Technical Report 2528-5-T

APPLICATIONS OF MULTISPECTRAL REMOTE SENSING TECHNIQUES TO HYDROBIOLOGICAL INVESTIGATIONS IN EVERGLADES NATIONAL PARK

A. L. HIGER
N. S. THOMSON
F. J. THOMSON
M. C. KOLIPINSKI

January 1970

INFRARED AND OPTICS LABORATORY
Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

U.S. GEOLOGICAL SURVEY • WATER RESOURCES DIVISION
WASHINGTON, D.C.

A JOINT REPORT OF
THE UNIVERSITY OF MICHIGAN
AND
U.S. DEPARTMENT OF THE INTERIOR

Contract WRD-4012-632-69

NOTICES

Sponsorship. The work reported herein was conducted by the Willow Run Laboratories of the Institute of Science and Technology and prepared jointly with members of the U. S. Geological Survey of the Department of the Interior under Contract No. WRD-4012-632-69. Contracts and grants to The University of Michigan for the support of sponsored research are administered through the Office of the Vice-President for Research.

This report has been published in the "Proceedings of the Sixth International Symposium on Remote Sensing of Environment, Volume I, Oct. 13–16, 1969, p. 79–95" by the Infrared Optics Laboratory, University of Michigan, Ann Arbor, Michigan.

2528-5-T

APPLICATIONS OF MULTISPECTRAL REMOTE SENSING TECHNIQUES TO HYDROBIOLOGICAL INVESTIGATIONS IN EVERGLADES NATIONAL PARK

Aaron L. Higer, Hydrologist
Fred J. Thomson, Electrical Engineer
Norma S. Thomson, Research Ecologist
Milton C. Kolipinski, Aquatic Biologist

U. S. Geological Survey
Tallahassee, Florida

Willow Run Laboratories
Institute of Science and Technology
The University of Michigan
Ann Arbor, Michigan

January 1970

ACKNOWLEDGMENTS

The authors express their appreciation to the National Aeronautics and Space Administration for funding both the data collection and processing efforts. The authors also acknowledge the cooperation of the National Park Service in allowing part of the Everglades National Park to be used for this experiment.

Appreciation is expressed to members of The University of Michigan's Infrared and Optics Laboratory, especially Robert Marshall and Philip Hasell, for their comments and corrective criticism of all phases of this effort. Special thanks are given to James H. Hartwell, hydrologist, of the U. S. Geological Survey, Water Resources Division, Miami, Florida, for his interpretive expertise in the Everglades project, and to E. R. Hampton and other colleagues in the Florida District who read the manuscript and offered valuable suggestions for its improvement. Appreciation is also expressed to Mr. Daniel Lirones of Film Central, Incorporated, who prepared the color-composite recognition map.

FOREWORD

This report is a product of a cooperative effort between the U. S. Geological Survey of the Department of Interior and the Willow Run Laboratories of the Institute of Science and Technology of The University of Michigan. Investigations are designed to determine the feasibility of using multispectral techniques to solve problems related to the water resources of the nation. These studies are part of the EROS program (Earth Resources Observation Satellites), aimed at gathering facts about the natural resources of the earth from earth-orbiting satellites that will carry sophisticated remote-observation instruments. Project EROS is being carried out by the U. S. Geological Survey with NASA, universities, and other institutions.

Multispectral imagery and video data are collected over scenes of interest from an airborne platform. Multiband images are analyzed and interpreted using conventional photographic interpretation techniques, and the spectral characteristics of targets and background objects are analyzed to determine how to electronically process spectral information from a scene (using both analog and digital techniques) for improved remote sensing. The program is designed to develop methods of improving and extending current aerial survey capabilities; improvements are sought in the kinds and quantity of data obtainable and in the quality and economy of imagery interpretation. The electronic processing of the spectral information portion of the program was initiated and is being guided by Marvin R. Holter, Head of the Infrared and Optics Laboratory of Willow Run Laboratories.

The multispectral aspects of the report were prepared under a U. S. Geological Survey contract, "Investigations of Multispectral Discrimination of the Earth Surface Features." The principal investigator for the multispectral discrimination research was J. E. King, head of the analysis group of the Infrared and Optics Laboratory. The field determinations and environmental interpretation aspects of the report were prepared by the Water Resources Division of the Geological Survey under the general direction of C. S. Conover, Chief, Florida District, and T. J. Buchanan, Chief, Miami office, as part of the remote sensing research program directed by C. J. Robinove, Chief, Office of Remote Sensing, Washington, D. C.

Aaron L. Higer, Hydrologist, U. S. Geological Survey, Miami, Florida served as principal investigator for this project. He coordinated ground-truth, data input, and data-processing activities for the project team. Fred J. Thomson, Electrical Engineer, University of Michigan, operated the analog computer program, Norma S. Thomson, Research Ecologist, University of Michigan, and Milton C. Kolipinski, Aquatic Biologist, U. S. Geological Survey, Miami, Florida, analyzed and interpreted the hydrobiological data.

RELATED REPORTS

AN INVESTIGATIVE STUDY OF A SPECTRUM-MATCHING IMAGING SYSTEM, D. S. Lowe, J. Braithwaite and V. L. Larrowe, Final Report, Report No. 8201-1-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Contract NAS 8-21000, October 1966.

A SPECTRUM-MATCHING TECHNIQUE FOR ENHANCING IMAGE CONTRAST, D. S. Lowe and J. Braithwaite, Applied Optics, Vol. 5, p. 893, June 1966.

APPLICATIONS OF AERIAL PHOTOGRAPHY AND REMOTE SENSING TO HYDROBIOLOGIC RESEARCH IN SOUTH FLORIDA, M. C. Kolipinski and A. L. Higer, Workshop, Infrared Color Photography in Plant Sciences, edited by G. Norman, Florida Department of Agriculture, Winter Haven, Florida, May 1967.

INVESTIGATIONS OF SPECTRUM-MATCHING SENSING IN AGRICULTURE (U), F. Polcyn and W. A. Malila, Report No. 6590-7-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Grant No. NsG 715, September 1967 (Volume I: UNCLASSIFIED, Volume II: CONFIDENTIAL).

A SIMPLE SPECTRAL DISCRIMINATION TECHNIQUE FOR TARGET RECOGNITION (U), F. J. Thomson, Report No. 6400-118-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, September 1967, AD 384 011 (CONFIDENTIAL).

MULTISPECTRAL DISCRIMINATION OF SMALL TARGETS (U), F. J. Thomson, Report No. 6400-135-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Contract DA-28-043-AMC-00013(E) (CONFIDENTIAL).

SPECTRAL DISCRIMINATION, VOLUME I: METHODS AND RESULTS OF COMPUTING SPECTRAL RADIANCE STATISTICS FOR REMOTE SENSING IN THE 0.4 TO 1.2 MICRON REGION (U), I. W. Ginsberg and J. L. Beard, Report No. 7850-18-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Contract AF 33(615)-3654, July 1967 (CONFIDENTIAL).

SPECTRAL DISCRIMINATION, VOLUME II: ANALYSIS OF SPECTRAL DISCRIMINATION SYSTEMS (U), R. R. Legault, R. E. Hamilton and J. Penquite, Report No. 8492-9-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Contract F33615-67-C-1293, August 1967 (CONFIDENTIAL).

STATISTICAL SPECTRAL ANALYZER AND TARGET RECOGNITION COMPUTER (SPARC) (U), F. J. Kriegler and M. M. Spencer, Final Report, Report No. 8640-17-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Contract F33615-67-C-1384, September 1968 (CONFIDENTIAL).

SPARC, A SPECIAL COMPUTER FOR TARGET RECOGNITION IN REAL TIME BY STATISTICAL SPECTRAL ANALYSIS OF MULTI-CHANNEL SCANNER DATA, F. J. Kriegler and M. M. Spencer, presented at the 16th National Infrared Information Symposium (IRIS), Ft. Monmouth, New Jersey, May 7-9, 1968.

INVESTIGATION OF SPECTRUM-MATCHING TECHNIQUES FOR REMOTE SENSING IN AGRICULTURE: VOLUME I, P. G. Hasell et al., Report No. 8725-13-P, Section 5, Infrared and Optical Sensor Laboratory, Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor, July 1968.

REMOTE SENSING APPLICATIONS TO HYDROBIOLOGY IN SOUTH FLORIDA, M. C. Kolipinski and A. L. Higer, National Aeronautics and Space Administration Symposium on water resources investigations, Houston, Texas, September 1968.

PHOTO-INTERPRETATION FROM COLOR, WATER RESOURCES: W. J. Schneider and M. C. Kolipinski, Manual of Color Aerial Photography, American Society of Photogrammetry, Falls Church, Virginia, 1968.

ABSTRACT

Multispectral data collection and processing techniques were used to map tree islands, emergent aquatic grassland vegetation, surface water of two different depths, and exposed limestone in a portion of the Everglades National Park in south Florida. Before multiband scanners, photographic techniques were the only practical way to inventory hydrobiological features in the park. Mapping with multiband-scanner data was tried here for the first time on a strip of park land 8 miles long and 2000 ft wide, in September 1967. The recognition maps were produced by electronically processing selected combinations of video signals in the narrow spectral bands between 0.4 and 1.0 μm. The computer recognition maps were printed in different colors and superposed to provide a color-composite recognition map of the area. Periodic data collection and processing in this form would yield quantitative data concerning the direction and extent of plant successional changes in the park. This in turn would provide more accurate information for water management practices in the park.

