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WALLOPS ISLAND, VIRGINIA 23337

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Head, Administrative Management Branch

Enclosures

NASA CR-62097

# COLLECTION AND ANALYSIS OF REMOTELY SENSED DATA FROM THE RHODE RIVER ESTUARY WATERSHED

Report

Contract No. NAS6-1913
National Aeronautics and Space Administration
Wallops Station, Wallops Island, Virginia 23337

Chesapeake Bay Center for Environmental Studies
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(1972)

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# INTRODUCTION

The National Aeronautics and Space Administration (NASA) has selected the Chesapeake Bay and its immediate tributaries as one of four major test sites for the study of remote sensing techniques by the Earth Resources Technology Satellite (ERTS) and the Skylab Project. As a part of this program, NASA chose the watershed of Rhode River, a small sub-estuary of the Bay, as a representative test area for intensive studies of remote sensing, the results of which could be extrapolated to other estuarine watersheds around the Bay. A broad program of ecological research was already underway within the watershed, conducted by the Smithsonian Institution's Chesapeake Bay Center for Environmental Studies (CBCES) and cooperating universities. This research program offered a unique opportunity to explore potential applications for remote sensing techniques. This led to a joint NASA-CBCES project with two basic objectives: to evaluate remote sensing data for the interpretation of ecological parameters, and to provide essential data for ongoing research at the CBCES. A third objective, dependent upon realization of the first two, was to extrapolate photointerpretive expertise gained at the Rhode River watershed to other portions of the Chesapeake Bay.

In pursuit of the first two objectives, this project has investigated the applications of remote sensing to three types of research now in progress at the CBCES:

1. Detection and mapping of drainage patterns (for studies of stream discharge into the estuary)

2. Identification and mapping of plant species in deciduous forest, cultivated and abandoned fields, and salt marshes, both by photointerpretation and ground truth. This was accomplished through the following projects:

   A. Preparation of a vegetation map of the watershed

   B. Photointerpretation and ground truth correlation at a deciduous forest site

   C. Recording of phenological changes as photointerpretive aids

   D. Photointerpretation of late summer crops

   E. Photointerpretation and ground truth correlation at two salt marsh sites

3. Detection and mapping of physical factors (bank erosion, sediment movements, etc. ) and aquatic vegetation in Rhode River estuary.

Use and evaluation of remote sensing is planned by CBCES investigators for study of planktonic blooms, ground water seepage, distribution of waterfowl, and land use patterns.

The basic approach applying remote sensing to the above research was (a) to examine the available remote sensing data, (b) to determine methods of correlating these data with ground truth, and (c) to use both types of data to statistically evaluate the photo-interpretive techniques used. This approach was best for analysis of vegetation cover types. For mapping drainage patterns and estuarine conditions, most emphasis had to be placed on photo-interpretation.

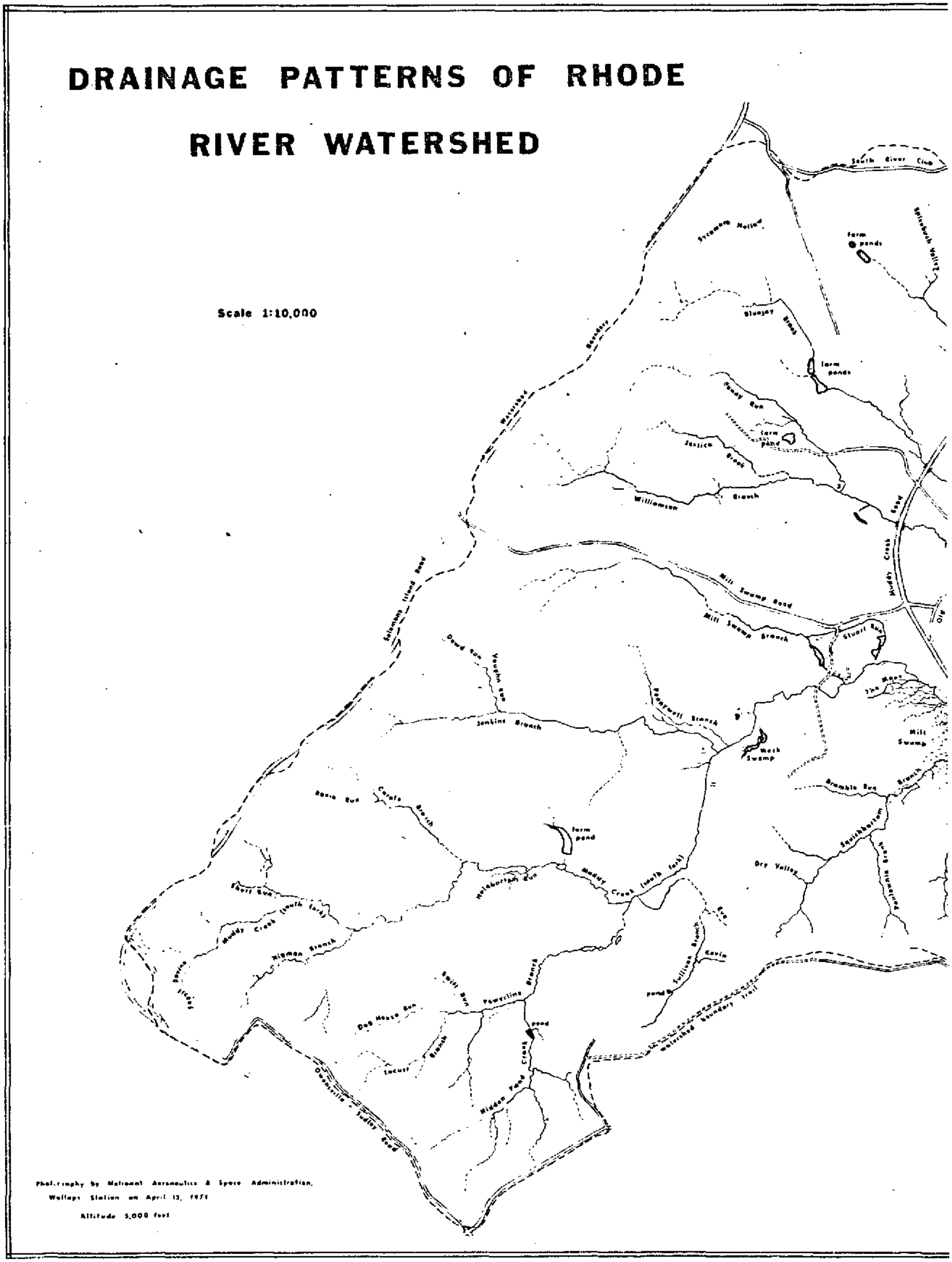
# DESCRIPTION OF RHODE RIVER WATERSHED

Rhode River watershed comprises 18 square miles of which 14 square miles is land including forests, old fields, pastures, cropland, freshwater marshes, salt marshes, and residential areas, and approximately 4 square miles of the study area is estuary.

