C. LISETTE DOTTAVIO*
NASA Goddard Space Flight Center
Greenbelt, MD 20771
F. DOMINIC DOTTAVIO
National Park Service
Clemson Cooperative Park Study Unit
Clemson University
Clemson, SC 29631

Potential Benefits of New Satellite Sensors to Wetland Mapping

Given large homogeneous land-cover categories, the Landsat TM and MSS sensors provide comparable classification performance values for wetland community mapping

ABSTRACT: *The potential utility of NASA's recently launched Thematic Mapper remote sensing system is evaluated. Simulated Thematic Mapper data are compared with simulated multispectral scanner data to determine if satellite digital data from the Thematic Mapper will offer (a) a more powerful tool than the multispectral scanner for wetland mapping and (b) if spectral advances on the Thematic Mapper will in fact improve discrimination among wetland cover types.*

Data were collected using NASA's NS-001/MS Thematic Mapper Simulator. The spectral, spatial, and radiometric characteristics of the Thematic Mapper were examined separately. The comparison of simulated multispectral scanner and Thematic Mapper data resulted in comparable classification performance values for large homogeneous areas.

Examination of the discrimination capabilities of the Thematic Mapper indicated that the infrared wavelength region from 1.0 to 1.3 μm, which is available on the Thematic Mapper Simulator but not the actual Thematic Mapper, had the greatest discriminatory power for the six cover types examined. A distinct separation also occurred between low marsh and high marsh species in the middle infrared band (TM5). This property of the Thematic Mapper should assist in the inventory of wetland habitats using remotely sensed data.

INTRODUCTION

On 16, July 1982, the most recent of NASA's remote sensing systems, the Thematic Mapper (TM), was launched on the Landsat-4 satellite. The sensor's spectral, spatial, and radiometric characteristics are expected to provide resource managers with the most sophisticated satellite imagery available for public use. Prior to launching the TM, NASA scientists examined data simulated to match TM characteristics in order to determine what improvements in land-cover identification can be expected from the new data. Specifically, a two-part study was initiated to compare Thematic Mapper Simulator (TMS) data with simulated multispectral scanner (MSS) data. To accomplish this, the study examined the potential utility of Thematic Mapper data for identifying wetland plant communities along the eastern shore of the Chesapeake Bay. In the first stage of the study, TM spectral (visible, near infrared, and middle infrared only), spatial, and radiometric characteristics were examined separately to determine which of these characteristics, when compared to the current capabilities of the MSS, improved wetland mapping accuracy. The second part of the study was a closer examination of the spectral characteristics of the TM (excluding the thermal channel) for

* Currently a Scientific Consultant located in Clemson, South Carolina.

0099-1112/84/5005-0599$02.25/0

determining which wavelength bands would provide the greatest discrimination among two specific wetland plant communities: low marsh and high marsh.

The usefulness of satellite data for wetland mapping is documented in a number of studies (Carter, 1978; Ernst and Hoffer, 1979; Carter and Richardson, 1981). These authors and others have demonstrated that broad wetland communities can be identified using data from the Landsat multispectral scanner. Moreover, a recent study of wetland canopy spectral reflectance using Landsat MSS wavebands has shown a high correlation between MSS Band 4 (0.5 to 0.6 μm) and MSS Band 5 (0.6 to 0.7 μm) and live vegetation in both low marsh and high marsh plant communities (Bartlett and Klemas, 1982). These authors also found that infrared reflectance displayed significant dependence on canopy parameters such as biomass and height. This and other wetland studies indicate a good potential for spectral discrimination of plant communities from satellite sensors as the optical properties of these communities are better understood. However, spatial, spectral, and radiometric constraints limit the operational utility of Landsat MSS data for wetland community mapping. The technological improvements of the Landsat Thematic Mapper promise to make satellite digital data a more powerful tool for wetland inventory work.

TM, MSS, and TMS Characteristics

Numerous publications have documented the current configuration and resolution capabilities of the Landsat-4 Thematic Mapper and how these sensor characteristics were determined (Morgenstern *et al.*, 1976; Salmonson and Park, 1979; Dottavio and Williams, 1982). In comparison to the MSS (Table 1), the TM provides seven narrower spectral bands, increases the spatial resolution of the visible, infrared, and thermal bands, improves radiometric sensitivity, and increases the number of quantization levels.