CONTENTS

Acknowledgments ii
Foreword iii
List of Related Reports v
Abstract vii
List of Figures x
List of Tables x

1. Introduction 1
   1.1. Research Objectives 1
   1.2. The Everglades Situation 2

2. Multispectral Data Collection and Processing 4
   2.1. Multispectral Data Collection 6
      2.1.1. General Discussion 6
      2.1.2. Data Collection for the Everglades Experiment 9
   2.2. Multispectral Data Processing 9
      2.2.1. General Discussion 9
      2.2.2. Theoretical Discussion of Automatic Processing 10
      2.2.3. Processing of the Everglades Data 13

3. Analysis of the Everglades Data 15
   3.1. Introduction 15
   3.2. Discussion of the Recognition Results 19
      3.2.1. Deep Water (Map Unit 1) 19
      3.2.2. Shallow Water (Map Unit 2) 20
      3.2.3. Tree Islands (Map Unit 7) 20
      3.2.4. Medium Dense to Dense Sawgrass Grassland (Map Unit 6) 22
      3.2.5. Sparse to Medium Dense Sawgrass Grassland (Map Unit 5) 22
      3.2.6. Sparse to Medium Sparse Spikerush Grassland (Map Unit 4) 23
      3.2.7. Very Sparse Spikerush Grassland (Map Unit 3) 23

4. Recommendations 23
References 25

FIGURES

1. The 50%-Sensitivity Points of Various Film-Filter Combinations and of the 12-Channel Spectrometer 2
2. Location Map of Everglades National Park 3
3. Typical Vegetation Types in the Shark River Slough 5
4. Multispectral Scanner Operation 7
5. 12-Channel Spectrometer 8
6. Block Diagram of Multispectral Data Processing Operations 11
7. Color-Composite Recognition Map of Hydrobiological Features in a Portion of the Shark Valley Slough in the Everglades National Park 16, 17

TABLES

I. Classification of Landscape Site Units 18
II. Areas Not Recognized Correctly 21

APPLICATIONS OF MULTISPECTRAL REMOTE SENSING TECHNIQUES TO HYDROBIOLOGICAL INVESTIGATIONS IN EVERGLADES NATIONAL PARK

1 INTRODUCTION

1.1. RESEARCH OBJECTIVES

For the first time, the advanced techniques of remote sensing and data processing (using a multispectral scanning system) have been applied to mapping aquatic vegetation and determining areal extent and general ranges of depth of water for a natural area. Similar techniques have been applied to the mapping of crop species by groups supported by the U. S. Department of Agriculture, and have resulted in successful identification of many of the common food plants in the Midwest [1, 2].

The broad objective of the cooperative research effort between the U. S. Geological Survey's (USGS) Miami office and the Willow Run Laboratories (WRL) of the Institute of Science and Technology of The University of Michigan has been to determine the capability of multispectral data collection and processing systems to provide means for classifying and mapping landscape site units in the Everglades National Park in south Florida. The purpose of the research reported herein was to determine the feasibility of classifying and mapping vegetation, substrata, and water as indicators of surface-water supply conditions. Rapid, wide-area, water supply inventory techniques are needed in the Everglades National Park for two major reasons: (1) to better assess the effects of seasonal and annual fluctuations in surface water levels on the stability of the glades' ecosystem; and (2) to predict the consequences of water management practices on the biological populations within the park. The success of this study indicates that the multispectral scanning techniques employed in the Everglades may be profitably used in other hydrological situations.

Remote sensing with a multispectral scanning system has certain advantages over conventional aerial photography previously used for inventories of water resources. Instead of a multilens camera, it employs an optical-mechanical scanner. The spectral range of the scanner system extends from 0.35 to 14.0 μm. Of the 18 spectral bands spanning this range, four groups are in spatial and temporal registry. These groups consist of 12 bands in the range from 0.4 to 1.0 μm, four bands from 1.0 to 5.5 μm, and one each in the ranges from 0.35 to 0.38 μm and 8.0 to 14.0 μm. Instead of the variety of films and filters necessary in photography to cover most of the spectrum of radiation from ultraviolet to infrared, the spectrometer and array of detectors in a multispectral scanning system cover a wider range of wavelengths in narrower bands without gaps in spectral coverage in the interval from 0.40 to 1.00 μm (see fig. 1). Instead of unwieldy sets of photographs in several regions of the spectrum, which are difficult to interpret, the multispectral scanning system simultaneously records the full range of radiation signals in the range from 0.40 to 1.00 μm on magnetic tape in a form which can be interpreted automatically by a specially designed computer.

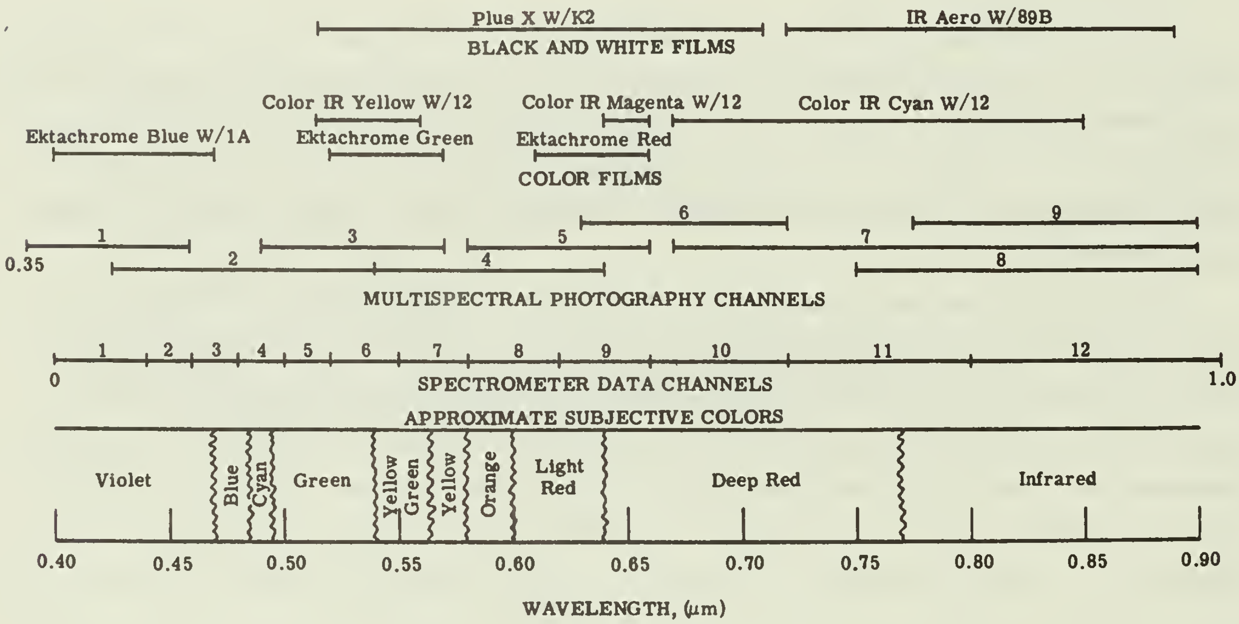


FIGURE 1. THE 50%-SENSITIVITY POINTS OF VARIOUS FILM-FILTER COMBINATIONS AND OF THE 12-CHANNEL SPECTROMETER

1.2. THE EVERGLADES SITUATION

The Everglades National Park in southern Florida (fig. 2) encompasses a relatively flat fresh-water marsh with tree islands that often shelter alligator holes. The alligator holes, important to the ecological balance of the glades, are ponds excavated and inhabited by alligators. As water levels decline in the dry season, each alligator hole serves as a vital "last-ditch" water refuge for the fish and other animals in the adjacent open glades. Toward the coast, the fresh-water marshes merge into brackish-water marshes. These marshes, in turn, merge into dense mangrove forests along the shoreline.

For centuries, alternate dry and wet seasons have created and maintained the ecological balance in the Everglades. However, water developments north of the park since the turn of the century have altered the natural surface flow of water. Water still enters the park, but part of

