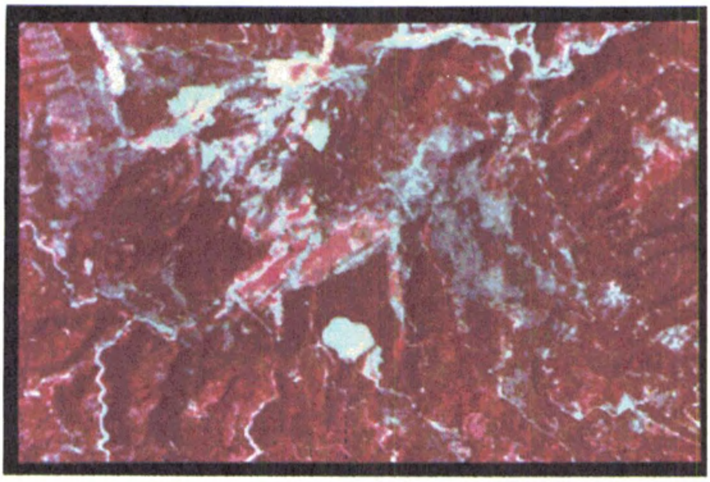
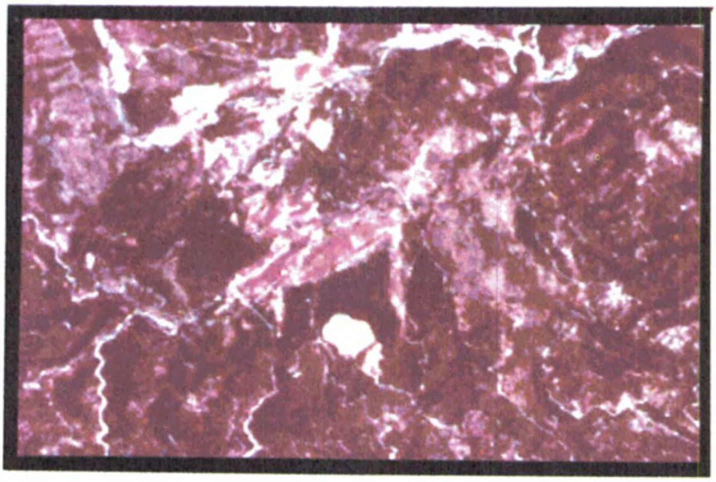


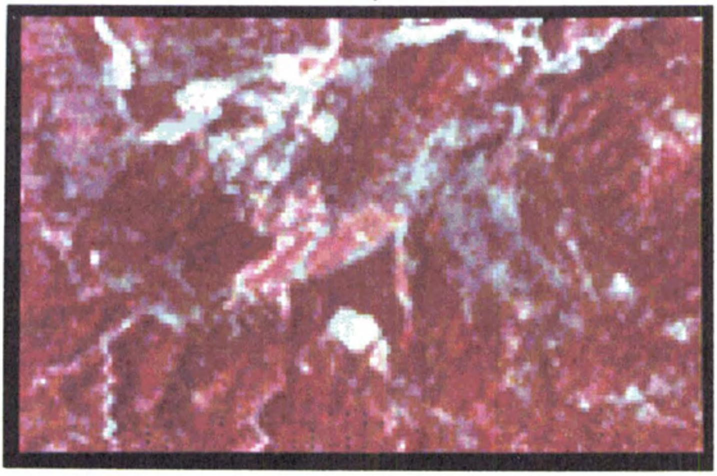
Plate 1. Selective photointerpretation key and examples of the four image types tested: C = high density conifer, L = low density conifer, H/C = hardwood conifer mix, H = dry and wet site hardwood, B = brush, G = grassland, S = bare soil, and R = rock.



TM IMAGE 4, 3 AND 2



TM IMAGE 5, 3 AND 2



MSS IMAGE 4, 2 AND 1

spectral information than the other TM image types based on a qualitative evaluation of film products and of the correlation matrix shown in Table 3.