In order to simulate TM and MSS data for this study, an aircraft scanner, the NS-001/MS Thematic Mapper Simulator, was used. The scanner is carried on a C-130B aircraft and was developed at the Johnson Space Center. The optical system of the TMS

> "...is designed to image a 2.5-milliradian instantaneous field of view (IFOV) of the ground simultaneously onto eight discrete detectors, each covering a fixed wavelength band. These bands correspond to the Landsat-4 TM bands. An extra (eighth) band, which covers the 1.00 to 1.30 μm region, is also included in the NS-001/MS scanner system. A rotating mirror scans the IFOV over a 100° angle across the ground track of the aircraft. The radiometric sensitivity of each band meets or exceeds specifications of the Landsat-4 TM, and the data are quantized to 256 levels. Aircraft roll is sensed by a gyro that generates an error signal to correct for roll (±15°). Spatial resolution is controlled by aircraft altitude. Considering the 2.5-milliradian IFOV and the altitude above the ground of about 6.1 kilometers (20,000 ft), this results in a nominal resolution cell of 15 by 15 m at nadir" (Dottavio and Williams, 1982).

A Zeiss camera with a 15-cm focal-length lens is operated simultaneously with the TMS to provide supplemental aerial photographs. More detail on the TMS can be found in Richard *et al.* (1978).

Data and Study Site Description

Thematic Mapper Simulator data were collected 27, August 1980 at approximately solar noon at a nominal resolution of 5.0 metres at nadir. All of the eight TMS spectral channels were operational during

Table 1. Comparison of Landsat-4 TM and MSS Sensor Characteristics

	Thematic Mapper TM		Multispectral Scanner (Subsystem MSS)	
	Micrometres	Radiometric Sensitivity (NEΔP)	Micrometres	Radiometric Sensitivity (NEΔP)
Spectral band 1	0.45-0.52	0.8%	0.5-0.6	0.57%
Spectral band 2	0.52-0.60	0.5%	0.6-0.7	0.57%
Spectral band 3	0.63-0.69	0.5%	0.7-0.8	0.65%
Spectral band 4	0.76-0.90	0.5%	0.8-1.1	0.70%
Spectral band 5	1.55-1.75	1.0%		
Spectral band 7	2.08-2.35	2.4%		
Spectral band 6	10.40-12.50	0.5K (NEΔT)		
RFOV		30M (Bands 1-5, 7) 120M (Band 6)	82M (Bands 1, 4)	
Data Rate		85 MB/S	15 MB/S	
Quantization Levels		256	64	

(Source: Dottavio and Williams, 1982).

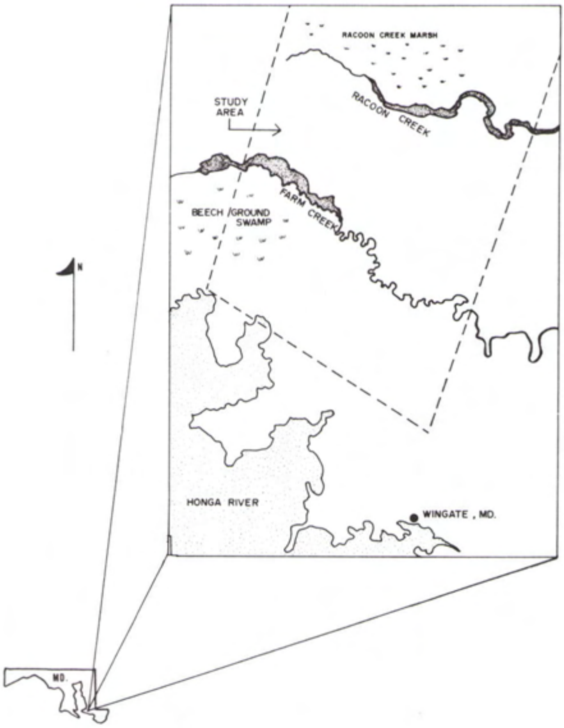

FIG. 1. Study area.

the overflight.* These data are located within Dorchester County, Maryland, and lie within the Wingate, Maryland 1:24,000 USGS topographic quadrangle (see Figure 1). The study area lies along the easter shore of the Chesapeake Bay and is dominated by wetland plant communities with some upland forest and agricultural land dispersed throughout. The wetland communities can be broken down into brackish high marsh, dominated by salt hay (*Spartina patens/Distichlis spicata)* and bullrush *(Scirpus spp)*, and brackish low marsh, dominated by saltmarsh cordgrass *(Spartina alterniflora)*. Color infrared (CIR) aerial photographs (scale = 1:13,000) were collected simultaneously with the Thematic Mapper Simulator data. Wetland type maps of the area generated from 1:6,000 color aerial photos collected in 1971 were used in conjunction with the CIR air photos to locate the predominant land-cover types and as the ground reference information for the study.