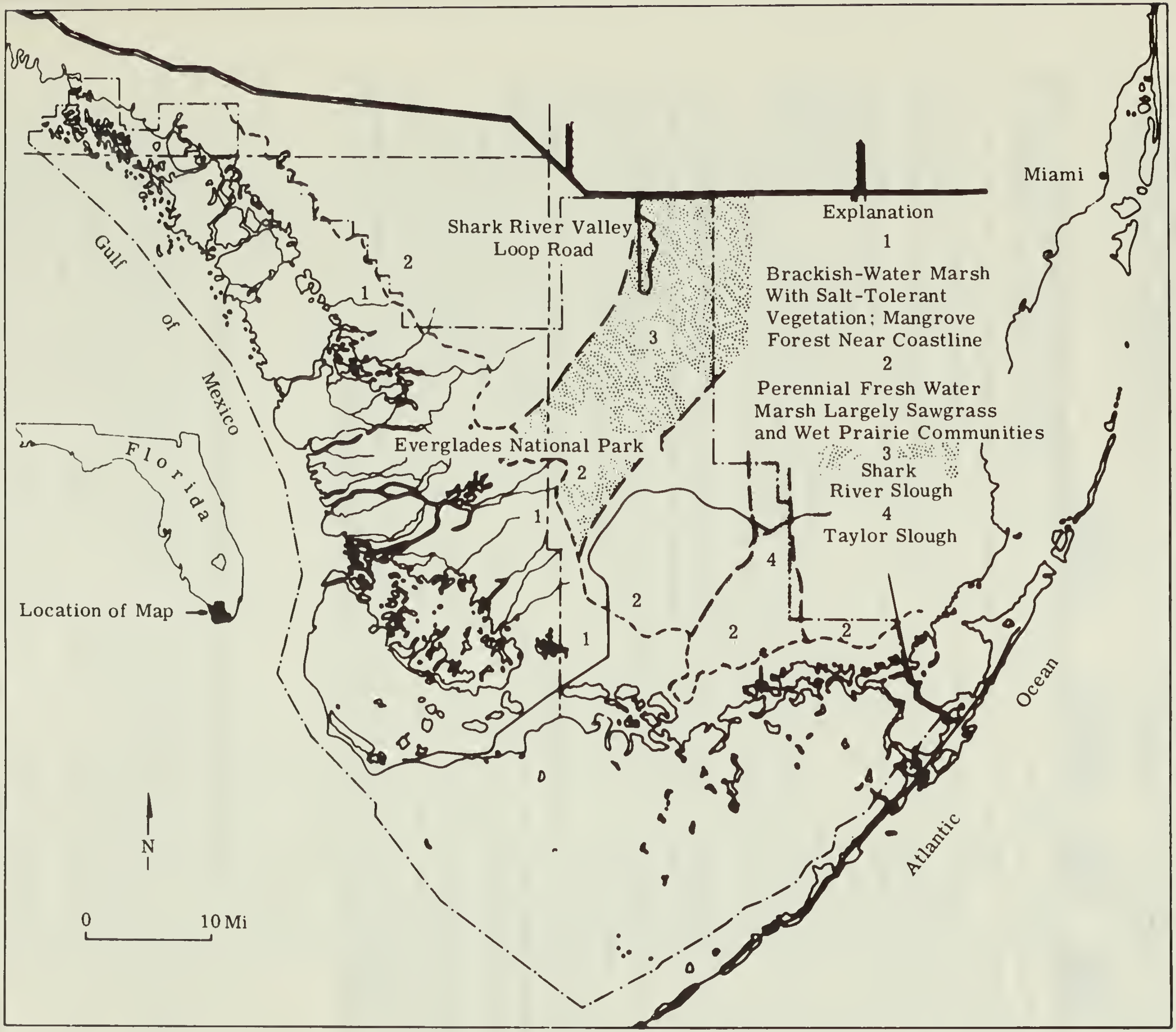


FIGURE 2. LOCATION MAP OF EVERGLADES NATIONAL PARK. Map indicates the location of Shark River Slough, Taylor Slough, and the approximate position of the interface between fresh water and brackish water along the coast.

the water that formerly flowed naturally southward is now impounded in large diked areas and directed by canals to the southeast Florida coast to sustain the aquifer system, and to inland agricultural areas.

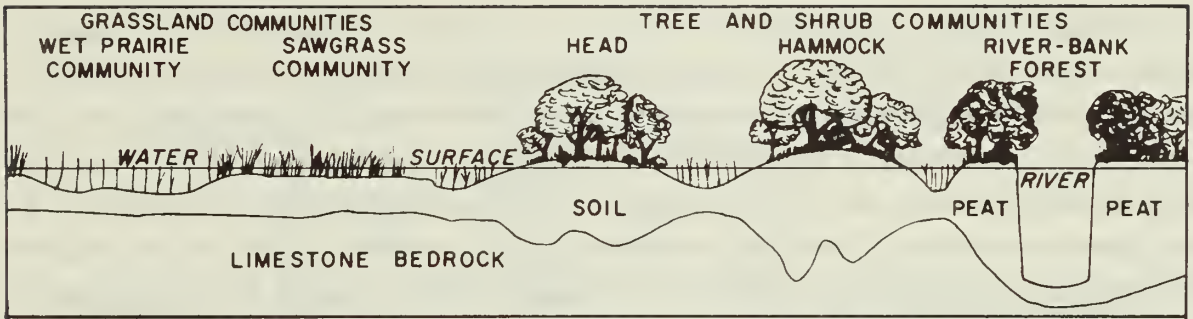
The Geological Survey, in cooperation with the National Park Service, has been investigating the water supply in and adjacent to the park since 1959. In 1964 the program was expanded to include ecological studies, in order to obtain additional facts on water needs of the plant and animal life. Knowledge of water needs is essential to the management and preservation of the park in perpetuity as a biological sanctuary. One objective of this program is to determine what vegetation changes may occur or have occurred within the Shark River Slough (fig. 2), a shallow, slowly flowing river whose average width is 6 miles. The area of this slough within the park is about 125,000 acres. Selected parts of the slough have been studied in terms of the major vegetation types present, the general patterns of their distribution, and the broad characteristics of the habitats occupied by the vegetation types. The major plant communities which have been identified (fig. 3) are: (1) tree-island communities, i.e., heads and hammocks; (2) sawgrass communities; and (3) wet-prairie communities. Each vegetation type (characterized by a particular species composition) occurs in a habitat relatively uniform in substratum composition, elevation above mean sea level, period of inundation, and fire history.

Previously, conventional photographic interpretation techniques have been used to delineate the boundaries of the three major plant communities, using panchromatic, color, color infrared, and multispectral photographs (fig. 1). In September, 1967, in cooperation with the National Aeronautics and Space Administration, data were collected with The University of Michigan's multispectral scanner along the Shark River Valley Loop Road, a well-defined area of the Shark River Slough (fig. 2). Descriptions of the collection and processing of these data, a discussion of the results, and recommendations for future investigations follow.

2
MULTISPECTRAL DATA COLLECTION AND PROCESSING

Every object on the ground reflects solar radiation and emits long-wavelength infrared radiation in a particular pattern called a spectral signature. The spectral signature is characteristic and may be used to identify a particular object. In the visible region of the spectrum, the spectral signature may be thought of as the color of the object. To identify objects or collections of small objects too small to be resolved by the scanner, data about the spectral signatures of these objects are collected. The data are then processed to determine when a particular spectral signature, representing an object of interest, is present.

Spectral-signature data are collected with the multispectral scanning system. The scanning system samples the spectral signatures of objects being spatially scanned, converts the samples



Common plants	Common plants	Common plants	Common plants	Common plants
Algal mat Spikerush Bladderwort Arrowhead Beak-rush	Sawgrass Arrowhead Spikerush Bladderwort Beak-rush	Willow Cocoplum Redbay Wax myrtle Dahoon holly Cypress	Strangler fig Oak Mahogany Gumbo limbo Wild tamarind Poisonwood	Red mangrove Buttonwood Pond-apple Willow Cocoplum
Characteristics	Characteristics	Characteristics	Characteristics	Characteristics
Sparsely vegetated, with periphyton covering the marly bottom. The marl over the limestone is generally only one foot thick.	Medium to dense vegetation. Peaty soils generally one to three feet thick cover the limestone. Slightly higher ground elevation than the surrounding wet prairie communities.	Islands of trees and shrubs where the ground is a few inches higher than it is in the surrounding marshes.	Islands containing hardwood forests of a variety of broad-leaved trees. Land elevation higher than it is in heads.	Woody growth along the banks of rivers. Colonized by trees and shrubs that tolerate the seasonally brackish conditions.

FIGURE 3. TYPICAL VEGETATION TYPES IN THE SHARK RIVER SLOUGH. Annotated diagram of the major plant communities in Shark River Slough. Note relation of communities to the position of the water surface and thickness of the soil.

into electrical signals, and records the signals on magnetic tape. The spectral sampling is accomplished through the use of various optical filters or by a combination of a spectrometer and a fiber-optic bundle and must be fine enough to preserve the distinctions between spectral signatures of different objects. After the radiation has been sampled by the filters or spectrometer, it is converted to electrical signals by detectors. The detector signals are amplified and recorded on magnetic tape for ease of storage and for compatibility with data processing devices described below.

The tape-recorded data are processed in the laboratory by special purpose analog, digital, or hybrid computers to determine when a particular spectral signature selected by the operator is present in the data. Before the advent of computer-implemented processing, human interpreters decided when a particular spectral signature was present in the data. This was very inefficient because the amount of information that had to be recorded to adequately define a spectral signature was too much to handle. In computer-implemented processing, an operator selects a section of multispectral data known to contain the object of interest. The identification and location of the object are obtained from ground-truth information. The computer stores the sampled spectral signature (training set) of this area, and is programmed to recognize all areas with a similar spectral signature in other data presented to it for processing. From the data supplied by the computer, a recognition map, which is a filmstrip or paper image of all areas having the same spectral signature as the training set, is generated.

Automatic data processing does not replace human interpretation; the investigator interacts with the computer by deciding which spectral signatures he wants it to recognize. He presents these data to the computer in the form of a training set, and the computer responds by reducing the data on any tape to a recognition map, which is more suited to human interpretation.