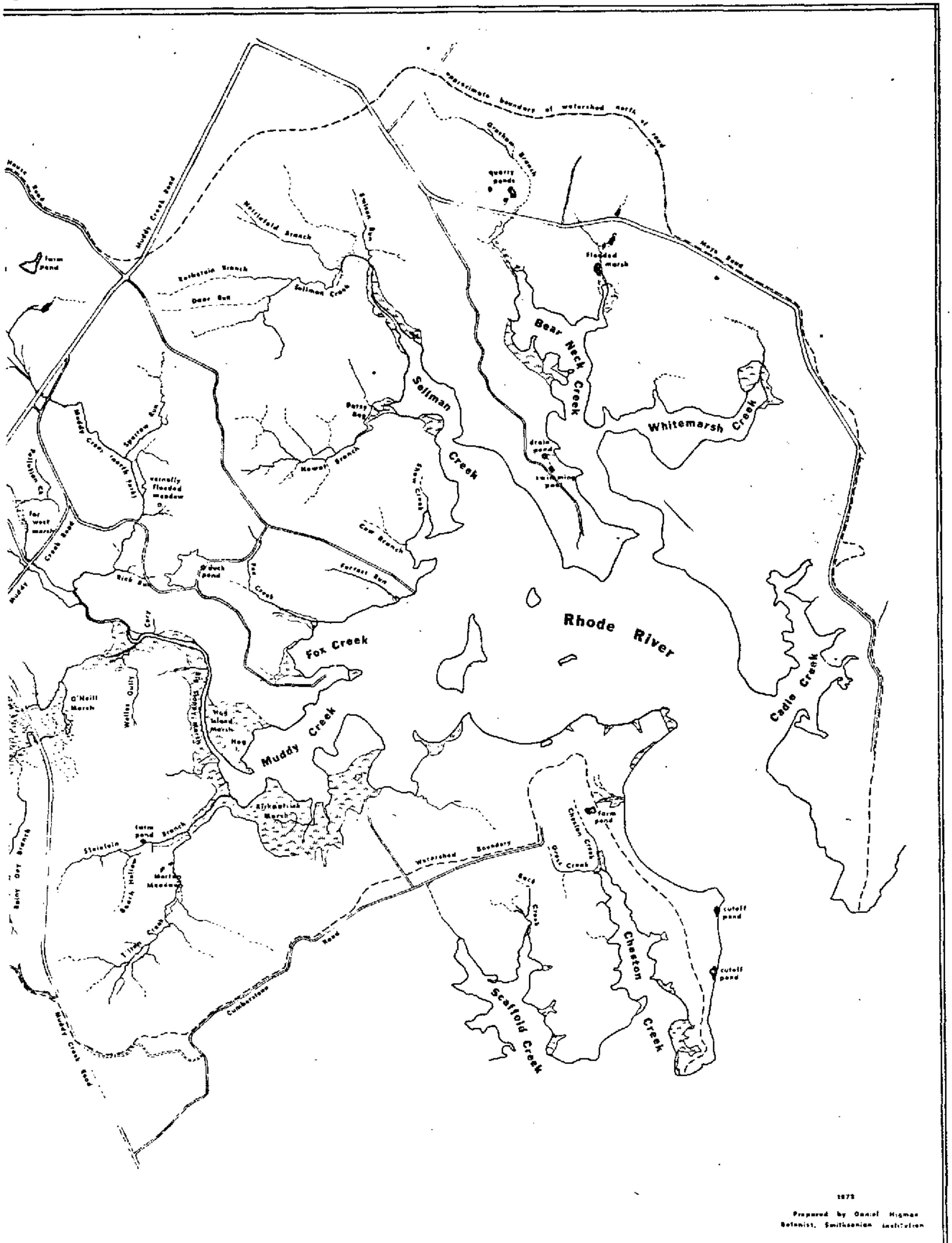
The watershed is predominantly an agricultural area which is slowly becoming more heavily populated by suburban encroachment. The eastern shore of Rhode River is populated by the towns of Mayo and Beverly Beach. The western shore remains undeveloped, as most of it is owned either by the Smithsonian or by families deeply concerned with the preservation of wildlife and the natural environment. This particular shoreline (approximately 13.5 miles long) is one of the largest relatively undisturbed areas remaining on the western side of the Chesapeake Bay.

Approximately 45% of the land area of the watershed is cultivated with grain, tobacco, and truck farms. Recent farmers have wisely left most of the stream valleys and floodplains covered with forest, so soil erosion is presently minimal. Forests cover approximately 35% of the watershed. The remaining 20% includes abandoned fields, marshes, and the towns of Mayo and Beverly Beach. This is shown on the drainage map in Figure 1.

Figu


DRAINAGE PATTERNS OF RHODE
RIVER WATERSHED
Scale 1:10,000
Jenkins Branch
Mill Swamp Road
Mill Swamp Branch
Williamson Branch
farm pond
Dry Valley
Powerline Branch
Mill Swamp

re 1


Rhode River
Muddy Creek
Fox Creek
Sellman Creek
Bear Neck Creek
Whitemarsh Creek
Cadle Creek
Scaffold Creek
Chaston Creek
Muddy Creek Road
Mayo Road
Cumberstone Road
Watershed Boundary
approximate boundary of watershed north of road
Hog Island Marsh
O'Neill Marsh
Kirkpatrick Marsh
Martin Meadow
vernally flooded meadow
farm pond
quarry ponds
flooded marsh
drain pond
swimming pool
duck pond
cutoff pond
Rich Run
Deer Run
Forrest Run
Cow Branch
Howat Branch
Steinlein Branch
Prepared by Daniel Higman
Botanist, Smithsonian Institution

The topography of the watershed is chiefly rolling upland, much dissected by narrow stream valleys which broaden to level flood-plains along the courses of Muddy Creek, the principal tributary stream. The eastern shore of Rhode River consists of relatively level lowland, where no streams originate. Maximum elevation in the watershed is 207 feet on the western boundary. Elsewhere the maximum elevation averages 160 feet.

The streams provide good drainage of the upland and flow all year except during summer droughts. Springs and seepages are numerous. The south fork of Muddy Creek and its tributaries drain into Mill Swamp, a partially forested freshwater swamp covering approximately one-quarter square mile. The swamp probably serves as a reservoir for sediments, nutrients, and pollutants washed down from the surrounding upland.

Soil erosion from Rhode River watershed and siltation of the estuary itself have been severe since initial European settlement and clearing of the forest. Extensive salt marshes have developed along the lower course of Muddy Creek and around its mouth. The available data on the depth of Rhode River indicate progressive shoaling since the initial surveys in 1846.

The soils of the watershed range in texture from sand to silt loam. Some overlie the geologic sediments from which they were formed but others have evidently been washed together from other sources. Stones in the soil are rare, a fact attributed to the repeated washing of the soil particles by successive previous ocean levels and upland streams.

The climate of Rhode River watershed and the surrounding region is humid and temperate, usually with mild winters and hot summers. Storms typically move in from the west but there are also onshore winds from the sea which bring cool breezes in summer and north-eastern storms in winter. The Chesapeake Bay moderates the diurnal range of temperatures over adjacent land areas and raises the annual temperature.

The seasonal weather is highly variable, with extremes of temperature (both maximum and minimum) likely to occur at any time of year with no discernible pattern. Spring is the most variable season. Summers tend to be hot and dry with sudden thunderstorms which may cause brief flooding and severe erosion. The growing season usually lasts from late March to late October. Catastrophic storms are rare but locally serious rains are common.

The Rhode River estuary has a surface area of three to four square miles and a mean depth of approximately six feet. The six foot depth contour parallels the shore about 400 feet offshore, except in the shallower region west of Big Island. Salinities vary locally and seasonally, and range from 4-5 to 11-13 parts per thousand.

The range of tide in Rhode River is usually about 18 inches, but strong southeast winds may cause excessively high tides by pushing more water into the estuary, and strong northwest winds may drive it out. Most of the estuary is sheltered from strong winds and currents, so that wave erosion is not severe, but near its mouth strong contrasts in erosion and deposition occur, especially along the western shore (Cheston Peninsula).

The bottom of the estuary frequently consists of soft black silt, carpeted in some places with waterlogged tree trunks. The shallow area near the mouth of Muddy Creek usually supports a variety of aquatic flowering plants, notably red-headed pondweed (Potamogeton perfoliatus) and Eurasian milfoil (Myriophyllum spicatum). The latter species became so abundant in 1964-65 as to be a serious pest. Scientists at the Johns Hopkins University have been studying its fluctuations of abundance and the recovery of the native aquatic species.

The floristic composition and patterns of vegetation in the terrestrial areas of the Rhode River watershed have been intensively studied within the boundaries of the Chesapeake Bay Center, and for purposes of this study have extended to include the entire watershed. The forests of this area are an interface of the oak-pine coastal plain with the oak-chestnut piedmont (Braun, 1950). Characteristic of these types are white oak with sweetgum, willow oak, pin oak, and sour gum on poorly drained uplands, mixed hardwood and loblolly. Virginia pine stands on abandoned upland fields, beech, tulip, and white oak on slopes, and oak-tulip codominants with hickory subdominants on the piedmont uplands. Chestnut, previously codominant with oak, has been gradually replaced by tulip. These forests represent mature secondary growth in this region.