PREPROCESSING OF REMOTELY SENSED DATA

Initial inspection of the simulated Thematic Mapper data revealed a distinct brightness shift in TM2 (0.52 to 0.60 μm) across the flight line. This led to the examination of both the gain setting and sensor calibration data to determine if these were consistent throughout the data. Computer programs designed to read Thematic Mapper Simulator data tapes and to generate plots of the calibration and active scan data (Irons and McKinney (1982), Personal Communication) were run for each spectral channel of the data set. Plots revealed that the internal calibration lamp and black body temperatures were uniform throughout the flightline for each of the spectral channels. However, when the gain record for each spectral channel was examined, only the gain setting for TM2 showed a marked change. Time constraints did not allow for adjustments of the TM2 data to be made. Therefore, to avoid the possibility of inaccurate results, the TM2 spectral channel was eliminated from consideration in further project activities.

After the initial examination of the data, extensive preprocessing was undertaken to insure that the simulated data would approximate the data that will be obtained from the Landsat-4 Thematic Mapper. Three preprocessing steps (Dottavio and Williams, 1982) were required:

(1) *Radiometric Adjustment*. As the TMS scans across the flight path, the look angle and atmospheric path length through which the instrument views the ground vary systematically. These variations affect the reference data in a manner that confounds the recognition of land-cover categories. This scan-angle effect was compensated for by modeling the TMS response as a function of scan angle and normalizing the raw data to the predicted response at nadir. A complete description of the radiometric adjustment process can be found in Irons and Labovitz (1982).

(2) *Geometric Correction*. Geometric distortions perpendicular to the flight direction were evident in the TMS data. These tangential distortions were caused by changes in look angle (up to ±50° from nadir) during collection of aircraft scanner imagery. This problem was corrected by generating a control grid for a specified geometric transformation in which the grid cell size is equal to the resolution cell size at nadir. The image is then resampled to fit a 5.0-metre grid using a nearest-neighbor algorithm.

(3). *Degradation of Data*. The NS-001/MS Thematic Mapper Simulator data were resampled to a nominal resolution of 7.5 m at nadir. The data needed to be further degraded to 30 m to match future TM data. This was accomplished using a spatial resolution degradation filter similar to that developed by Sadowski and Sarno (1976).

Following preprocessing of the aircraft scanner data to simulate Thematic Mapper characteristics, a second image set was created from the raw data to simulate Landsat multispectral scanner characteristics. The preprocessing steps undertaken to achieve this end were

(1) *Radiometric Adjustment*.

* To avoid confusion between TMS and TM spectral bands, Thematic Mapper Simulator wavelengths are identified by their Thematic Mapper equivalent. An exception to this is the additional infrared band on the NS-001/MS, which will be referred to as TMSIR.

TABLE 2. DESCRIPTION OF DATA SETS GENERATED FROM RAW NS-001/MS AIRCRAFT SCANNER IMAGERY TO STUDY INCREMENTAL IMPROVEMENTS OF TM OVER MSS

Spectral Data Set Name	Spatial Channels	Radiometric Resolution	Resolution
(1) TM Simulation	TM 1 (0.45-0.52 μm) TM 3 (0.63-0.69 μm) TM 4 (0.76-0.90 μm) TM 5 (1.55-1.75 μm) TM 7 (2.08-2.35 μm) TMSIR (1.0-1.30 μm)	30 m	8 bit
(2) MSS Simulation	TM 3, TM 4, TMSIR (MSS 5) (MSS 6) (MSS 7)	60 m	6 bit
(3) TM Spectral/MSS Spatial and Radiometric Simulation	TM 1, TM 3, TM 4, TM 5, TM 7, TMSIR	60 m	6 bit
(4) TM Spatial/MSS Spectral and Radiometric Simulation	TM 3, TM 4, TMSIR	30 m	6 bit
(5) TM Radiometric/MSS Spectral and Spatial Simulation	TM 3, TM 4, TMSIR	60 m	8 bit