2.1. MULTISPECTRAL DATA COLLECTION

2.1.1. GENERAL DISCUSSION

The multispectral data collector consists of an optical-mechanical scanner mounted in an aircraft. As the aircraft flies over the terrain to be mapped, a rotating mirror scans the field of view of a parabolic-mirror telescope across the ground perpendicular to the direction of flight. This action, in conjunction with the aircraft motion, covers a strip of terrain centered under the aircraft with a continuous scan (see photo in fig. 4). Two telescopes and one double-sided (the two sides are rotated 90^{o} with respect to each other) rotating mirror comprise the scanner used by WRL. Two scanners are employed in the C-47 aircraft operated by WRL. Filtered detectors convert the radiation from the ground into electrical signals, which are amplified and recorded on magnetic tape along with synchronizing signals necessary to reconstruct the images.

In the WRL scanner system, multiple filtered arrays of detectors, filtered single detectors, and a spectrometer-detector combination are used to cover the visible and infrared spectra from 0.4 to 14 μm in as many as 18 different spectral bands. In the visible and near-IR region (0.4-1.0 μm), the entrance slit of a prism spectrometer is placed at the telescope focus (see diagram in fig. 4). Photomultiplier detectors, coupled to the exit plane of the spectrometer by fiber optics, convert radiation from the scene (in narrow spectral regions defined by the prism dispersion and fiber-optic bundle width) into electrical signals (fig. 5). The spectral regions of the spectrometer operation are shown in the lower part of figure 1; these may be compared with the spectral sensitivity of black and white, color, and multispectral photography which appear in the upper part of figure 1.

In order to get the spectral signature by which the processor recognizes distinctive objects on the ground, the scanner must collect simultaneous spectral information. As the scanner looks

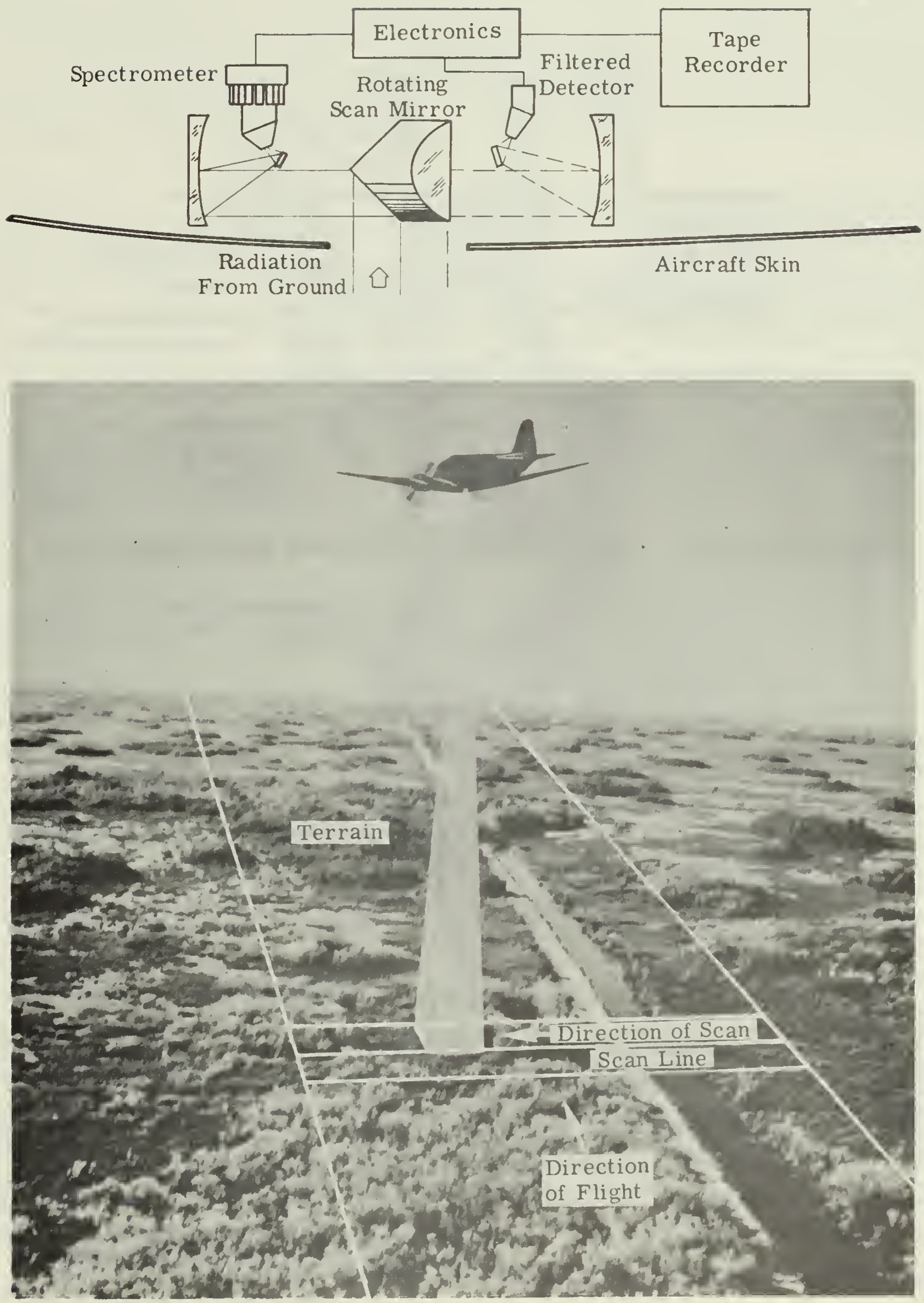


FIGURE 4. MULTISPECTRAL SCANNER OPERATION

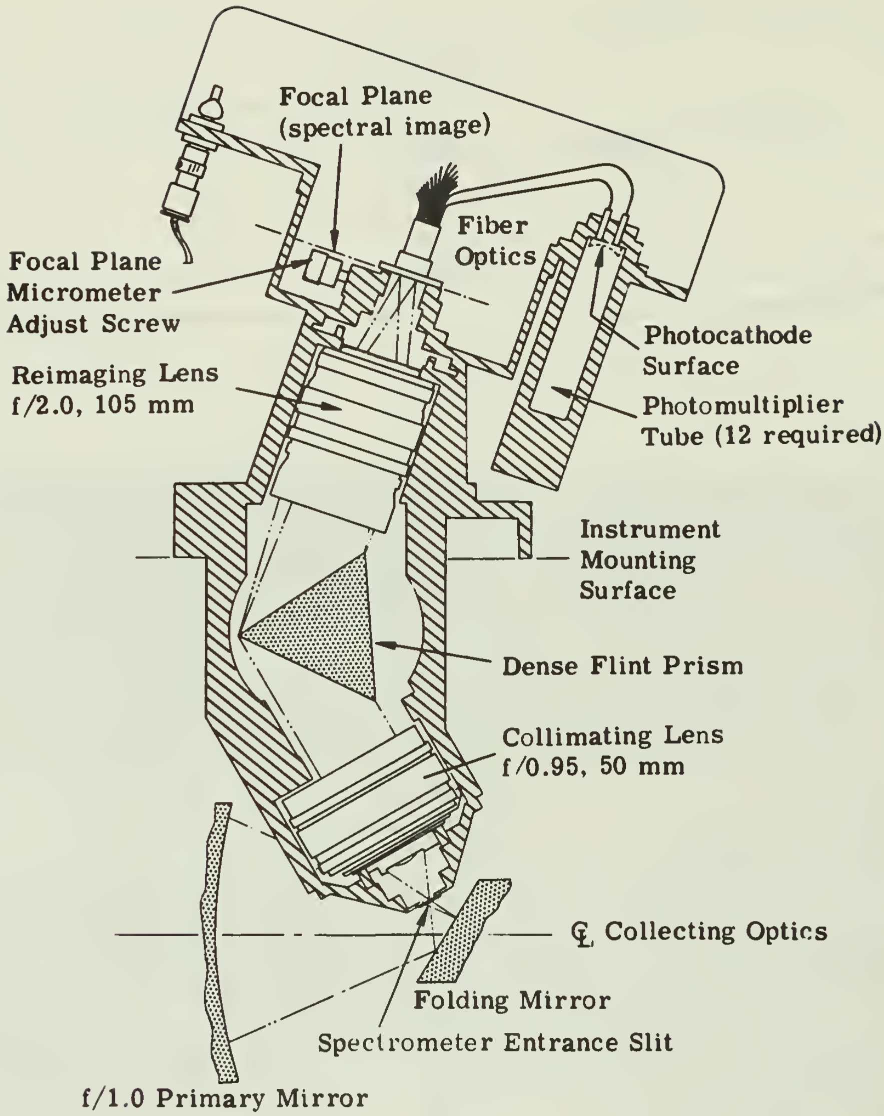


FIGURE 5. 12-CHANNEL SPECTROMETER

at each ground point, any spectral information about the point must be obtained instantaneously. The spectrometer-detector combination does this with 12 different photomultipliers which continuously convert radiation in narrow spectral bands into electrical signals. The spectral signature of a ground point, which is the spectral radiance of the point seen by the scanner, may be constructed by sampling the 12 photomultiplier voltages at the instant of time that the scanner views the point. Signals from the other detectors in the system are not synchronized with the spectrometer data and cannot be processed with current technology.

A final remark on scanners concerns spatial resolution. The spatial resolution of the scanner is poorer than photographs on film for two reasons. Because the detector size is many times larger than the grain size of film, scanner spatial resolution in those wavelength bands covered by the filtered detectors is poorer than with photographic film. Similarly, because the entrance slit of the spectrometer must be large enough to pass a detectable amount of energy into the spectrometer, scanner spatial resolution for radiation in those wavelength bands covered by the spectrometer is also poorer than with photographic film.

