E7.5-10.3.2.0
CR-142922

(E75-10320) ERTS-1 INVESTIGATION OF WETLANDS ECOLOGY Final Report (American Univ.) 113 p HC $5.25 CSCL 08H
N75-26464
Unclas
G3/43 00320

ERTS-1 Investigation of Wetlands Ecology

Richard R. Anderson
Virginia Carter
John McGinness

FINAL REPORT

Prepared for:
Goddard Space Flight Center
Greenbelt, Md.
NASA Contract NAS5-21752

Department of Biology
The American University

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION: BACKGROUND OF STUDY

Wetlands, especially salt marshes, play a primary role in estuarine productivity, providing food and shelter not only for organisms naturally inhabiting the wetlands, but also for the many organisms which spend all or part of their lives in the waters of the adjacent estuary or shallow ocean. Salt marshes are vitally necessary to the maintenance of virtually all major shallow salt-water fish and shellfish populations.

Decline in numbers and productivity of wetlands has led to the concomitant reduction in the populations of species which are directly or indirectly dependent upon them. Wetlands are an integral part not only of the terrestrial but also of the aquatic ecosystem, presenting a diverse array of biotic communities which are limited to and survive only when the peculiar nature of the wetland habitat is maintained. Such activities as dredging, draining, filling and dumping of wastes either totally destroy, or permanently alter, these unique habitats and their productivity in the estuarine ecosystem.

Shallow water areas also play an important role in the aquatic ecosystem. Submerged, rooted aquatic plants supply organic material to bottom animal communities, contribute to oxygen balance in the water, stabilize the bottom, reduce turbidity, and provide a place of attachment for smaller plants and animals, and a hiding place for young commercial fishes. These plants are also an important source of food for fish, wildfowl and mammals. Dredging, filling, and careless spoil disposal destroy the submerged aquatic plants in shallow water areas. This destruction reduces primary productivity and, hence, reduces the population of species directly dependent upon the submerged aquatic plants for food and/or shelter.

As human population increases in the Atlantic coastal states, demands for recreational, residential, and industrial development in the coastal zone conflict directly with the worldwide need for maintenance and improvement of human food sources (shellfish, finfish) based upon aquatic ecosystems. Coastal zone management decisions are dependent upon accurate, timely information such as the location, size, ecological (and cash) value of major wetlands, and identification of areas significantly impacted or threatened by man's activities.

A recent publication by Pope and Gosselink (1974) outlines a rationale and techniques for putting a cash value on the ecological aspects of a tidal marsh. Marsh-estuary values range from $100 per acre per day from the economic benefit to commercial and sports fisheries to $4,150 per acre per day for a total life support value. Using the latter value, an analysis was made of the cost of highway construction through coastal marshes which suggested that, except in cases of very shallow spoil removal, bridging is cheaper and ecologically preferable to filled roadway construction.

During the last five years a clear need has been established for development of a rapid, relatively low-cost method for mapping and monitoring coastal wetlands. This period has been one of unprecedented activity by state governments to preserve this sensitive and threatened part of the aquatic ecosystem. Laws regulating the types of activity in wetlands have been passed in almost all Atlantic coastal states. To implement this wetland legislation, practical methods are needed for mapping and evaluation of coastal wetlands.

The feasibility of using remotely sensed data from aircraft for mapping and evaluation of wetlands has been clearly established. Ongoing research programs at The American University provided much of the basic information on the uses of this data. Early studies made on the Patuxent River in Maryland, with U.S. Geological Survey funding, showed that low altitude (2000 m) color infrared (IR) photography was superior to natural color photography in delineation of principal wetland plant species and communities (Anderson, 1968). Valuable information for wetland ecological research such as plant species composition, productivity, and successional rates can be determined from this color IR photography (Anderson, 1969). The need for time-consuming and expensive ground surveys is reduced.

Analysis of NASA high (18,600 m) and low (3000 m) altitude photography in the wetlands of the Chesapeake Bay indicated that species composition, wetland boundaries, and general ecological condition may be interpreted from high-altitude color IR photography with little loss of information with increase in altitude (Anderson, 1970, 1971). These large wetland areas range in type from salt marsh to tidal fresh-water marsh.

New Jersey, Maryland, and South Carolina are among the most active users of aerial photography as a basis for wetland mapping (Anderson & Wobber, 1973; Garvin & Wheeler, 1973; Guss, 1972). The New Jersey program (Anderson & Wobber, 1973) is the most ambitious and will soon complete mapping all the state's coastal wetlands to national map accuracy standards using low-altitude color IR photography. However, this technique is too expensive for many states to use on a routine basis. Automated wetland mapping has also been attempted using aircraft data (Klemas et al., 1973).

Aircraft data is also being utilized for ecological studies by Reimold et al. (1972, 1973) and other investigators.

Identification and mapping of wetland species is important both for classification of wetlands and for gross estimates of productivity. Classification of coastal wetlands is often based upon salinity (Stewart, 1962; Nicholson & Van Deusen, 1944), but each category is related to salinity by species composition rather than by actual physical measurements. Recognition of key species such as *Spartina alterniflora* (salt marsh cordgrass), *Juncus roemerianus* (needlerush), *Nymphaea odorata* (water lily), and observation of marsh vegetative structure (location and distribution of species or vegetative types) play an important role in the assignment of marshes to a class or category. If the distribution of a species can be mapped and area measurements made, local productivity figures can be used to estimate total primary productivity (Stroud & Cooper, 1969; Reimold et al., 1973). In addition, the use of coastal marshes by wildlife is directly related to species composition (e.g., muskrats appear to favor brackish marshes). Waterfowl use of coastal marshes is dependent upon species composition, cover interspersion, and other factors (Stewart, 1962). Determination of successional trends is made by repetitive mapping of species.

With the launch of ERTS-1 in July 1972, repetitive satellite data first became available for the investigation of earth resources. The research described in this paper was initiated to determine the feasibility of using ERTS data for investigations of coastal wetland ecology and to monitor and map coastal wetlands.

II. OBJECTIVES

The primary goal of this study was to test the feasibility of using ERTS-1 data to provide information for studies of coastal wetland ecology. The data were analyzed with reference to four major objectives contained in the original proposal. These objectives are as follows:

(1) To develop methods for delineation and mapping of wetlands plant communities and for establishment of the boundaries of the wetlands ecosystem;

(2) To provide a method for identification and evaluation of wetland types for purposes of coastal zone management including preservation and maintenance of wildlife populations;

(3) Develop methodology for monitoring coastal wetlands on a regular basis for protection from man-made and natural reduction in productivity; and

(4) Develop methodology for delineation and mapping of shallow water areas.

During the course of the study, the first three objectives were accomplished. The fourth objective, mapping of shallow water areas, was not accomplished because the turbidity of the coastal water in the test site appeared to be too great to pursue this objective within the time allotted. The rest of this report discusses the methods used for analysis of ERTS data, the results of the analysis, and present and potential application of ERTS data to coastal wetlands.

III. TEST SITES

Figure 1 shows the entire test area, which includes the Chesapeake Bay estuary and the coastal areas of Delaware, Maryland, Virginia, North Carolina, South Carolina, and Georgia. This area represents a wide variety of wetland types because species composition and dominance differ on a north-south gradient along the coast. Several intensive study sites were chosen (Figure 1): the northern test area, sites 1 and 2; the Dismal Swamp, site 3; and the southern test area, sites 4 and 5. These sites will be discussed in detail below after a general description of the test area.

The southern and central Atlantic coast is largely formed by a series of long, narrow islands composed of sand dunes and beaches with scattered areas of tidal marsh on the inland side. A number of shallow sounds or bays, including Pamlico Sound, Albemarle Sound, and Chincoteague Bay, separate these islands from the mainland. West of the sounds or bays are abundant wetland areas: marshes, swamps, lakes, etc.

The Chesapeake Bay is one of the largest estuaries in the world. It is approximately 180 miles long with an average width of 15 miles and a mean depth of only 20 feet. There are countless small tributaries and approximately 50 major tributaries, all of which add fresh water, silt, and pollutants to the Bay proper. Population density is relatively high along the western shore of the Bay, but numerous small wetlands remain along both major and minor tributaries. The eastern shore of the Bay is less densely populated and contains extensive wetlands ranging in type from shallow fresh marsh to salt marsh, with the latter predominating.

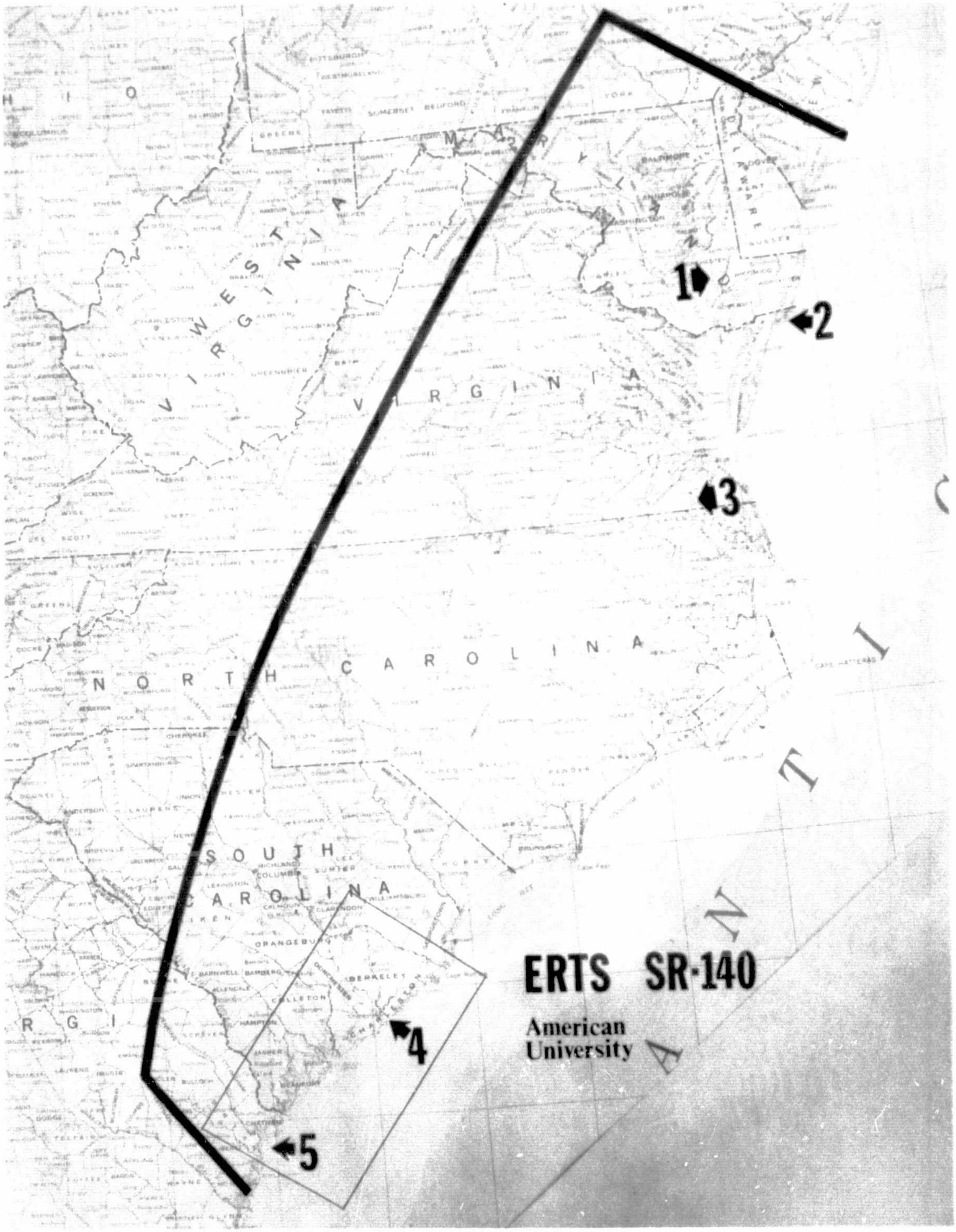


Fig. 1. Map of entire test area showing location of test sites. Site 1 is the Nanticoke River marsh, Site 2 Chincoteague Bay, Site 3 Dismal Swamp, Site 4 Charleston, S.C. and Site 5 Ossabawa Island, Ga.

Changes in land use around the Bay, including a projected significant increase in population and industrial development, bring increasing pressure for destruction or modification of these valuable wetland areas. These pressures are common to all the estuaries of the Atlantic coast.

A. Northern Test Sites

Figure 2 is a map of the northern test area showing two sites examined in detail in the following pages. This area includes the Chesapeake Bay and many of its tributaries. Maryland has approximately 300,000 acres of wetlands, 250,000 of which lie on the Eastern Shore, or what is commonly called the Delmarva Peninsula. Virginia has approximately 330,000 acres of wetlands, over half of which also lie on the Delmarva Peninsula. Site 1 is a large, near-saline marsh at the mouth of the Nanticoke River in Dorchester County, Maryland. Site 2 is a salt marsh complex located at the mouth of the Chincoteague Bay in Virginia. The tidal range in the northern test area is about 1 meter.

The frequently inundated saline and near-saline marshes in the Chesapeake Bay area contain many of the same species found in the southern marshes (Wass & Wright, 1969; Stewart, 1962). However, these species seldom grow to heights comparable to those achieved in southern marshes and, consequently, estimates of their primary productivity are lower (Keefe & Boynton, 1972). This is probably because of a shorter growing season and generally cooler air and water temperatures. Some species (*Batis maritima* [saltwort] and *Borrichia frutescens* [sea ox-eye]) are at the northernmost extent of their range here and are rarely encountered.

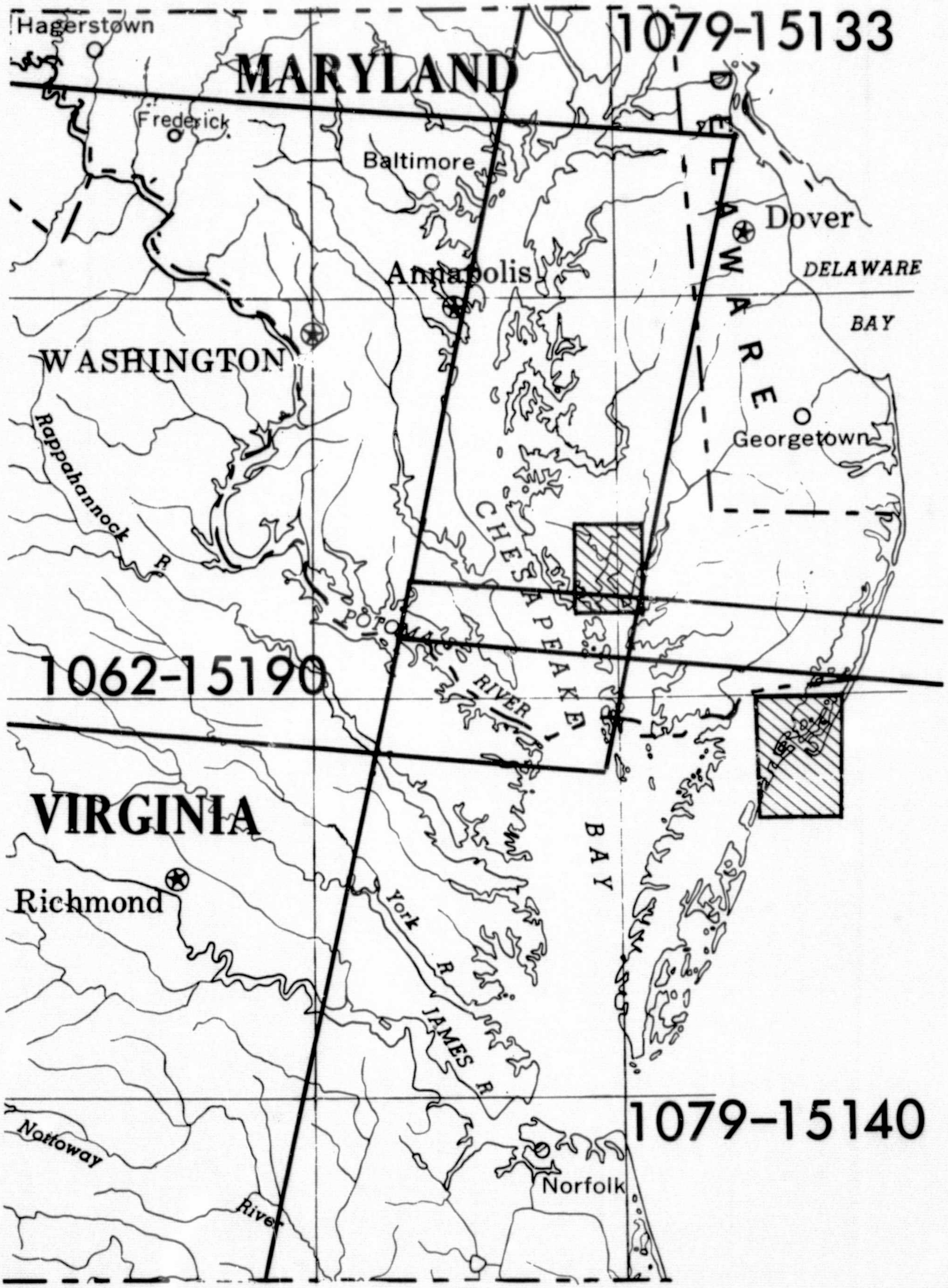


Fig. 2. Map of northern test area showing study sites. Site 1 is the Nanticoke River marsh and Site 2 is Chincoteague Bay.

B. Dismal Swamp

The Dismal Swamp is a vast wooded swamp or forested bog straddling the Virginia-North Carolina border. The federal government owns the Dismal Swamp Canal and the Dismal Swamp National Wildlife Refuge, an area of about 49,000 acres recently donated to the Department of the Interior by the Union Camp Corporation through the Nature Conservancy. The Swamp has been considerably modified by man in his many attempts at drainage. Drainage ditches and roads criss-cross the Swamp, which contains a variety of vegetative associations ranging from a hydric gum-cypress association to a mesic beech-oak-holly or loblolly pine association in drier areas (Meanley, 1972). Surface water in Lake Drummond (about 6 feet deep and 2-1/2 miles in diameter) is used for operating the locks on the Canal. The Dismal Swamp was not included under the original objectives of our NASA proposal, and therefore a complete summary of the work there can be found in Appendix D.

C. Southern Test Sites

The southern test area (Figure 3) is bordered on the south by Saint Catherine's Island, Georgia, and on the north by Charleston, South Carolina. Two areas examined in detail on the following pages are Charleston, South Carolina, and Ossabaw Island, Georgia. The coastal marshes from North Carolina southward represent the largest, most extensive saline marshes in the United States. Vegetative composition is quite similar along most of the southern coast, but grades to mangrove swamps in Florida. The species which dominate the frequently inundated saline and near-saline marshes of the southeast coast grow taller and are more productive than

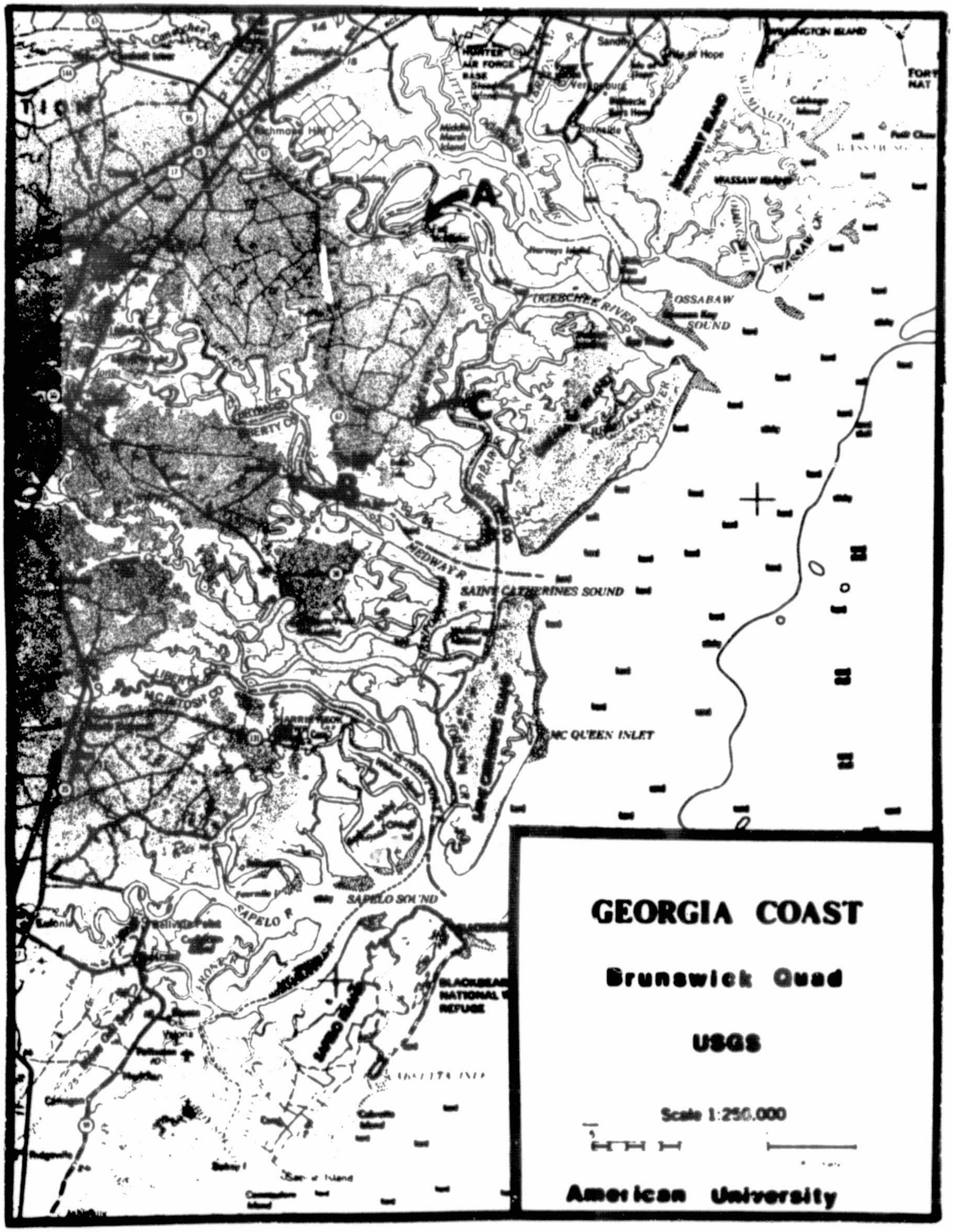


Fig. 3. Map of the southern test area near Ossabaw Island, Ga. The letters A, B, and C refer to tidal reference stations.

the same species in the northern test area. Tidal amplitudes vary from near 0 meters on upstream tributaries to approximately 3 meters on South Carolina and Georgia salt marshes.

IV. METHODS AND MATERIALS FOR ERTS DATA ANALYSIS

Aircraft support data and extensive field observations were used in the analysis of ERTS data. These are discussed briefly in sections A and B below.

A variety of methods for analyzing ERTS data were tested and evaluated. These include both visual and automated interpretation techniques, some of which are discussed in detail in sections C, D, and E. In the case of MIAS and ESIAC, results of the analysis are also given because only experimental use was made of the system.

A. Aircraft Support and Data Analysis

The authors are particularly indebted to the NASA aircraft supp t programs operated from Ames Research Center, California, and Johnson Spaceflight Center, Texas, and the Wallops Research Station, Virginia. Underflight data have been invaluable as interpretive aids for the ERTS imagery.

Aircraft data obtained over the ERTS test site, listed in Appendix B, is on file at The American University. A list of sources of other data, which includes the test site, is also provided. Aircraft data include color, color IR, and multiband B/W photographs and digital products from the Bendix 24-channel scanner.

Color IR photographs were analyzed by visual inspection prior to field trips to provide general information of the test site wetlands and spatial distribution of large plant communities. They were also used for orientation and location purposes in the field. In the preliminary stages of analysis of both ERTS imagery and digital data, color IR photographs were used extensively to verify boundary determinations, vegetation identification, and disturbed areas. High-altitude color IR photographs were used for identification of vegetation, drainage patterns, wetland boundaries, and special interest areas in the Dismal Swamp. Very limited use was made of color photographs. The multiband B/W photos were density sliced and composited, but generally failed to provide information useful to the project. Bendix scanner data were analyzed on the LARSYS at Goddard Space Flight Center.