(2) *Geometric Correction.*
(3) Degradation of Data. Using the spatial resolution degradation filter, the raw scanner data were reduced to 60-m resolution.
(4). *Reduction of Spectral Bands.* Aircraft scanner wavelength bands that were not similar to those on board the MSS were eliminated from the data set. Therefore, the following spectral channels were maintained: TM3 (0.63 to 0.69 μm), TM4 (0.76 to 0.90 μm), and TMSIR (1.00 to 1.30 μm).
(5). *Reduction of Radiometric Resolution.* The aircraft scanner data were reduced from 8-bit data to 6-bit data by dividing each pixel digital count by 4 and truncating.

Processing steps 4 and 5 were achieved using programs available on the ESL/Interactive Digital Image Manipulation System (IDIMS) software housed on an HP-3000 minicomputer at the NASA Goddard Space Flight Center (ESL, 1980).

In addition to the simulated multispectral scanner data set, three other image sets were generated from the raw aircraft data. Each data set was identical to simulated MSS imagery in all but one of the following sensor characteristics: (1) spatial resolution, (2) spectral resolution, and (3) radiometric resolution. Table 2 lists all of the data sets that were generated from the NS-001/MS Thematic Mapper Simulator data. All of these data sets were used to study the incremental improvements afforded by the TM's improved spectral, spatial, and radiometric resolution.

COMPARATIVE ANALYSIS OF SIMULATED DATA SETS

CLASSIFICATION OF DATA SETS

To evaluate which technical improvement in the Thematic Mapper System will have the most impact on wetland mapping, the five data sets described in Table 2 were classified using standard image processing techniques.

After acquisition and preprocessing of the remotely sensed data, training statistics were developed separately for each data set. The training technique used to generate these spectral statistics were similar to the multicluster-blocks approach described by Fleming and Hoffer (1977). This training technique involves selecting spectrally heterogeneous areas (i.e., data blocks) and applying a clustering algorithm to these areas to obtain a number of spectrally distinct classes. These classes are then identified using ground reference information, and the statistics for similar classes are pooled to create a final statistics file that describes separable informational classes. Fleming and Hoffer found this procedure to be the most effective in terms of analyst efficiency, computer time, and classification performance. All analyses were completed using the ESL/IDIMS software.

For each of the five data sets, the following six land-cover types were identified:

Agricultural land
Upland forest
Brackish low marsh (*Sp. alterniflora*)
Brackish high marsh I (*Sp. patens/D. spicata*)
Brackish high marsh II (*Scirpus spp.*)
Water

The statistics for each of the informational classes identified above were used in a maximum likelihood procedure to classify the respective data set from Table 2.* After each data set was classified, performance evaluations were initiated.

* The brackish high marsh I and II cover types were combined into a brackish high marsh category. The unequal cell sizes created by this combination was accounted for in the statistical analysis by weighting the variables.

Table 3. Percent Classification Performance for Each Cover Type and Each Data Set

a. *TM Simulation*

Actual Ground Cover Type	Classified Cover Type: Agriculture	Upland Forest	Brackish High Marsh	Brackish Low Marsh	Water
Agriculture	*83.3%*	—	16.7%	—	—
Upland Forest	3.3%	*93.4%*	3.3%	—	—
Brackish High Marsh	25.0%	11.7%	*46.7%*	13.3%	3.3%
Brackish Low Marsh	—	26.7%	13.3%	*50.0%*	10.0%
Water	—	3.3%	—	—	*97.0%*

Overall Performance = 69.4%

b. *MSS Simulation*

Actual Ground Cover Type	Classified Cover Type: Agriculture	Upland Forest	Brackish High Marsh	Brackish Low Marsh	Water
Agriculture	*63.4%*	3.3%	33.3%	—	—
Upland Forest	—	*90.0%*	6.7%	3.3%	—
Brackish High Marsh	15.0%	5.0%	*51.7%*	25.0%	3.3%
Brackish Low Marsh	6.7%	13.3%	10.0%	*60.0%*	10.0%
Water	—	3.3%	—	20.0%	*76.7%*