The spatial resolution of the WRL scanners is 3 mrad. Although the scanners have poorer spatial resolution than photographic film, the statistical accuracy of recognition maps made by computer is superior to manually interpreted photographs, because the computer defines boundaries between objects on a quantitative and unbiased basis, whereas human interpreters do not.

2.1.2. DATA COLLECTION FOR THE EVERGLADES EXPERIMENT

Flights were made over the Shark Valley Loop Road (fig. 3) at approximately 0930 hours on 7 September 1967, at altitudes of 500, 2000, and 5000 ft. Data were collected in 10 of the 12 spectrometer bands as follows:

Spectrometer Band	Wavelength Sensitivity (μm)	Characteristic Color
1	0.40-0.44	UV—violet
3	0.46-0.48	Violet
5	0.50-0.52	Blue
6	0.52-0.55	Green
7	0.55-0.58	Green—yellow—orange
8	0.58-0.62	Orange
9	0.62-0.66	Bright red
10	0.66-0.77	Deep red
11	0.72-0.80	Deep red—infrared
12	0.80-1.0	Infrared

Supplementary data were collected as follows: a three-element array of indium-arsenide detectors operating in the 1.0- to 1.4-μm, 1.5- to 1.8-μm, and 2.0- to 2.6-μm regions. In addition data were collected by a three-element array of indium-antimonide detectors operating in 1.0- to 1.4-μm, 2.0- to 2.6-μm, and 4.5- to 5.5-μm bands, and by a filtered, mercury-doped, germanium detector operating in the 8- to 14-μm band. Photographic data collected included panchromatic, color, and color infrared photography.

2.2. MULTISPECTRAL DATA PROCESSING

2.2.1. GENERAL DISCUSSION

The processing of scanner data depends upon the automatic recognition of objects by their spectral signatures. A spectral signature consists of the spectral radiance of an object, which is a continuous function of wavelength. The airborne spectrometer samples parts of the spectral signatures, and detectors convert the spectral samples to electrical signals proportional to radiance. The entire process of data collection consists of sampling the spectral signatures of ground objects, converting the data into electrical form, and storing it on magnetic tape. The spectral signatures of objects on the ground may be represented as sets of 12 video voltages, one from each of 12 spectrometer-detector channels.

The processing procedure consists of three steps:

(1) Selection of a decision rule which states in mathematical terms the criteria to be used in determining the nature of the scanned objects.

(2) Training of the computer by presenting it with a sample of data from the object to be mapped—a training set. The parameters of the decision rule are adjusted to this training set to optimize the detection process.

(3) Presenting the computer with new data and asking it to recognize all objects similar to those in the training sets.

The data may be displayed in various forms, the simplest of which is a recognition map. This is a conventional black-and-clear filmstrip transparency. The black tones represent the objects recognized by the computer as having spectral characteristics similar to those of the training-set objects. The clear areas of the recognition picture represent the objects which are considered by the computer to have spectral characteristics which are not similar to those of the training-set objects.

The flow of processing operations is summarized by figure 6. Tape-recorded data from the aircraft are edited by the operator to define the training set. The computer has previously been programmed to implement a particular decision rule. Unknown data are processed by the computer. The computer output, an electrical signal, is printed on a cathode-ray-tube-camera filmstrip printer to yield a recognition map. A repetition of this process with different training sets yields printouts of different object classes. These printouts are called recognition maps. Each recognition map is color coded and combined photographically with the others, producing a composite map in which each object class recognized appears in a different color.

2.2.2. THEORETICAL DISCUSSION OF AUTOMATIC PROCESSING

Deciding whether a sample of data contains the same object class as a training set may be done automatically, using various decision rules. A simple yet effective decision rule is the weighted Euclidean distance rule. This rule has also been referred to as the miss-distance or spectrum-matching technique [2, 4].

A sample of spectrometer data known to contain a particular object is required for implementing the weighted Euclidean distance rule. This sample typically covers 1% to 2% of the

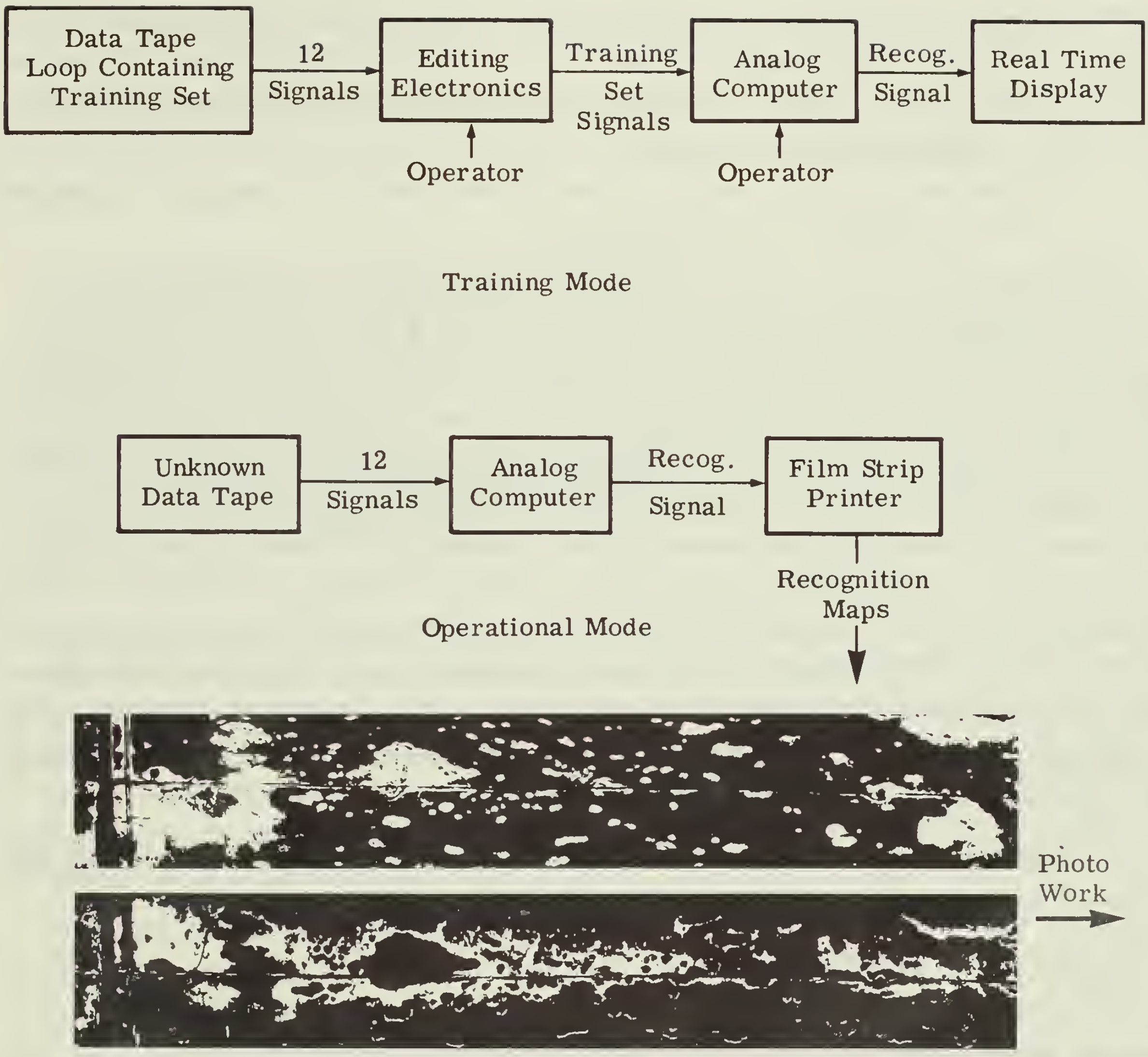


FIGURE 6. BLOCK DIAGRAM OF MULTISPECTRAL DATA-PROCESSING OPERATIONS

total data to be processed. From this sample, also called the training set, the mean value (V_n) and standard deviation (σ_n) of the electrical signal in each spectrometer channel are determined. These data comprise the spectral signature of the training set. To decide whether data outside the training set contain the same objects as the training set, spectrometer voltages in each channel are compared to those of the training set. This is done by a special purpose analog computer which computes a discriminating function L(t) defined by:

$$L(t) = \sum_{n=1}^{n=12} \left[\frac{V_n(t) - V_n}{\sigma_n} \right]^2$$

where $V_n(t)$ = video voltage in spectrometer channel n. This is a time-varying function, obtained from scanning the terrain.

$\bar{V}_n$ = mean value of voltage in spectrometer channel n for the area to be mapped. This is obtained from the training set.

σ_n = standard deviation of voltage in spectrometer channel n for the area to be mapped. This is obtained from the training set.

The equation shows that L(t) will be small when the scanner sees an area similar to the area to be recognized, because each $V_n(t)$ will be close to $\bar{V}_n$. The division by σ_n weighs the influence of spectral channels on L(t) in inverse proportion to the variance of the signal from the training set. This variation may arise from two sources. First, all training-set areas in natural environments have some variability in composition, on a scale too small to be resolved by the scanner. These variations in composition produce variations in the spectral signature. For example, variations in the percentage of cover of vegetation will produce changes in the spectral signature. Since individual plants usually cannot be resolved by the scanner, this variation appears as "noise." Second, the process of detection of radiation is noisy. This electrical noise is a source of variation added to the signals recorded on tape. Dividing by the standard deviation, σ_n, reduces the influence on L(t) of noisy channels or channels where variation in the training-set signature occur. Thus L(t) will be small when the area being scanned looks like the training-set area, and large when it does not.