B. Field Observations and Measurements

Field observations included collection and identification of wetland species in the test site and determination of vegetative zonation patterns as related to color IR photographs and ERTS images. Wetland boundaries were examined to determine whether they represented gradual transition zones or abrupt changes in vegetation or topography. Density and height of vegetation and extent of tidal flooding was noted and 35 mm photographs were taken to provide a permanent record.

A considerable amount of information on the spectral reflectance characteristics of important wetland plant species and other components, such as mud flats, sand, etc., was gathered prior to and during this project with two ISCO spectroradiometers equipped for field use. These data have been used to interpret gray levels on ERTS imagery and to aid in the development of coastal wetlands look-up tables using ERTS-MSS digital data (see ERTS_ANALYSIS System).

Table 1 is a summary of the average spectral reflectances, in percent, of a number of major wetland plant species and other wetland components. These are representative values, or ranges of values, chosen to illustrate the general relationship between wetlands reflectances during the growing season. For this table, a uniform response curve was assumed for each ERTS sensor and the ISCO percent reflectance values were averaged over MSS bandwidths. Actual reflectance of salt marsh plant associations can be expected to vary depending on percentage composition of species, canopy cover and background exposure, tidal inundation, and season.

The coastal saline and brackish marshes generally appear as a dark gray tone near the dense end of the scale on ERTS MSS band 6 and 7 images, and as a dark red-gray in a color infrared simulation (color composite) during the growing season. This is largely because the spectral reflectance of the dominant species, or species association, is generally low in MSS bands 6 and 7. These species include Spartina alterniflora (salt marsh cordgrass), Salicornia spp. (glasswort), and Juncus roemerianus (needlerush). In MSS bands 4 and 5, all marsh species have a low overall average reflectance, usually appearing less dark in tone than dryland vegetation and darker than spoil or agricultural fields with or without crops. Where the coastal marshes become fresher, the spectral reflectance of the species compositions is higher in the infrared region of the spectrum and the plant cover is generally denser. During the peak of the growing season, it is difficult to determine the landward boundaries of these fresh marshes.

Table 1: Average or Range of Average Spectral Reflectance, in Percent, for Wetland Species and Components in ERTS MSS Bands 4-7

Wetland Species or Component	MSS Band 4	MSS Band 5	MSS Band 6	MSS Band 7
Spartina alterniflora (salt marsh cordgrass)	3.6-5.2	3.9-5.3	12.7-17.4	16.0-23.5
Salicornia sp. (glass wort)	4.7	5.2	13.8	18.7
Spartina patens (salt meadow cord grass)	3.7-7.1	4.2-7.7	18.3-27.9	21.4-41.1
Juncus roemarianus (needlerush)	2.4	3.1	7.5	10.9
Spartina cynosuroides (giant cordgrass)	4.2	3.7	20.9	28.1
mudflat	3.9-6.0	4.4-7.7	6.1-11.5	7.0-11.6
sandy fill	12.9-13.7	17.0-20.0	22.8-26.1	25.8
water (turbid)	9.5	10.4	7.8	4.1

The American University — The U.S. Geological Survey

C. Visual Interpretation Techniques

1. Photographic Reproduction and Visual Interpretation

ERTS images in both 9.5" and 70 mm format were analyzed visually with light table or enlarging viewers. An overhead projector was used with the 1:1,000,000 scale imagery to make overlays of the Nanticoke Marsh test site. Diazo color composites using 2 or 3 MSS bands, either of the 1:1,000,000 scale imagery or of enlarged positive transparencies, were prepared for many scenes. These composites can be made to enhance selected features; for example, areas affected by man's activities can be quickly located. Illustrations reproduced using the Diazo system are quite useful in preparing reports and maps. Available NASA color composites were compared with the Diazo products--in many cases it was felt that the Diazo products gave better detail for wetlands studies.

Photographic reprocessing of ERTS MSS imagery was necessary to extract detailed information on marsh species, marsh boundaries, and tidal effects because NASA imagery is processed to emphasize upland areas. ERTS transparencies were used to produce contact negatives on Kodak Contrast Process Ortho and Contrast Process Panchromatic sheet film. MSS bands 4 (green), 5 (red), 6 and 7 (infrared) differ in density and contrast, due to atmospheric conditions and scanner capability. Contrast and exposure times were manipulated to make B/W prints for each MSS band. Improvement over NASA imagery was not obtained with MSS bands 4 and 5; however, reprocessing of MSS band 7 yielded better detail within the marsh.

Enlarged prints were produced using Omega D-2 and Bessler 45 MCXA enlargers. Kodak DK50 and Dektol developers were used for film negative production and paper print enlargments. Kodak Polycontrast Rapid Paper and Kodabromide Contrast papers were also tested. MSS band 7 enlargements gave the most detail with F-3 or F-4 contrast grade paper. Exposure times were determined to be critical when attempting to obtain maximum marsh information.

2. Zoom Transfer Scope

The Bausch and Lomb Zoom Transfer Scope was an extremely useful tool for preparing maps and overlays. Working with the 1:1,000,000 scale imagery, information can be transferred directly to a map base or overlay material at scales of 1:250,000 or 1:125,000. Figure 4 is a wetland map of the Charleston, S.C., area made from ERTS images 1081-15264-5,7 (12 October 1972, Figure 5) and 1243-15274-7 (23 March 1973) using the Zoom Transfer Scope (Anderson et al., 1973c). Details of this analysis are discussed in section V, Results.

D. Machine Analysis Techniques

1. Autographic Theme Extraction System (ATES)

The USGS is developing an Autographic Theme Extraction System (ATES) to apply photographic and digital processing to images to obtain specific theme isolations which retain the geometry and resolution of the original image. These extractions, or spectral images, are based on distinctive film densities or combinations of densities, and are presently being done on an experimental basis with ERTS-1 and Skylab images (Smith, 1973). The isolated thematic data are stored in the form of a photographic transparency resembling a high contract B/W negative. Two or more of these "negatives" can be combined into a photographic composite.

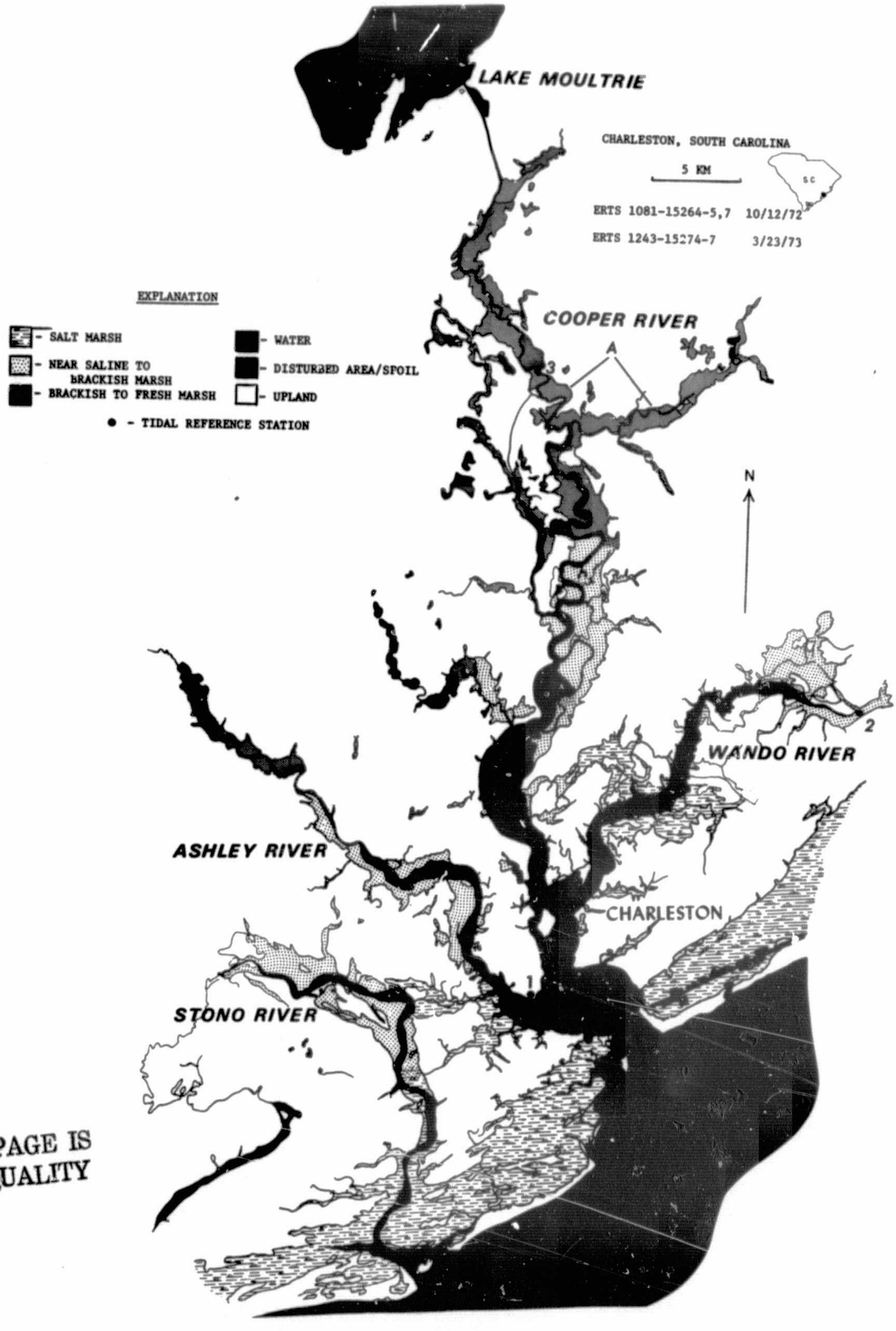


Fig. 4. Map of the Charleston, S. C. area illustrating wetland classification, disturbed areas and drainage pattern. A shows area affected by damming of Lake Moultrie. 1, 2, and 3 were tidal reference stations.

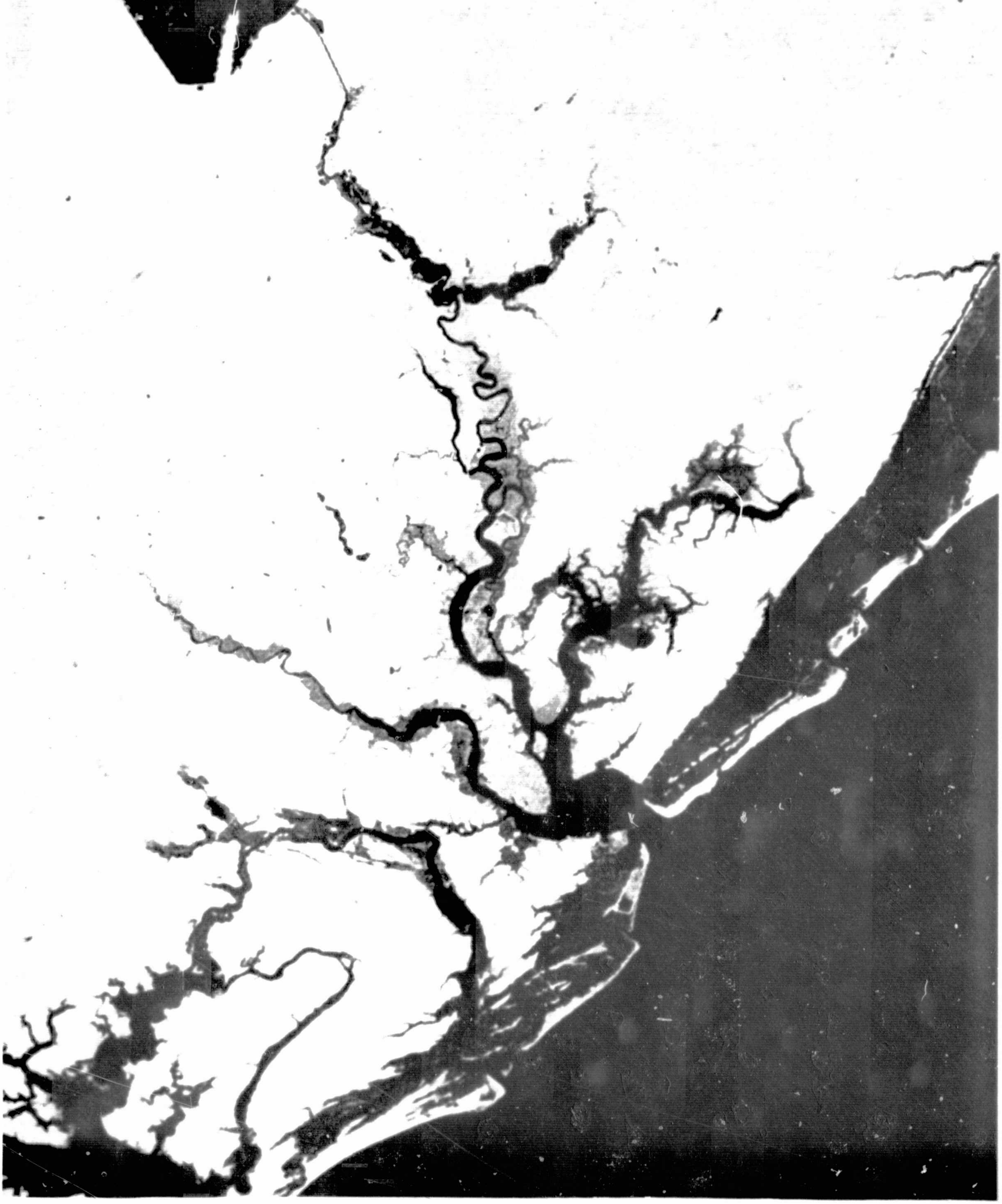


Fig. 5. ERTS image 1081-15264, band 7. This image was used to compose map shown in previous figure.

ERTS-1 images from October 11, 1972 (1079-15142-5,7) and February 13, 1973 (1205-15150-5,7) were used as the base for a series of wetlands extractions in the Dismal Swamp (Carter & Smith, 1973). These include an extraction of both the wettest areas and the drier deciduous or low-flat evergreen areas in the swamp (Appendix D).

The Multispectral Image Analysis System (MIAS), part of ATES, was used to do multi-image density slicing. The ability to display and combine both negative and positive images is a useful one, but because the machine was primarily intended to provide input to a photographic lab, registration is tedious and magnification is minimal.

2. ESIAC

Stanford Research Institute's ESIAC (Electronic Satellite Image Analysis Console) was used to analyze wetlands on repetitive ERTS imagery taken in the vicinity of Charleston, South Carolina, and Norfolk, Virginia (Serebreny, 1973). The following frames were entered on the ESIAC console:

Dismal Swamp — North Carolina/Virginia

10/10/72	1079-15142-5,7
1/26/73	1187-15145-5,7
2/13/73	1205-15150-5,7
6/1/73	1313-15150-5,7

Charleston, South Carolina — (1) Santee River
(2) Cooper and Wando Rivers

8/19/72	1027-15263-5,7
10/12/72	1081-15264-5,6
3/23/73	1243-15274-5,7
4/10/73	1271-15274-5,7
5/16/73	1297-15272-5,7
6/3/73	1315-15271-5,7

These data represent three time sequences, one over the Dismal Swamp, one over the Santee River Swamp (1), and one over the coastal marshes in the Charleston estuary and along the South Carolina coast (2).

ESIAC provides a sequential time-lapse capability for change detection. All images are carefully registered with the aid of a grid and a 2-band color composite for each date is output on a CRT, usually with band 6 or 7 in red and band 4 or 5 in cyan (simulated color IR). Gray scales may be added after the initial recording of partial images. Any number of composites can be cycled indefinitely on the CRT display, giving a good visual presentation of:

(1) Seasonal change in light intensity of earth surface due to the sun angle and atmospheric attenuation.

(2) Seasonal change in vegetation--deciduous trees reflect strongly in the IR in spring, less strongly in fall, and very weakly in winter when the leaves are off. Conifers, in contrast, show little seasonal change in reflectance.

(3) Seasonal change in the visibility of water or wet soil underlying wooded swamps as deciduous trees shed their leaves.

(4) Tidal effects as water stage changes in coastal marshes.

(5) Seasonal die-back of highly reflective fresh-water marsh vegetation which clearly defines the landward boundary of the wetlands.

In order to examine the usefulness of a 2-band ratio technique (Serebreny, 1973) as a possible method for separation of wetland from other scene elements, a number of sample measurements were made of large stands of vegetation and scene water using SRI's new two-dimensional color space capability. Study of these measurements indicated many possibilities for separation of vegetation--e.g., conifers vs. deciduous trees, fresh marsh vegetation vs. salt marsh vegetation.

3. Density Slicing

Several density slicing systems have been used for single band density slicing. These systems have a capability for area measurement which could be extremely useful. Wetlands, both inland and coastal, are very low in reflectance during some seasons, and density slicing from a single band may help to identify these areas. As far as the present study is concerned, density slicing appears to be of relatively little value for looking at marsh species or classifying marshes.

E. Machine Analysis Techniques--Digital Data

1. ERTS_ANALYSIS System

ERTS MSS data is available in computer-compatible tapes (CCTs) containing digital values in the four spectral bands. One pixel (Resolution element) represents the average reflectance level (radiance level) over an 80 x 80 meter field of view. The overlap of adjacent pixels in the E-W scan direction causes the actual unique field of view of each pixel to be 57 x 80 meters or approximately 0.45 hectare. ERTS digital data provides the users with the maximum spatial and radiometric resolution derivable from ERTS. These data can be manipulated either singly or in combination to extract information not readily available from analogue techniques (Schubert & MacLeod, 1973).

The ERTS_ANALYSIS System (Schubert & MacLeod, 1974) accesses ERTS CCTs directly and, by utilizing CCT header-record calibration data, produces a geographically referenced printer-plot map of analyzed data at an approximate scale of 1:20,000. The basis for vegetation analysis in this system is an automatic classification algorithm based on the International Biological Programme (IBP) classification system (Peterken, 1967). Vegetation-analysis look-up tables for coastal wetlands are incorporated into the ERTS_ANALYSIS System.

ERTS MSS digital data from the Chincoteague test area were analyzed using the ERTS_ANALYSIS System at GSFC. The following basic classes, typical of the central Atlantic coastal saline wetlands, were established: water (open), spoil and/or bare sand, sandy mudflat, marsh vegetation, and upland vegetation. The marsh vegetation was further subdivided into five major plant associations:

(1) Spartina alterniflora (saltmarsh cordgrass) association: included in this category are mixtures of S. alterniflora and Salicornia spp. (glasswort) and some pure stands of Salicornia spp. which seldom exceed 10-15 meters.

(2) Spartina patens (saltmeadow cordgrass) association: included with this species which grows on slight elevations in the marsh is Distichlis spicata (spike grass) which is only occasionally found in pure stands in this area.

(3) Iva frutescens (marsh-elder) association: this shrub grows in slight elevations in association with Spartina patens.

(4) Organic mudflat: usually covered with a low, sparse growth of Spartina alterniflora, Salicornia spp., or detritus, with occasional bare spots.

(5) *Juncus roemerianus* (needlerush) association: included with this species are *Scirpus* spp. (threesquares).

Seasonally determined ISCO spectral reflectance curves for wetland plant associations and features were used to provide information on discrimination. This information includes optimum dates for separation of classes, ERTS MSS bands giving maximum separation, and ranges of reflectance values within these bands in each season. Assuming a uniform response curve for the MSS sensors, ISCO percent reflectance values over spectral bandwidths corresponding to MSS bandwidths were averaged to give a single reading for each band for each date. Figures 6 and 7 show the ISCO measurements of seasonal variation in reflectance of *Spartina patens*, *Spartina alterniflora*, and *Iva frutescens* in ISCO band 5 and 7 equivalents. The reflectance of spoil and mudflats is also shown.

Two look-up tables were developed for use in the ERTS_ANALYSIS System. The first, called MARSH (Table 2), is a stepwise classification using MSS ERTS band 7 digital values to separate open water, MSS band 5 analysis to perform the initial separation of vegetation on the basis of chlorophyl absorption and, finally, using MSS band 7 to separate closely related plant communities based on canopy structure and background. MSS band 4 data are also used to discriminate classes not completely separable in MSS band 5. The second look-up table, called MARSH4 (not shown), is a stepwise classification making initial separation of wetland classes on the basis of MSS band 7 and final separation on the basis of MSS band 4. MSS band 5 digital values are used to separate classes with a high MSS band 7 reflectance. Both look-up tables were developed for October data. When radiometrically normalized data from other dates are analyzed, MARSH analysis is successful

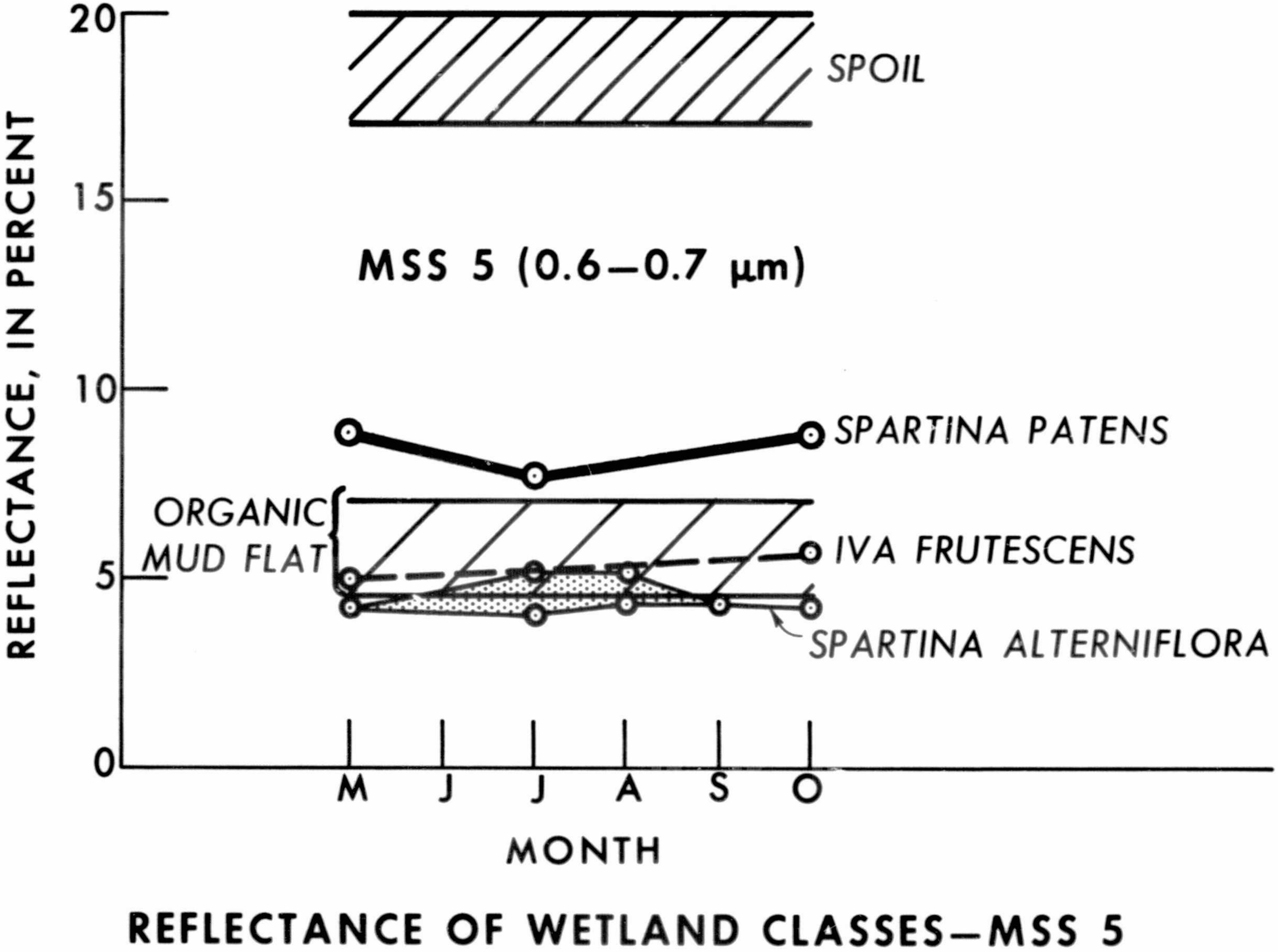


Fig. 6. Seasonal reflectance values of wetland features in the spectral region corresponding to ERTS MSS band 5.