Overall Performance = 65.6%

c. *Spectral Simulation*

Actual Ground Cover Type	Classified Cover Type: Agriculture	Upland Forest	Brackish High Marsh	Brackish Low Marsh	Water
Agriculture	*90.0%*	—	10.0%	—	—
Upland Forest	3.3%	*90.0%*	3.3%	3.3%	—
Brackish High Marsh	20.0%	6.7%	*55.0%*	11.7%	6.6%
Brackish Low Marsh	3.3%	26.7%	13.3%	*40.0%*	16.7%
Water	—	3.3%	—	6.7%	*90.0%*

Overall Performance = 70.0%

d. *Spatial Simulation*

Actual Ground Cover Type	Classified Cover Type: Agriculture	Upland Forest	Brackish High Marsh	Brackish Low Marsh	Water
Agriculture	*86.7%*	—	13.3%	—	—
Upland Forest	3.3%	*80.0%*	3.3%	13.3%	—
Brackish High Marsh	21.7%	6.7%	*53.3%*	18.3%	—
Brackish Low Marsh	10.0%	23.3%	3.3%	*56.7%*	6.7%
Water	—	—	—	10.0%	*90.0%*

Overall Performance = 70.0%

e. *Radiometric Simulation*

Actual Ground Cover Type	Classified Cover Type: Agriculture	Upland Forest	Brackish High Marsh	Brackish Low Marsh	Water
Agriculture	*66.7%*	—	33.3%	—	—
Upland Forest	3.3%	*93.4%*	3.3%	—	—
Brackish High Marsh	11.7%	3.3%	*55.0%*	26.7%	3.3%
Brackish Low Marsh	6.7%	16.6%	6.7%	*60.0%*	10.0%
Water	—	3.3%	—	20.0%	*76.7%*

Overall Performance = 67.8%

A stratified random sample of 180 pixels (30 pixels per class) was selected from each data set, and the pixel location was noted on the ground reference information. Boundary pixels were discarded and replaced by homogeneous pixels. The actual land-cover class for each pixel was compared to the classified image and tallied to generate a confusion matrix for each data set. The confusion matrices were then used to determine the classification performance of each simulated data set.

A two-way analysis of variance (ANOVA) was used to test for significant differences among data sets and cover type classification. Percent classification performance was used in the analysis. To insure that the data were approximately normally distributed and would conform to the basic assumptions of the analysis of variance, an arcsine transformation was applied to the percentage figures. The interaction term was tested against the variance of the angular (arcsine) transformation and found to be insignificant. The sums of squares for interaction between data set and cover type were then combined with the error term. A detailed discussion of the two-way ANOVA and interaction test is given in Langrebe *et al.* (1976).

Table 3 lists the percent classification performance for each of the five simulated data sets. Note that the *overall classification performance* does not vary significantly from one data set to another, although slightly higher performances are achieved from the TM and spatial resolutions. This observation is further substantiated by the results of the two-way ANOVA (see Table 4). However, there are significant differences in performance *among cover types;* that is, some cover types are classified better than others regardless of data set.

Table 4. Results of Two-way ANOVA to Test the Significance of Simulated Data Sets and Cover Type on Classification Performance

Source of Variation	Degrees of Freedom	Mean Square	F Value	F at $\alpha = 0.05$
Data Set	4	0.0075	0.536	3.01
Cover Type	4	0.2575	18.39*	3.01
Interaction & Error	16	0.014		

* = significant effect

Spectral Discrimination among Wetland Cover Types

The previous analyses indicated that little, if any, improvement in identifying broad cover type classes can be expected from Thematic Mapper data as compared to the MSS. However, for both MSS and TM data, differences in discrimation among cover types is evident. Therefore, to determine if the TM spectral advances will in fact improve discrimination among wetland cover types, statistical analyses were used to examine the TM spectral bands in relation to the six major cover types found in the Dorchester County study site.

A stepwise discriminant analysis was run on a stratified random sample of pixels from the TMS data set (Dixon and Brown, 1979). The purpose of the stepwise procedure was to separate the six known cover types (i.e., agriculture, forest, *Sp. alterniflora, Sp. patens/D. spicata, Scirpus spp*, and water) by their spectral characteristics. Each class contained 30 pixels that had been previously identified on the wetland type maps and current aerial photos. The spectral response values of each of the TM simulator wavelength bands for each point were used to compute sample statistics to serve as estimates of the population parameters.