A threshold detector can be used on L(t) to decide whether or not the area to be mapped is present. The threshold is represented mathematically as:

$L(t) \leq K \Rightarrow$ target object is present

$L(t) > K \Rightarrow$ target object is absent

where K = threshold level.

The selection of the threshold level, K, is crucial to processor performance. If K is made too large, areas which closely resemble the target area will be recognized. If K is made too small, not all occurrences of the target will be detected. In practice, the threshold is set to recognize 90% of the training set.

Trial runs are made through the data to verify that the choice of threshold level is adequate. Upon examination of results, the threshold may be modified to give better results.

Not all spectrometer channels are used for forming L(t); only those channels are used for which the target-object radiance is different from the radiance of other objects to be mapped. A selection of these channels can usually be made quite easily from an examination of single-channel imagery of each of the spectral channels. With some care, the selection may also be made from an examination of color and color infrared photographs. As with the threshold-level choice, the success of a selection of a preliminary set of channels is determined from trial recognition maps. If persistent confusion of two objects occurs at all threshold levels, additional channels are used to form L(t). The additional channels are selected by noting on the imagery those channels in which the contrast between the target object and the interfering objects is greatest.

2.2.3. PROCESSING OF THE EVERGLADES DATA

Previous studies in the Everglades have demonstrated that specific relationships exist among the ground elevation, mean period of inundation at a given site, and the type of biotic community which the site supports [3]. Although the recording of data at numerous locations throughout the Everglades would be a desirable approach to the study of fluctuating water supply, it would be impractical because of the size of the area, the restricted mobility within the area, and the time and manpower involved in handling recording instruments and analyzing the data.

Because ground elevation and mean period of water inundation are characteristics of the Everglades environment which cannot be remotely sensed by present scanning systems, selection of suitable indicators of water level conditions and ground elevations was necessary. From both a remote sensing and an ecological viewpoint, the three basic components of the glades' ecosystem which seem to be most relevant as indicators of surface water conditions are: (1) depth of water, (2) vegetation and (3) substratum type. The purpose of the data processing was to delineate sites relatively uniform in water, plant, and substratum characteristics.

The 2000-ft data were selected for processing as the best compromise between high resolution (which is obtained at low altitudes) and broad area coverage (which is obtained at high altitudes). Only the spectrometer data collected simultaneously were used for processing because such data permit rapid processing by implementing the decision rule on a special purpose analog computer, SPARC (Spectral Processing and Recognition Computer). After initial setup, data may be rapidly processed; that is, data that took one minute to collect may be processed in one minute.

Ground-truth observations made on 8 September 1967 and aerial photographs and multispectral imagery collected on 7 September 1967 were studied to determine the probable number of sites which could be differentiated by automatic processing, suitable areas for location of the training sets representative of each of the site types, and suitable spectral channels for processing. Training sets for two different water depth sites, for a limestone site, and for five vegetation classes were selected for processing. Each training set was located in an area which appeared to be typical of the type to be mapped, was relatively uniform in composition, and was at least 20 ft in diameter, in order to insure an adequate number of data samples.

The water depth training sets were located in two areas of known water depth: (1) an area downstream from a water control structure representing the deepest water in the scene, 5-15 ft deep; and (2) an area adjacent to a borrow pit representing shallow water of 3-5 ft in depth. A pile of excavated limestone located near a borrow pit was selected for the limestone training set.

Training sets for five different vegetation classes were selected using the criteria of physiognomy, dominant plant species, vegetation coverage, substratum type, and water depth. Physiognomy is defined as the gross external appearance of vegetation, determined chiefly by the life-form of the dominant plants. A classification of vegetation based solely on physiognomic criteria would group all vegetation types, regardless of species composition or structure, into units based on the dominant life-form of the vegetation; e.g., all vegetation types having grasses or grasslike plants as the dominant life-form would be classified as grassland. The three different physiognomic types observed from the imagery were forest, emergent semi-aquatic scrub, and emergent aquatic grassland.

A dominant species is here defined as a plant which occupies the most space within a site (50% or more of the plant cover). The criterion of dominant plant species was used to select two different grassland vegetation training sets. One training set had sawgrass as the dominant species, and the other had spikerush as the dominant species.

Vegetation coverage is defined as the area of the ground covered by plants of one or more species, as viewed from above the plant canopy. The degree of cover for each physiognomic unit was estimated from the imagery within broad classes as follows:

Cover Class	Coverage Description
1	5%-25%, vegetation very sparse
2	25%-50%, vegetation sparse to medium dense
3	50%-75%, vegetation medium dense to dense
4	75%-100%, vegetation dense

Two broad categories of substrata occurred within the scene: one type composed of peat, marl, or limestone and covered with a benthic algal mat (periphyton), and the other composed of peat but not covered by periphyton. Vegetation cover and substratum were used as the criteria to select training sets representative of two different categories of sawgrass vegetation. One training set had an estimated cover range of 60% to 90% with a peat substratum, and the other had an estimated cover range of 35% to 45% with the bottom type covered by a periphyton mat.

Two different categories of spikerush grassland (wet prairie) were selected, using coverage and water depth criteria as follows: (1) spikerush grassland having 25% to 35% cover, and water 3 in. to 6 in. deep; and (2) spikerush grassland having 5% to 15% cover, and water 6 in. to 18 in. deep.

Different combinations and numbers of channels were selected for processing each site unit. Trial recognition maps were produced to verify that the choice of channels and threshold levels was adequate. A final recognition map for each site type was then printed on film. Each black and white recognition map was exposed on color print paper through a different color filter, yielding a color-composite recognition map with unrecognized areas rendered in black (fig. 7).

3
ANALYSIS OF THE EVERGLADES DATA

3.1. INTRODUCTION

The purpose of the data analysis was to determine how well the processor could delineate sites which were relatively uniform in water depth, vegetation, and substratum type. Eight recognition maps were selected for producing the color-composite recognition map given in figure 7. The display colors in each recognition map were chosen arbitrarily. The limestone recognition map was excluded from the color-composite display because of the small size and number of areas of limestone which were mapped. Areas of limestone therefore are rendered in black in figure 7.

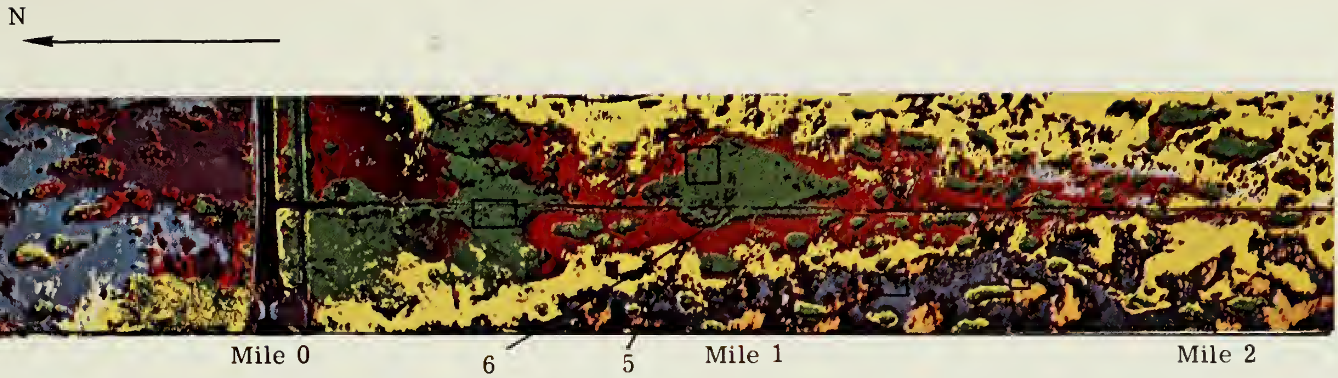
Evaluation of recognition success was made on the basis of the following data:

(1) Color infrared photographs obtained at the time of the multispectral flight mission (7 September 1967); and

(2) Ground-truth observations made along the Shark Valley Loop Road on 8 September 1967 and on 17 February 1969.

Because of time and funding limitations, quantitative ground survey techniques were not used to determine the total area covered by each general site type, or to determine the boundaries of each specific site unit. The degree of accuracy of the processed recognition maps, therefore, was determined only in a qualitative manner, based chiefly on a comparison of the areas of each site type interpreted from color infrared photographs with those delineated on the recognition maps.

Using conventional photographic interpretation techniques, the boundaries of each site unit were drawn on mylar overlays of the color infrared photographs. The criteria used for delineating each site type are listed in table 1 under the heading "Criteria for Classification of Landscape Units." Each descriptive element (i.e., water depth, substratum type, physiognomic type, etc.) for each site type was correlated with limited ranges of color, texture, and pattern on the color infrared photographs.