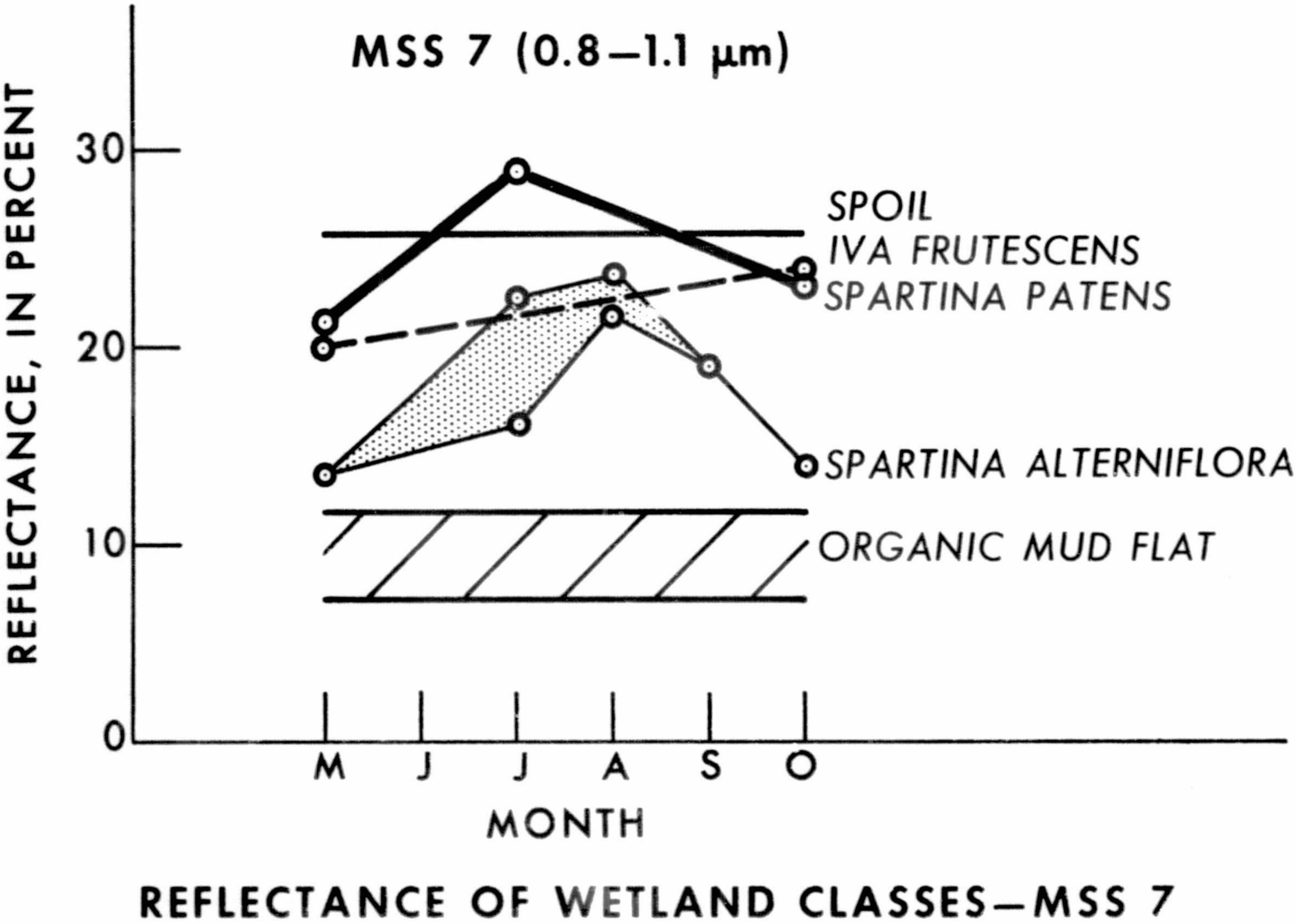


Fig. 7. Seasonal reflectance values of wetland features in the spectral region corresponding to ERTS MSS band 7.

TABLE 2: MARSH: ERTS MSS SIGNATURE ANALYSIS FOR COASTAL WETLANDS[1]

<table>
<tr><th rowspan="2">MSS 7 Digital Values</th><th colspan="5">MSS 5 Digital Values</th></tr>
<tr><th>>55</th><th>40-55</th><th>23-39</th><th>15-22</th><th><14</th></tr>
<tr><td><5</td><td colspan="5">Water (.)</td></tr>
<tr><td>5-6</td><td rowspan="2">Sandy mud flat (-)</td><td rowspan="4">Scrub over sand (:)</td><td rowspan="4">Spoil* (+)
or
<u>Spartina patens*</u> (P)</td><td colspan="2">Organic mud flat (/)</td></tr>
<tr><td>7-10</td><td colspan="2"><u>Spartina alterniflora</u> (A)</td></tr>
<tr><td>11-14</td><td rowspan="3">Bare soil or sand (_)</td><td rowspan="3"><u>Spartina patens</u> (P)</td><td><u>Iva frutescens</u> (I)</td></tr>
<tr><td>15-21</td><td>Deciduous trees (D)</td></tr>
<tr><td>22-26</td><td rowspan="2">Herbs, grass over sand (:)</td><td rowspan="2">Herbs* and grasses (#)
or
<u>Spartina patens*</u> (P)</td><td>Trees bushes (B)</td></tr>
<tr><td>>27</td><td>White beach or desert sand (=)</td><td colspan="2">Grass (G)</td></tr>
</table>

[1]Modification of existing ERTS MSS signature analysis for International Biological Programme vegetation classes (Schubert and MacLeod, 1974).

*MSS 4 used for final separation.

in identifying wetland classes but MARSH4 is not because of atmospheric effects on MSS band 4.

2. LARSYS (Remote Terminal GSFC)

Bendix 24-channel scanner data were collected during July 1972 (NASA Mission No. 207) over three test areas in the northern test site. The LARSYS remote terminal at GSFC and a set of programs developed by LARS (Purdue University) have been used in analysis of these data.

3. General Electric IMAGE-100

A preliminary analysis of ERTS digital data from the Dismal Swamp, February 13, 1973 (1205-15150), and the Georgia coast, September 7, 1972 (1046-15324), was made using General Electric's IMAGE-100, an interactive multispectral analysis system.

V. RESULTS OF DATA ANALYSIS

The results of analysis of ERTS data are presented in this section of the report. The use of aircraft data has been discussed previously; only the results from the Northwest River study are discussed here.

A. Typing or Classification of Wetlands

This project has attempted to determine the applicability of ERTS data for coastal wetland typing or classification. A wetland classification system based on satellite data would be useful for making and updating coastal inventories. Shaw and Fredine (1956) suggested classification of coastal marshes into the following types on the basis of vegetation and inundation:

Type 12 - coastal shallow fresh marshes

Type 13 - coastal deep fresh marshes

Type 14 - coastal open fresh water

Type 15 - coastal salt flats

Type 16 - coastal salt meadows

Type 17 - irregularly flooded salt marshes

Type 18 - regularly flooded salt marshes

Type 19 - sounds and bays

Type 20 - mangrove swamps

Some of these categories can be differentiated using ERTS imagery. The differentiation is based largely on the reflectance differences of indicator species (e.g., _Spartina alterniflora_ [Type 18], _Juncus roemerianus_ [Type 17], or _Spartina patens_ [Type 16]). Type 20 does not occur in our test area. Although ERTS cannot be used to ascertain water depth, Type 14 and Type 19, which are based on water depth, could be classified by using available bathymetric data in conjunction with areas of water detected with ERTS data. We have not successfully differentiated Type 15 with ERTS images. It would be very difficult to separate Type 12 from Type 13 because it is based on water depth; a single category--fresh marsh--can be delineated.

A broad classification according to water salinity is possible because the overall species composition is sufficiently different within each category to make it spectrally unique. Figure 4 is a map of the Charleston, South Carolina, coastal marshes (Anderson et al., 1973c). The map was made using a zoom transfer scope and images 1081-15264-5,7 (12 October 1972) and 1243-15274-7 (23 March 1973). The wetlands are typed or classified according to the following salinity categories:

Category 1.--Salt marsh containing predominantly *Spartina alterniflora* with the following subdominants present in varying amounts, usually at or near the upper wetland boundary: *Juncus roemerianus*, *Salicornia* spp. (glasswort), *Distichlis spicata* (spike grass), *Spartina patens* (salt meadow cordgrass), *Borrichia frutescens*, and *Iva frutescens* (marsh-elder). This is Shaw and Fredine's Type 16 and 18 coastal marsh.

Category 2.--Near-saline to brackish marsh containing predominantly *Juncus roemerianus* with stream channels bordered by *Spartina alterniflora* at the more saline and *Spartina cynosuroides* at the fresher end. Subdominants in this area may include *Distichlis spicata*, *Salicornia* spp., *Spartina patens*, *Scirpus* spp., and *Iva frutescens*. This is Shaw and Fredine's Type 17 coastal marsh.

Category 3.--Brackish to fresh marsh containing large stands of *Spartina cynosuroides* along stream margins with *Scirpus americanus* or *Olneyi* (threesquare) or *Juncus roemerianus* often filling in the remaining area. Subdominants include *Scirpus* spp., *Zizania aquatica* (wildrice), and *Juncus* spp. As the water becomes fresher, *Sagittaria* spp. (arrowhead), *Nuphar advena* (yellow water lily), *Pontedaria cordata* (pickerelweed), *Peltandra virginica* (arrow arum), *Lilaeopsis chinensis*, and *Typha* spp. (cattail) become co-dominants with *Spartina cynosuroides*. This is Shaw and Fredine's Type 12 and 13 coastal marsh.

As the water becomes less saline, the species mixture is more complex and increasingly dominated by broad-leafed emergents such as *Z. aquatica*, *Sagittaria* spp., *N. advena*, *P. cordata*, and *P. virginica*. The reflectance of the marsh vegetation approaches that of upland species, making the upper wetland boundary difficult to ascertain on imagery taken during the growing season. The areal extent of spectrally unique communities of plants or monospecific stands was too small for discrimination with the imagery.

Classification of wetlands is very strongly linked to recognition of indicator species or spectrally separable plant communities. Accordingly, the next sections discuss the determination of wetland boundaries and the identification of wetland species or communities. Classification is discussed further in these sections where appropriate.

B. Identification and Delineation of Wetland Boundaries

1. Upper Wetland Boundary

The wetland/upland boundary in tidal marshes is of two general types. The first is a sharp change in topographic relief and a concomitant change in vegetational composition. In this type, there is a high contrast between two very different environmental situations and the boundary between wetland and upland is shown clearly on both photography and imagery. Both ERTS MSS bands 6 and 7 show the boundary very well (Figure 8, letter F).

The other general type of upper wetland boundary is a gradual change in topographic relief from wetland to upland. This gradual slope results in broad transitional vegetation zones which have their own peculiar plant species. When this type of boundary is present, it is considerably more difficult to detect or delineate with remote sensing techniques. Gray level changes across this transition zone are quite subtle on ERTS MSS bands 6 and 7, and hence the exact boundary is difficult to detect. Special photo processing techniques and color enhancement of gray levels are useful to aid in interpretation of these boundaries.

In slightly brackish and fresh-water marshes, the dominant vegetation may be dense and highly reflective. Determination of the upper wetland boundary during the growing season is difficult or impossible, whether the transition is abrupt or gradual; but winter imagery shows the boundary very clearly.

2. Land/Water Interface

The land/water interface can be determined on MSS band 7, but the location of this boundary depends to a large extent on tidal stage. In the interior of the marsh, where drainage patterns are complex and sparse patches of vegetation are interspersed with pools of water, the boundary cannot be determined with any real accuracy with ERTS. In the winter, these boundaries may be quite different than those located during the growing season.

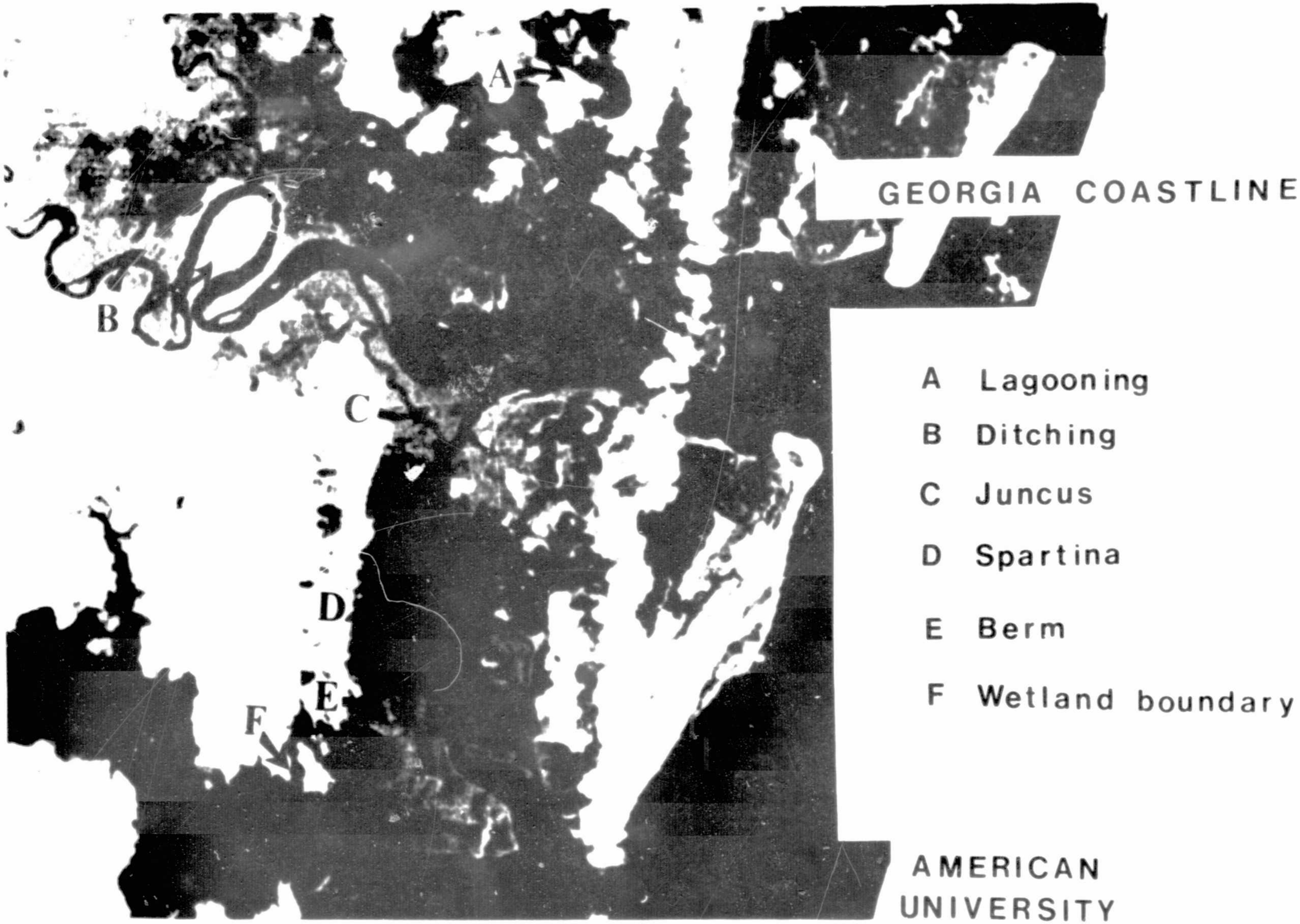


Fig. 8. ERTS image enlargement (1046-15324-7), Sept. 7, 1972, of the Ossabaw Island, Ga., area showing features and species composition.

C. Determination of General Species Composition

1. Northern Test Site--Nanticoke River, Chesapeake Bay, Maryland

The general vegetative composition of this area is typical of near-saline to slightly brackish tidal marshes of the central Atlantic coast. The areal extent of plant communities range from small to very large. These marshes represent Shaw and Fredine's Type 17.

A detailed vegetation map (Figure 9) was produced from the 7 July 1973 MSS 7 image (1349-15134) and the 30 August 1973 MSS 7 image (1403-15124). Two different dates were used in order to evaluate the tidal differences. The imagery was placed in a Bessler enlarger and tonal patterns traced by hand. The general categories identified are listed in order of decreasing reflectivity: tree island, high marsh, low marsh, low marsh/water, and water. The high marsh includes those plant species and communities which are generally found above mean high water. The vegetation is usually dense, with little background reflectance and soil moisture. The high marsh category is more reflective and images lighter on MSS band 7 than other marsh categories. This category is made up of varying amounts of *Spartina cynosuroides*, *Spartina patens*/*Distichlis spicata* association, *Iva frutescens*, *Baccharis halimifolia*, and *Phragmites communis*.

Low marsh covers the greatest area within the test site, and is composed mostly of large stands of *Juncus roemerianus*. Other species of the low marsh category, *Scirpus* spp., *Distichlis spicata*, *Spartina alterniflora*, and *Salicornia* spp., may be found in homogeneous stands but are predominantly seen in large mixed-plant communities. *Juncus* stands were indistinguishable from *Scirpus* stands or mixed *Juncus* and *Scirpus* communities.

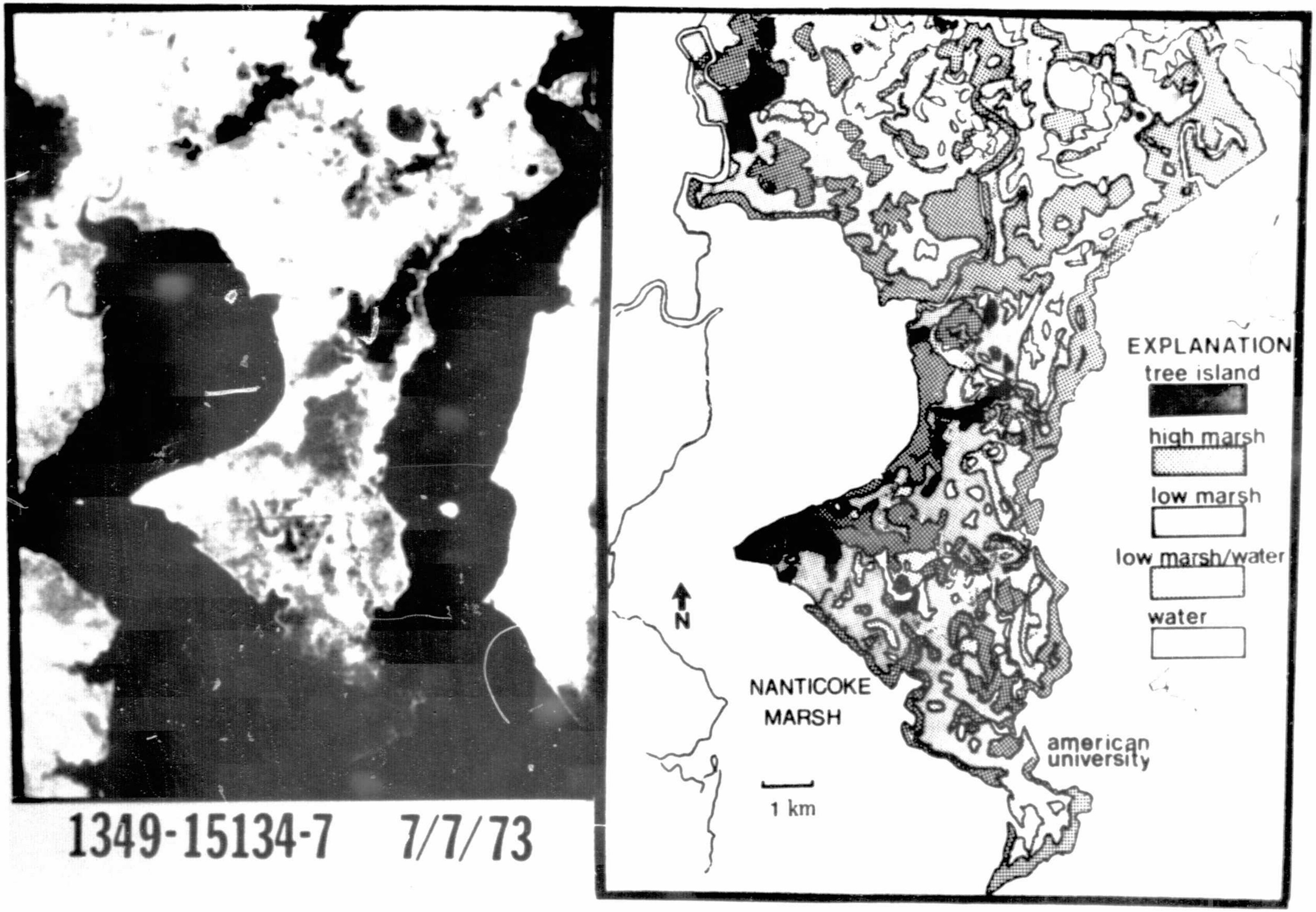


Fig. 9. Wetland map made from an enlarged ERTS image of the Nanticoke River marsh.

Low marsh/water contains shorter _Juncus_ and _Scirpus_ stands, or areas with sparse plant cover which exhibit a very low reflectance in MSS band 7 due to the water background. In many instances, it is impossible to determine the interior low marsh/water interface using satellite data.

High and low marsh patterns on the ERTS imagery are more distinct in summer than in winter, due to the greater differences in reflectance of growing vegetation. Seasonal development or change within the high marsh category can be distinguished by comparing the spring and summer imagery. Increases in reflectance are especially noticeable in the areas bordering streams and water bodies of the marsh interior in MSS 7.

An attempt was made to establish the size a plant community must be to be detected on the ERTS imagery. Comparisons of aerial photography and large-scale photomaps with ERTS data indicated that most marsh features visible from satellite were larger than 160 meters by 120 meters. Enlargements of MSS band 7 imagery show small tree islands (approximately 30 meters by 60 meters). This could possibly be due to the Spread function (Schade, 1974), where bright features are more easily detectable on dark backgrounds than are dark features on bright backgrounds. The critical factor for an object's detectability is contrast.

Small creeks and streams between 20 meters and 40 meters wide are detectable on the ERTS imagery. These streams are flanked by high marsh vegetation which provides contrast, while the convoluted and linear characteristics of the stream aid its detectability. Small tidal pools are very difficult to detect, and manipulation of negative images was helpful when attempting to determine some interior water areas.

2. Northern Test Site--Chincoteague Bay, Virginia

This area is typical of northern coastal saline marshes. The vegetative composition is relatively simple, with only a few dominant species. It was used to test the feasibility of mapping this type of wetland using both analog and digital data.

Analog (visual) interpretation.--Figure 10 is a 1:250,000 scale enlargement of an ERTS MSS 7 image (ERTS image 1079-15140, September 7, 1972) of the Chincoteague salt marsh complex and a 1:250,000 scale map of the same area showing four categories: (1) upland vegetation and beach, (2) water, (3) *Spartina alterniflora*/*Salicornia* spp. association, and (4) *Spartina patens*/*Distichlis spicata*/*Iva frutescens* association. The map was made using a zoom transfer scope. The spectral reflectance of the *Spartina alterniflora*/*Salicornia* spp. association was generally low, in part because of the wet mud or peat background below the vertically oriented vegetated layer. The relatively high reflectance of *Spartina patens* permitted sufficiently large areas of the *Spartina patens*/*Distichlis spicata*/*Iva frutescens* association to be delineated. The upper wetland boundary was generally sharp except where broad transition zones exist. The marsh-water interface was sometimes difficult to determine in areas interlaced with numerous small tributaries or sparse patches of vegetation. Sand and marsh at the mouth of Chincoteague Bay (A) are not shown on the USGS 1:250,000 map (Eastville; NJ 18-8,11) published in 1946. Spoil areas (B and C) may be easily separated from reflective vegetation by referring to bands 4 and 5 or by using a color composite, since they are highly reflective in all four bands. Fresh-water impoundments (D) in the Chincoteague Wildlife Refuge are also discernible.