Separation of cover types of spectral-response patterns was achieved in the statistical analysis by deriving linear combinations (discriminant functions) of the TMS bands that provided the greatest discrimination among classes. A stepwise procedure was chosen so that individual bands would be selected and placed into the linear function in order of the band's decreasing discriminating power. That is, at each step in the procedure, the band that maximized the separation between classes, while minimizing the multiple correlation among the bands selected in the previous step, was included in the derivation of the linear discriminant function.

Table 5 lists the sequence in which the Thematic Mapper Simulator bands were selected by the discriminant function. The Wilks-Lambda is a measure of the discriminating power provided by each variable in the discriminant function.

In the discriminant analysis, the TMS band which is *not* found on the actual Thematic Mapper (TMSIR) was identified as having the greatest discriminatory power for the cover types examined. This result would suggest that the infrared wavelength region

Table 5. Summary Table for Stepwise Discriminant Analysis

Step Number	Variable Entered	Wilk's Lambda	Δ Wilk's Lambda
1	TMSIR* (1.0-1.3 μm)	0.1925	—
2	TM 4 (0.76-0.90 μm)	0.1236	0.0689
3	TM 5 (1.55-1.75 μm)	0.0764	0.0472
4	TM 3 (0.63-0.69 μm)	0.0568	0.0196
5	TM 7 (2.08-2.35 μm)	0.0469	0.0099
6	TM 1 (0.45-0.52 μm)	0.0402	0.0067

* TMSIR is an infrared band on the Thematic Mapper Simulator (NS-001/MS) not found on the actual Thematic Mapper.

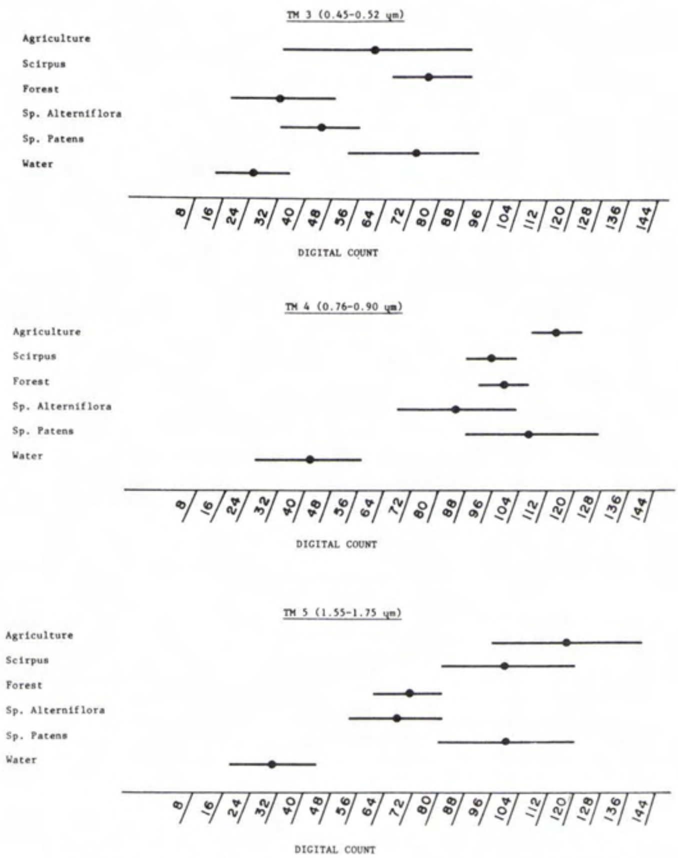

FIG. 2. Spectral response pattern of six major cover types found along the Chesapeake eastern shore.

from 1.0 to 1.3 μm should be considered for future satellite sensors.

The second, third, and fourth spectral bands selected by the discriminant analysis are TM4, TM5, and TM3, respectively. This result agrees with earlier studies of forest communities which showed that optimum separation of cover types is achieved by classifying multispectral data having at least one band from each of the major regions of the electromagnetic spectrum (visible, near infrared, and middle infrared) (Hoffer *et al.*, 1975; Dottavio and Williams, 1982).

The ability of TM4, TM5, and TM3 to discriminant among the six land categories under examination is also apparent when the spectral response patterns of each of the cover types are charted (Figure 2). Figure 2 is composed of a series of graphs which show the mean spectral response, plus or minus one standard deviation, for each cover type in the near infrared, middle infrared, and visible portion of the spectrum. Of particular interest is the clear separation between low marsh and high marsh species in the middle infrared band (TM5). This clear separation may be the result of a greater amount of water associated with low marsh species, and can be readily exploited when discriminating among wetland plant communities using the improved Thematic Mapper sensor.