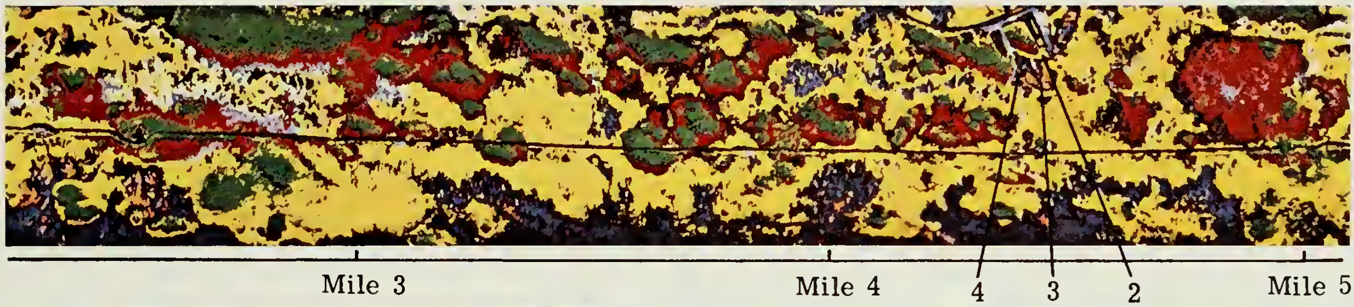
Map Unit 1

Map Units 3 and 4

Map Units 5 and 6

FIGURE 7. COLOR-COMPOSITE RECOGNITION MAP OF HYDRO-BIOLOGICAL FEATURES IN A PORTION OF THE SHARK VALLEY SLOUGH IN THE EVERGLADES NATIONAL PARK. Numbered leaders point to areas illustrated by ground photographs.

Map Unit No.	Map Unit Color	Description of Recognition-Map Units
1	Violet	Water deeper than 5'
2	Cyan	Water shallower than 5'
3	Orange	Sparse spikerush grassland in deep water sites (6" to 3')
4	Dark blue	Sparse to medium dense spike-rush grassland in shallow water sites (3" to 1')
5	Yellow	Sparse to medium dense saw-grass grassland in shallow water sites
6	Red	Medium dense to dense saw-grass grassland in shallow water sites
7	Green	Head and hammock islands composed of trees and shrubs
8	Black	Features not recognized (sparse sawgrass grassland in shallow water sites with exposed limestone, roads)



Map Unit 2

Map Unit 7

Map Unit 8

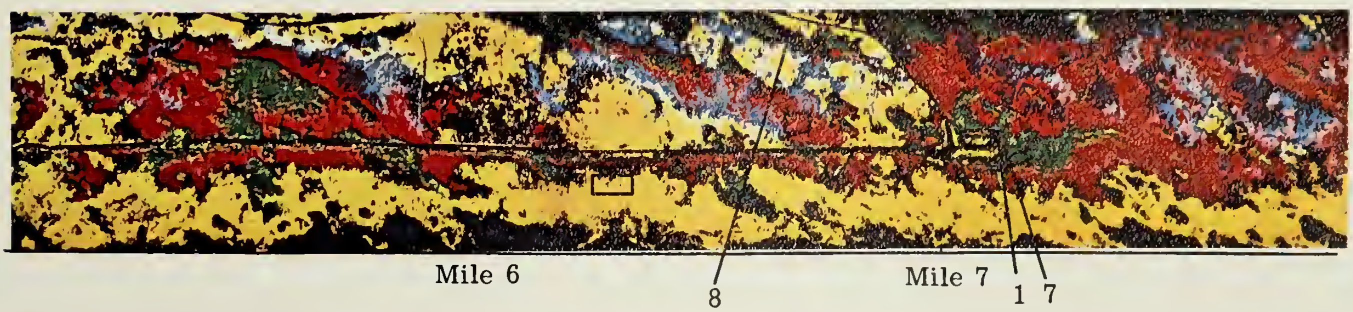


TABLE 1. CLASSIFICATION OF LANDSCAPE SITE UNITS

RECOGNITION-MAP UNIT DESCRIPTION				CRITERIA FOR CLASSIFICATION OF LANDSCAPE UNITS					ANALOGOUS VEGETATIVE TYPE*
Map Unit No.	Map Unit Color Code	Channels used for Processing	Map Unit Name	Vegetation Physiognomic Type	Dominant Plant Species	Estimated Range of Plant Cover	Characteristic Substratum Type	Estimated Range of Water Depth (at flight time)	
1	Violet	9, 10, 11, 12	Deep water					5 to 15 ft	
2	Cyan	8, 9, 10, 11, 12	Shallow water					3 to 5 ft	
3	Orange	7, 8, 11	Very sparse spikerush grassland	Grassland	Spikerush	5%-25%	Periphyton mat normally overlying marl, occasionally with exposed limestone	6 in. to 3 ft	Deep wet prairie community
4	Dark blue	7, 8, 9, 10	Sparse to medium dense spikerush grassland	Grassland	Spikerush	25%-50%	Periphyton mat normally overlying marl, occasionally with exposed limestone	3 in. to 1 ft	Shallow wet prairie community
5	Yellow	3, 7, 8, 9	Sparse to medium dense sawgrass grassland	Grassland	Sawgrass	25%-50%	Periphyton mat overlying peat, marl, or limestone	2 in. to 1 ft	Sparse sawgrass community interspersed with small stands of shallow wet prairie
6	Red	3, 5, 6, 7, 8, 9, 10, 11, 12	Medium dense to dense sawgrass grassland	Grassland	Sawgrass	50%-100%	Peat, sometimes overlain by periphyton	2 to 6 in.	Sawgrass community
7	Green	6, 12	Tree island	Scrub	Willow & various codominant species, e.g., cocoplum	50%-100%	Peat with occasionally exposed limestone		"Head" community
7	Green	6, 12	Tree island	Forest	Willow & various codominant species, e.g., cocoplum, gumbo limbo, myrtle, & strangler fig	75%-100%	Peat		Hammock community
8	Black	3, 5, 12	Limestone				Excavated limestone above surface of water, not including natural limestone outcrops		

*Vegetative units defined in previous studies (fig. 3).

The areal distribution of each site type (as defined from color infrared photographs and ground observations) was compared with the areal distribution of the recognition-map units for each of the eight recognition types. The following is a discussion of the recognition results. The locations of the training set areas described below are indicated on the color-composite recognition map (fig. 7) by black outline boxes. Although some of the ground photographs illustrated in figure 7 were taken outside the training-set areas, they illustrate the typical appearance of the site types recognized.

The flight line chosen for this study covered a part of Everglades National Park centered on the Shark River Valley Loop Road. This road traverses a transitional region between the open Everglades at the north end and the Shark River Slough at the south end. The Shark River Slough is aligned in a northeast-southwest direction and intersects the flight line at a point very near the observation tower at Mile 7. Because the flight line covers this transition from the open Everglades to the slough, water conditions at the north end of the run are quite different from those at the south end. In general, the water at the south end is deeper by 1 or 2 ft than the water at the north end of the run. The water depth pattern is complicated by the presence of deeper water in borrow pits and the water control canal running east-west at Mile 0. In the canal and borrow pits, the maximum water depth was 8 ft, and the maximum water depth at the control gate (Mile 0) was estimated at 15 ft at the time of flight.

3.2. DISCUSSION OF THE RECOGNITION RESULTS

3.2.1. DEEP WATER (MAP UNIT 1)

The deep water training set was located at the water control structure at Mile 0. The maximum water depth in the training set was 15 ft. Water less than 5 ft in depth was excluded from the training set. The deepest water in the moat at Mile 7 was detected with this signature. The deep water north (upstream) of the control structure (approximately 5 ft deep) was also detected. No other deep water measurements were available to permit verification of other deep water detections. The ground photograph of map unit 1 in figure 7 shows an alligator in a deep part of the moat at Mile 7.

Numerous small areas within the boundaries of tree islands and on their western sides were detected as deep water. In some cases, these detections of small areas were due to the presence of deep water in limestone-solution holes or in drainage channels within the tree islands. In other cases, tree shadows were detected as deep water. The false detection of tree shadows as deep water constituted approximately 1.5% of the total deep water recognition. The tree shadows occurred on the west sides of the tree islands because the data were collected early in the morning. In the spectral channels used for processing, tree shadows closely resembled deep water since both had very low radiance values.

3.2.2. SHALLOW WATER (MAP UNIT 2)

The shallow water signature was obtained from a training set at Mile 4.50 having water 3 to 5 ft deep. The typical appearance of shallow water areas is illustrated by the water in the foreground of the ground photograph of map unit 2 in figure 7. The light-colored substratum can be seen at the 3 ft water depth. Overlapping detections of shallow water occurred in some areas having dense sawgrass cover and sparse sawgrass cover (table 2). The former areas are pink on the color-composite recognition map, and the latter are light yellow or white. These areas of overlapping detection had deeper water than was typical for the sawgrass vegetation classes.

3.2.3. TREE ISLANDS (MAP UNIT 7)

The tree-island signatures were derived from two different training sets of known species composition. One set, at Mile 0.5, was a young, even-aged stand of nearly pure willow (Salix amphibia); the other, at Mile 1.0, was an uneven-aged stand of mixed tree and shrub species, e.g., gumbo limbo (Bursera simaruba), strangler fig (Ficus aurea), cocoplum (Chrysobalanus icaco), dahoon holly (Ilex cassine), and myrtle (Myrica cerifera). The ground photograph of map unit 7 (fig. 7) was taken south of the moat at Mile 7 and shows willow as the dominant species of the tree island. Both sawgrass and spikerush grasslands can be seen adjacent to this tree island in the background.

Two separate recognition operations were performed, one on each training set, and the results were combined in a logical "OR" circuit before printing. The resultant recognition picture showed tree islands present when either of the two training-set signatures was matched by the data signature.