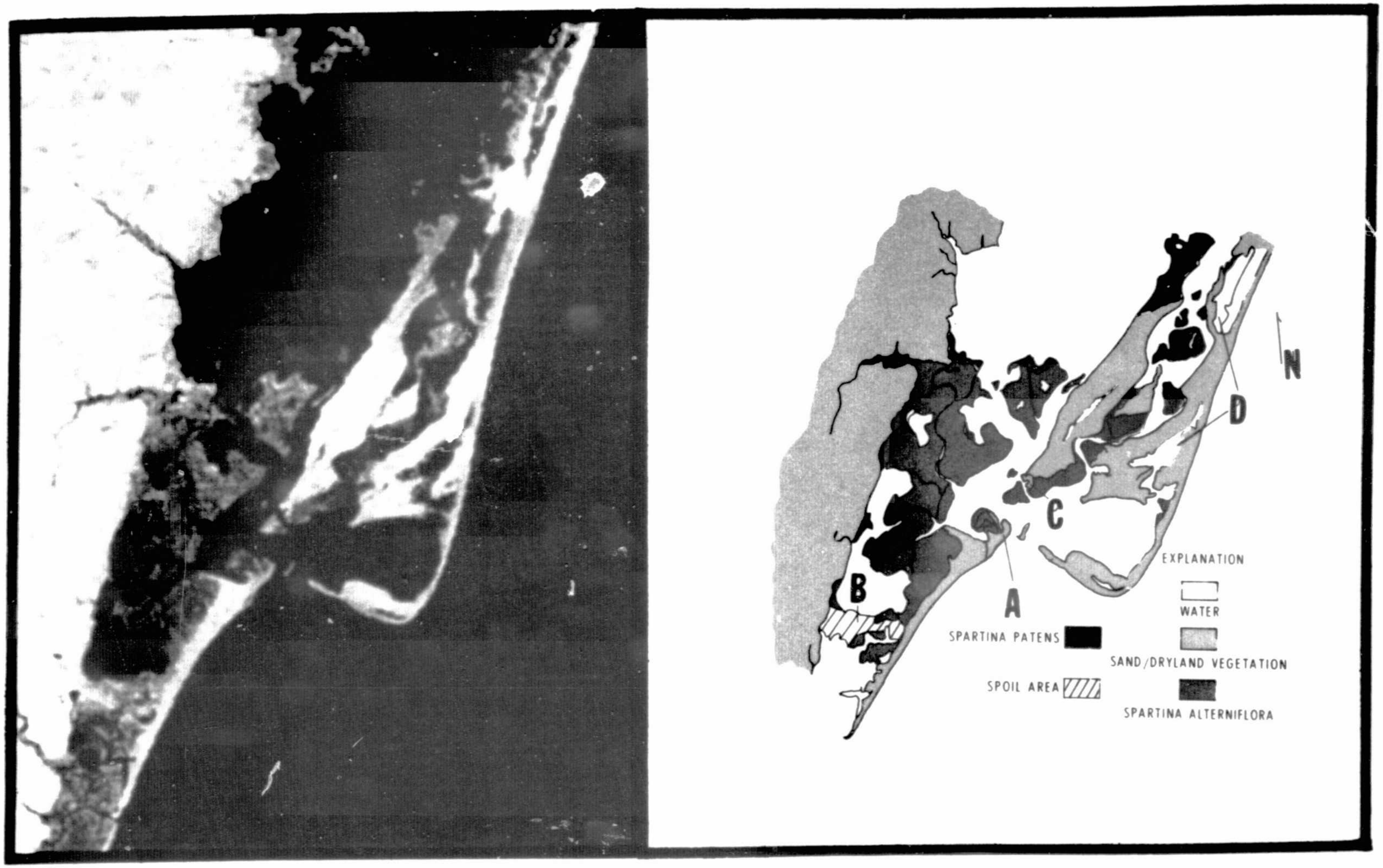
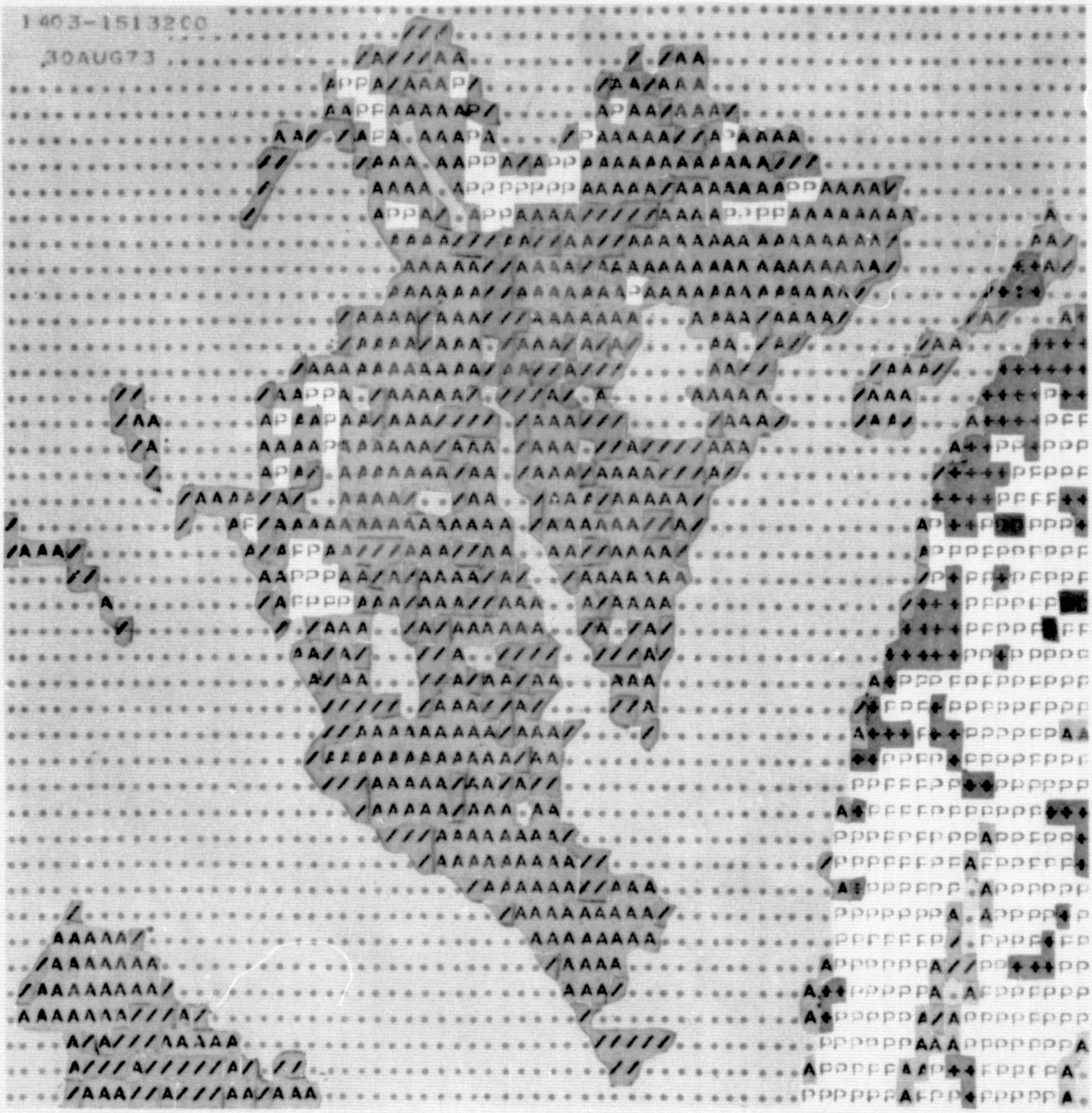


Fig. 10. Vegetation map of a salt marsh, Chincoteague Bay, Va., made from an enlarged (1:250,000) ERTS image 1079-15140-7. Letter A refers to sand/marsh area, B to old spoil area, C to recent spoil fill and D to fresh water impoundment.

Digital interpretation.--Figure 11 is the computer map generated using the coastal wetland look-up table MARSH in the ERTS_ANALYSIS System to analyze data from August 30, 1972 (1403-15132). The printer-plot maps for October 10, 1973 (1079-15140) made with look-up tables MARSH and MARSH4 (not shown) are very similar (Carter & Schubert, 1974).

The major difference between the maps of the marsh island is loss of *Iva frutescens* as an identifiable class in August. It is included in either the *Spartina alterniflora* association or the *Spartina patens* association. This could be predicted from the spectral reflectance curves (Figures 6 and 7) because the separation of *Spartina patens* and *Iva frutescens* is based on MSS 5 and the separation of *Spartina alterniflora* and *Iva frutescens* is based on MSS 7. The relative amounts of *Spartina alterniflora* (A) and organic mudflat (/) are somewhat different on the two dates. This separation is dependent on vegetation density, which changes during the growing season. On the small island between Chincoteague marsh and the mainland, spoil (+, :) and upland vegetation (D, B, #, G) are identified. The sandy mudflat class is not represented. Extensive areas of sandy mudflat are only exposed at very low tide. The predicted tide height for October 10, 1973 and August 30, 1973 was approximately 0.6 meters above mean sea level (MSL). Therefore, differences in the two maps are not related to tidal stage.

The marsh island is approximately 3.0 kilometers E-W and 3.3 kilometers N-S. Table 3 shows the size of the marsh as planimetered (including interior water) from the 1:24,000 scale USGS map (Chincoteague West, 1965) and as calculated from the October (MARSH and MARSH4 analysis) and August (MARSH analysis) maps. There is a 2 percent difference



WORK SUPPORTED BY USGS, NASA/GSFC, AND THE AMERICAN UNIVERSITY

SYMBOL EXPLANATION

.	WATER	A	*SPARTINA ALTERNIFLORA*
/	ORGANIC MUD FLAT	P	*SPARTINA PATENS*
+	SPOIL	I	*IVA FRUTESCENS*
:	SPOIL	D	UPLAND VEGETATION

Fig. 11. ERTS digital classification of a marsh in Chincoteague Bay, Va., using bands 4, [illegible], and 7. Image 1403-1[illegible]132, Aug. 30, 1973.

Table 3

CHINCOTEAGUE MARSH AREA MEASUREMENTS IN HECTARES

	Planimeter-USGS 1:24,000 Topographic Map	Oct. '72 MARSH4 Analysis	Oct. '72 MARSH Analysis	Aug. '72 MARSH Analysis
Total Area	387	381	381	386
Total Marsh	--	337	337	353
Total Water	--	44	44	33
Low Marsh (A & /)	--	312	311	331
High Marsh (P & I)	--	25	26	22

between the total area of marsh planimetered and that calculated from the map by pixel count in October. There is less than 1 percent difference between the planimetered area and the calculated areas from August.

The look-up table MARSH has been successfully tested on secondary sites in upper Chincoteague Bay, lower Delmarva Peninsula, and Charleston, South Carolina. It has also been tested on the near-saline Nanticoke marsh in Chesapeake Bay in October. Separation of the *Juncus roemerianus* and *Spartina alterniflora* classes was unsuccessful on that date.

3. Southern Test Site--Ossabaw Island, Georgia

The major vegetative types which dominate the frequently inundated saline and near-saline marshes of the southeast coast are *Spartina alterniflora* and *Juncus roemerianus* (Chapman, 1970; Odum, 1961; Reimold et al., 1972, 1973). *S. alterniflora* occurs as at least two, and in some areas three, growth forms. Apparently this is related to tidal inundation and soil aeration (Adams, 1963; Romig and Cotnoir, 1971). High growth (to 3 meters) is found along the banks of creeks where the substratum is very soft and tidal inundation is longest. The next growth form (to 1 meter) is found at a slightly higher elevation in a more firm substratum. The third growth type (less than 1 meter) is at the highest elevation for *S. alterniflora* in a firm substratum where other species may mix with it occasionally. *Juncus roemerianus* occurs as small to large zones mostly at the next highest elevation or where the water is somewhat fresher. The highest elevations in the southern test site contain mixed communities of *Salicornia* spp., *Iva frutescens*, *Batis maritima*, *Borrichia frutescens*, and *Distichlis spicata*. Large stands of *Spartina patens* are relatively rare. *Spartina cynosuroides* is common in near-saline areas.

Figure 8 shows the marshes in the vicinity of Ossabaw Island, Georgia. D, the dark, mottled area with light borders, contains predominantly Spartina alterniflora; C is an area affected by fresh water discharge from the Ogeechee River. The dominant species is Juncus roemerianus. Spartina cynosuroides dominates the brackish marsh, B, with Typha spp. and Scirpus spp. as subdominants. At E, on a slightly elevated berm or levee, are extensive mudflats, sparsely populated with Salicornia spp., patches of Borrichia frutescens, and low growth Spartina alterniflora.

Thematic extractions of coastal marshes in Georgia were made with the GE IMAGE-100. These include: (1) total marsh; (2) saline marsh, Spartina alterniflora dominant; (3) near-saline marsh, Juncus roemerianus dominant; (4) fresh marsh, Spartina cynosuroides dominant; and (5) high levees composed of mudflats with sparse vegetative cover (Figure 12). The identification and location of these features appear to be quite accurate.

D. Effects of Tidal Stage on Interpretation

Differences in scene reflectance from date to date are partly caused by variation in soil moisture or water background. Such differences cause some difficulties in interpretation. However, a variety of useful information is provided for wetland analysis from images taken at different tidal stages.

Images taken over the Georgia coast, Ossabaw Island area, Port Royal Sound, South Carolina, and Nanticoke marsh, Chesapeake Bay, on different dates were analyzed for effects of tidal height on imagery interpretation. In addition, ERTS images and U-2 photography from different dates over

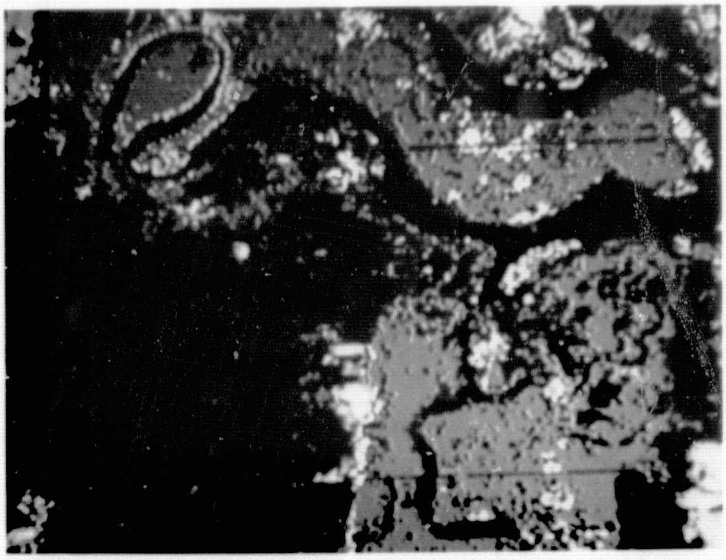


Fig. 12. General Electric Image 100 theme extraction of the Ossabaw Island, Ga., area. ERTS image 1046-15324, Sept. 9, 1972. The color blue is *Juncus roemerianus*, red is *Spartina cynosuroides*, yellow is mudflat, pink is *Spartina alterniflora*, black is upland and white is clouds.

the Charleston, South Carolina, area were used to examine tidal effects in the upper reaches of tidal rivers. The approximate time of imagery relative to high or low tide, tidal height above mean low water, and tidal range were calculated using the Tide Table--"High and Low Water Predictions for the East Coast of North and South America," 1972 and 1973, published by the National Ocean Survey, Washington, D.C. The calculations are approximate; factors of rainfall, wind direction, and velocity affect actual tidal conditions. Because the tidal range is very different, the results for the southern test site and the northern test site are discussed separately below.

Tidal information for Ossabaw Island, Georgia, is summarized in Table 4 (Anderson et al., 1973c). Figure 3 shows the location of tidal reference stations in Georgia used for the calculations. Figures 13 (8/2/72), 14 (8/19/72), 15 (9/7/72), and 16 (3/23/73) are MSS-7 images of the Ossabaw Island test site on the Georgia coast. Examination of this imagery shows the following:

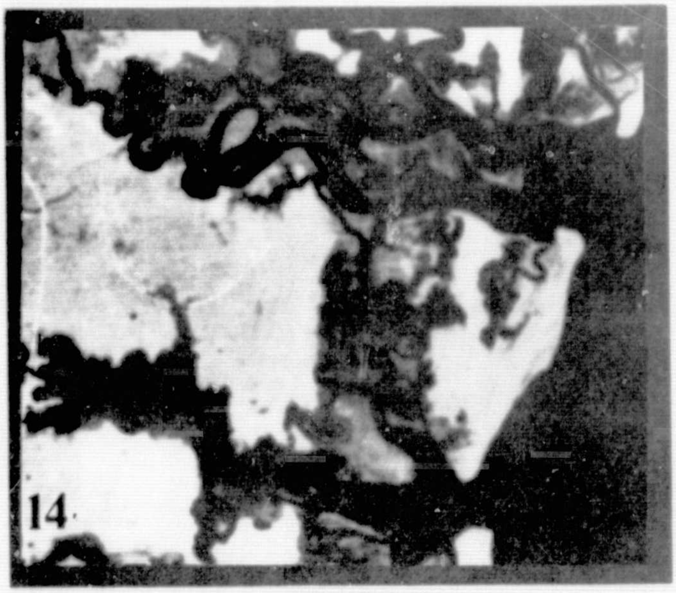
(1) Drainage patterns show clearly in the 8/2/72 and 8/19/72 imagery when the approximate tide height was very low. "A"(in all figures) indicates the location of a high berm or levee where mudflats, Borrichia frutescens, and Spartina alterniflora predominate. The levee can barely be resolved on the 8/19/72 imagery, but can be seen on the 8/2/72 imagery. This is probably because a light cloud cover on 8/19/72 reduces the contrast in the scene; tree islands are also difficult to locate. The berm can be seen on both the 9/7/72 and the 3/23/73 images.

(2) Examination of the 9/7/72 image, when the tide height was about mid-tide, shows good differentiation between low growth and high growth

TABLE 4
TIDAL INFORMATION CORRELATED WITH ERTS IMAGERY
OSSABAW ISLAND, GEORGIA

ERTS Image # and Date	Location #	Tidal Range (ft.)	Time Referenced to Tidal Stage	Approx. Tide Height (ft. above Mean Low Water	Comments
1010- 15322 8/2/72	*1	7.7	2 hrs 4 min after LW	2.1	Some cloud cover; drainage detail excellent; relatively little species difference.
	*2	8.3	2 hrs 37 min after LW	2.7	
	*3	8.7	3 hrs 4 min after LW	3.6	
1027- 15265 8/19/72	1	4.5	12 min before LW	1.1	High, thin cloud cover over test site; drainage detail fair; almost no detail in marsh.
	2	6.1	19 min after LW	1.1	
	3	6.5	48 min after LW	1.4	
1046- 15324 9/7/72	1	7.9	1 hr 58 min after HW	6.1	Relatively cloud-free; drainage detail obscurred in darker portions of marsh; marsh detail excellent.
	2	8.5	2 hrs after HW	6.4	
	3	8.9	2 hrs 17 min after HW	5.8	
1243- 15280 3/23/73	1	6.8	1 hr 34 min before HW	5.5	Cloud-free; drainage detail excellent; marsh detail excellent.
	2	7.4	1 hr 40 min before HW	6.0	
	3	7.8	1 hr 15 min before HW	6.8	

*1 - Ft. McAllister, Ga.; 2 - Sunbury, Ga.; 3 - Kilkenny Creek, Ga.



A. Berm

B. Spartina alterniflora (high growth form)

C. Spartina alterniflora (low growth form)

D. Juncus roemarianus

E. Spartina cynosuroides

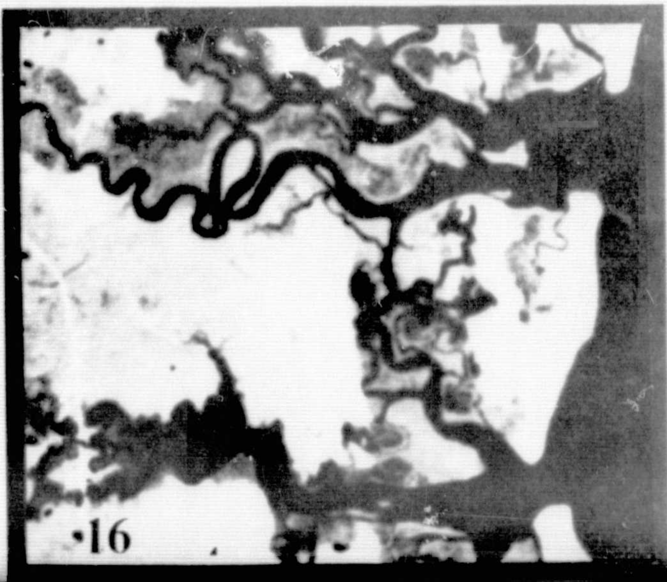


Fig. 13. 1010-15322, 8/2/72

Fig. 14. 1027-15265, 8/19/72

Fig. 15. 1046-15324, 9/7/72

Fig. 16. 1243-15280, 3/23/73

forms of Spartina alterniflora. Areas of creek-side and creek-end Spartina alterniflora are light in tone (B). Low growth forms of Spartina alterniflora occur on high ground, but grow so sparsely that the water shows (C, dark area). Areas containing predominantly Juncus roemerianus (D) can be separated from those containing predominantly Spartina alterniflora at this tidal stage since an overall light reflectance is characteristic of Juncus roemerianus in MSS band 7, whereas a mottled, dark-light appearance is characteristic of Spartina alterniflora when large amounts of background water are present. Fresher marshes containing Spartina cynosuroides and associated species (E) have a higher reflectance than the more brackish Juncus marshes and may be separated from them on this image. The color composite from 8/2/72 shows these same reflectance differences except that, because of a lower tidal stage, no difference is discernible between the growth forms of Spartina alterniflora.

(3) The 3/23/73 imagery was taken at an intermediate water level. While direct comparisons may be made between images from the other three dates, the question on seasonal effects upon the imagery was raised here. March 23 is very near the beginning of a new growing season in the Georgia marshes, and it is highly probable that much of the detail within the saline marsh is due to the presence or absence of water rather than the reflectance of Spartina alterniflora. Drainage patterns are very clear and low areas containing water can be delineated with ease. Areas of Juncus roemerianus and Spartina cynosuroides cannot be separated, but the upper wetland boundary of the marsh can be detected further inland than on the late summer and fall imagery. The detritus is only moderately reflective, and less vegetation is present to mask underlying moisture.

Tidal stage, range, and height above mean low water was calculated for twelve ERTS images of the Nanticoke marsh. Table 5 presents the results of the tidal analysis for the Nanticoke imagery from September 23, 1972 through August 30, 1973. Two tidal reference stations, approximately five miles apart on either side of the Nanticoke River test site (Roaring Point, Maryland, and Fishing Point, Fishing Bay, Maryland) were used to estimate the approximate water depth within the marsh. These stations did not differ in calculated water depth on six of the image dates, but did differ as much as 0.7 m (0.2 feet) on the other six image dates. The greatest tidal height estimated for the marsh was 7.6 m (2.5 ft) on February 13, 1973. Lowest tidal height estimated for the marsh was -0.6 m (-0.2 ft) on August 30, 1973.

The high marsh category is composed of plant species generally found above mean high water. Tidal stage did not appear to affect the tonal patterns of the high marsh category.

Tonal differences within the low marsh and low marsh/water categories were related to tidal stage. Greater water depth in the marsh resulted in a darker appearance of the low marsh and low marsh/water categories in MSS bands 6 and 7 (5/14/73, 7/7/73, and 8/12/73). Greater marsh detail is available during periods of low water (10/10/72 and 8/30/73), when the interior low marsh and low marsh/water categories can be more easily separated.