SUMMARY AND CONCLUSIONS

In this study, a number of the advantages and limitations that can be expected from the Landsat-4 Thematic Mapper for wetland community mapping were identified, including

(1) Given large homogeneous land-cover categories, the TM and MSS sensors provide comparable classification performance values for wetland community mapping; and

(2) The spectral study of wetland communities using Thematic Mapper bands which are available on the Landsat-4 satellite demonstrates that the middle infrared wavelength region provides a clean separation between brackish low marsh and brackish high marsh communities. It would appear that the increased number of spectral bands may improve wetland mapping capabilities. Future research on the TM should follow patterns established

for the MSS in which ancillary data sets and multitemporal data are combined with TM data to provide greater separation among cover types.

REFERENCES

Bartlett, D. S., and V. Klemas, 1982. In situ spectral reflectance studies of tidal wetland grasses. *Photo. Eng. and Rem. Sens.*, Vol. 47, No. 12, pp. 1695-1703.

Carter, V., 1978. Coastal wetlands: role of remote sensing. In *Coastal Mapping Papers Reprints from Coastal Zone '78 Symposium on Technical, Environmental, Socioeconomic and Regulatory Aspects of Remote Sensing*, San Francisco, CA. March 14-16, 1978. pp. 1261-1279.

Carter, V., and K. Richardson, 1981. Landsat digital analysis: implications for wetland management. *Seventh International Symposium on Machine Processing of Remotely Sensed Data*. Purdue University. pp. 220-229.

Dixon, W. J., and M. H. Brown (Editors), 1979. *Biomedical computer programs P-Series*. Univ. of California Press, Berkeley, p. 711-739.

Dottavio, C. L., and D. L. Williams, 1982. Mapping a southern pine plantation with satellite and aircraft scanner data: A Comparison of present and future landsat sensors. *Journal of Applied Photographic Engineering*. Vol. 8, No. 1, pp. 58-62.

Electromagnetic Systems Laboratory, 1980. *IDIMS Functional Guide*, ESL-TM705, Sunnyvale, CA.

Ernst (Dottavio), C. L., and R. M. Hoffer, 1979. Using Landsat MSS data with soils information to identify wetland habitats. In *Satellite Hydrology*, Fifth Pecora Memorial Symposium, Sioux Falls, SD. P-474-478.

Fleming, M. D., and R. M. Hoffer, 1977. *Computer-aided analysis techniques for an operational system to map forest lands utilizing Landsat MSS data*. LARS information Note 911579, Purdue University, West Lafayette, IN. pp. 24-102.

Hoffer, R. R., and Staff, 1975. *Computer Aided Analysis of Skylab Multispectral Scanner Data in Mountainous Terrain for Land Use, Forestry, Water Resource, and Geologic Applications*. LARS Information Note 121275, pp. 188-233.

Irons, J. R., and Labovitz, M., 1982. A data analytic approach to look-angle radiance adjustment. *Journal of Applied Photographic Engineering*. Vol. 8, No. 3, pp. 125-137.

Landgrebe, P. A., and Staff, 1976. *Skylab Report*. Laboratory for Applications of Remote Sensing. Purdue University. West Lafayette, IN.

Morgenstern, J. P., R. F. Nalepka, E. D. Kent, and J. D. Erikson, 1976. *Investigation of Landsat follow-on Thematic Mapper spatial, radiometric, and spectral resolution* (sic). NASA/JSC Contract Report NAS9-14819. pp. 29-71.

Richard, R. R. F. Merkel, and G. R. Meeks, 1978. NS-001/MS - Landsat-D Thematic Mapper Band Aircraft Scanner. *Proceedings, 12th International Symposium on Remote Sensing of the Evnironment*. Vol. 1, pp. 719-727.

Sadowski, F., and J. Sarno, 1976. *Forest classification accuracy as influenced by MSS spatial resolution*. NASA/JSC Contract Report NASA-14123. pp. 82-116.

Salmonson, V. V., and A. B. Park, 1979. An overview of the Landsat-D Project with emphasis on the flight segment. *Fifth International Symposium on Machine Processing of Remotely Sensed Data*. Purdue University. pp. 2-11.

(Received 26 February 1983; accepted 25 November 1983; revised 16 January 1984)

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