The boundaries of the tree islands, as observed on the ground and from aerial photographs, were more distinct than those of the other vegetation classes in the scene. Therefore, verification of the accuracy of the tree-island recognition-map units was much simpler than for the other map units. It appears that all tree islands were detected. The boundaries of some tree islands delineated by the automatic processor were found to be more precise than could be delineated on the color infrared photographs.

Areas characterized by small scattered detections of tree and shrub vegetation within a matrix of another vegetation type represent transitional regions of vegetation. Examples of tree and shrub vegetation mixed within sparse sawgrass grassland (yellow) and within dense sawgrass grassland (red) occur between Miles 1 and 2, and between Miles 5 and 6 on the color-composite recognition map. The subtle boundaries of such transitional areas are difficult to determine by ground survey techniques. It was not possible to differentiate these transitional areas on the color infrared photographs. However, even if the boundaries had been distinguish-

TABLE 2. AREAS NOT RECOGNIZED CORRECTLY

A. AREAS NOT RECOGNIZED

Color Code	Area Description	Location
Black	Sparse sawgrass with limestone	Mile 6.75 on the east side of the road
	Sparse sawgrass with water depth greater than 3 in., and with periphyton bottom having been removed by fire in the recent past	Between Miles 6.00 and 6.25

B. AREAS OF OVERLAPPING RECOGNITION

Color Code	Area Description	Location
Pink (Cyan + Red)	Dense sawgrass and shallow water	Mile 1.75 Mile 2.75 Mile 5.75 Mile 6.50 Mile 7.50
Light Yellow or White (Cyan + Yellow)	Sparse sawgrass and shallow water	Between Miles 2.00 and 3.00 Between Miles 5.50 and 6.00 Between Miles 6.25 and 7.00

C. AREAS RECOGNIZED INCORRECTLY

Color Code	Area Description	Location
Yellow	Lawn enclosed by moat	Mile 7.25
Violet	Shadows on west sides of tree islands	Throughout scene
Red	Pickerelweed vegetation	Mile 0.25
Red	Cattail vegetation	Mile 7.25

able on the color infrared photographs, accurately drawing the small scale boundaries by hand would have been impractical. The precision with which the transitional boundaries were mapped by the processor indicates that this technique may serve as a very sensitive tool for assessing slight vegetation changes induced by changes in surface water conditions.

3.2.4. MEDIUM DENSE TO DENSE SAWGRASS GRASSLAND (MAP UNIT 6)

The training set for the dense sawgrass signature was located at Mile 6.75, in an area typical of the medium dense to dense cover of sawgrass (Mariscus jamaicensis). The ground photograph of map unit 6 (fig. 7) shows dense sawgrass in the background and a deer running through sparse sawgrass in the foreground. The photo was taken during higher water conditions than prevailed during the flight. The detection of medium dense to dense sawgrass throughout the scene was accurate. No detection failures were evident from the color infrared photographs and ground spot checks. However, field observations revealed that scattered small stands of dense herbaceous vegetation (e.g., solid stands of pickerelweed and cattail) were falsely detected with this sawgrass signature (table 2). This false detection constituted less than 1% of the total dense sawgrass detection. Other false detections occurred in areas having overlapping recognitions of dense sawgrass and shallow water (table 2). The water in these sawgrass areas was deeper than was typical for this sawgrass type. The dense sawgrass areas between Mile 0 and Mile 0.25 are a darker red than the other dense sawgrass areas on the color-composite recognition map. This color difference occurred because the original black-and-white recognition filmstrip was a darker shade of gray in that area.

3.2.5. SPARSE TO MEDIUM DENSE SAWGRASS GRASSLAND (MAP UNIT 5)

The signature for sparse sawgrass grassland was obtained from a training set at Mile 6.5, in an area having approximately 40% sawgrass cover and 60% periphyton cover. The water in this portion of the slough was approximately 2 in. deep at the time of the flight. Areas in the scene having similar sawgrass cover, periphyton cover, and water depth were detected with this signature. The photograph of map unit 5 (fig. 7) shows sparse sawgrass in the foreground. The photograph illustrates a higher surface water level than existed at the time of the data collection flight. The only apparent false detections for this signature occurred in light yellow areas, where overlapping detection with shallow water occurred (table 2).

Spot checks on the ground between Miles 6.00 and 6.25 revealed that the unrecognized area coded in black in the color-composite recognition map (fig. 7) was sparse to medium dense sawgrass grassland that had been burned in the recent past. The periphyton cover in the area was thus less than for the training set, and a darker peat substratum was exposed. The water on the east side of the road was a few inches deeper than on the west side of the road (table 2). A small area located at Mile 6.75 on the east side of the road (map unit 8 in fig. 7) also is coded black (unrecognized) in the color-composite recognition map. Field observations in this area showed that the vegetation consisted of sparse to medium dense sawgrass in clumps, interspersed with limestone outcrops too small to be resolved by the scanner. Sufficient exposed limestone was present, however, to affect the spectral signature of the area so that it was not recognizable as sawgrass grassland (see ground photograph of map unit 8 in fig. 7).

3.2.6. SPARSE TO MEDIUM SPARSE SPIKERUSH GRASSLAND (MAP UNIT 4)

The training set for sparse to medium sparse spikerush grassland was located near Mile 1.25 in an area having approximately 30% plant cover, 70% periphyton cover, and water 3 to 6 in. deep. Three species of Eleocharis were predominant in the training-set area. The foreground of the ground-truth photograph of map unit 4 (fig. 7) shows a typical sparse spikerush grassland with both floating and submerged periphyton. A small clump of sawgrass appears in the right mid-foreground, and very sparse spikerush grassland appears in the background. Ground spot checks of this map unit type in the vicinity of Mile 4.50 indicated close agreement of plant cover, periphyton cover, and water depth in that area with those of the training set area.

3.2.7. VERY SPARSE SPIKERUSH GRASSLAND (MAP UNIT 3)

The training set for very sparse spikerush grassland was located near Mile 1.60. The signature for this map unit was based chiefly on the integrated spectral radiance of the periphyton substratum (approximately 90% cover) and water ranging in depth from 6 to 18 in. The plant cover varied within the training set from 5% to about 15%. Observations in the field near Mile 4.50 indicated that the computer recognition of this unit was correct. The ground-truth photograph showing sparse to medium dense spikerush grassland in the foreground shows very sparse spikerush grassland in the mid-background.

4
RECOMMENDATIONS

Larger areas should be mapped with these techniques in future studies. This will require improvements in three phases of the effort: airborne data collection, ground-truth data collection, and processing operations. More specifically, these improvements are:

A Airborne Data Collection

1) Fly at 6000 ft over terrain to achieve wider coverage. Some processing of 5000-ft data indicates that automatic processor performance is not seriously degraded. If this is also true at 6000 ft, data collected at this elevation would give a map scale of 1:12,000, or 1 in. to 1000 ft. A reduction of this map scale to half size, 1:24,000, would produce a scale equivalent

to that of the U. S. Geological Survey topographic quadrangle sheets, and would be a useful map size for the Everglades as well as for other investigations.

2) Measure aircraft attitude at time of flight (particularly yaw or crab angle) to permit partial rectification of images or recognition maps.

B. Ground-Truth Data Collection

1) Collect and interpret aerial photographs prior to the multispectral data flight to select training sets for the processor.

2) Concentrate ground-truth measurements in the training-set areas. These measurements, which are taken at the time of the multispectral flight, should include parameters likely to influence the spectral signature of the training set, e.g., quantitative species composition, water depth measurements, and substratum composition.

3) Study methods of using data from existing ground instrumentation (reflectance panels, color panels, spectrophotometers, radiometers, etc.) to assist in interpretation of the multispectral data.

C. Data Processing Operations

1) Evaluate a prototype processor for removing the geometrical distortion inherent in all scanning systems. When operational, this processor will produce a rectified image of the scene from raw scanner data.

2) Study the use of hybrid computers (combination of CDC 1604 digital and SPARC analog computers) to process data. The division of the processing work load should be defined since there are tasks which the digital computer can do more efficiently than SPARC and vice versa. The design criterion should be maximum processing speed.

3) Consider the use of a computer program, atmospheric-illumination and transmission model, developed by WRL for the Air Force. This program simulates the theoretical attenuation of energy reflected or emitted from a recognized target, given different altitudes.

D. Satellite Data Collection

1) Evaluate the potential of using a multispectral scanner in an Earth Resources Technology Satellite.

2) Determine the types of ground-truth measurements that would be necessary for interpreting scanner data from a satellite.

REFERENCES

1. Remote Multispectral Sensing in Agriculture, Volume 3, Purdue University, Laboratory for Agricultural Remote Sensing, Report No. 844, September 1968.

2. P. G. Hasell et al., Investigations of Spectrum-Matching Techniques for Remote Sensing in Agriculture, Interim Report, March 1967 to December 1967, Report 8725-13-P, Volumes 1 and 2, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, July 1968.

3. M. C. Kolipinski and A. L. Higer, Some Aspects of the Quantity and Quality of Water on Biological Communities in Everglades National Park, U. S. Geological Survey open-file report, September 1969.

4. D. S. Lowe and J. G. N. Braithwaite, A Spectrum-Matching Technique for Enhancing Image Contrast, Applied Optics, Volume 5, No. 6, June 1966.