The tidal amplitude may also be a factor contributing to the reflectance differences in the marsh. Greater flooding during spring tides (ranging 1.03 m in the Nanticoke area) requires more drainage time and a

TABLE 5

TIDAL INFORMATION CORRELATED WITH ERTS IMAGERY

NANTICOKE RIVER TEST SITE

DATE	ERTS IMAGE #	STATION	TIDAL STAGE	TIDAL RANGE (ft)	APPROX TIDAL HEIGHT (ft.)
23 Sep '72	1062-15190	*1	2 hrs 19 min A LW	3.0	0.9
		*2	2 hrs 20 min A LW	3.2	0.9
10 Oct '72	1079-15133	1	26 min A LW	2.5	0.2
		2	27 min A LW	2.7	0.2
11 Oct '72	1080-15192	1	3 min B LW	1.9	0.3
		2	2 min B LW	2.1	0.3
3 Dec '72	1133-15141	1	2 hrs 11 min B HW	2.4	1.7
		2	2 hrs 15 min B HW	2.6	1.9
9 Jan '73	1170-15193	1	1 hr 3 min B LW	1.7	-0.1
		2	1 hr 2 min B LW	1.9	-0.1
26 Jan '73	1187-15140	1	2 hrs 38 min A HW	1.7	1.3
		2	2 hrs 34 min A HW	1.9	1.4
13 Feb '73	1205-15141	1	14 min B HW	2.1	2.3
		2	18 min B HW	2.3	2.5
14 May '73	1295-15142	1	1 hr 56 min B HW	2.0	1.7
		2	2 hrs B HW	2.2	1.6
1 Jun '73	1313-15141	1	1 hr 56 min A LW	1.9	0.2
		2	1 hr 55 min A LW	2.1	0.2
7 Jul '73	1349-15134	1	2 hrs 53 min A HW	2.0	1.4
		2	2 hrs 49 min A HW	2.2	1.4
12 Aug '73	1385-15131	1	2 hrs 43 min B HW	2.0	1.5
		2	2 hrs 47 min B HW	2.2	1.4
30 Aug '73	1403-15125	1	27 min A LW	3.2	-0.2
		2	28 min A LW	3.4	-0.1

*Tidal reference station: 1. Roaring Point, Md., 2. Fishing Point, Fishing Bay, Md. abbreviations: A, after; B, before; LW, low water; HW, high water, Approximate tide height in feet above mean low water greater portion of the marsh remains moist longer. This water will tend to darken tonal patterns on the imagery and must be considered when mapping interior marsh areas.

E. Drainage Patterns

The extent and pattern of the natural drainage system in wetlands is important to know for a number of reasons. The density of the drainage network is usually related to the degree of tidal inundation and, therefore, to the vegetation. For instance, Spartina alterniflora will predominate in complex dendrite or braided patterns. The successional status and contribution of nutrients from the wetland may be inferred by drainage pattern.

This study indicates that drainage patterns can be interpreted from ERTS if the data are taken near low tide. Figures 13-16 illustrate this. When the tide is low, the more highly reflective exposed vegetation contrasts well with water that is confined mostly to the stream beds. At high tide, water floods much of the marsh and this contrast is lost.

F. Monitoring of Wetlands for Natural or Man-Made Reductions in Productivity

Natural reductions in productivity due to successional trends (e.g., wetland to dryland) must be ascertained over longer periods of time than this study permitted, but present baseline data will be extremely useful for this purpose. Deposition of silt causes a rise in land elevation relative to water level. Along the Atlantic coast, saline wetland succession usually proceeds along the following lines. Bare mudflats or vegetated shallow water areas are invaded by high growth Spartina alterniflora. Continued accretion of silt causes replacement by low growth Spartina alterniflora. As the elevation continues to increase, Spartina patens and/or Distichlis spicata become established (in areas with a fresh water source, this step may include Juncus). Further elevation through accretion brings Spartina cynosuroides and Phragmites communis in brackish water, and marsh shrubs such as Iva frutescens and Borrichia frutescens in both saline and brackish areas. The uppermost wetland communities often consist of Panicum virgatum and Baccharis halimifolia. Since each vegetational community is closely tied to marsh elevation, it is possible to determine the stage in succession. On a long-term basis, it should be possible to determine the rates of succession.

Wetlands affected by man's activities--such as damming and river flow diversion, dredge and fill, road construction and lagooning--can be detected with ERTS data. These are discussed below.

1. Damming and river flow diversion: The physical effects of each of these activities on an estuary or river are similar. Both alter rate of flow (cubic feet/second) and salinity gradients along coastlines. Dams may cause reductions in flow which result in greater intrusion of the "salt wedge" up the estuary. Flow diversions which increase water quantity may result in much lower salinities in the river and alter mixing patterns and gradients. Since most wetland plants and animals have rather clearly defined tolerances to inundation and salinity, damming and flow diversion can have a considerable effect on the biology of disturbed rivers and estuaries.

Figures 4(A) and 5 (Charleston, S.C.) show the Cooper River south of Lake Moultrie. Most of the ERTS images showed both branches of the river as unusually wide with no adjacent marshes. It appeared that the natural water levels were being affected by events other than tidal. The riverine drainage channel could be delineated from the 8/19/72 imagery when "predicted" tide height was relatively low (as calculated from tide tables). Imagery on 3/23/73 and color IR photography on 9/22/72 at "predicted" high or medium tide heights showed the marsh adjacent to the channel to be flooded. Only a thin line of vegetation along the original channel levees gave a strong vegetative signature. Field checking verified standing water in many of the areas shown on the map as marsh.

A search of the literature revealed that prior to construction of the Santee-Cooper project of the South Carolina Public Service Authority in 1942, the annual freshwater inflow to the Charleston Harbor estuary from the Cooper River was 2 cubic meters/second (72 cubic feet/second) (Ketchum, 1972). The annual inflow is now 15,000 cubic feet/second because of the construction of a diversion canal into the river. This accounts for the heavy flooding of this area, independent of tides. As a result of this project, sedimentation in the navigation channel adjacent to Charleston has increased from about 180,000 to 10,000,000 cubic yards per year, solid and domestic wastes are trapped in the estuary, and the salinity regime has been drastically decreased (Ketchum, 1972). A proposed Corps of Engineers project will redirect some of the water, thus altering the estuarine environment again.

2. Dredge, fill, and drainage activities: Because wetlands are low-lying, frequently or permanently flooded lands, they must be altered to make them habitable for man. Dredging of spoil from a part of the wetland or from river channels and depositing the spoil on another part to elevate the land for more suitable building sites is a common practice along the eastern coastline. Ditching for wetland drainage has also been extensively used to control mosquito populations. Spoil deposition and drainage permanently change wetlands to drylands. Analysis of ERTS data showed an excellent capability for detecting and, therefore, monitoring dredge, fill, and ditching activities. Areas of spoil disposal are illustrated on Figure 10 and also Figure 17. They appear as highly reflective zones within the less reflective, undisturbed wetland.

3. Lagooning for waterside homes: Spoil removed for lagoon construction is placed on the wetland for building sites. Figure 17 is an ERTS image of a portion of the New Jersey coast. Lagooning is easily observed, as well as other dredge and fill activities.

4. Highway construction: The impact of this activity is the impediment of water flow to or from wetlands because of bridges and causeways. Highway construction across wetlands is typically done by filling to the point of river or stream crossing, bridging, and then filling to the opposite shoreline. The restriction of water flow to the bridge opening may result in flooding of wetlands and changes in species composition. Figure 18 shows construction of highway I-95 along the Georgia coast. Wetland filling is easily observed and changes in species composition above or below wetland crossings could be monitored with ERTS.

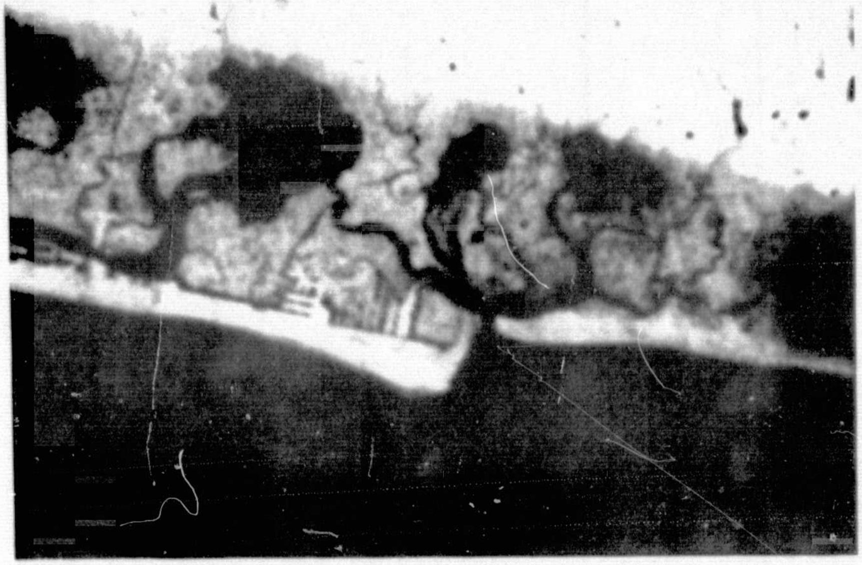


Fig. 17. ERTS image enlargement (1312-15032-7, May 31,1973) of New Jersey coast illustrating lagooning for water-side homes and spoil disposal in wetlands.

Fig. 18. ERTS image enlargement (1243-15280-7, Mar. 23, 1973) of Ossabaw Island, Ga., illustrating impact of highway construction on wetlands.

G. Biological Indications of Fresh-Water Discharge

Examinations of MSS-7 imagery of the Georgia and South Carolina coasts taken during the growing season suggests that good correlation can be established between the seaward extent of Juncus roemerianus marshes (near-saline to brackish) along river margins and coastal inlets and the amount of fresh-water discharge from the associated drainage basin.

For example, examination of the 9/7/72 imagery in the Ossabaw Island, Georgia, area shows that Juncus marshes along the Ogeechee River north of Ossabaw Island extend out into the embayed coastal marsh itself, along the southern margin of the river to within 4 river miles of the barrier beach front. Spartina cynosuroides marshes (brackish to fresh) extend to within 12 river miles of the beach front. A similar situation can be observed at the mouth of the Altamaha River, where Juncus and Spartina cynosuroides marshes are found in deltaic islands almost at the river's mouth. In the Newport River and Medway River, Spartina alterniflora marsh extends inland about 12 to 14 river miles from the seaward outlet of St. Catherine's Sound.

The size of the drainage basins and average annual discharge of the Ogeechee, Altamaha, and Newport Rivers are grossly predictable from these observations, with the Altamaha representing an extremely high average annual discharge, the Ogeechee a moderately large average annual discharge, and the Newport a rather small average annual discharge. Table 6 presents a part of the available data on each riverine system (Inman, 1971; Dyar et al., 1972).

While salinity of water is not the only factor contribution of vegetation in estuarine rivers, it does play a dominant role. Juncus

TABLE 6
DRAINAGE AREA AND AVERAGE DISCHARGE
OF SELECTED GEORGIA COASTAL RIVERS

Riverine System	Drainage Area	Average Discharge
1. Althamaha River 3/ Doctortown, Georgia (59 miles above mouth)	13,600 square miles	13,400 cfs (30 years record)
Penholoway Creek	210 square miles	229 cfs (30 years record)
TOTAL	13,810 square miles	(13,629 cfs)
2. Ogeechee River 3/ N. of Eden, Georgia -- main stem of Ogeechee R.	2,650 square miles	2,317 fs (30 years record)
Canoochee River	555 square miles	446 cfs (30 years record)
TOTAL	3,205 square miles	2,763 cfs
3. North Newport River 4/	very small; less than 150 square miles	mean annual runoff 0.6 cfs m; (cu ft/sec/mile) (3 years record)

roemerianus, found in highly saline coastal marshes, is frequently in a zone surrounding upland vegetation--tree or barrier islands or along the inland upper wetland boundary. These zones may occur in areas of fresher ground water seepage; actual outflows of fresh water may occasionally be found just on the inland border of the zone if there is a slight rise in topography.

H. Results of Interpretation of Supporting Aircraft Data

1. Northeast River Study Results

A study was initiated in the spring of 1972 to determine the source of sediment in the upper Northeast River, Maryland. Underflight photography was used extensively for this study. The sediment was clearly visible on both color and color IR aerial photography from NASA aircraft missions 166 (May 1971) and 144 (September 1970), both flown at 60,000 feet.

Two major sources of sediment, located as a result of considerable field work and analysis of color photography, are as follows:

(a) Runoff from agricultural fields into both the Big and Little Northeast Creeks, major tributaries of the Northeast River; and

(b) Discharge effluent from sand and gravel washing operations in the Little Northeast Creek and some other minor tributaries.

The removal of natural ground cover adjacent to the river and its tributaries for agricultural purposes appears to be a contributing factor to the large sediment content of the river water following moderately heavy and heavy rains.

Algal blooms were also visible on the photography, and it was subsequently discovered that raw sewage overflow enters upper Northeast River via a small unnamed tributary. Although a direct relationship between the algal blooms and sewage effluent was not established in this program, studies in other areas have shown a cause-and-effect relationship between sewage effluent and algal blooms.

The aerial photographs were also used to estimate tree and shrub cover on tributary basins and to identify land use in the area. The photography was not useful for actual location of sediment sources because ground truth was not collected during the overflight, and the high altitude made pinpointing sources of sediment from smaller tributaries difficult to establish.

2. Bendix 24-Channel Scanner

Data from the Bendix 24-channel scanner (Mission 207) was tested on the LARSYS at GSFC. Data from a small fresh-water marsh along the Patuxent River were analyzed. Ten channels appear to have potential value for mapping wetland species. These channels are:

0.38 — 0.40 micrometers
*0.40 — 0.44 micrometers
*0.53 — 0.58 micrometers
*0.59 — 0.64 micrometers
0.72 — 0.76 micrometers
0.77 — 0.81 micrometers
0.82 — 0.88 micrometers
0.98 — 1.05 micrometers
*1.06 — 1.10 micrometers
1.20 — 1.30 micrometers

The four which appear most useful for fresh-water marshes are indicated by an asterisk (*).

VI. SUMMARY AND CONCLUSIONS

ERTS data were analyzed to test their usefulness for a variety of coastal wetland ecology studies. Both digital data and imagery were analyzed: interpretation systems used in making these analyses were both manual and digital. Most of the original objectives of the project were accomplished, as summarized below.

A. Identification and Classification of Wetland Types

ERTS data were used to classify wetlands in several different ways. A zoom transfer scope was used to map three classes of wetlands--saline, near-saline to brackish, and brackish to fresh--in the vicinity of Charleston, South Carolina (southern test site). The classification was made using MSS bands 5 and 7 from a winter and late summer scene. The upper wetland boundary was determined with MSS 7 (winter), vegetative composition with MSS 7 (summer), and spoil was separated with MSS 5 (summer or winter). Identification of the dominant vegetation, Spartina alterniflora (saline), Juncus roemerianus (near-saline to brackish), or a highly reflective mixture of species (brackish to fresh) provided the basis for the classification. The boundaries between classes are not clearly defined because the vegetation forms a continuum between salt marsh species and those growing in fresh water.

In the Nanticoke River marsh (northern test site), three categories--high marsh, low marsh, and low marsh/water--were mapped. The basis for the classification was the existence of three vegetation communities, separable on the basis of reflectivity, whose species composition appears to be tied to elevation.

In the Chincoteague marsh, the ERTS_ANALYSIS System was used to identify six wetland classes using ERTS digital data. These classes are actually plant associations or wetland features which form a part of the saline marsh. They correspond, if combined together, with a high marsh, low marsh classification similar to that described above. They also represent several of the wetland classes suggested by Shaw and Fredine (1956). The same marsh was also mapped using imagery, but fewer classes were identified and many small areas were not detected.

Different wetland types or classes have different value for waterfowl and other wildlife. For this reason, it is impossible to say, for example, that a saline marsh is more valuable than a fresh marsh. When local primary productivity data have been collected and species are identified by ERTS, it is possible to say that certain marshes supply more nutrients to the estuarine system than others. Whether this is sufficient information to evaluate wetlands for wetland management purposes remains to be determined.

The identification of wetland classes was verified with field observations and high-altitude color IR photography. On the basis of this experimental work, it is believed that the same classes could be mapped in similar areas where photography is not available. Field work will probably always be needed to check accuracy of interpretation.

B. Delineation and Mapping of Wetland Plant Communities and Boundaries

As indicated above, vegetation associations in coastal wetlands can be identified and mapped using ERTS data. This was successfully done in both the northern and southern test sites. The presence of certain vegetative indicators plus the low reflectance of saline and brackish wetlands in the summer or of all wetlands in the winter would form the basis of any coastal wetland classification system for satellite data. It is unusual to be able to identify and map individual species using ERTS imagery except along the southern Atlantic coast, where very large monospecific stands of Spartina alterniflora or Juncus roemerianus occur. The probability of isolating individual species is greater with digital data.

The land/water interface can be mapped using MSS 7, but its location is dependent upon tidal stage. The upper wetland boundary can usually be determined using MSS 7. Winter images must be used to determine this boundary in fresh water or brackish marshes, whereas summer or winter images can be used for saline marsh boundaries. The location of the upper wetland boundary is difficult to determine in areas where the vegetation forms broad and highly reflective transition zones, such as the Spartina patens/Distichlis spicata/Iva frutescens zone often found in the northern test site adjacent to the upland.

C. Monitoring Wetlands

The following can be identified and monitored with ERTS data: damming and river flow diversion, dredge and fill activities, lagooning for waterside homes and highway construction. Natural successional trends and rate of change can be monitored if observed over a sufficient period of time, probably 2-3 years at minimum.

D. Delineation and Mapping of Shallow Water Areas

Excessive turbidity in coastal waters in the test area prohibited the mapping of shallow water areas.

VII. POTENTIAL FUTURE APPLICATIONS

A. Coastal Inventory and Monitoring

ERTS provides the first opportunity to view coastal areas synoptically and repetitively. There is need for small-scale inventory of coastal wetland, particularly along the eastern and gulf coastline. Classification into fresh, brackish, saline types can be done with ERTS data. Each of these types support a unique array of plant and animal species. State management programs could be directed toward undisturbed wetlands in each of these types.

In addition to classification, ERTS provides information on drainage patterns, large area species associations, erosion and deposition of wetland soils and areas affected by man's activity. Wetland acreage estimates could be updated with ERTS. The last general acreage estimate in eastern coastal marshes was done by Spinner (1969). Marsh areas comprising 50 acres or less and those located near high population densities were omitted. Some of the data used needs updating to make it more reliable in areas where wetland destruction is a common occurrence. ERTS data could also be used to monitor, on a periodic basis, the extent of remaining types of wetlands.

The conversion of coastal wetlands to housing developments, industrial sites, etc., is continuing despite laws in several states regulating such activity. Currently, there is no accurate estimate of the rate at which wetlands are being permanently altered. With increasing population pressures on coastal areas, this type of data will be needed for planning and management purposes. Because dredging, filling, lagooning, and road construction can be detected, ERTS data may be useful for estimating the rate of loss of wetland due to relatively large-scale alterations. The data may also be used to identify sites for intensive studies on the ecological impact of development on contiguous wetland areas.

B. Federal Programs

1. Coastal Zone Management Act of 1972: This law authorizes the Secretary of Commerce to make annual grants to states for coastal zone management programs. Among activities which will be funded are the following: (a) boundaries of the coastal zone, (b) inventory of natural resources, and (c) guidelines on priority uses. Undoubtedly, ERTS data will be very useful in many of these activities, including definition of boundaries and inventory of species in wetlands.

2. National Wetlands Act: This bill is currently pending before Congress. It would cover inland as well as coastal wetlands. A primary need for meeting the requirements of this Act will be development of remote sensing techniques for identification and delineation of inland wetlands, in order to realistically map all of our wetlands.

C. Estuarine Simulation Modeling (R. A. Baltzer, 1974 USGS Memo):

Mathematical simulation models of waterways, lakes, estuaries, and coastal embayments are now beginning to be recognized as one of the most useful and comprehensive means for investigating the effects of man and his society on these waterbodies. Such models can be used to study the movement of injected wastes, the movement and dissipation of excess thermal energy, the effects of storm surges and other unusual (and potentially hazardous) events, the movement, deposition, resuspension and dispersal of sediment, and the effects of proposed geographic configurational changes.

In order to implement a general-purpose mathematical simulation model to represent a specific prototype waterbody, two general types of data are required; namely, initial condition data and boundary data. Initial condition data describe all of the properties--size, shape, depth, density, salinity, temperature, etc.--of the waterbody at the moment simulation begins. Boundary data depict how conditions--for example, water levels--surrounding the modeled area change with time. The shape, geometry, and bathymetry of the waterbody must be initially quantified mathematically over the whole region of the model. The size, elevation, and configuration of the estuarine tidal marshes, which flood and dewater with each tide, are the least well defined aspect of the prototype. Successive ERTS images having known observation times and, thus, known tidal elevations, can be used to better quantify the bathymetric data used to initialize estuarine and coastal embayment simulation models.

Another type of initial-condition information which can be obtained from ERTS imagery data is the type, character, and density of aquatic growth in the tidal marshes. The imagery can also be used to determine changes in such factors from point to point, as well as seasonally. These data are needed in modeling to quantify the amount of flow resistance or energy dissipation taking place in the marshlands. The imagery data can be used to "span" or to "fill in" the similar but very sparse ground-determined data which is obtained currently.

REFERENCES

Adams, D. A.. 1963. "Factors influencing vascular plant zonation in North Carolina salt marshes." Ecology 44:445-456.

Anderson, R. R. 1968. "Remote sensing of marshlands and estuaries using color infrared photography." In: Earth Resources Aircraft Program Status Review. NASA, Vol. III, pp. 26-1 to 26-23.

________. 1969. "The use of color infrared photography and thermal imagery in marshland and estuarine studies." In: Earth Resources Program Review, Vol. III, pp. 40-3 to 40-29.

________. 1970. "Spectral reflectance characteristics and automated data reduction techniques which identify wetland and water quality conditions in the Chesapeake Bay." In: Third Annual Earth Resources Program Review, Manned Spacecraft Center, Vol. III, pp. 53-1 to 53-30.

________. 1971. "Multispectral analysis of aquatic ecosystems in the Chesapeake Bay." In: Proceedings of the 7th International Symposium on Remote Sensing of the Environment. University of Michigan, Vol. III, pp. 2217-2227.

Anderson, R. R., V. Carter and J. W. McGinness. 1973a. "Mapping Atlantic coastal marshlands, Maryland-Georgia, using ERTS-1 imagery." In: Symposium on Significant Results Obtained from the Earth Resources Technology Satellite 1, Vol. I: Technical Presentations, Section A, pp. 603-614.

________. 1973c. "ERTS-1 investigation of wetlands ecology." Type II Progress Report, November 1972 to May 1973. Goddard Space Flight Center/ERTS.

Anderson, R. R. and F. V. Wobber. 1973. "Wetlands mapping in New Jersey." Photogrammetric Engineering 39(4):353-358.

Carter, V., J. W. McGinness and R. R. Anderson. 1973. "Mapping northern Atlantic coastal marshlands, Maryland-Virginia, using ERTS-1 imagery." In: Remote Sensing of Earth Resources, Vol. II, pp. 1005-1011.

Carter, V. P. and D. G. Smith. 1973. "Utilization of remotely sensed data in the management of inland wetlands." In: Proceedings of the Symposium on Management and Utilization of Remote Sensing Data. American Society of Photogrammetry, October 29-November 2, 1973.

Carter, V. P. and J. S. Schubert. 1974. "ERTS-MSS digital data and field spectral measurements for coastal wetland analysis." In: Proceedings of the 9th International Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Michigan. (In press.)

Chapman, V. J. 1970. Salt Marshes and Salt Deserts of the World. Interscience Pub., Inc., N.Y., 392 pp.

Dyar, T. R., G. D. Lasher, R. L. Wait et al. 1972. "Hydrology of the Riceboro area, coastal Georgia." U.S. Geological Survey Final Report to the Georgia Water Quality Control Board and Interstate Paper Corporation.

Garvin, L. E. and R. H. Wheeler. 1973. "Coastal wetlands inventory in Maryland." In: Proceedings, 33rd Annual Meeting, American Congress on Surveying and Mapping. March 11-16, 1973, Washington, D.C., pp. 19-31.

Guss, P. 1972. "Tidelands management mapping for the coastal plains region." In: Proceedings of a Symposium on Coastal Mapping. American Society of Photogrammetry, Washington, D.C., pp. 243-262.

Inman, E. J. 1971. "Flow characteristics of Georgia streams." Open File Report, U.S. Geological Survey, Atlanta, Georgia.

Keefe, C. W. and W. R. Boynton. 1972. "Standing crop of salt marshes surrounding Chincoteague Bay, Maryland-Virginia." Chesapeake Science 14(2):117-123.

Ketchum, Bostwick H. 1972. "The water's edge: Critical problems of the coastal zone." MIT Press, Cambridge, Massachusetts.