# AERIAL OVERFLIGHTS

A total of 17 overflights has been made for this study to date, 15 of them under the direction of NASA, Wallops (Table 1). All but two of the NASA-directed flights have been low-level (1200-5000 feet) photographic missions using a T-11 camera with a six inch focal length mounted in a helicopter. Film and filters were used as follows:

| Film | Filter |
|---|---|
| panchromatic black and white (DXN 2405) | Wratten 57 |
| black and white infrared (2424) | Wratten 25A |
| natural color (8442) | Wratten HF-2 |
| natural color (SO-397) | Wratten A-1 |
| color infrared (8443) | Wratten 15 |
| color infrared (2443) | Wratten 12 + 20B<br>Wratten 12AV + 20M<br>Wratten 15 + 20B |

Most of the flights utilized natural color and color infrared film since these types have proved to be the most useful for this study. The film is developed as positive color transparencies on a 9 x 9 inch format.

Other overflights include one taken by NASA, Wallops from an RB-57 at 60,000 feet with color infrared and natural color film, a flight by the University of Michigan's Willow Run Laboratory from a C-47 at 5000 feet with film and multispectral scanner, and two flights by Rome Air Force Base. The Air Force flights include one from a C-131 at 2000 feet using a modified AM-AAS-18 MAIRS thermal infrared scanner and the other with a RC-8 sensor using natural color film (2448) from an altitude of 3000 feet.

Hydrological and weather conditions recorded at the CBCES pier and at the weather station in front of the main building are given in Tables 2 and 3. Except for precipitation, cloud conditions and air temperature, all data were taken from a continuously recording Honeywell monitoring system at the CBCES pier with permission of Mr. Robert Cory, U. S. G. S. Data coincide with the starting time for each flight.

In the near future, a continuously recording air temperature monitor will be installed at the main building area. In addition, two stream monitoring stations have been installed on the north fork of Muddy Creek. Both continuously record stream temperature and one also records stream flow. These temperature records will be invaluable for correlations with thermal overflights.

TABLE 1

AERIAL DATA TAKEN FOR CBCES PROJECT BY NASA

| Flight # | Date & Season | Imagery Type | Amount (frames) | Altitude (feet) | Scale | Area Covered | Stereo |
|---|---|---|---|---|---|---|---|
| 15 | 6/30/70 Summer | b/w IR<br>b/w Pan<br>col Nat<br>col IR | 25 ea. | 3500 | 1:7000 | eastern half of watershed | Some |
| 17 | 7/1/70 Summer | b/wIR<br>b/w Pan<br>Col Nat<br>Col IR | 71 ea. | 3500 | 1:7000 | whole watershed | Some |
| RB-57 Mission 144 Flight 2 | 10/22/70 Fall | col IR | 2 | 60, 000 | 1:60, 000 | whole watershed | Yes |
| 27 | 10/17/70 Fall | b/w IR<br>b/w Pan<br>col Nat<br>col IR | 17/2<br><br>21/2 | 1200<br><br>5000 | 1:2400<br><br>1:10, 000 | Hog Is. marsh and western Java forest | Some |
| U. of Mich. DC-7 | 11/6/70 | b/w IR<br>b/w Pan<br>col Nat<br>col IR | ——— | 5000 | 1:10, 000 | Beverly Beach to Shadyside (2 flight lines) | Yes |

scan bands:
.32 - .38
.40 - .44
.44 - .46
.46 - .48
.48 - .50
.52 - .55
.55 - .58
.58 - .62
.62 - .66
.66 - .72
.72 - .80
.80 - 1.00
4.50 - 5.50
8..00 - 14.00

Table 1 (Continued)

| Flight # | Date & Season | Imagery Type | Amount (frames) | Altitude (feet) | Scale | Area Covered | Stereo |
|---|---|---|---|---|---|---|---|
| 32 | 11/8/70 Fall | b/w IR<br>b/w Pan<br>col Nat<br>col IR | 44 ea. | 1200 | 1:2400<br>1:10, 000 | Beverly Beach to Shadyside (2 flight lines) | Yes |
| 36. | 12/5/70 Winter | b/w IR<br>col IR | 80 ea. | 2500<br>1200 | 1:5000<br>1:2400 | Parts of water-shed | No |
| | | col Nat | 10 ea. (2 sets) | 1200 | 1:2400 | 4 test sites | Yes |
| 43. | 2/2/71 | b/w IR<br>col Nat<br>col IR | 56 ea. | 5000 | 1:10, 000 | Whole watershed | Yes |
| 48 | 3/16/71 Winter | col Nat<br>col IR | 25 ea. | 1200 | 1:2400 | 4 test sites | Yes |
| 51 | 4/13/71 early spring | col Nat<br>col IR | 68 ea. | 1200 | 1:2400 | 5 test sites | Yes |
| | | | | 5000 | 1:10, 000 | Whole watershed | Yes |
| 57 | 5/5/71 Spring | col Nat<br>col IR | 63 | 2500 | 1:5000 | Most of Rhode River watershed | Yes |
| 60 | 5/18/71 | col Nat<br>col IR | 108 | 1200<br>2500 | 1:2400<br>1:5000 | 5 test sites<br>Whole watershed | Yes |
| 73 | 7/13/71 Summer | col Nat<br>col IR | 16 ea.<br>80 ea. | 1200<br>2500 | 1:2400<br>1:5000 | 5 test sites<br>Parts of Water-shed | Some<br>Some |
| 80 | 8/24/71 Late Summer | col Nat<br>col IR | 103 ea. | 3500 | 1:7000 | Whole watershed | Some |
| 89 | 10/7/71 Fall | col Nat<br>col IR | 43 ea. | 5000 | 1:10, 000 | Parts of watershed | Some |
| IR-71-21 | 4/7/71 Early Spring | MAIRS Modified AM-AAS-18 | 9 | 2000 | 1:10, 000 | Most of watershed and estuary | |
| 71-67 | 11/15/71 | col Nat | 140 | 3000 | 1:6000 | Most of watershed | |

## TABLE 2

## HYDROLOGICAL CONDITIONS DURING NASA OVERFLIGHTS

| Flight # | Date | Starting Time | Water Temp. (°C.) | Salinity (ppt) | pH | Dissolved Oxygen (ppm) | Turbidity (JCU) | Tide Level * (feet) |
|---|---|---|---|---|---|---|---|---|
| 15 | 6/30/70 | 1000 | 24.5 | 8.7 | — | 7.0 | 15 | 6 |
| 17 | 7/1/70 | 1500 | 27.0 | 8.4 | — | 7.5 | — | 5.5 |
| RB-57: 144(2) | 9/22/70 | 1530 | 27.4 | — | 8.4 | 8.5 | — | — |
| 27 | 10/17/70 | 1300 | 17.0 | 13.0 | 8.1 | 6.6 | — | 4.0 |
| U. of Mich. | 11/6/70 | 1430 | 12.0 | 11.4 | 8.2 | 8.4 | — | 5.7 |
| 32 | 11/8/70 | 1500 | 12.4 | 11.4 | 8.1 | 7.5 | — | 6.1 |
| 36 | 12/5/70 | 0900 | 8.4 | 12.1 | — | 11.4 | — | — |
| 43 | 2/2/71 | 1330 | — | — | 8.2 | — | 6 | — |
| 48 | 3/16/71 | 1600 | 10.4 | 6.1 | 9.0 | 13.6 | 16 | 5.5 |
| 51 | 4/13/71 | 1200 | 13.8 | — | 7.9 | 11.0 | — | — |
| 57 | 5/5/71 | 0930 | — | — | — | — | — | — |
| 60 | 5/15/71 | 1030 | 13.0 | 6.9 | 8.0 | 9.4 | — | 6.7 |

Table 2 (Continued)

| Flight # | Date | Starting Time | Water Temp. (°C.) | Salinity (ppt) | pH | Dissolved Oxygen (ppm) | Turbidity (JCU) | Tide Level * (feet) |
|---|---|---|---|---|---|---|---|---|
| 73 | 7/13/71 | 1300 | 27.5 | ___ | 8.0 | 6.7 | ___ | 6.4 |
| 80 | 8/24/71 | 1000 | ___ | ___ | ___ | ___ | ___ | ___ |
| 89 | 10/7/71 | 1230 | 21.2 | 10.4 | 8.5 | 9.0 | 20 | 5.8 |