Construction of the Photointerpretation Keys

We developed selective interpretation keys for the four Landsat-4 images for the following two reasons. Because of the relatively poor spatial resolution of satellite imagery, association and location are important image characteristics that must be used to identify a forest resource category; these two characteristics are presented most easily in selective keys. Secondly, the primary use of these keys was to familiarize skilled interpreters with the expected spectral responses of the resource categories on the different image types; again, the range of these responses can be presented most effectively in selective keys.

Photointerpretation Test Design

On each of the four image types, ten points were randomly allocated for each of the eight resource categories resulting in 80 test points per image type. The points were randomly located on each of the image types so that interpreter-recall would be minimized. Six interpreters were given the photointerpretation tests during one 60-minute session.

After the testing was completed, the answer sheets were corrected and error matrices were constructed for each interpreter by image type. The resulting 24 matrices were then aggregated to produce an error matrix based on 480 interpreter responses for each image type. For each interpretation error matrix, percent correct and percent commission error were calculated as follows:

Table 3. Correlation Matrix of the Seven Thematic Mapper Bands for Data Extracted for the Plumas Forestry Study Site (DeGloria, 1984)

Band	1	2	3	4	5	7	6
1	1.00	0.94	0.96	0.15	0.74	0.84	0.30
2		1.00	0.96	0.24	0.80	0.87	0.77
3			1.00	0.18	0.81	0.90	0.81
4				1.00	0.43	0.18	0.06
5					1.00	0.93	0.85
7						1.00	0.97
6							1.00

n = 40,000 pixels

If the Delta Kappa calculated between two matrices exceeded 1.96, we concluded that the Kappa values were significantly different at the 95 percent confidence level; if the calculated value was less than 1.96 we concluded that the Kappa values were not significantly different and that the image types represented by those matrices were equally interpretable. A complete description of the use of the Kappa statistic can be found in Congalton *et al.* (1984a, b).

RESULTS AND DISCUSSION

Summaries of the interpretation test results are given in Tables 4 and 5. Table 4 lists the ranked image types based on the Kappa statistics calculated for all eight resource categories, and Table 5 lists the ranked image types based on the individual resource categories. In these two tables, lines have been drawn to the right of the Kappa-ranked images which represent those image types that are not significantly different at the 95 percent confidence level. In Table 5, the percent correct (%C) and percent commission error (%CE) associated with each image type have been included for each resource category. These two types of error matrices were used to calculate the values given in Table 4. Examples of the error matrices for TM bands 5, 4, and 3 are given in Tables 6 and 7. Table 6 represents the interpretability of the TM bands 5, 4, and 3 based

$$\text{Percent Correct} = \frac{\text{Number of correct interpretation responses for a resource category}}{\text{Total number of that resource category present}} \times 100 \qquad (2)$$

$$\text{Percent Commission Error} = \frac{\text{Number of incorrect interpretation responses for a resource category}}{\text{Total number of that resource category indicated by the interpreter(s)}} \times 100 \qquad (3)$$

In addition, for each matrix, a Kappa statistic was calculated as follows:

$$\text{Kappa} = \frac{\Sigma\ \text{Diagonal}/N - \Sigma(\text{row total} \times \text{column total})/N^2}{1 - \Sigma(\text{row total} \times \text{column total})/N^2} \qquad (4)$$

The Kappa statistic, which is a nonparametric measure of agreement between "ground truth" and photointerpretation labels, was used to rank the error matrices. The rankings were considered to be significantly different, or not, based on the values obtained through the use of the following relationship:

$$\text{Delta Kappa} = \frac{|\text{Kappa}_i - \text{Kappa}_j|}{[\text{Variance Kappa}_i + \text{Variance Kappa}_j]^{1/2}} \qquad (5)$$