Klemas, V., F. C. Daiber, D. S. Bartlett, O. W. Crichton, and A. O. Fornes. 1973. Coastal Vegetation of Delaware. College of Marine Studies, University of Delaware.

Meanley, B. 1972. Swamps, River Bottoms and Canebrakes. Barre Publishers, pp. 27-40.

Nicholson, W. R. and R. D. Van Deusen. 1944. "Maryland marshes." Job Completion Report, Pittman-Robertson Inv. Project No. W-30-R1, 10 pp.

Odum, E. P. 1961. "The role of tidal marshes in estuarine production." In: The New York State Conservationist, June-July 1961.

Peterken, G. F. 1967. "Guide to the checksheet for I.B.P. areas." I.B.P. Handbook No. 4. Blackwell Scientific Publications, London, England.

Pope, R. M. and J. G. Gosselink. 1973. "A tool for use in making land management decisions involving tidal marshland." Coastal Zone Management Journal 1(1):65-74.

Reimold, R. J., J. G. Gallagher, and D. E. Thompson. 1972. "Coastal mapping with remote sensors." In: Proceedings of a Symposium on Coastal Mapping. American Society of Photogrammetry, Washington, D.C., pp. 99-112.

Reimold, R. J., J. L. Gallagher, and D. E. Thompson. 1973. "Remote sensing of tidal marsh." Photogrammetric Engineering 39(5):477-488.

Romig, R. F. and L. J. Cotnoir. 1971. "Effect of oxygen on zonation, growth and reproduction of salt marsh grasses." Presented at the Second Coastal and Shallow Water Research Conference, sponsored by Geography Program, Office of Naval Research. University Press, University of Southern California, September 1971.

Schade, Otto. 1964. "An evaluation of photographic image quality and resolving power." Journal of the Society of Motion Picture and Television Engineers, February 1964.

Schubert, J. S. and N. H. MacLeod. 1973. "ERTS_ANALYSIS: A remotely accessed computer system for analysis of Earth Resources Technology Satellite data." NASA GSSC Publication x-920-74-40.

Schubert, J. S. and N. H. MacLeod. 1974. "Vegetation analysis with ERTS digital data: A new approach." In: Proceedings of the 9th International Symposium of Remote Sensing of Environment. University of Michigan, Ann Arbor, Michigan. (In preparation.)

Serebreny, S. M. 1973. "Study of the time lapse processing for dynamic hydrologic conditions." ERTS-1 Type II Progress Report. G.S.S.C.

Shaw, S. P. and C. G. Fredine. 1956. "Wetlands of the United States: Their extent and their value to waterfowl and other wildlife." Circular 39, Fish and Wildlife Service, U.S. Department of Interior. U.S. Government Printing Office, Washington, D.C., 67 pp.

Smith, D. G. 1973. "Autographic theme extraction system." Presented at the 7th UN Regional Cartographic Conference for Asia and the Far East. Tokyo, Japan, October 15-27, 1973.

Spinner, G. P. 1969. Serial Atlas of the Marine Environment. American Geographical Society.

Stewart, R. E. 1962. "Waterfowl populations in the upper Chesapeake region." Special Scientific Report; Wildlife No. 65. Bureau of Sport Fisheries and Wildlife, U.S. Department of Interior. U.S. Government Printing Office, Washington, D.C., 208 pp.

Stroud, L. M. and A. W. Cooper. 1969. "Color-infrared aerial photographic interpretation and net productivity of a regularly flooded North Carolina salt marsh. Water Resources Research Institute of the University of North Carolina, Report No. 14, 86 pp.

Wass, M. L. and T. D. Wright. 1969. "Coastal wetlands of Virginia." Virginia Institute of Marine Science, Gloucester Point, Virginia.

APPENDIX A

REPORTS AND PUBLICATIONS

Anderson, R. R., Carter, V. P., and McGinness, J. W. 1973c. ERTS-1 Investigation of Wetlands Ecology. Type II Progress Report, November 1972 to May 1973, Goddard Space Flight Center/ERTS.

Anderson, R. R., Carter, V. P., and McGinness, J. W. 1973a. Mapping Atlantic Coastal Marshlands, Maryland-Georgia, Using ERTS-1 Imagery. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. 1: Technical Presentations, Section A, pp. 603-614.

Anderson, R. R., Carter, V. P., and McGinness, J. W. 1972. Wetlands Ecology. Type II Progress Report, June-October 1972, Goddard Space Flight Center/ERTS.

Anderson, R. R. 1974. Remote Sensing of Ecological Conditions in Wetlands. Proceedings: Wetland Conference, University of Connecticut Institute of Water Resources.

Anderson, R. R., Carter, V. P., and McGinness, J. W. 1973. Mapping Northern Atlantic Coastal Marshlands, Maryland-Virginia, Using ERTS-1 Imagery: Remote Sensing of Earth Resources. University of Tennessee, Space Institute, Tullahoma, Tennessee, edited by F. Shahrokhi, Vol. II, pp. 1011-1020.

Anderson, R. R., Carter, V. P., and McGinness, J. W. 1974. Applications of ERTS Data to Coastal Wetland Ecology with Special Reference to Plant Community Mapping and Typing and Impact of Man. Proceedings of 2nd ERTS Significant Results Symposium, Vol. I, pp. 1225-1242. NASA Sp.-351.

Carter, V. P., McGinness, J. W., and Anderson, R. R. 1973. Mapping Southern Atlantic Coastal Marshlands, South Carolina-Georgia, Using ERTS-1 Imagery: Remote Sensing of Earth Resources, University of Tennessee, Space Institute, Tullahoma, Tennessee, edited by F. Shahrokhi, Vol. II, pp. 1021-1028.

Carter, Virginia, and Schubert, Jane. 1974. Coastal Wetlands Analysis from ERTS MSS Digital Data and Field Spectral Measurements: 9th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, April 15-19, 1974, Proceedings: Environmental Research Institute of Michigan, pp. 1241-1260.

Carter, Virginia. 1974. The Dismal Swamp--Remote Sensing Applications. In: Secretary of the Interior Study on the Great Dismal Swamp and Dismal Swamp Canal, North Carolina-Virginia Protection and Preservation, Feasibility Study, U.S. 92nd Congress, October 9, 1972, Public Law 92-478, coordinated by U.S. Bureau of Sport Fisheries and Wildlife, 19 pp.

Carter, Virginia. 1974. The Use of Remote Sensing Data in the Management of Inland Wetlands: Delineation of Wetlands Conference, Storrs, Connecticut, January 9, 1974. Proceedings, University of Connecticut Institute of Water Resources, 30 pp. (In preparation.)

Carter, Virginia. 1974. Remote Sensing Applications to the Dismal Swamp: The Great Dismal Swamp Symposium, Proceedings, Old Dominion University, Norfolk, Virginia, March 14, 1974, 34 pp. (In preparation.)

Carter, Virginia, and Smith, D. G. 1973. Utilization of Remotely-Sensed Data in the Management of Inland Wetlands: Management and Utilization of Remote Sensing Data Symposium, Sioux Falls, South Dakota, October 29-November 1, 1973. Proceedings: American Society of Photogrammetry, Falls Church, Virginia, pp. 144-158.

PAPERS PRESENTED

Anderson, R. R., and Carter, Virginia. Coastal Wetlands: Prospects for Satellite Inventory. Eleventh Space Congress, Cocoa Beach, Florida, April 17-19, 1974.

Anderson, R. R., and Carter, Virginia. Mapping Atlantic Coastal Wetlands Using ERTS-1 and Skylab Data. American Association for the Advancement of Science, San Francisco, California, February 27, 1974.

Carter, Virginia, Anderson, R. R., and Alsid, L. J. Multispectral Analysis for Wetland Studies. American Society of Agricultural Engineers, 1974 Winter Meeting, Chicago, Illinois, December 10-13, 1974, paper no. 74-3516, 16 pp.

Carter, Virginia, and Anderson, R. R. Application of Aircraft Photography and ERTS-1 Imagery to Wetland Mapping. National Meeting of the American Society of Limnology and Oceanography, Inc., Salt Lake City, Utah, June 10-14, 1973.

Carter, Virginia, and Schubert, Jane. ERTS-MSS Digital Data, Field Spectral Measurements, and Multiband Photography for Wetlands Vegetation Analysis. Atlantic Estuarine Research Society Meeting, April 1973.

Carter, Virginia. Remote Sensing Applications to the Dismal Swamp. Annual Meeting, Virginia Academy of Science, Botany Section, May 10, 1974.

APPENDIX B

PRIMARY AIRCRAFT DATA AND SOURCES

DATE	ID	AIRCRAFT	SITES	SENSORS	SOURCE
20 June 1968	MSN 74 FLT 5, 6	RB 57	Patuxent River and Assateague	RC-8, Reconoflax IV	NASA-HOUSTON
12-13 Sept 1968	MSN 79 FLT 4,5,6	RB 57	Patuxent River, Potomac River, and Virginia	RC-8, PRT-5, RS-7	"
13 Sept 1969	MSN 104	RB 57	Carets	RC-8, Hasselblad Reconoflax IV	"
15 Sept 1969	MSN 103 FLT 8	RB 57	Carets	RC-8, Hasselblad Zeiss	"
7 July 1970	MSN 132	RB 57	Carets	RC-8, Zeiss Hasselblad	"
22-25 Sept 1970	MSN 144 FLT 2,3,4,5	RB 57	Carets	RC-8, Zeiss Hasselblad	"
18 May 1971	MSN 166 FLT 6, 7	RB 57	Carets	RC-8, Zeiss Hasselblad	"
15 Sept 1971	FLT 71-032	U-2	Carets	Vinten System A	NASA-AMES
29 Sept 1971	FLT 71-038	U-2	Carets	Vinten System A	"
4 Nov 1971	FLT 71-059	U-2	Carets	Vinten System A	"

APPENDIX B (Continued)

DATE	ID	AIRCRAFT	SITES	SENSORS	SOURCE
2 Dec 1971	FLT 71-070	U-2	Carets Expanded	Vinten System	NASA-AMES
27 April 1972	FLT 72-067	U-2	Carets, North Carolina	Vinten System A	"
7 June 1972	FLT 72-094	U-2	Carets, North Carolina	Vinten System A MSS	"
15 August 1972	MSN 207	C 130	Patuxent River, Nanticoke, and Chincoteague	RC-8, MSS, Hasselblad	NASA-HOUSTON
19 August 1972	FLT 72-116	U-2	Coastal Virginia, and Carolinas	Vinten, RC-10	NASA-AMES
19 Sept 1972	FLT 72-144	U-2	Coastal Virginia, and Carolinas	Vinten, RC-10	"
22 Sept 1972	FLT 72-167	U-2	Coastal North and South Carolina	Vinten, RC-10	"
2 Dec 1972	FLT 72-208	U-2	South Expanded Carets	Vinten, RC-10	"
4 June 1973	MSN 237	RB 57	Coastal South Carolina and Georgia	AMPS	NASA-HOUSTON
22 Sept 1973	MSN 248	RB 57	Coastal South Carolina and Georgia	Hasselblad	"

APPENDIX C

List of ERTS CCTs

Image No.	Date	Site
1046-15324	7 Sep '72	Georgia coast
1079-15142	10 Oct '72	Dismal Swamp
1081-15264	12 Oct '72	South Carolina
1187-15140	26 Jan '73	Lower Chesapeake Bay (Va.)
1187-15142	26 Jan '73	Lower Chesapeake Bay (Va.)
1205-15141	13 Feb '73	Chesapeake Bay, Delaware
1205-15144	13 Feb '73	Lower Chesapeake Bay (Va.)
1205-15150	13 Feb '73	Dismal Swamp
1243-15274	23 Mar '73	South Carolina
1243-15280	23 Mar '73	Georgia coast
1261-15274	10 Apr '73	Georgia coast-South Carolina
1261-15280	10 Apr '73	South Carolina
1279-15273	28 Apr '73	South Carolina
1279-15280	28 Apr '73	Georgia coast-South Carolina
1297-15272	16 May '73	South Carolina
1297-15275	16 May '73	Georgia coast
1315-15274	3 June '73	Georgia coast
1386-15201	13 Aug '73	Cape Fear (North Carolina)
1387-15264	14 Aug '73	Georgia coast
1403-15132	30 Aug '73	Chesapeake Bay, Delaware
1403-15134	30 Aug '73	Dismal Swamp
1439-15125	5 Oct '73	Dismal Swamp
1459-15250	25 Oct '73	Georgia coast
1460-15305	26 Oct '73	Georgia coast
1548-15170	22 Jan '74	Cape Fear (North Carolina)

APPENDIX D

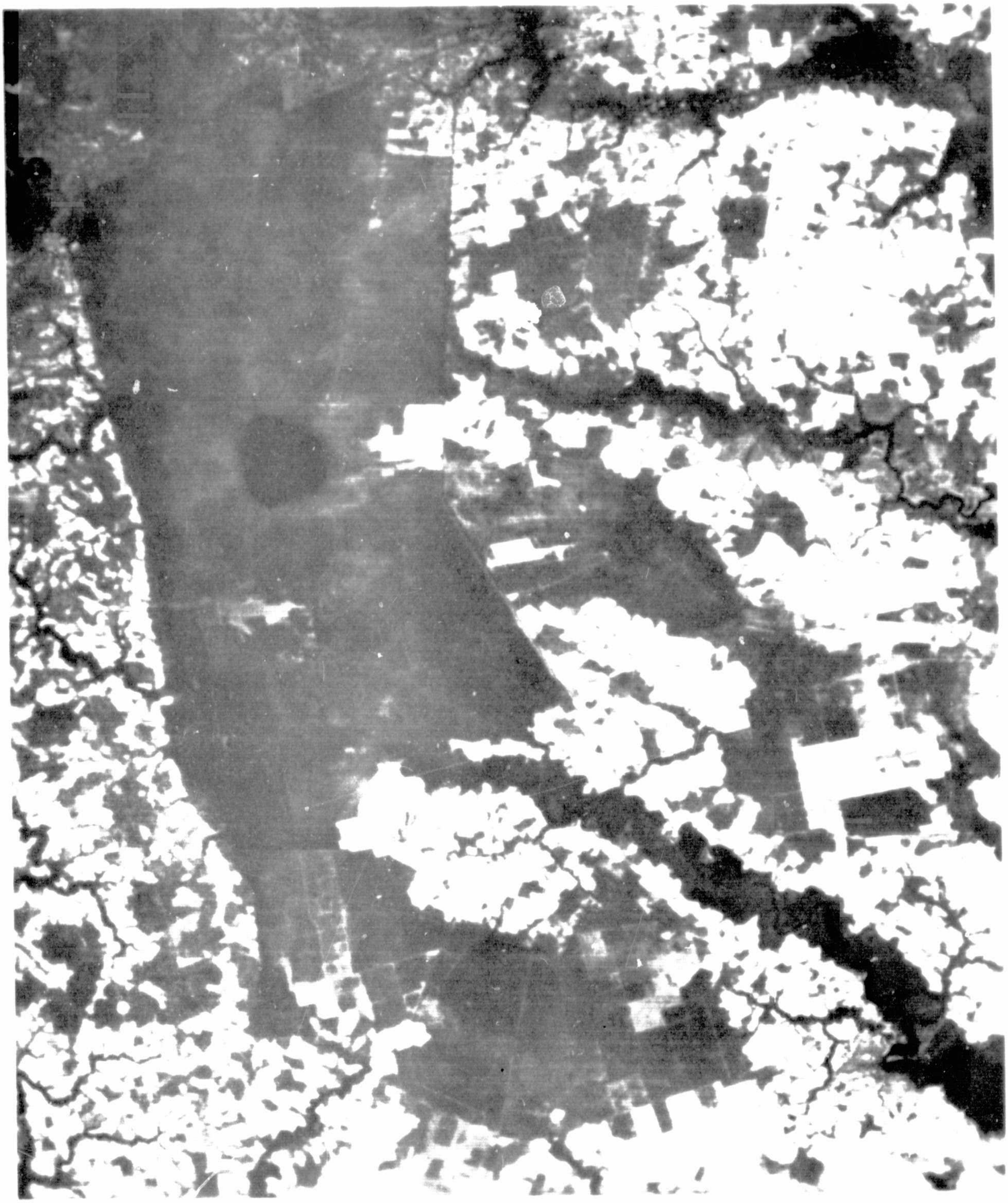
DISMAL SWAMP WORK SUMMARY

The Great Dismal Swamp

In 1972, Congress authorized the Department of Interior to conduct a comprehensive study of the Great Dismal Swamp and the Dismal Swamp Canal. The study is designed to determine the desirability and feasibility of protecting and preserving the ecological, scenic, recreational, historical, and other resource values of the Swamp and Canal and to consider the alternatives for preservation in terms of effectiveness and cost. Eight federal agencies are participating in the investigation, including the U.S. Geological Survey, which is responsible for water dynamics, mineralogical data, and remote sensing applications.

ERTS data and color IR photography (NASA flight 720208; December 1972) from the American University ERTS project were used for the study. A complete listing of available data and remote sensing applications in the Dismal Swamp is included in a separate report (Carter, 1974) submitted to the Fish and Wildlife Service for presentation to Congress.

The Dismal Swamp is a vast wooded swamp or forested bog straddling the Virginia-North Carolina border. The Dismal Swamp has been considerably modified by man in his many attempts at drainage. Surface water in Lake Drummond (about 6 feet deep and 2-1/2 miles in diameter) is used for operating the locks on the Canal. The lake, drainage ditches, canals, and roads may be clearly seen in color IR photography taken by NASA U-2 in December of 1972. Approximately eight photographs at the



0 Kilometers 20

Scale is approximate

N

Fig. 19. ERTS image enlargement (1205-15150-7, Feb. 13,1973) showing the Great Dismal Swamp and associated drainage systems.

scale of 1:130,000 are needed to show the entire Swamp and major drainage.

The study of the Great Dismal Swamp utilized ERTS imagery and color IR and B/W photography in (1) overall study area selection, (2) location of intensive study areas, (3) hydrologic studies, (4) vegetation mapping, and (5) field studies including identification of special interest areas. Because of the large size of the entire Swamp and inaccessibility of many interior parts, remote sensing provides a powerful tool to meet the needs of the current study and future research and management.

Choice of Study Area

Choice of the study area by the BSFW was assisted by the use of both color IR and B/W photographs and required approximately 3 man-weeks. The NASA high-altitude color IR photographs from December 1972 were mosaicked by BSFW to give a complete picture of the entire Swamp and adjoining drainage. ERTS imagery provided the big picture--the entire Swamp and its geographic setting are visible on one ERTS frame. Figure 19 is an enlargement of a part of an ERTS-MSS image (1205-15150-7) taken in February 1973. This imagery was used to verify the selected study area. Comparison of this image with the map of the area illustrates the utility of ERTS data in determination of wetland boundaries. Delineation of the study area from ERTS imagery would have reduced the time required to select the study area from 3 weeks to less than 3 man-days, including field checking. Many of the roads, canals, and vegetation associations can be clearly identified on a 1:250,000-scale enlargement of the ERTS image. Moreover, ERTS imagery could be used to construct a reliable map of similar large wetland areas without the need for either extensive or repetitive field work or low-altitude aircraft coverage.

Field Inspection

Both the color IR (December 1972, scale 1:130,000) and the recent B/W (scale 1:78,000) orthophotos in the 9.5-inch format, taken by the USGS for mapping purposes, were extremely useful for field work within the Swamp. The lake, drainage ditches, canal, and roads can be clearly identified so that locating sites for ground studies is accomplished rapidly and economically. The eight color IR or sixteen B/W photographs are easier to reference in the field than the 7.5-minute topographic maps (scale 1:24,000, approximately fifteen in number) of the area; moreover, they are more up to date. All major vegetation associations or phytocommunities are recognizable on the photography.

Hydrologic Studies

Hydrologic studies considered water conditions and movement within the Swamp, as well as flow into and out of the Swamp by both surface and subsurface routes. These studies were carried out by the Virginia District of Water Resource Division. Water distribution and drainage patterns within and adjacent to the Swamp can be observed from photography or imagery taken during the winter, when deciduous trees are leafless. Winter aerial photography was used to help select areas for preliminary ground-water investigations. This photography is a useful tool to aid in the selection of representative sites for drilling test wells for future hydrologic studies.

High- and low-altitude aerial photography and ERTS imagery were used for vegetation analysis or mapping. The various vegetation communities are associated with differences in water regime and soils.

Vegetation Mapping

Cover typing or tree mapping for the Dismal Swamp study was done by the U.S. Forest Service using the USGS B/W orthophotos rectified to an existing topographic map base at a scale of 1:24,000. The high-altitude color IR photography was used to assist and verify the B/W interpretation. Levy (verbal communication, 1973) and Meanley (1972) have indicated that several discrete phytocommunities exist in the Swamp. Both aerial photography and ERTS imagery provide a useful basis for identifying these phytocommunities as well as for discriminating between deciduous and evergreen species. Areas disturbed by cutting or fire can also be identified on the photography.

Location of Special Interest Areas

One useful and important outcome of the study was the identification of special interest areas within the Swamp boundaries. Two such areas were located in the Swamp using the color IR photographs. The first is a small marsh area in which the water table is just below the ground surface. The second special interest area is one of the driest in the Swamp. It possibly represents the highest ground originally present in the sloping hillside on which the Swamp was formed.

Thematic Extractions

Thematic extractions for the Dismal Swamp were made with ATES (section IV-D-2) and the GE IMAGE 100 (section IV-E-3). The extractions made with digital data were not directly used in the current Dismal Swamp study, but it is clear that the major vegetative associations and areas of standing water in the Swamp can be mapped thematically and their areas measured using the ERTS data. Canals, roads, standing water, and special interest areas can be clearly identified on photographs made of the interactive color display screen.

Suggested Future Applications

Suggested future applications of remote sensing to the Dismal Swamp include: (1) making a detailed hydrologic study utilizing ERTS data or thermal imagery, (2) monitoring the effects of water-level management with repetitive satellite data, (3) detecting vegetative changes with additional high-altitude color IR photography or ERTS data, and (4) making detailed ecological studies using low-altitude aircraft coverage of selected sites.

APPENDIX E

Selected Publications

UTILIZATION OF REMOTELY-SENSED DATA IN THE MANAGEMENT OF INLAND WETLANDS

Virginia Carter
and
Doyle G. Smith
U.S. Geolcgical Survey, National Center, Reston, Va.

presented at

Management and Utilization of Remote Sensing Data Symposium

Sioux Falls, South Dakota

Oct 29-Nov 1, 1973

AMERICAN SOCIETY OF PHOTOGRAMMETRY, Falls, Church, Va.
p. 144-158

82

UTILIZATION OF REMOTELY-SENSED DATA IN THE MANAGEMENT OF INLAND WETLANDS

Virginia Carter
U.S. Geological Survey
Washington, D.C. 20244

Doyle G. Smith
U.S. Geological Survey
Washington, D.C. 20244

BIOGRAPHICAL SKETCH

Virginia Carter is an Aquatic Biologist for the U.S. Geological Survey, specializing in wetland ecology, remote sensing of wetlands, and spectral reflectance studies of marsh vegetation. Mrs. Carter received her B.A. from Swarthmore College and her M.S. from American University. She is a member of the Atlantic Estuarine Research Society and the American Society of Photogrammetry. She is a co-investigator on both an ERTS-1 and SKYLAB investigation of Wetland Ecology at the American University in Washington, D.C.

Mr. Smith is a Research Specialist with the Topographic Division of the USGS. He has a B.S. (C.E.) from the University of Colorado and is a member of Sigma Tau and Tau Beta Pi Honorary Societies. He recently completed additional work in ADP (Automatic Data Processing) equipment and programing and 9 months of advanced training in applied optics at the University of Rochester Institute of Optics. Mr. Smith has been assigned to the research staff of the Topographic Division since July 1966. During the past 7 years, he has been active in the design, calibration, and testing of optical and electronic surveying instruments. Recently, he has been serving in an advisory capacity on practical hardware requirements for calibration of RBV (Return Beam Vidicon) camera components and for proposed special processing systems for thematic mapping with SKYLAB and other space imagery.

Analysis of ERTS data referenced in this paper supported by NASA Contracts NAS 5-21752 (The American University-UN006), S-70243 AG (The U.S. Geological Survey-IN-385), and NAS 272 (The U.S. Geological Survey-I-414).