* Water level at end of CBCES pier

TABLE 3

WEATHER CONDITIONS DURING NASA OVERFLIGHTS

| Flight # | Date | Starting Time | Daily Precipitation (Inches) | Cloud Type (Daily) | % Cover (Daily) | Wind Speed (mph) | Wind Direction | Air Temp. °C. Daily Max. | Air Temp. °C. Min. |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 6/30/70 | 1000 | 0 | clear | 0 | 8 | SSW | 34.5 | 18.9 |
| 17 | 7/1/70 | 1500 | 0 | clear | 0 | 6 | E | 30.0 | 19.4 |
| 57:144 (2) | 9/22/70 | 1530 | 0 | clear | 0 | ___ | ___ | 35.0 | 8.3 |
| 27 | 10/17/70 | 1300 | 0 | cirro-cumulus | 10 | 0-10 | W | 12.3 | 1.7 |
| U. of Mich. | 11/6/70 | 1430 | 0 | clear | 0 | 5-10 | WNW | 16.[illegible] | 1.7 |
| 32 | 11/8/70 | 1500 | 0 | ___ | ___ | 0- 5 | E | 17.3 | 3.3 |
| 36 | 12/5/70 | 0900 | 0 | cumulus | 0-40 | 0- 5 | S | 21.1 | 2.2 |
| 43 | 2/2/71 | 1330 | 0 | | | 5 | WNW | 10.0 | -14.4 |
| 48 | 3/16/71 | 1600 | 0 | cumulus | 0-40 | 10 | SW | 21.1 | 2.2 |
| 51 | 4/13/71 | 1200 | ___ | ___ | ___ | 10-15 | ESE | 2[illegible].1 | - 1.1 |
| 57 | 5/5/71 | 0930 | 0 | cumulus | 0-100 | ___ | ___ | 24.5 | 7.[illegible] |
| 60 | 5/18/71 | 1030 | ___ | ___ | ___ | 5 | NE | ___ | ___ |
| 73 | 7/13/71 | 1300 | 0 | cumulus | 20 | ___ | ___ | 27.8 | 17.[illegible] |
| 80 | 8/24/71 | 1000 | 0 | clear | 0 | 0- 5 | ___ | 27.2 | 10.0 |
| 89 | 10/7/71 | 1230 | ___ | clear | 0 | 7 | ___ | ___ | ___ |

## COMPARISON OF FILM TYPES IN PHOTOINTERPRETATION

Natural color and color infrared film were found to be superior in this study to panchromatic and black and white infrared film for plant species identification and for detection of soil moisture, drainage, siltation, and turbidity. This difference is largely due to the additional information provided by hue and chroma characteristics of color as opposed to only value (light and dark) characteristics of black and white film. The relative merits of color infrared and natural color film for vegetation study are not agreed upon by photointerpreters. Northrop (1968) studying mixed hardwoods in Alabama and Krumpe (1971) working in mixed hardwoods in Tennessee agree that natural color is superior to color infrared for tree species identification. Anson (1966), studying forests in South Carolina and Maruyasu et al (1971) in Japanese deciduous forests, claimed the superiority of color infrared over natural color photos. The latter investigators also reported color infrared superiority in evaluating forest mixture types, crown densities, stand composition with height classes, and ground flora. Pestrong (1970) working on San Francisco Bay marshland and Anderson (1971) studying marshland in Chesapeake Bay state that color infrared is superior to natural color while Egan and Hair (1971), also working on Chesapeake Bay marshland claim the superiority of natural color used with microdensitometry in the red band region. Those investigators maintaining that natural color is inferior to color infrared film invariably mention the haze problem, a factor mentioned in this study, which is dependent on flying altitude and to some extent season. A near consensus of opinion is reached with regard to drainage mapping; the present investigators agree with Pestrong (1970), Anson (1966), and Norton (1964) that color infrared is superior to natural color. Anson also adds that natural color is superior to infrared color for mapping soils and cultural features.

In this study it was found that no clear distinction could be made between the effectiveness of natural color and color infrared film. Each type had advantages and disadvantages in different instances. Generally, natural color film was better for vegetation interpretation if haze during exposure was negligible. Natural color was less confusing than color infrared, especially in fall when colors were greatly varied; with natural color it was possible to translate field experience directly into photointerpretive ability. This was especially useful in marsh and forest vegetation mapping. Under haze conditions, caused either by weather or flying altitude, color infrared was preferable. For interpretation of drainage patterns, color infrared was superior, while for sedimentation detection, natural color was more desirable. Comparisons of the relative effectiveness of the two types of film under specific conditions are given in Table 4.

## TABLE 4

## FACTORS AFFECTING PHOTOINTERPRETATION

| Ground Feature / Film Types | Deciduous Forest | Pine Forest | Cultivated Fields | Old Fields | Salt Marsh | Other |
|---|---|---|---|---|---|---|
| Natural Color | Species subcanopy (Spring) F<br>Species canopy (summer) G<br>Species canopy (fall) G | Discernible by color (winter) G<br>Discernible by texture (other seasons) F | Recognition by texture G<br>Recognition by color F | Species recognition (fall, winter, spring) G | Species G | Drainage (winter, early spring) F<br>Aquatic Veg. F<br>Estuarine Siltation G |
| Color Infra-red | Subcanopy (spring) G<br>Canopy (summer) F<br>Canopy (fall) G | Discernible by color (winter, summer, spring) G<br>Discernible by texture (fall) F | Same as above | Species recognition (fall, winter, spring) F<br>Evergreen Component Recognition (winter) G | Species F | Drainage (winter, early spring) G<br>Aquatic Veg. F<br>Estuarine Siltation P |

G = good detection
F = fair detection
P = poor detection

Table 4 (Continued)

| Ground Feature | Deciduous Forest | Pine Forest | Cultivated Fields | Old Fields | Salt Marsh | Other |
|---|---|---|---|---|---|---|
| Altitude<br><br>(Alt. /Scale Ratio = 1:2) | species recognition:<br>1200, 2500 ft. G<br>3500, 5000 ft. F<br><br>age class distinction:<br>under 5000 ft. F<br>5000 ft. G | species recognition:<br>below 5000 ft. G<br>above 5000 ft. P | crop recognition:<br>1200-5000 ft. G<br>above 5000 ft. F-P | species recognition:<br>3500 ft. & below G<br>above 3500 ft. P | species recognition:<br>5000ft. & above F<br>below 5000 ft. G | Estuarine Siltation, current flow:<br>5000 ft. G<br>below 5000 ft. P |
| Haze | for all recognition purposes, usefulness of natural color much reduced, infrared color slightly reduced. | | | | | |
| Season | phenological species recognition:<br>spring G<br>fall G<br>winter & summer F<br>structural feature recognition:<br>summer G<br>winter G<br>spring & fall F | discernibility & species recognition:<br>winter G<br>summer, fall, spring F | crop recognition:<br>summer-fall G<br>winter-spring F | dense stand recognition:<br>winter G<br>fall, spring, summer F<br><br>evergreen ground-cover recognition:<br>winter G<br>other seasons P | species recognition:<br><br>summer, fall G<br>winter, spring F | soil conditions:<br>winter, early spring G<br><br>fall, summer (after plowing only) F |