TABLE 4. SUMMARY OF IMAGE RANKINGS FROM THE PLUMAS FOREST STUDY SITE LANDSAT-4 IMAGE INTERPRETATION TESTS. TEST RESULTS BASED ON EIGHT RESOURCE CATEGORIES: (1) HIGH DENSITY CONIFER, (2) LOW DENSITY CONIFER, (3) HARDWOOD/CONIFER, (4) HARDWOOD, (5) BRUSH, (6) GRASSLAND, (7) BARE SOIL, AND (8) ROCK. THE LINES TO THE RIGHT OF THE RANKED KAPPA VALUE INDICATE THOSE IMAGE TYPES THAT ARE NOT SIGNIFICANTLY DIFFERENT AT THE 95 PERCENT CONFIDENCE LEVEL

Rank	Image Type	Kappa and Significance	Percent Correct Range	Percent Correct Mean
1	TM 5,4&3	.502	41.3–73.8	56.5
2	MSS 4,2&1	.486	46.3–70.0	55.0
3	TM 4,3&2	.467	30.0–71.3	53.3
4	TM 5,3&2	.388	23.8–63.0	46.5

on the six interpreters; and Table 7 represents the interpretability of the image type based on the "best" photointerpreter. The data from this second matrix should be used when evaluating the information content of the respective image types, for in operational applications of these images, the most able interpreter would be given the task of information extraction.

By examining the rankings in Table 4 we concluded that image types TM 5, 4, and 3; MSS 4, 2, and 1; and TM 4, 3, and 2 were statistically more interpretable than image type TM 5, 3, and 2. This indicates that any image type for this mixed conifer forest environment must contain a band that is sensitive to the photographic infrared region of the electromagnetic spectrum. Even the MSS image, despite its relatively poor spatial resolution, proved to be more interpretable than the higher spatial resolution TM 5, 3, and 2 image which did not include a band sensitive to the photographic infrared region. Of the four images tested, all six interpreters commented that they considered TM 5, 4, and 3 to be the most easily interpretable. They stated that this was particularly true when they attempted to separate the brush fields from hardwood stands in this image, for many more subtle differences are present than with conventional color infrared image (TM 4, 3, and 2). These comments are confirmed when you examine Table 5 in which TM 5, 4, and 3 was statistically more interpretable than the other image types for the Brush category.

Of interest is that for four of the individual resource categories, the MSS 4, 2, and 1 image surpassed in absolute terms the higher spatial resolution TM images: low-density conifer, hardwood, bare soil, and rock. Why the MSS image was more interpretable than the others for the hardwood category remains an enigma, for this category is typically located in riparian zones which should be more easily detected and identified on the higher resolution imagery. The other three categories, however, represent large, contiguous nonvegetated categories. Perhaps the interpreters were better able

TABLE 5. SUMMARY OF IMAGE RANKINGS FROM THE PLUMAS FOREST STUDY SITE LANDSAT-4 INTERPRETATION TESTS. RESULTS ARE BASED ON INDIVIDUAL RESOURCE CATEGORIES. THE LINES TO THE RIGHT OF THE RANKED PERCENT CORRECT CORRECT/PERCENT COMMISSION ERROR VALUES (%C/%CE) ARE NOT SIGNIFICANTLY DIFFERENT AT THE 95 PERCENT CONFIDENCE LEVEL BASED ON THE KAPPA STATISTIC