ABSTRACT

Remote sensing provides a powerful tool to meet critical management needs for inventory and classification of inland wetlands as well as for evaluation of the wetland role in the hydrologic cycle, identification of significant wetlands for wildlife preservation, and monitoring of wetland change. Remotely-sensed data are being presently utilized for wetland management in the Dismal Swamp (Virginia-North Carolina) and in wetlands of central and southern Florida.

Congress recently authorized the Department of the Interior to conduct a comprehensive study to establish the feasibility of preserving and protecting the Great Dismal Swamp. The Dismal Swamp is partly owned by the Department of the Interior and is of importance to the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, and numerous state and local organizations as well. High altitude photography flown by U-2 aircraft can be used for gross vegetation mapping, boundary determination, and selection of sites for intensive study. Low altitude photography is useful for more detailed mapping. Black and white orthophoto quadrangles currently under preliminary stages of preparation in the U.S. Geological Survey will provide up-to-date maps of the Swamp at 1:24,000 scale. ERTS (Earth Resources Technology Satellite) provides the big picture--the entire Swamp is visible on one ERTS frame--and permits observation of seasonal change and monitoring of significant ecological shifts.

In southern Florida, ERTS is providing information for water management in the wetlands north and south of Lake Okeechobee where droughts place significant demands on water that is also needed for maintenance of the Everglades National Park. Water level and precipitation data are collected in near real time by the DCS (Data Collection System). These data are correlated with ERTS imagery that portrays the areal extent of standing water for prediction and management of water flow.

INTRODUCTION

Management problems with inland wetlands in the United States are coming into sharp focus in a new era of public concern for the environment. State and local governments--e.g., Connecticut, Rhode Island, Massachusetts, Delaware--are mandated by legislation to inventory and regulate uses in inland wetlands. On the Federal level, wetland classification on an overall national basis is a controversial and challenging problem. Preservation and protection of unique wetlands is often a Federal task. Wider recognition and better understanding of wetland values have been followed by concern that competing usages as exemplified by agriculture, residential housing, and industrial growth may destroy vast acreages of valuable natural habitat, potential water supply, or recreational and scenic potential. The extent to which wetlands can be considered a multiple-use resource remains to be established.

Most of the needs and requirements for wetland management on the local, state, and national level can be placed in two general categories:

1. Basic research to establish criteria for decision making.

This need is pointed up by the scarcity of current data relating to the hydrologic relationships of inland wetlands--recharge, discharge, flood storage, and water quality. Only a few local or regional studies have been made such as those on the prairie potholes by Eisenlohr et al., 1969. Another area where additional research is needed is exemplified by a recent paper by Gupta (1972) which is entitled "The Economic Criteria for Decisions on Preservation and Use of Inland Wetlands in Massachusetts."

2. Near real-time information systems to provide wetland managers with information for inventory, classification, and monitoring of wetlands and for water-resource management decisions.

Remotely-sensed data can provide a powerful tool to meet needs in both categories. For example, Gupta's evaluation criteria for wetlands include land-use contrast (what is the surrounding area like?--urban, rural, etc.) and landform contrast (what is the topographic relief in the area?). Both of these parameters can be easily measured by aerial photography or even ERTS imagery.

The advantages of applying remote-sensing techniques to solve problems in category two are several:

A. Reduction in costs and manpower for extensive ground surveys.

B. More rapid completion of inventory or mapping.

C. More efficient monitoring and change detection, whether seasonal, successional, or manmade.

D. Collection of multipurpose data useful to future projects and projects not under consideration when data collection was planned.

The disadvantages of using remote sensing include:

A. The necessity for field checks or "ground truth" data.

B. The difficulties encountered in scheduling simultaneous ground data collection for subsequent interpretation of the remote-sensing imagery data.

C. The lack of efficient storage and retrieval methods for the large quantities of data generated by remote sensors such as the ERTS-MSS (Earth Resources Technology Satellite-Multispectral Scanner) or low altitude cameras.

To illustrate the utility of remotely-sensed data to the field of inland wetland management, this paper will discuss applications in the Great Dismal Swamp of Virginia-North Carolina and in the Water Conservation District of southern Florida, which includes Lake Okeechobee, several water conservation areas, and the Everglades National Park.

THE GREAT DISMAL SWAMP

In 1972, Congress authorized the Department of Interior to conduct a comprehensive study of the Great Dismal Swamp and the Dismal Swamp Canal. The study is designed to determine the desirability and feasibility of protecting and preserving the ecological, scenic, recreational, historical, and other resource values of the Swamp and Canal and to consider the alternatives for preservation in terms of effectiveness and cost. Consideration must also be given to potential alternative uses of the water and related land resources for residential, commercial, industrial, agricultural, and transportation services. Eight Federal agencies are participating in the investigation, including the U.S. Geological Survey, which is responsible for water dynamics and mineral data. The study is presently being coordinated through the Boston Office of the U.S. Fish and Wildlife Service under the direction of Robert H. Shields.

The Great Dismal Swamp is a vast wooded swamp or forested bog straddling the Virginia-North Carolina border. The Federal Government owns the Dismal Swamp Canal and the Dismal Swamp National Wildlife Refuge, an area of about 49,000 acres recently donated to the Department of the Interior by the Union Camp Corporation through the Nature Conservancy. The Swamp has been considerably modified by man in his many attempts at drainage. Surface water in Lake Drummond (about 6 feet deep and 2-1/2 miles in diameter) is used for operating the locks on the Canal. The lake, drainage ditches, canals, and roads may be clearly seen in color IR photography taken by NASA U-2 in December of 1972. Approximately eight photographs at a scale of 1:120,000 are needed to show the entire Swamp and major drainage.

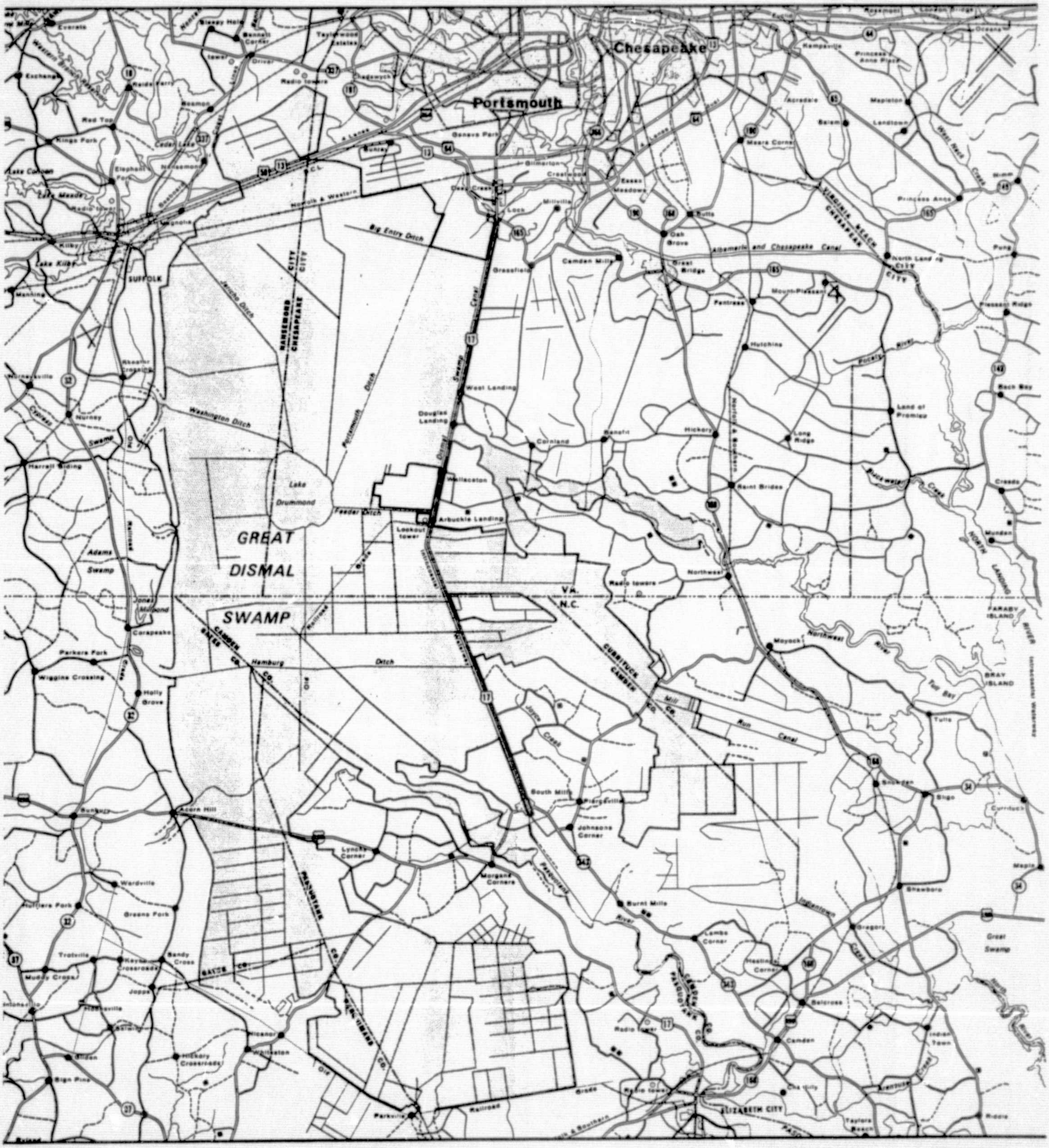
While estimates of the original size of the Swamp have been as high as more than one million acres, the study area recently designated by the U.S. Fish and Wildlife Service (Press Release/USDI, July 28, 1973) comprises approximately 210,000 acres considered to be viable wetland. Choice of the study area (Figure 1) by the U.S. Fish and Wildlife Service was assisted by the use of NASA color IR photographs and low altitude black and white photographs taken in conjunction with a U.S. Geological Survey mapping project. Black and white orthophoto quadrangles currently under preliminary stages of preparation by the U.S. Geological Survey will provide up-to-date maps of the entire Swamp at a scale of 1:24,000. Fifteen of these maps are required for full coverage.

UNITED STATES
MENT OF THE INTERIOR

ORIGINAL PAGE IS
OF POOR QUALITY

PL 92-478

FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIF



PILED IN THE DIVISION OF ENGINEERING
. SURVEYS BY U.S.G.S.
ION, MASSACHUSETTS JUNE 1973

Scale 0 8000 16000 24000 32000 FEET
Scale Is Approximate

LEGEND
Primary Study Area
Water Study Area

Figure 1. Great Dismal Swamp Study Area

Figure 2. Enlarged ERTS-MSS 7 (2/13/73) winter image showing the Great Dismal Swamp and associated drainage systems.

ERTS imagery provides the big picture--the entire Swamp and its geographical setting are visible on one ERTS frame. Figure 2 is an enlargement of a part of an ERTS-MSS image (#1205-15150-7) taken in February 1973. Comparison of this image with Figure 1, the map of the Study Area, gives a good indication of the utility of ERTS data in determination of wetland boundaries. Many of the roads and canals may be clearly identified on a 1:250,000 enlargement of the ERTS image, and a reliable map could be constructed of similar areas in the future without the need for extensive and repetitive field work or low altitude aircraft coverage.

Hydrologic studies inside and outside of the formal study area will consider water conditions and movement within the Swamp as well as drainage into and surface and sub-surface flows out of the Swamp. Remote sensing data can contribute to these studies in several ways:

1. Both ERTS images and aircraft photography show surface drainage patterns--surface input and output can be identified and studied. Figure 2 shows the major Swamp drainage clearly, with streams entering from the Suffolk Scarp to the west of the Swamp and exiting to the south, east, and north. Once surface drainage is located, detailed studies of discharge and water quality can be done as needed.

2. Water relations and drainage patterns within the Swamp can be observed with photography or imagery taken during the winter, when deciduous trees are leafless. Thematic extractions from ERTS data show standing water beneath trees and other moisture conditions. This is discussed further under subheading "Autographic Theme Extraction System" below.

3. Aerial photography can be used to establish areas for detailed study, such as the drilling of observation wells, location of stream gauges, and observation of stress.

4. High and low altitude aerial photography and ERTS imagery can be useful for vegetation mapping, whether gross or detailed. The various vegetation communities are associated with differences in water level and soils, discussed later under the subheading "Vegetation Mapping."

5. Thermal imagery of the Dismal Swamp taken from low altitude during the winter could yield important information on areas of ground-water inflow. As wetlands represent a surface-groundwater interface, the movement of water beneath the surface is as important to the Swamp's existence as the surface water.

Autographic Theme Extraction System

The U.S. Geological Survey is developing an Autographic Theme Extraction System (ATES) to apply photographic and digital processing to images to obtain specific theme isolations, which retain the geometry and resolution of the original image. These extractions, or spectral images, are based on distinctive densities, or combinations of densities, and are presently being done on an experimental basis with ERTS-1 and SKYLAB images (Smith, 1973).

ERTS-1 images from October 11, 1972 (1079-15142-5,7), and February 13, 1973 (1205-15150-5,7), have been used as the base for a series of wetlands extractions in the Dismal Swamp. The isolated theme data are stored as two-level or binary theme extractions in the form of a photographic transparency. Two or more of the properly processed spectral images can be combined into a photographic composite to cancel out unwanted or spurious data and isolate the desired theme.

Figure 3 is an enlarged MSS-7 positive (10/10/72) of the Dismal Swamp on the North Carolina-Virginia border south of Norfolk, Virginia. Part of Currituck Sound and Great Swamp in North Carolina can be seen on the east. A bend in the Chowan River including a part of the Chowan Swamp appears in the southwest corner. Figure 4 is a density clipping of the February 13, 1973, original to isolate wooded swamp (grey). Figure 5 reduces the picture to the binary form where the wooded swamp is white except where there is standing water, dense white cedar, or snow in clear-cut areas (black). Salt marsh and snow-covered agricultural fields are also black. Figure 6 is a change-detection extraction. The white areas show where MSS-7 differs from October 10, 1972, to February 13, 1973. Clouds are evident, as are seasonal differences in areas of deciduous trees in which water is standing. Figure 7 shows the wettest area of the swamp, dense white cedar, and also the urban communities of Norfolk and Suffolk (black). Figure 8 shows the drier deciduous, or low flat evergreen areas where snow can accumulate (white).

Vegetation Mapping

Use of color IR photography for vegetation mapping in wetlands has increased recently (Anderson and Wobber, 1972; Seher and Tueller, 1973). Plant associations with distinct or unique tonal signatures may be differentiated and mapped to a scale commensurate with the scale of the photography. Where sufficiently large plant associations exist, as in the Dismal Swamp, it seems highly possible that mapping of vegetation types can be done from ERTS, using the ATES approach.

The flora of the Great Dismal Swamp is a diverse mixture of northern and southern species. Many plants primarily associated with the swamplands of the deep South reach their northernmost extent here and in the Pocomoke River Swamp on the western shore of Maryland. The Pocomoke River Swamp differs, however, from the Dismal Swamp in being under tidal influence, with an average rise and fall of water of 2.8 to 3 feet (Beaver and Oostang, 1939).

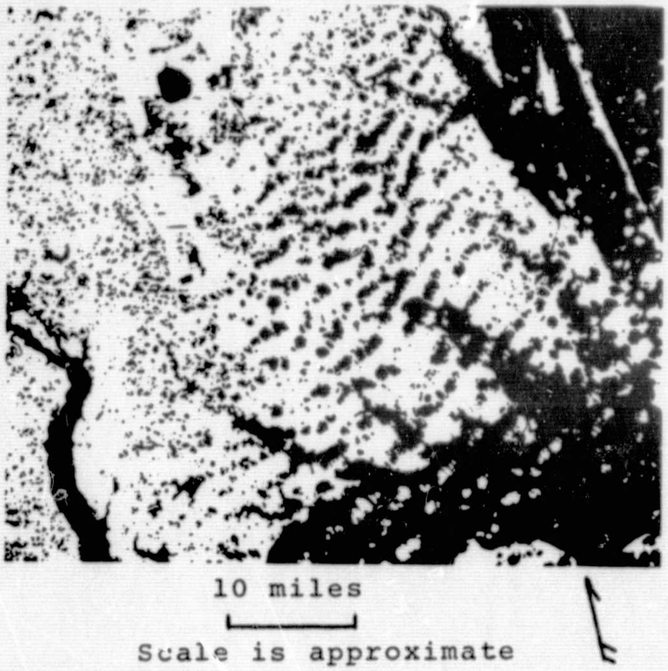


Figure 3. ERTS-MSS 7 (10/10/73) fall image showing the Great Dismal Swamp. Currituck Sound is on the right and the Chowan River appears in the southwest corner.

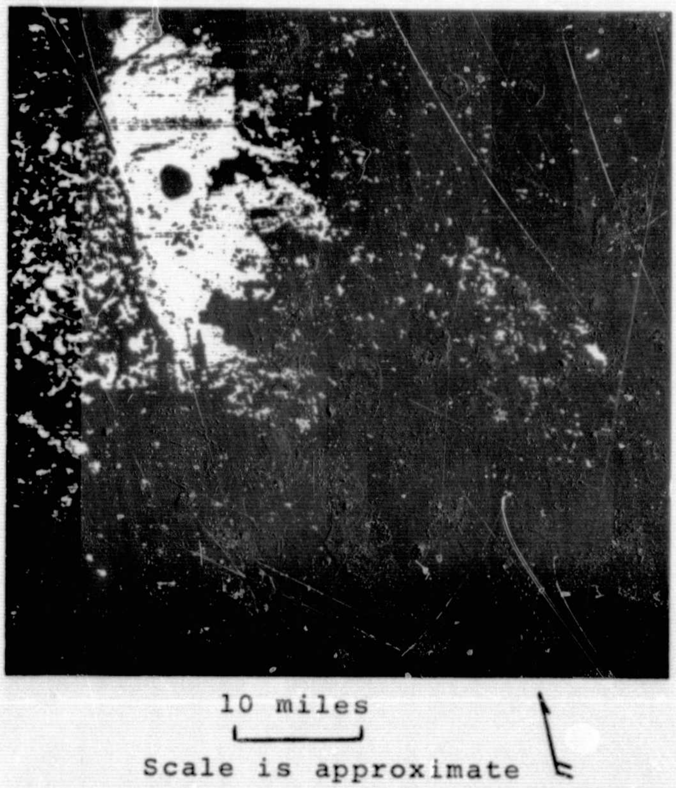
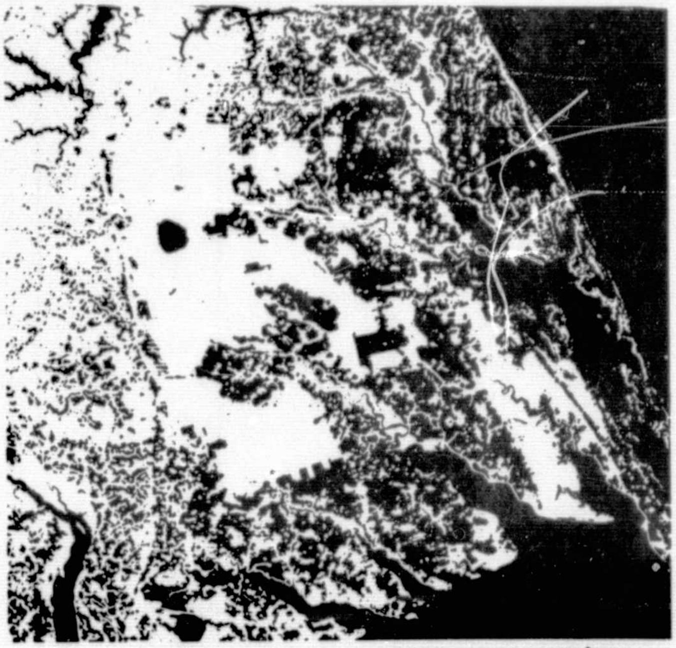


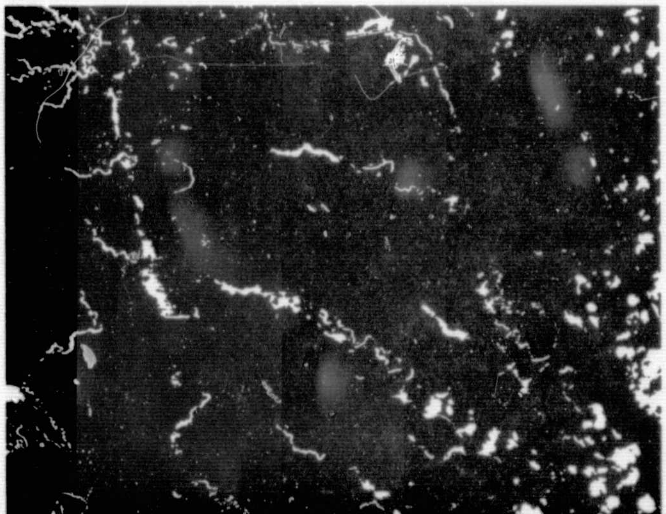
Figure 4. Density enhancement of ERTS 2/13/73 image. Wooded swamp is grey.



10 miles

Scale is approximate

Figure 5. Binary extraction from the ERTS 2/13/73 image. Wooded swamp is white except where there is standing water, dense white cedar, or snow in clear-cut areas (black). Salt marsh and snow-covered agricultural fields are also black.



10 miles

Scale is approximate

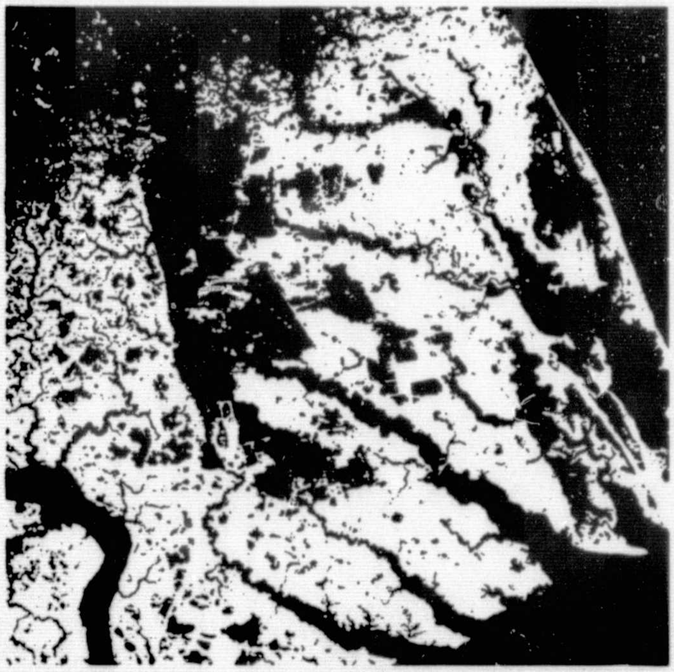
Figure 6. Change detection extraction showing where MSS-7 differs from October 1972 (black) to February 1973 (white).

C-2

10 miles

Scale is approximate

Figure 7. Theme extraction showing wettest areas of swamp, dense white cedar, and urban communities of Norfolk and Suffolk.



10 miles

Scale is approximate

Figure 8. Theme extraction showing drier deciduous or low, flat evergreen areas where snow accumulates.

Distribution of vegetation in the Swamp is controlled by moisture, soil, and light conditions. Vast acreages have been logged once and are now covered with second growth plant associations. Levy (1973) and Meanley (1972) have indicated that several discrete phytocommunities can be distinguished. Some of these are identified on Figure 9 (a black and white copy of color IR photograph taken by NASA-U2 at an altitude of 60,000 feet). The hydric or deep water swamp (A) is characterized by cypress, gum, and maple (deciduous) growing in as much as 2 feet of water. Dense, monospecific stands of Atlantic White Cedar (B) (evergreen) occupy areas with very little standing water. The evergreen shrub-bog community (C) is also in areas with little surface water and is characterized by broad-leafed evergreen shrubs, bay trees, and pond pine. These communities are low and relatively open, as are the revegetating clear-cut areas and are often referred to as "lights." A pond pine-*Ilex* association (D) may be differentiated from (C) by its light tone. The semi-hydric, or mixed swamp hardwood forest (E), grows in areas without standing water most of the year. Gum, red maple, water oak, and bay dominate this forest type, and the evergreen understory distinguishes it from the denser hydric forest in winter photography. The mesic or hammock forest (F) is rather dry and contains deciduous oaks, beeches, tulip poplar, and holly. Pure stands of pine also grow in some areas. Distinguishing between semi-hydric and mesic forest is difficult, but winter photography and imagery may provide a useful method for the discrimination.