G = good detection
F = fair detection
P = poor detection

# PHOTOINTERPRETATION OF VEGETATION USING COLOR AND STRUCTURE

In recent years, much emphasis has been placed on color as a tool in photointerpretation of vegetation types and individual species (Heller et al. 1964, Krumpe 1971, Krumpe et al. 1971a, 1971b, Northrop 1968, Northrop and Johnson 1970, Silvestro 1969, and Parry et al. 1969). Color has proved to be very useful, and in some cases indispensable for correct identification of deciduous forest species. However, the tendency has been to rely heavily on color comparisons between transparencies and the opaque Munsell color standards. These standards are precisely classified according to hue, chroma, and value. There are a number of drawbacks to the use of Munsell standards in vegetation photointerpretation: (1) color fidelity of aerial films does not warrant such precise color classifications. Color varies from frame to frame and from the middle of the frame to the edge (vignetting), resulting in color value changes (Parry et al., 1969) Norton (1964) recommends standardization of exposure and processing of film as well as standardized lighting for viewing transparencies and color standards. (2) The visual comparison of an opaque color standard with a transparent color leads to subjective errors since the types of light reaching the eye, reflected vs. transmitted, are different in quality. (3) Color ranges representative of a given species are difficult to pinpoint due to (a) variation in relative rates of color change within the species, within a season and from year to year, and (b) variation in color ranges between individuals of the same species and sometimes within a single individual due to seasonal idiosyncracies, habitat, age, and genetic makeup of the individual. Krumpe (1971) and Krumpe et al. (1971a, 1971b) tried to overcome the variation factor by standardizing the phenological state at which his forest study area should be observed and by differentiating the "cluster" or most common color range of a species at that time from the "phase" or more variable and less common colors characteristic of the species. Thus, an investigator using Krumpe's crown key can get some idea of which colors are the expected ones for a species at a given time of year. It becomes clear that absolute color is not as important as relative color in species differentiation, or, in the words of Anson (1966) "color fidelity is not as much a consideration in photointerpretation as color differentiation."

Color criteria notwithstanding, crown structural characteristics are also important for species identification, especially in the case of conifers. Northrop (1968) recommends the following structural characteristics for use in forest photointerpretation:

crown texture, shape, size, pattern, and shadow. Heller et al. (1964) also includes crown apex shape, crown margin, limb exposure, branch shape, and tone spots in the crown. In the case of conifers, Sayn-Wittgenstein (1960) emphasizes that despite minimal color differences, conifers are easier to differentiate than hardwoods by structural characteristics because of their regular growth pattern.

In the present study, both color and structural characteristics as well as habitat and topographic data (recommended strongly by Northrop, 1968) were used for species identification in forests, marshes, old field, and cropland. Both color and texture were necessary in the spring for differentiating beech and tulip trees from later-leafing trees such as oaks and hickories. Color was an excellent criterion for differentiating tree species in the fall while in winter and summer, structural characteristics were more important. Color in winter was useful for differentiating beech and sycamore from species having darker crowns. For crop determination, texture was more important than color differences. In winter and spring, cultivation patterns could be used to predict crop type when color was of little use. Aerial criteria most useful for differentiating types of vegetation are given in Table 4.

## DRAINAGE MAP OF RHODE RIVER WATERSHED

The drainage map of Rhode River watershed (Figure 1) was constructed primarily to satisfy a requirement for detailed and up-to-date hydrographic data by the CBCES research program. Since the most recent and detailed coverage of the watershed is provided by photographic flights under the remote sensing program, the preparation of a drainage map offered an opportunity to compare the values of natural color and infrared color photography for the detection of hydrographic features.

The drainage map shows all discernible streams, intermittent channels, marshes, and natural or artificial ponds. A gray screen representing the forested portions of the watershed provides a background, since forest extends along most of the stream courses. The boundaries of the forest indicate the watersheds of tributary streams, including those which were dry during preparation of the map. Major roads are included on the map for help in orientation. The boundaries of the watershed were drawn from a topographic map.

All data for the map were copied from 9x9 inch transparencies photographed in April 1971 at a scale of 1:10, 000 (flight 51). This flight was chosen because the predominantly deciduous forest of the Rhode River watershed had not yet begun to develop foliage, so that streams running through the forest were readily discernible. The forest outlines, roads, and hydrographic data were traced from each transparency onto sheets of acetate, since it was impractical to cut transparencies from the roll of film. The acetate sheets were then assembled into an uncontrolled mosaic of the Rhode River watershed, and the map was drawn from this mosaic. Slight distortions in the individual photographs tended to produce cumulative distortions in parts of the mosaic, so that frequent corrections were needed. Distortions on the assembled map never exceed 1/4 inch (equivalent to approximately 200 feet on the ground) and are usually much less. Greater accuracy would have required the use of specialized cartographic equipment, which was not available.

The comparison between natural color and infrared color film was made by first tracing the hydrographic and base data from natural color film, then comparing the tracings with corresponding infrared color film. Natural color proved satisfactory except for determining the courses of narrow streams and intermittent drainage channels, and for delimiting swampy areas. For these purposes, the infrared color was superior, since all water surfaces showed blue against a predominantly reddish brown background, whereas natural color offered much less contrast. Approximately 20% of the streams required revision after comparison with infrared color film, usually in the upper reaches of the watershed. A few stream courses could not be accurately traced even on infrared film, either because the overlying vegetation was too dense or because the ravines were too narrow. These obscure courses usually interrupt discernible portions of the streams, and are shown on the map by broken lines. Broken lines also show intermittent channels at the sources of streams. The boundaries of freshwater marshes and swamps were easier to determine on infrared film because of the bluish tinge in wet areas. Salt marshes were easily recognized on both types of film, since they contrast sharply in color and texture from the forest which usually borders them.

The names of streams and marshes on the map were chosen arbitrarily, except for Muddy Creek, Mill Swamp Branch, and Mill Swamp. These latter streams are the only ones named on recent U. S. Geological Survey maps. It was decided to name the other streams in anticipation of an increasing need to refer to them in research projects throughout the watershed. Personal names, former place names, and names descriptive of conditions at the sites were used. Estuaries were given the names that already appear on the U. S. Geological Survey maps.