Rank	Category	%C/%CE	Rank	Category	%C/%CE
	High-Density Conifer			*Low-Density Conifer*	
1	TM 4,3&2	85/15	1	MSS 4,2&1	90/39
2	TM 5,3&2	85/33	2	TM 5,4&3	77/44
3	TM 5,4&3	62/10	3	TM 4,3&2	50/45
4	MSS 4,2&1	80/38	4	TM 5,3&2	50/71
	Hardwood/Conifer			*Hardwood*	
1	TM 4,3&2	57/38	1	MSS 4,2&1	40/41
2	TM 5,4&3	52/34	2	TM 5,4&3	37/39
3	MSS 4,2&1	47/63	3	TM 4,3&2	30/40
4	TM 5,3&2	23/62	4	TM 5,3&2	20/40
	Brush			*Grassland*	
1	TM 5,4&3	80/49	1	TM 5,3&2	67/49
2	TM 4,3&2	50/55	2	TM 5,4&3	63/53
3	MSS 4,2&1	20/40	3	MSS 4,2&1	43/47
4	TM 5,3&2	22/72	4	TM 4,3&2	60/59
	Bare Soil			*Rock*	
1	MSS 4,2&1	78/50	1	MSS 4,2&1	42/29
2	TM 5,3&2	67/53	2	TM 5,3&2	38/36
3	TM 5,4&3	62/53	3	TM 4,3&2	35/51
4	TM 4,3&2	60/57	4	TM 5,4&3	20/37

TABLE 6. ERROR MATRIX BASED ON A POOL OF SIX INTERPRETERS FROM THE PLUMAS FOREST STUDY SITE FOR IMAGE TYPE TM 5, 4, AND 3

P.I. Results	Ground Truth 1	2	3	4	5	6	7	8	Total	Percent Commission Error
1 Hi Conifer	*37*	3	0	0	0	0	1	0	41	10
2 Lo Conifer	12	*46*	13	2	3	1	5	0	82	44
3 Hard/Con	7	1	*31*	4	4	0	0	0	47	34
4 Hardwood	2	2	0	*22*	4	2	2	2	36	39
5 Brush	1	0	15	28	*48*	2	1	0	95	49
6 Grassland	1	6	1	1	0	*38*	11	23	81	53
7 Bare Soil	0	1	0	3	1	14	*37*	23	79	53
8 Rock	0	1	0	0	0	3	3	*12*	19	37
Total	60	60	60	60	60	60	60	60	480	
Percent Correct	62	77	52	37	80	63	62	20		

Total Correct = 271 Percent Correct = 56.5
Total Error = 209 Percent Error = 43.5
Estimated Kappa = 0.502 Estimated St. Dev. = 0.026

TABLE 7. ERROR MATRIX BASED ON THE "BEST" INTERPRETER FROM THE PLUMAS FOREST STUDY SITE FOR IMAGE TM 5, 4, AND 3

P.I. Results	Ground Truth 1	2	3	4	5	6	7	8	Total	Percent Commission Error
1 Hi Conifer	*9*	0	0	0	0	0	0	0	9	0
2 Lo Conifer	0	*10*	0	0	0	0	0	0	10	0
3 Hard/Con	1	0	*10*	0	1	0	0	0	12	17
4 Hardwood	0	0	0	*2*	1	0	0	1	4	50
5 Brush	0	0	0	7	*7*	0	0	0	14	50
6 Grassland	0	0	0	0	0	*7*	1	1	9	22
7 Bare Soil	0	0	0	1	1	2	*9*	3	16	44
8 Rock	0	0	0	0	0	1	0	*5*	6	17
Total	10	10	10	10	10	10	10	10	80	
Percent Correct	90	100	100	20	70	70	90	50		

Total Correct = 59 Percent Correct = 73.8
Total Error = 21 Percent Error = 26.3
Estimated Kappa = 0.700 Estimated St. Dev. = 0.056

to exploit associative characteristics on the individual MSS test images which covered larger areas than did the individual TM test images.

CONCLUSIONS

Based on our analysis of image products, statistical data, and interpretation test results, the following two conclusions are drawn regarding the spectral quality of Landsat-4 TM and MSS data:

- Color composites which include TM band 5 with other visible bands (TM bands 1–3) are inferior for discriminating important forest types which are highly reflective in the photographic infrared (TM band 4).
- The optimum combination of reflective TM bands for discriminating forest cover types would be either TM bands 5, 4, and 2 or TM bands 5, 4, and 3 where both the reflective and absorptive properties of the diverse cover types can be exploited.

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