C. LISETTE ERNST-DOTTAVIO NASA/Goddard Space Flight Center Greenbelt, MD 20771 ROGER M. HOFFER Department of Forestry and Natural Resources Purdue University West Lafayette, IN 47906 RICHARD P. MROCZYNSKI Laboratory for Applications of Remote Sensing West Lafayette, IN 47906

# Spectral Characteristics of Wetland Habitats

Field spectral measurements offered an excellent means to examine the spectral characteristics of wetland cover types and to predict Landsat classification results.

#### INTRODUCTION

A MERICA'S WETLANDS represent one of our nation's most limited and valuable natural resources. They are essential not only to wildlife but also the biologic and hydrologic regimes. As resource managers become increasingly aware of the importance of wetlands, more attention is given to the inventory and evaluation of wetlands as evidenced by the U.S. Fish and Wildlife Service National Wetland Inventory (Cowardin *et al.*, 1979). aircraft data is best for enumerating small prairie wetlands (Gilmer *et al.*, 1980). Multitemporal Landsat data were used to identify and map vegetation classes in the Great Dismal Swamp of Virginia and North Carolina (Gammon and Carter, 1976; Carter *et al.*, 1977). Other Landsat-related research included evaluating the interpretability of Landsat data for compiling information on land-use classes and wetland vegetation in northwestern Tennessee (Jones and Shahrokki, 1977),

ABSTRACT: Spectral characteristics of the six major wetland types found in northeastern Indiana were measured during the summer of 1978 using an EXOTECH-100 radiometer mounted in a helicopter. The spectral measurements were compared to a computer classification of Landsat multispectral scanner data. Analysis of the spectral characteristics indicated that deep marshes and open water can be separated based on spectral reflectance. In contrast, shallow marshes, shrub swamps, and hardwood swamps were spectrally similar to each other and to upland cover types and were therefore difficult to separate using spectral responses alone. Discriminant analysis of EXOTECH-100 measurements of spectral response and the Landsat computer classification showed similar results. The field spectral measurements offered an excellent means to examine the spectral characteristics of wetland cover types and to predict Landsat classification results.

The identification and inventory of wetlands is essential to good management. Consequently, considerable research has been done to examine the utility of spacecraft remote sensing techniques to identify and inventory wetlands. Studies have shown that Landsat data are useful for monitoring changes in large ponds and lakes in the prairie pothole region of North Dakota (Work and Gilmer, 1975). Subsequent research has demonstrated that a double-phase sampling approach of Landsat and and examining automatic techniques for measuring marsh plant productivity by inference from species classifications using Landsat Mss data (Butera, 1979).

These projects demonstrate the utility of Landsat for mapping large wetland areas. However, many vital freshwater wetlands exist only as small pockets within other major land covers. This study was designed to determine if the Landsat multispectral scanner (MSS) provided sufficient spectral

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING, Vol. 47, No. 2, February 1981, pp. 223-227. resolution to identify small wetlands in northern Indiana. This study was divided into two parts. The first examined the spectral characteristics of fully developed wetland habitat types. The second examined the separability of wetland types from other cover types using Landsat data.

#### SPECTRAL CHARACTERISTICS OF WETLAND TYPES

Reflectance measurements were taken over the Pigeon River Fish and Wildlife Area (Figure 1) which contains the six major wetland types found in Indiana: shallow marsh, deep marsh, open water, shrub swamp, hardwood swamp, and bog. The wetland types and a description of each are given in Table 1. Nine sets of spectral measurements were taken, including one for each of the previously mentioned homogeneous wetland types plus three water and vegetation mixtures. Water and vegetation mixed classes included

- Mixture Class 1—Less than 30 percent Vegetation; More than 70 percent Water;
- Mixture Class 2—30 to 60 percent Vegetation; 40 to 70 percent Water
- Mixture Class 3—More than 60 percent Vegetation; Less than 40 percent Water.

Spectral reflectance measurements were made using an EXOTECH-100 Landsat Ground Truth Radiometer mounted on a helicopter strut. The Model 100 has a 15° field of view precision scope co-aligned with four spectral channels that correspond to the Landsat Mss. A Nikon 35-mm camera, aligned to the radiometer, was attached to the helicopter strut such that concurrent photographics could be taken at each point. A Fluke Data Logger, attached to the radiometer, was carried inside the helicopter and used to record measurements. The data were collected 45 metres above ground level. Measurements were taken on ground cells approximately .12 hectares in size.