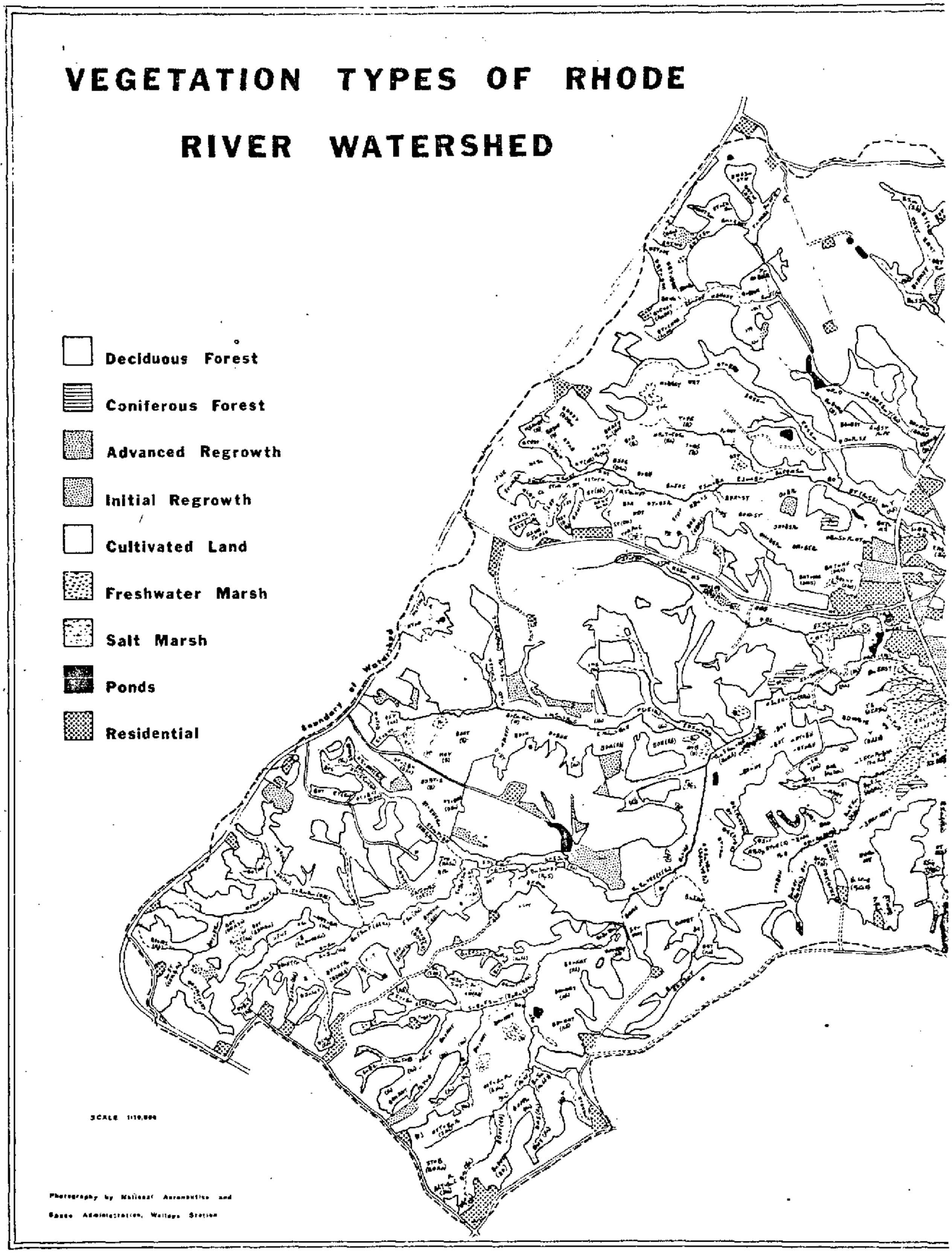
## VEGETATION MAP OF RHODE RIVER WATERSHED

The vegetation map of Rhode River watershed (Figure 2) was constructed to show species composition of forest areas and abandoned fields for research projects by the CBCES. The map facilitated the interpretation of remote sensing data in the various forest habitats throughout the watershed, and improved photointerpretive techniques.

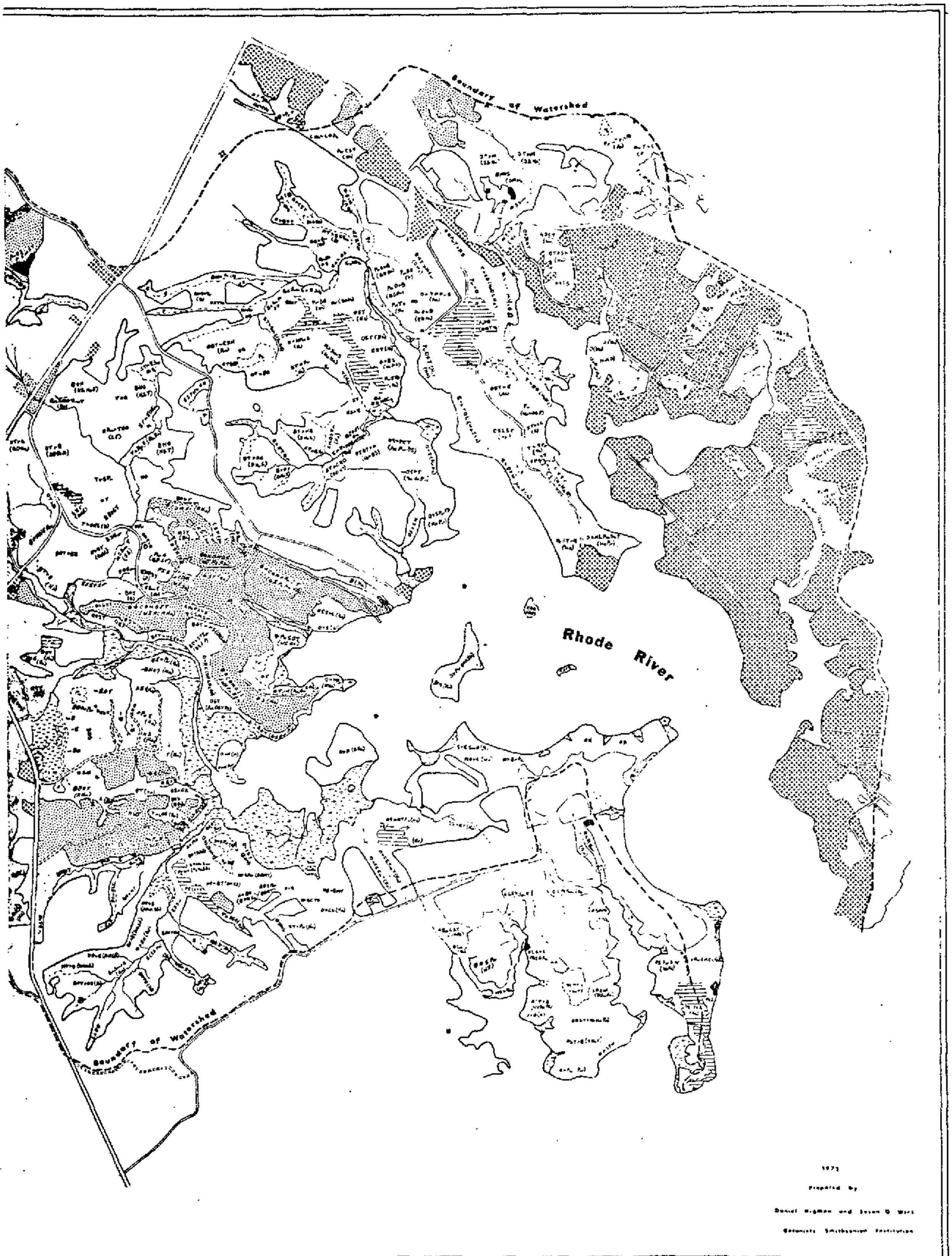
The map shows the distribution of seven major cover types: deciduous and coniferous forest, cultivated and abandoned fields, freshwater and salt marshes, and residential areas. The map describes the dominant and subordinate species found at approximately 500 sites within the forest and abandoned fields, which together cover approximately half the watershed area. Cultivated fields cover most of the remainder of the watershed, but since the crops grown on them are frequently changed they are not described on the map. The vegetation of residential areas (except preserved stands of forest) is not described for the same reason. Most of the marshes are too small to be adequately described on a map of this scale, but a separate section of this report describes the vegetation of the two largest salt marshes.

A prototype of the vegetation map was constructed from a mosaic of black and white aerial photographs taken in 1968 at a scale of

Figu


VEGETATION TYPES OF RHODE RIVER WATERSHED
Deciduous Forest
Coniferous Forest
Advanced Regrowth
Initial Regrowth
Cultivated Land
Freshwater Marsh
Salt Marsh
Ponds
Residential
Boundary of Watershed

re 2



1:5, 000. This scale was excellent for recording field data but was too large for inclusion in this report. The final version of the vegetation map was drawn from the outlines of the drainage map (Figure 1) at a scale of 1:10, 000. The natural color and infrared color photos used to prepare the drainage map were then used to locate precisely the major cover types on the watershed. Infrared photos proved more useful than natural color photos for this purpose since they more accurately revealed not only the boundaries of marshy areas but also the distribution of coniferous forest and evergreen subcanopy vegetation in the deciduous forest and abandoned fields.

In contrast to the drainage map, preparation of the vegetation map required the collection of extensive ground truth. The species composition of the forest canopy and understory was noted whenever any change in the dominant species was apparent, dominance being subjectively determined in each forest habitat by the relative size and abundance of each species. The presence of evergreen shrub and ground layer vegetation (principally honeysuckle) was also noted.

It was impractical to delineate the boundaries of canopy cover types in the deciduous forest, either by recognition from aerial photographs or from ground observations, because the types graded into each other. Species composition of a forest area may be determined by comparing descriptions of the vegetation at several points within it.

The drainage patterns of the forest, shown by the courses of streams, indicate the distribution of stream valley and floodplain vegetation cover types.

Coniferous forest stands are represented by a pattern when coniferous trees constitute 75% or more of the canopy, but more frequently the conifers are scattered through the deciduous forest without forming definite stands large enough to be represented on the map. In these cases, the pattern for deciduous forest is used, and coniferous species are mentioned as co-dominant or subdominant to the hardwoods at individual sites.