SOUTH FLORIDA

Water supply for the east coast of Florida, with a population of 2-1/4 million, depends on retention of water in four major impoundment areas or shallow wetlands (less than 3 feet deep) south of Lake Okeechobee. These large water conservation areas (1,400 square miles) serve also as water supply for the Everglades National Park. Ultimately, the water discharge to the Gulf of Mexico is by slow-moving sheet flow through the Shark River Slough. The Big Cypress Swamp near the west coast of southern Florida also supplies a part of the water necessary to maintenance of the dynamic environment of the Everglades.

Data Collection Platforms (DCP's) in the impoundments, the Everglades, and the Big Cypress Swamp presently supply near real-time data on water level and precipitation by satellite relay to the Miami Office of the USGS via NASCOM (Wimberly, Higer, Cordes, Coker, 1973). The data are analyzed and disseminated to water management agencies such as the U.S. Corps of Engineers and the Central and Southern Florida Flood Control District.

ERTS-DCP information can be used immediately for water management and correlated with enhanced ERTS imagery, which delineates the areal extent of fresh water inundation.

Distribution of vegetation in the Swamp is controlled by moisture, soil, and light conditions. Vast acreages have been logged once and are now covered with second growth plant associations. Levy (1973) and Meanley (1972) have indicated that several discrete phytocommunities can be distinguished. Some of these are identified on Figure 9 (a black and white copy of color IR photograph taken by NASA-U2 at an altitude of 60,000 feet). The hydric or deep water swamp (A) is characterized by cypress, gum, and maple (deciduous) growing in as much as 2 feet of water. Dense, monospecific stands of Atlantic White Cedar (B) (evergreen) occupy areas with very little standing water. The evergreen shrub-bog community (C) is also in areas with little surface water and is characterized by broad-leafed evergreen shrubs, bay trees, and pond pine. These communities are low and relatively open, as are the revegetating clear-cut areas and are often referred to as "lights." A pond pine-Ilex association (D) may be differentiated from (C) by its light tone. The semi-hydric, or mixed swamp hardwood forest (E), grows in areas without standing water most of the year. Gum, red maple, water oak, and bay dominate this forest type, and the evergreen understory distinguishes it from the denser hydric forest in winter photography. The mesic or hammock forest (F) is rather dry and contains deciduous oaks, beeches, tulip poplar, and holly. Pure stands of pine also grow in some areas. Distinguishing between semi-hydric and mesic forest is difficult, but winter photography and imagery may provide a useful method for the discrimination.

SOUTH FLORIDA

Water supply for the east coast of Florida, with a population of 2-1/4 million, depends on retention of water in four major impoundment areas or shallow wetlands (less than 3 feet deep) south of Lake Okeechobee. These large water conservation areas (1,400 square miles) serve also as water supply for the Everglades National Park. Ultimately, the water discharge to the Gulf of Mexico is by slow-moving sheet flow through the Shark River Slough. The Big Cypress Swamp near the west coast of southern Florida also supplies a part of the water necessary to maintenance of the dynamic environment of the Everglades.

Data Collection Platforms (DCP's) in the impoundments, the Everglades, and the Big Cypress Swamp presently supply near real-time data on water level and precipitation by satellite relay to the Miami Office of the USGS via NASCOM (Wimberly, Higer, Cordes, Coker, 1973). The data are analyzed and disseminated to water management agencies such as the U.S. Corps of Engineers and the Central and Southern Florida Flood Control District.

ERTS-DCP information can be used immediately for water management and correlated with enhanced ERTS imagery, which delineates the areal extent of fresh water inundation.

5 miles

Scale is approximate

Figure 9. Black and white reproduction of NASA-U2 color IR photograph of the Dismal Swamp. (A) hydric (deep water) swamp, (B) Atlantic white cedar, (C) evergreen shrub-bog association, (D) pine-*Ilex* association, (E) semi-hydric swamp, (F) mesic forest.

ORIGINAL PAGE IS
OF POOR QUALITY

Water storage information developed using this system can benefit both the water users of southern Florida and the Everglades by providing a more reliable and timely source of information for decision making. Maintenance of data collection stations is less of a problem with DCP's than analog types of ground stations because malfunctions are detected immediately. Expansion of the Data Collection System to include sufficient water budget parameters to calculate evapotranspiration is presently under consideration in south Florida.

SUMMARY AND CONCLUSION

ERTS data and aerial photography are proving to be a useful tool for the inventory and management of inland wetlands. Two examples of the application of remotely-sensed data to specific wetland management needs or requirements are discussed in this paper.

Studies of the Great Dismal Swamp are utilizing ERTS imagery and color IR photography in (1) study area selection, (2) field inspection, (3) vegetation mapping, (4) identification of drainage characteristics and moisture regime, (5) location of intensive study areas and (6) detection of change. Thematic extractions of ERTS data made using the United States Geological Survey's Autographic Theme Extraction System are aiding analyses of swamp hydrologic regime and providing information pertinent to quick recognition and inventory of wetlands from ERTS.

DCP's in south Florida wetlands provide near-real time data for water resource managers. Data relayed by satellite can be entered into models to provide predictive data and water storage information for long-term and short-term decision making.

REFERENCES

Anderson, R. R., and Wobber, F. J., 1973, Wetlands Mapping in New Jersey, Photogrammetric Engineering, 39: 353-358.

Beaven, George F., and Oostang, Henry J., 1939, Pocomoke Swamp: A Study of a Cypress Swamp on the Eastern Shore of Maryland, Bulletin of the Lorrey Botanical Club, 66: 367-389.

Eisenlohr, W. S., Jr., et al., 1972, Hydrologic Investigations of Prairie Potholes in North Dakota, 1959-68, Geological Survey Professional Paper 585-A, 101 pp.

Gupta, T. R., 1972, Economic Criteria for Decisions on Preservation and Use of Inland Wetlands in Massachusetts, Journal Northeastern Agricultural Economics Council 1(1): 201-210.

Levy, G., 1973, Personal Communication, Old Dominion University, Norfolk, Virginia.

Meanley, Brooke, 1972, Swamps, River Bottoms and Canebrakes, pp. 27-40, Barre Publishers.

Press Release, U.S. Department of the Interior Fish and Wildlife Service Regional Information, Great Dismal Swamp Study Area Identified, July 28, 1973.

Seher, J. Scott, and Tueller, Paul T., 1973, Color Aerial Photos for Marshland, Photogrammetric Engineering, 39: 489-499.

Smith, Doyle G., 1973, Autographic Theme Extraction System, to be presented at the 7th UN Regional Cartographic Conference for Asia and the Far East, Tokyo, Japan, October 15-27, 1973.

Wimberly, E. T., Higer, A. L., Cordes, E. H., and Coker, A. E., 1973, Acquisition and Processing Program of ERTS Data in South Florida, ERTS Type II Progress Report.

MAPPING SOUTHERN ATLANTIC COASTAL MARSHLANDS, SOUTH CAROLINA-GEORGIA, USING ERTS-1 IMAGERY

Richard R. Anderson,* Virginia Carter,+ and John McGinness≠

Biology Department
The American University
Washington, D.C.

Abstract

Southeastern coastal marshes are among the most extensive and productive in the United States. A relatively low cost, moderately accurate method is needed to map these areas for management and protection. Ground-based and low altitude aircraft methods for mapping are time-consuming and quite expensive. The launch of NASA's Earth Resources Technology Satellite has provided an opportunity to test the feasibility of mapping wetlands using small scale imagery. The test site selected was an area from the South Carolina border to Saint Catherine's Island, Georgia. Results of the investigation indicate that the following may be ascertained from ERTS imagery: (1) upper wetland boundary; (2) drainage pattern in the wetland; (3) plant communities such as *Spartina alterniflora*, *Spartina patens*, *Juncus roemerianus*; (4) ditching activities associated with agriculture; (5) lagooning for water-side home development. Conclusions are that ERTS will be an excellent tool for many types of coastal wetland mapping.

Performed under contract NAS5-21752, National Aeronautics and Space Administration. The authors appreciate the assistance of the Game and Fish Division, Department of Natural Resources, Georgia.

*Chairman, Biology Department, The American University
+Research Associate, The American University
≠Graduate Research Assistant, The American University

Introduction and Characteristics of the Study Area

Eastern coastal areas are receiving increasing pressure from a variety of sources, mainly due to population growth. The northeastern coast is under the most pressure at the present time, but laws regulating development have been passed in several of the states. The southeastern coastline (except Florida) has had less developmental pressure, mainly from agriculture and some industry. Dredge and fill operations have altered some portions of the coastline. The prognosis is for a tremendous increase in pressure in this area during the next decade. Laws regulating development are helpful but usually require costly mapping of coastal resources. A relatively low cost and moderately accurate method for mapping these areas, including wetlands, mud flats, drainage patterns, impact of man and vegetation productivity would be very attractive to states and assure that at least a portion of this valuable ecosystem would be preserved.

Investigators such as Anderson (1) and Reimold (3) have shown the reliability of using aircraft remote sensing techniques to do a variety of wetlands studies, including species mapping and vegetation productivity. With the launch of the NASA Earth Resources Technology Satellite (ERTS-1) in July, 1972, it became possible to investigate the use of small scale imagery for doing large area wetlands ecological studies.

ERTS-1 data provide repetitive synoptic coverage of the earth's surface. It is the first time that information of this nature has been available to investigators on a routine basis. The satellite is in a near polar, sun-synchronous orbit, making about 14 revolutions around the earth each day with complete global coverage every 18 days. The altitude is 912 kilometers with equatorial crossing at about 9:45 local time. ERTS-1 is equipped with two sensing systems. The Return Beam Vidicon (RBV) system is three co-aligned cameras, each viewing the same scene but in different spectral bands. These are 0.475-0.575, 0.580-0.680, and 0.690-0.830 microns. The second is the Multispectral Scanner Subsystem (MSS), which scans the earth, simultaneously detecting energy in four spectral bands: Green Band 4, 0.5-0.6; Red Band 5, 0.6-0.7; I.R. Band 6, 0.7-0.8 and I.R. Band 0.8-1.1 microns. Information is either stored in on board type recorders or transmitted to ground tracking stations. Images, 185 kilometers square of earth surface, are prepared at Goddard Spaceflight Center.

The coastal marshes from North Carolina and southward represent the best development of saline marshes in the United States. Those in South Carolina and Georgia are particularly well developed. Cooper (2) has summarized the current knowledge of eastern coastal areas. Vegetational composition is quite similar along most of the coast but grades to mangrove swamps in Florida. Tidal amplitudes vary from two feet in some portions of North Carolina to eight feet in South Carolina and Georgia.

The two major community types which dominate the marshes of this area are Spartina alterniflora and Juncus roemerianus. These species are restricted to areas with frequent tidal inundation. S. alterniflora occurs as at least two and in some areas three growth forms. This is apparently related to tidal inundation and soil aeration. High growth (to 3 meters) is found along the banks of creeks where the substratum is very soft and tidal inundation is for the longest period of time. The next growth form (to 1 meter) grows at slightly higher elevations in a more firm substrate. The third growth type (less than 1 meter) is at the highest elevation for S. alterniflora in a firm substrate where other species may mix with it occasionally. Juncus roemerianus occurs as small to large zones mostly at the next highest elevation and where the water is somewhat fresher.

Higher, less frequently tidally inundated portions of these marshes contain several species which grow as mixed communities or in relatively small single species zones. These include Spartina patens and Spartina cynosuroides, Distichlis spicata, Baccharis halimifolia and Borrichia frutescens.

Mapping of wetlands has been approached in a variety of ways depending on the investigator and requirements of the project. Ground based ecological studies in wetlands have produced maps of relatively small areas with a high degree of accuracy. These have been valuable in developing remote sensing techniques but the process is too slow and costly for large areas. Low altitude (2,000 meters) aerial photography has been applied in New Jersey to produce wetland maps which meet national map accuracy standards. This is a relatively rapid method, but the cost may be prohibitive for some states. In order to decrease the time and cost involved in wetland mapping, it will be necessary to reduce the accuracy somewhat. It appears from this research that ERTS-1 data may be applied to rapid, relatively low cost wetland mapping on broad regional scales.

Results of Analysis of ERTS Imagery for Wetland Mapping

A. General for whole area

ERTS positive transparencies at a scale of 1:1,000,000 have high resolution and excellent contrast. Unfortunately processing procedures at Goddard Spaceflight Center favor the more highly reflective, upland features. Due to the high moisture content in marshlands, reflectance values are lower and are quite dark on all ERTS MSS bands. Special processing is required to bring out detail in coastal features. Detail in uplands is lost when optimum processing techniques for coastal areas are used.

The marsh-water interface and the upper wetland boundary are clearly seen on MSS bands 6 and 7. Large plant associations or communities can also be detected on either MSS band 7 or on color composites made using the Diazo subtractive color technique. In bands 4 and 5 (visible: green and red), all marsh species have a low overall average reflectance and appear very dark in tone as does the dryland vegetation. As the coastal marshes become fresher, the spectral reflectance of the species composing these marshes is higher and approaches that of dryland vegetation making the boundary less clear. It may be necessary to develop special processing techniques where wetland grades to dryland in order to clearly define this boundary.

B. Specific analysis of the test area

The area for testing the feasibility of mapping coastal wetlands from ERTS-1 was bordered on the south by Saint Catherine's Island, Georgia, and on the north by Charleston, South Carolina. The southern portion of the test site around Ossabaw Island, Georgia, was studied intensively due to the availability of good ERTS imagery.

The vegetation of this area is characteristic of the southern coastline in general. There are large zones of high and low growth *S. alterniflora* and *J. roemerianus*, and smaller zones of *S. cynosuroides*, *B. frutescens* and *S. patens*. There is marshland ditching in Ogeechee River related to agriculture and "lagooning" for water-side homes on the Vernon River. Fig. 1 is a map showing the location of the test area.

Fig. 2 is a 1:250,000 scale reprocessed enlargement of MSS band 7 (No. 1046-15324, Sept. 7, 1972) of the test site. Note good tonal differentiation in the coastal marshland but

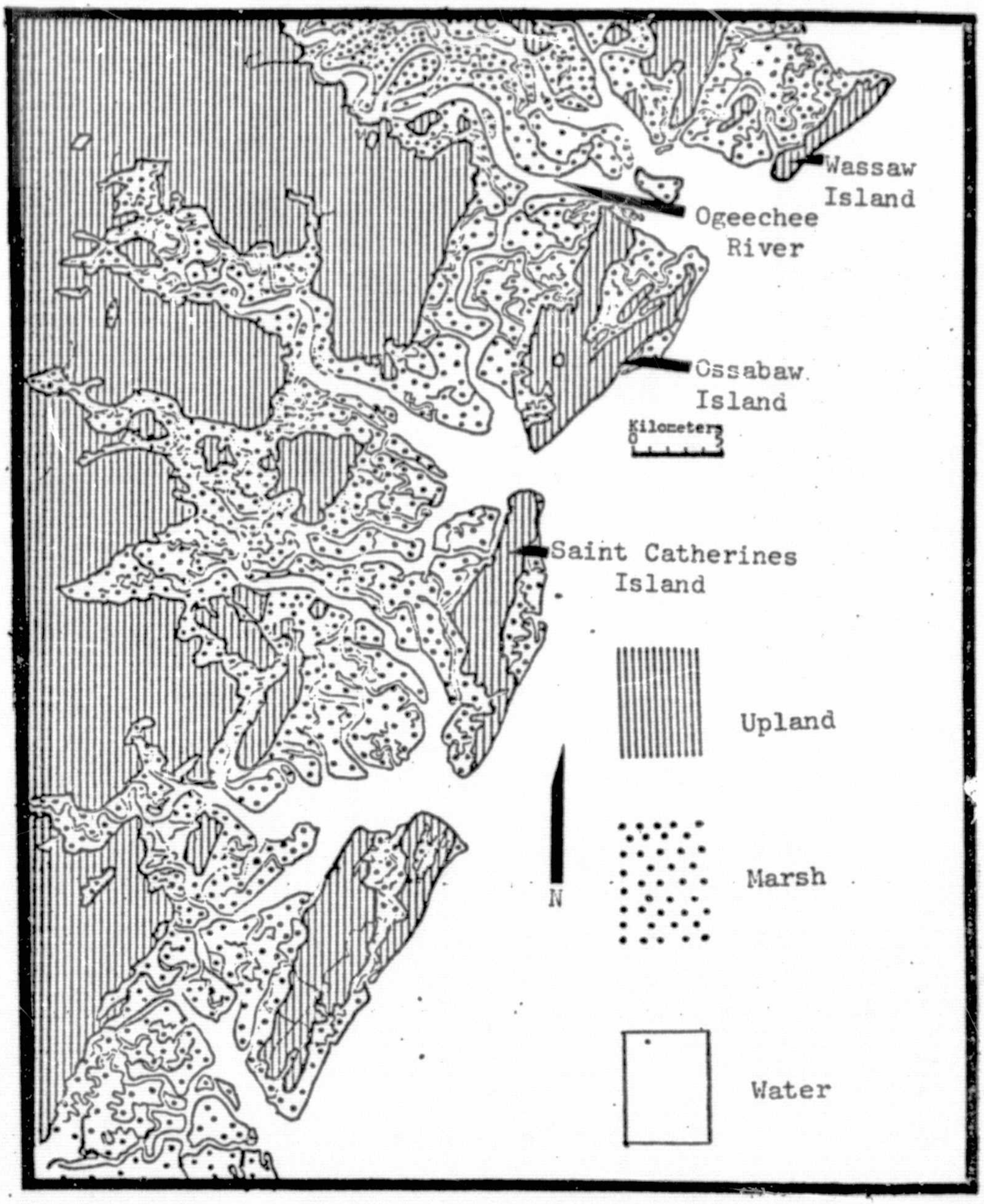


Fig. 1. Map of portion of Georgia coastline showing areas of intensive analysis.

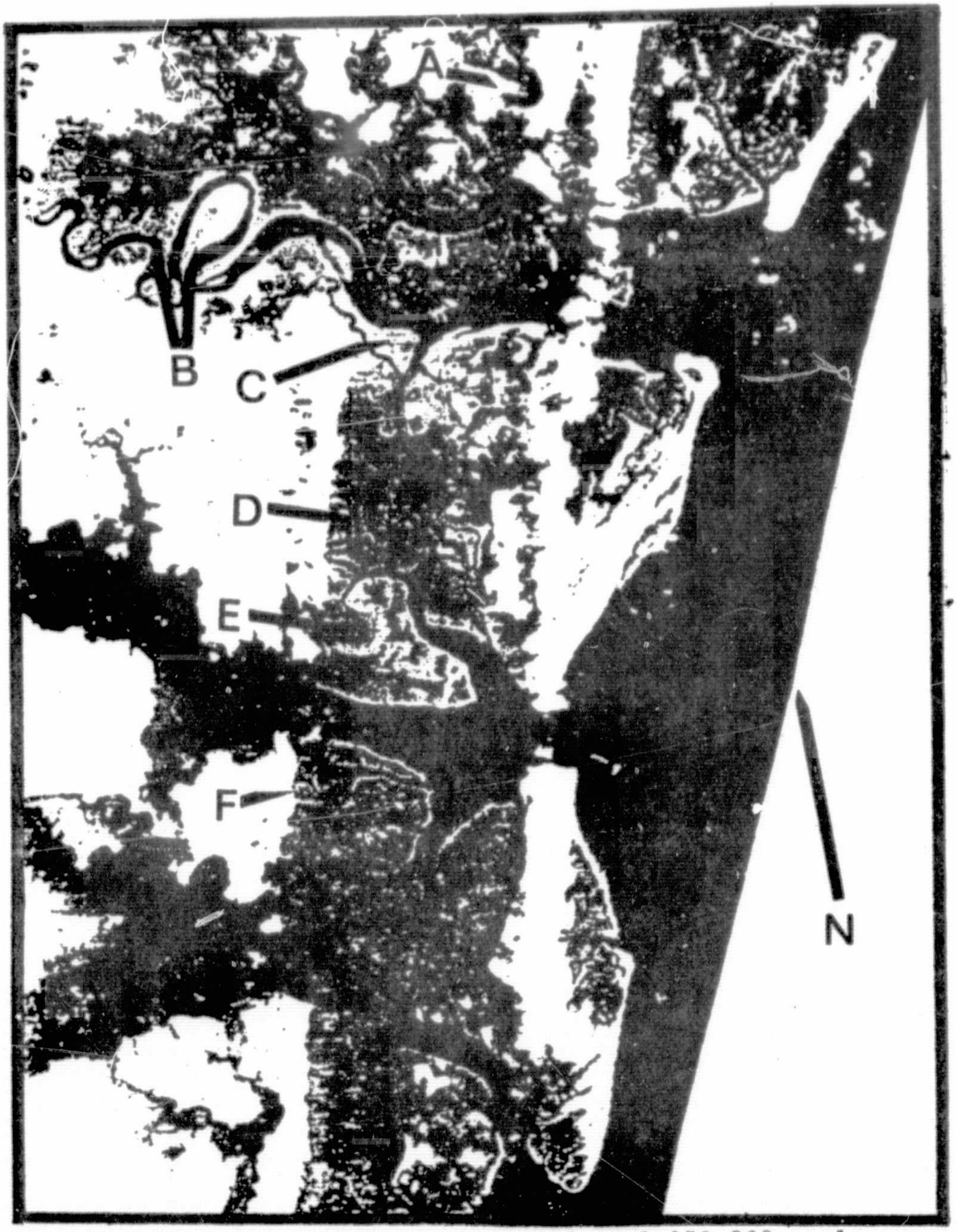


Fig. 2. ERTS image, band 7, enlarged to 1:250,000 scale. A - "lagooning" for water-side homes; B - wetland ditching with Spartina cynosuroides; C - zone of Juncus roemerianus; D - Spartina alterniflora high growth form along creek edges (interior dark areas are low growth form of this species); E - berm with Spartina alterniflora and Borrichia frutescens; F - upland-wetland border.

loss of detail in the upland. The upper wetland boundary is clearly seen in most of the image although patchy clouds may be mistaken for upland or tree islands in the marsh. Lagooning for water-side home development is visible near Burnside, Georgia, on the Vernon River. Of possible greater significance is the marshland ditching visible in the Fort McAllister area of the Ogeechee River. Ditching causes drying out and accelerates vegetational succession to dryland species and is therefore undesirable as currently practiced for mosquito control and agriculture in many areas. It has been assumed that the resolutional limitation of ERTS imagery would not allow definition of ditching practices. At least in this area that assumption was incorrect.

Various vegetational features are also clearly shown. Tonal characteristics of marshland vegetation in Ogeechee River are considerably different from the nearby Medway River. On the ground investigations have shown that *Juncus roemerianus* is the dominant vegetation in the Red Bird Creek area. The lighter tones of this species contrast nicely with the darker tones of *Spartina alterniflora* which makes up the bulk of the vegetation in Medway River.

Tonal structure in the Bear River marshes indicate that separation of at least two growth forms of *S. alterniflora* will be possible. The tall form along the creeks images lighter than the shorter forms. It appears that gross productivity estimates may be made from the imagery. The lightest tones in these marshes at the "loop" in the Ogeechee River and off Kilkenny Creek near Belle Isle are mixed populations of *Spartina cynosuroides* and *Borrichea frutescens*.

Conclusions

ERTS-1 imagery is an excellent tool by which large area coastal marshland mapping may be undertaken. If states can sacrifice some accuracy (amount unknown at this time) in placing of boundary lines, the technique may be used to do the following:

(1) Estimate extent of man's impact on marshes by ditching and lagooning.

(2) Place boundaries between wetland and upland and hence estimate amount of coastal marshland remaining in the state.

(3) Distinguish among relatively large zones of various plant species including high and low growth S. alterniflora, J. roemerianus, and S. cynosuroides.

(4) Estimate ·arsh plant species productivity.

References

[1]Anderson, R. R. and Wobber, F. W., "Wetlands Mapping in New Jersey," Photogrammetric Engineering (in press).

[2]Cooper, A. W., "Salt Marshes," in Coastal Ecological Systems of the United States, Environmental Protection Agency, Washington, D. C.

[3]Reimold, R. J., Gallagher, J. L., and Thompson, D. E., "Coastal Mapping with Remote Sensers," Proceedings of a Symposium on Coastal Mapping, Washington, D.C., American Society of Photogrammetry, pp. 99-112.