FIG. 1. Location of Pigeon River study site.

A statified random sampling procedure was used to locate sample points. Several large homogeneous wetland types had been located within the wildlife area from ground visits on previous dates. Within each of these areas, or sample plots, a number of random points were identified on topographic maps for field spectral measurements.

The radiometric measurements were calibrated to a reflectance standard so that readings could be expressed in terms of percent reflectance. Sample point reflectances were calculated as follows:

$$R_{t,i} = \frac{V_{t,i} - d_i}{V_{s,i} - d_i} \times R_{s,i}$$

where

- $R_{t,i}$  = reflectance factor of the sample point, t, for band i;
- $V_{t,i}$  = the response of the radiometer for the sample point, *t*, for band *i*;
- $V_{s,i}$  = the response of the radiometer for the standard, *s*, for band *i*;
- $d_i$  = the dark level response of the radiometer for band *i*; and
- $R_{s,i}$  = reflectance factor of the standard, s, for band *i*.

TABLE 1. DESCRIPTION OF THE SIX MAJOR WETLAND TYPES FOUND IN THE PIGEON RIVER STUDY AREA

Wetland Type	Description					
Shallow March	<ul> <li>—Soil waterlogged for much of growing season.</li> <li>—Inundated in spring with as much as 6" water.</li> <li>—Vegetation consists of rooted herbaceous hydrophytes (grasses, sedges, smartweed).</li> </ul>					
Deep Marsh	<ul> <li>—Soil covered with 1½-3' water (permanently flooded).</li> <li>—Vegetation consists of submersed plants, floating-leaved plants, herbaceous species (spatterdock, white water lily, cattail, bulrushes).</li> </ul>					
Open Water	<ul> <li>Water of variable depth.</li> <li>Wegetation consists of submersed species only (vascular plants).</li> </ul>					
Shrub Swamp	<ul> <li>Dominated by woody vegetation less than 6 m height.</li> <li>Soil waterlogged or inundated.</li> </ul>					
Wooded Swamp Tamarack Bog	<ul> <li>—Seasonally inundated with water (flooded plains).</li> <li>—Dominant vegetation 6 m in height and greater (aspen, swamp white oak, silver maple).</li> <li>—Saturated with water.</li> <li>—Vegetation consists of needle leaf deciduous (Tamarack).</li> </ul>					

224



F1G. 2. Spectral reflectance values of homogeneous wetland types. Response values in each band are connected for ease of interpretation. Lines do not represent actual reflectance.

The mean spectral reflectance of each wetland class is plotted against individual wavelength bands in Figure 2. The spectral response curve for deep marsh represents 100 percent vegetation. Figure 3 shows the spectral response of deep marshes having different percentages of water and



FIG. 3. Spectral reflectance values of water and vegetation mixed classes. Response values in each band are connected for ease of interpretation. Lines do not represent actual reflectance.

vegetation mix. Field spectral measurements of the six homogeneous wetland classes illustrate typical vegetation and water responses (Gates *et al.*, 1965; Hoffer, 1978; Tucker, 1979). The chlorophyll absorption of red light causes classes containing vegetation to exhibit a slight decrease in the percent reflectance within Band 5 ( $0.6 \,\mu\text{m}$ - $0.7 \mu\text{m}$ ). These same classes show a marked rise in the percent infrared reflectance, Band 6 and 7 ( $0.7 \,\mu\text{m}$ - $1.1 \,\mu\text{m}$ ), which is typical of healthy green vegetation. The range of near infrared reflectance values for the wetland types is much greater than that of visible reflectance values.

Discriminant analysis was used to determine if the wetland types had distinct spectral responses which would facilitate their identification from remotely sensed data. Percent reflectance in each wavelength band for every wetland type was input to the Statistical Package for Social Sciences (Nie *et al.*, 1975) program DISCRIMINANT to generate a set of discriminant functions which would describe a wetland class in terms of the class spectral reflectance.

The interrelationship among homogeneous wetland classes can be observed by plotting the mean discriminant score of the first two discriminant functions for each homogeneous wetland type (Figure 4). Hardwood swamp, shrub swamp, and shallow marsh have nearly identical group means, indicating that their spectral response may not be sufficient to separate these cover types. In contrast, deep marsh, open water, and tamarack bog function values are not similar to any other class, indicating distinct spectral responses.