The species composition of vegetation cover types on the map is represented by combinations of symbols, the symbol for each species usually being the first letter of its common name. This system makes it easier for researchers in different disciplines to interpret the map. Because the species of some genera such as oak and hickory are difficult to distinguish on aerial photographs, it was decided not to separate these species on the map. In these cases, the first letter of the common generic name is used. When two or more names begin with the same letter, they are distinguished on the map either by the addition of a suffix or by using the first letter of the generic name. For example, the letters H, Hb, and Ho on the map denote hickory, hornbeam, and holly. But hercules-club is more easily distinguished by the letters

Al, for *Aralia*, its generic name. The selection of letters for these symbols has been arbitrary, determined by convenience and to minimize confusion of species. Table 5 gives the symbols and their respective species. In addition to the letter symbols used to denote species, a few asterisks and parentheses are used to distinguish dominant, sub-dominant, and understory species, as well as young stands, lumbered stands, and stands with thin canopies but dense understories.

## TABLE 5

## SYMBOLS USED FOR THE VEGETATION MAP OF RHODE RIVER WATERSHED

Aspect of Stand

* denotes sapling-sized stands

-· denotes recently lumbered stands now growing back

⊗ denotes a stand with thin canopy, not necessarily as a result of lumbering.

> separates dominant species (left) from subordinate species (right) in the canopy

() encloses understory, shrub layer, and ground layer species

Species Symbols

Ad Alder (Alnus serrulata)

Al Tree of heaven (Ailanthus altissima)

Ap Apple (Pyrus malus)

Ar Hercules club (Aralia spinosa)

B Beech (Fagus grandifolia)

Be Box elder (Acer negundo)

Br Birch, river (Betula nigra)

C Cherry, black (Prunus serotina)

Cy Cypress, bald (Taxodium distichum)

D Dogwood, flowering (Cornus florida)

E Elm, American (Ulmus americana)

Ed Elder (Sambucus canadensis)

F Ash (Fraxinus spp.)

Gb Greenbriar (Smilax rotundifolia)

Gs Grass, short (species unspecified)

Gt Grass, tall (Species unspecified)

H Hickory (Carya glabra, C. tomentosa)

Hb Hornbeam, American (Carpinus caroliniana)

Ho Holly, American (Ilex opaca)

Hs Honeysuckle, Japanese (Lonicera japonica)

J Juniper (Juniperus virginiana)

K Mountain laurel (Kalmia latifolia)

L Locust, black (Robinia pseudoacacia)

M Maple, red (Acer rubrum)

N Sour gum (Nyssa sylvatica)

O Oak (Quercus spp.)

P Persimmon (Diospyros virginiana)

Pa Paulownia (Paulownia tomentosa)

Pi Poison ivy (Rhus radicans)

Po Poplar (Populus grandidentata)

Pp Pawpaw (Asimina triloba)

Ps White pine (Pinus strobus)

Pt Loblolly pine (Pinus taeda)

Pv Virginia pine (Pinus virginiana)

R Raspberry (Rubus spp.)

S Sweetgum (Liquidambar styraciflua)

Sa Sassafras (Sassafras albidum)

Sb Spicebush (Lindera benzoin)

Sm Sycamore (Platanus occidentalis)

Su Staghorn sumac (Rhus typhina)

T Tuliptree (Liriodendron tulipifera)

Tv Trumpetvine (Campsis radicans)

V Viburnum (species unspecified)

Vt Grape (Vitis spp.)

W Walnut (Juglans nigra)

Wl Willow, black (Salix nigra)

Ws Weeds, short (unspecified)

Wt Weeds, tall (unspecified)

Examples from the vegetation map:

| | | |
|---|---|---|
| OST > BrPv<br>(SHs) | = | Canopy of oak (one or more species), sweetgum, and tuliptree as dominants, river birch and Virginia pine as subdominants. Understory of Sweetgum; ground layer of honeysuckle. |
| - B<br>(ArD>OSHs) | = | Recently lumbered stand of beech (thin canopy, dense understory). Understory dominated by Hercules club and dogwood, with young or sprouting oak and sweetgum as subordinates. Ground layer of honeysuckle. |

# CORRELATION OF GROUND TRUTH WITH AERIAL PHOTOGRAPHS FOR FOREST SPECIES IDENTIFICATION

An intensive study on identification of forest species, by combining ground truth and remote sensing data, was made on a 5-acre site. The study revealed several fairly reliable criteria which influence this identification. Precautions and techniques were determined which are applicable to similar studies elsewhere. The relative accuracy of photo identification obtainable varies with the species, season, and types of photography employed. Significant correlations of ground truth and remote sensing imagery were obtained on an oval-shaped island (Hog Island) at the mouth of Muddy Creek (see Figure 1). The island supports a mature mixed upland hardwood canopy of white and black oak species, sour gum, and scattered Virginia pine. The understory consists of beech, oaks, and sour gum, with an ericaceous shrub layer predominantly of mountain laurel and blueberry. The island is especially valuable for a ground truth correlation study because an accurate survey grid covers both the island and adjacent salt marsh. This survey grid provides fixed landmarks at 100 meter intervals, two of which occur on the island. Although the landmarks on the island were hidden from the air by the forest canopy, their approximate position could be determined on aerial photographs by measuring distances from other landmarks located in the surrounding salt marsh and marked with tarpaulins to insure their visibility from the air.

Ground truth data were collected in the autumn of 1970 and in the spring and summer of 1971. The presence of the survey grid made it feasible to map the positions of individual tree trunks using an alidade, plane table, and stadia rod. Spring and autumn phenology were noted for distinctive species. The large number of trees on the island made it impractical to map them all, so only those trees having a trunk diameter greater than eight inches at breast height (approximately 4 1/2 feet) were selected for mapping. This eliminated most of the understory trees, but it was expected that the canopy trees would mask them on aerial photos. The trunk diameters of the mapped trees were recorded, to facilitate their correlation with the appropriate crowns on the aerial photos. Many understory trees showed up on the photos, especially when the scales were enlarged. Since many of these trees belonged to different species (beech) than those of the canopy (oaks and sour gum), it would have been worth while to map them. The position of evergreen subcanopy species (principally mountain laurel) would also be useful for correlation with photos in the winter and early spring. However, the major effort required and the crowded appearance of the map which would have resulted discouraged the collection of these supplementary data.

A total of 182 trees were mapped. These included most of the canopy trees on the island except at the southern tip and southwestern slopes, where the steep terrain seriously reduced the accuracy of the mapping. Problems with steep terrain on the western and northwestern sides of the island were corrected by mapping trees along the perimeter of the island from survey points in the marsh. Pine trees, dead trees, and trees leaning out over the marsh were mapped in anticipation of their value as landmarks on the aerial photos.

The ground truth was compared with both natural color and infrared color photos taken at all seasons, to establish correlations between the mapped trunks and the appearance of the crowns. The films which proved most useful were flight 51 (late winter), flight 57 (spring), flight 73 (summer), flight 89 (mid-autumn), and flight 32 (late autumn). Natural color was good for the identification of hardwood species at all seasons, while color infrared was most useful in the autumn and to a lesser extent in winter and spring. Infrared imagery often proved helpful in verifying identifications made from natural color. The values of these film types and seasons in identifying tree species at Hog Island are summarized below.

| Season | Altitude (feet) | Natural Color | Infrared Color |
|---|---|---|---|
| Late Winter (flight 51) | 1200 | Good for evergreen species. Good for locating beech (by white bark). Fair for locating oaks (by branching habit). Poor for locating individual trunks because of confusing shadows. | Good only for evergreen species. |

| Season | Altitude (feet) | Natural Color | Infrared Color |
|---|---|---|---|
| Spring (flight 57) | 2500 | Good for locating beech even in understory by crown texture and color. (Leaves are much brighter green than oak or sour gum.) | Good for verifying beech, but tends to confuse them with pine. |
| Summer (flight 73) | 1200 | Good for distinguishing oaks by branching habit. Fair for distinguishing sour gum. | Good mainly for locating dead trees. |
| Mid-autumn (flight 89) | 5000 | Good for locating sour gum (leaves turn red early). | |
| Late autumn (flight 32) | 1200 | Good for locating oaks and beech by crown color and branching. Fair for locating sour gum (leaves gone). | Fairly good for separating species by crown color. |

Correlations between frames on the above flights were necessarily approximate, because distortions in the photographs prevented exact matching, even when the scales were the same. The use of an enlarging-reducing table at NASA Wallops facilitated this matching, but the time was insufficient for making all potential correlations. Trees around the perimeter of the island could be matched fairly well by visual comparison. An overhead projector at the Smithsonian Institution was used to match the above flights to the field map, with moderate success.