The interrelationship among homogeneous and mixed classes can also be observed by plotting the mean discriminant score of the first two discriminant functions for each class (Figure 5). The same relationship is seen among the homogeneous wetland types. However, the addition of mixed classes result in similar group means for mixture class 2 (30 to 60 percent vegetation) and tamarack, and mixture class 1 (30 percent vegetation) and open water. The comparable group means are indicative of similar spectral responses.

The discriminant analysis indicated that some



FIG. 4. Plot of discriminant function group means for homogeneous wetland types.



Fig. 5. Plot of discriminant function group means for homogeneous wetland types and mixed classes.

wetland types have distinct spectral characteristics that might enable identification from reflectance data. However, when using Landsat data, wetlands must be classified in relation to other cover types and with larger spatial resolution. Therefore, a complete examination of the utility of remotely sensed data for mapping small wetlands must include an evaluation of a wetland classification generated from the Landsat multispectral scanner data.

#### LANDSAT CLASSIFICATION OF WETLAND TYPES

Computer compatible tapes of the 8 June 1979 Landsat pass over northern Indiana were geometrically corrected and precision registered so that a computer printout of the data could be directly overlain onto corresponding 71/2 minute USGS topographic quadrangles. A maximum likelihood classification of the Pigeon River Area was generated using the software package, LARSYS (Phillips, 1973). The classification showed that certain wetland types could be identified by their spectral characteristics; however, confusion occurred within the wetland types and between wetland and upland cover types. Six cover type classes were identified in the classification: agriculture, hardwoods, shallow marsh, deep marsh, open water, and shrub swamp.

Hardwoods were separable from other cover types in the Landsat classification. However, the spectral response of upland hardwoods and hardwood swamps were nearly identical. Hence, these classes could not be separated using the standard classification procedures. Tamarack and other conifers exhibited spectral responses on the Landsat data similar to deep marshes with greater than 50 percent vegetation. For this reason, conifers could not be spectrally separated.

Although major ground cover types were identified in the Landsat classification, the accuracy with which these classes were identified was not high in all cases. Table 2 gives the classification performance of each cover type based on a two percent ground sample of the area (1739 pixels). Classification performance for shallow marsh and shrub swamp is low (26.7 and 34.0 respectively). Classification performance for deep marsh and open water (62.7 and 87.8 respectively) is considerably higher. These results are comparable to what would have been expected based on the discriminant analysis of the wetland reflectance measurements.

#### SUMMARY AND CONCLUSIONS

This study has shown that discriminant analysis of reflectance measurements taken from helicopter altitudes offers a means by which to examine the spectral characteristics of ground cover types over relatively large areas. This information is also valuable for understanding the spectral interaction of different land covers and, consequently, Landsat classification results.

Examining the spectral characteristics of several wetland habitat types and evaluating a Landsat wetland classification in light of the discriminant analysis of the spectral response patterns, leads to several conclusions:

- Hardwood swamps, shallow marshes, and shrub swamps are spectrally similar to each other and numerous upland cover types. This results in extremely poor Landsat classification accuracies for these wetland types.
- The mixing of water and vegetation in deep marshes results in a spectral response pattern that is similar to conifers such as tamarack. This may result in errors of commission where conifers are classified as deep marshes.
- Open water has a unique spectral response which allows for good identification of this cover type on Landsat Mss data.
- Barring confusion with conifers, deep marsh classification accuracy is still relatively high.

TABLE 2. LARSYS MAXIMUM LIKELIHOOD CLASSIFICATION PERFORMANCE

COVER TYPE	Number Samples	Percent Correct	Agric.	Hard- woods	Shallow Marsh	Deep Marsh	Open Water	Shrub Swamp
Agriculture	951	81.7	777	40	33	20	11	70
Hardwood	380	70.5	30	268	29	16	0	37
Shallow Marsh	165	26.7	41	50	44	8	2	20
Deep Marsh	75	62.7	21	3	1	47	1	2
Open Water	74	87.8	6	0	0	3	65	0
Shrub Swamp	94	34.0	11	37	8	6	0	32

Overall classification performance 70.9%.

#### References

- Butera, M. K., 1979. Computer implemented remote sensing techniques for the measurement of coastal productivity and nutrient transport systems. In Satellite Hydrology, Proceedings of the Fifth Annual William T. Pecora Symposium, June 1979. (In press)
- Carter, V., D. M. K. Garret, L. Shima, and P. Gammon, 1979. The Great Dismal Swamp: Management of a hydrologic resource with the aid of remote sensing. *Water Resources Bulletin*, 13(1) pp. 1-12.
- Cowardin, L. M., V. Carter, C. Golet, and T. LaRoe, 1979. Classification of wetlands and deepwater habitats of the United States. Office of Biological Sciences, Fish and Wildlife Service. U.S. Dept. of the Interior. FWS/OBS-79/31. 103p.
- Fleming, M. D., and R. M. Hoffer, 1977. Computeraided analysis techniques for an operational system to map forest lands utilizing Landsat MSS data. LARS Information Note 11227. Purdue University. 236 p.
- Gammon, P. T., and V. P. Carter, 1976. Comparison of vegetation classes in the Great Dismal Swamp using two individual Landsat images and a temporal composite. Proceedings of Purdue Symposium on Machine Processing of Remotely Sensed Data. p. 3B-1.
- Gates, D. M., H. J. Keegan, J. D. Schletes, and V. R. Weidner, 1965. Spectral property of plants. *Applied Optics* 4(1) pp. 11-12.
- Gilmer, S., E. A. Work, Jr., J. E. Colwell, and D. L. Rebel, 1980. Enumeration of prairie wetlands with

Landsat and aircraft data. *Photogrammetric Engineering and Remote Sensing*. 46(5) pp. 631-634.

- Hoffer, R. M., 1978. Biological and physical considerations in applying computer-aided analysis to remote sensing data. In *Remote Sensing: The quantitative approach*. (P. Swain and S. Davis, Eds.) McGraw Hill, New York. pp. 227-289.
- Jones, N. C., and F. Shahrokhi, 1977. Application of Landsat data to wetland study and land use classification in west Tennessee. Proceedings of Thirteenth Symposium on Remote Sensing of the Enrionment, University of Michigan, Ann Arbor, Michigan, pp. 68-69.
- Nie, N. H., C. H. Hull, J. G. Henkins, K. Stenbrenner, and D. H. Bent, 1975. Statistical package for the social sciences. McGraw-Hill, New York. 676 p.
- Phillips, T. L. (ed.), 1973. LARSYS Version 3 User's Manual. Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, IN.
- Swain, P. H., and R. C. King, 1973. Two effective feature selection criteria for multispectral remote sensing. LARS Information Note 042673. 5 pp. (Purdue University, West Lafayette, Indiana).
- Tucker, C. J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote* Sensing of Environment 8(2) pp. 127-150.
- Work, E. A., and D. S. Gilmer, 1975. Monitoring wetland conditions in the northern prairies using satellite data. Skylab Workshop. Purdue University. 15 p.

(Received 3 May 1980; revised and accepted 7 September 1980)

## New Sustaining Member

### Top Flight, Inc.

#### 1001 Enterprise Ave., Bay 22, Oklahoma City, OK 73128; (405) 524-1221

T HE PAST and present accomplishments of Top Flight have established its reputation as the foremost supplier of new and used equipment to all spheres of the photogrammetric profession. Accoutered with an extensive background in photogrammetry, Top Flight offers the technical knowledge and consultation prerequisite to any equipment aquisition. Emphasis is on tailoring systems to suit a company's immediate needs with the flexibility for future growth.

Refurbished, warranteed equipment only touches the surface of the Top Flight inventory. Demand is continually adding to the line of Top Flight engineered and manufactured equipment. As the newest addition, Top Flight has recently introduced the Top Flight T-12. This eight-fiducial camera with a distortion free Planigon lens has been converted to meet the most recent USDA specifications. It's a very capable camera with a very reasonable price tag.

The capabilities and quality of the Top Flight facilities enable each project to normally be entirely supervised in house for the ultimate in precision and quality control. The 11,000 square feet in house area allocates space for shop, machining, engineering, and camera calibration, as well as the ever essential warehouse. Additionally available from Top Flight are approved camera port conversions on any suitable aircraft, including Cessna and Aero Commander twin engine aircraft.

In the future Top Flight will continue to serve the photogrammetric community with the same integrity and value on which it was founded. For more information contact Ron Warner at (405) 524-1221 or write Top Flight, Inc., 1001 Enterprise Ave., Bay 22, Oklahoma City, OK 73128.