Correlations between the photographs and ground truth proved fairly accurate toward the middle of the island, where the terrain was relatively flat, and at localized points around the perimeter. Slight distortions in the photographs and inaccuracies in the ground truth both of which were intensified by the steep terrain around the sides of the island and by the tendency of trees to lean instead of growing straight, accounted for this difficulty. It was necessary to shift either the photo or the map repeatedly, and attempt correlations at only one segment of the island at a time. Since hole diameter is a fairly good indicator of crown diameter, the diameters of the tree trunks were recorded as part of the ground truth. These proved to be a useful guide for matching a given trunk with one of several adjacent crowns on the photo. Correlation of the largest canopy trees, which proved fairly accurate, utilized the late autumn data (flight 32) and comparison of crown characteristics of the trees on frames from the other flights, especially flight 73.

A map of all the discernible tree crowns on the island (Figure 3) was drawn from a 3X enlargement of a frame from flight 32. The map shows 260 crowns, of which 156 have been identified. Only 54 of these identifications were made or verified by comparison with the ground truth map; the remaining crowns either could not be matched to trunks shown on the ground truth map or were not included in it. The ground truth map shows 182 trees.

The remaining identifications were made on the basis of crown characteristics at as many seasons as possible, to achieve the best reliability. The success of identifications by species and season is summarized in Table 6.

Figure 3

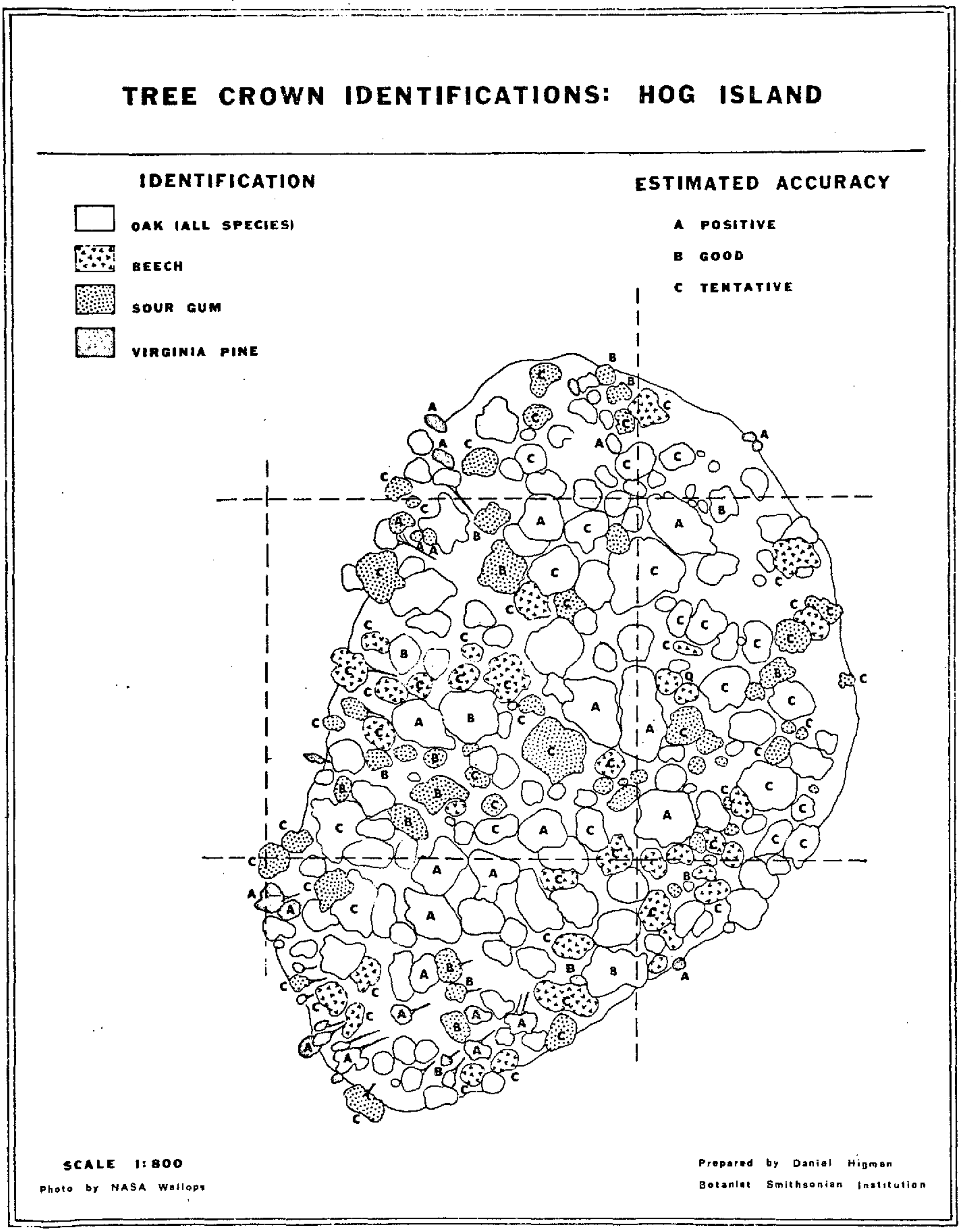

TREE CROWN IDENTIFICATIONS: HOG ISLAND
IDENTIFICATION
OAK (ALL SPECIES)
BEECH
SOUR GUM
VIRGINIA PINE
ESTIMATED ACCURACY
A POSITIVE
B GOOD
C TENTATIVE
SCALE 1:800
Photo by NASA Wallops
Prepared by Daniel Higman
Botanist Smithsonian Institution

TABLE 6

IDENTIFICATIONS OF TREE CROWNS: HOG ISLAND

| | Number of Individuals |
|---|---|
| OAK (canopy) | |
| Identified by winter aspect (flight 51) | 14 |
| Identified by spring aspect (flight 57) | 0 |
| Identified by summer crown characters (flight 73) | 3 |
| Identified by late autumn phenology (flight 32) | 10 |
| Identified by ground truth map | 6 |
| BEECH (chiefly understory) | |
| Identified by winter aspect (flight 51) | 9 |
| Identified by spring aspect (flight 57) | 36 |
| Identified by summer crown characters (flight 73) | 0 |
| Identified by late autumn phenology (flight 32) | 37 |
| Identified by ground truth map | 2 |
| SOUR GUM (chiefly canopy) | |
| Identified by winter aspect (flight 51) | 0 |
| Identified by spring aspect (flight 57) | 0 |
| Identified by summer crown characters (flight 73) | 2 |
| Identified by mid-autumn phenology (flight 89) | 6 |
| Identified by late autumn phenology (flight 32) | 50 |
| Identified by ground truth map | 8 |

The identifications tabulated above are not cumulative, since the same tree was often identified on more than one flight.

The criteria used for estimating reliability of crown identifications are

| | | |
|---|---|---|
| A. | Correlation of ground truth with photos from two or more flights | = Positive identification |
| B. | Correlation of the ground truth map and photographs from one flight, or of photographs from two flights without the ground truth map | = Good identification |
| C. | Identification by ground truth alone or by photographs from one flight only | = Tentative identification |

These reliability estimates are shown on the crown identification map of Hog Island (Figure 3). Almost half the oaks were positively identified while most of the sour gums and beech understory were tentatively identified.

The identifications of tree crowns shown in Figure 3 and Table 6 result from two different kinds of correlations: correlations between the ground truth map and frames from one or more of the flights consulted, or photointerpretive correlations resulting entirely from the aspect of a given tree on one or more of the flights, with reference to structural or phenological features characteristic of particular species. The latter technique was resorted to when tree trunks on the ground truth map could not be matched to crowns observed on the photographs.

It was possible to extrapolate from the crowns which did correlate with the ground truth map to those which did not, using late autumn phenological and structural characters (flight 32). First, the natural and infrared coloration of 130 crowns was described from the photo, whether the trees being described had been included on the ground truth map or not. Then 54 of these crowns were correlated with the ground truth map using an overhead projector. The correlated trees were grouped by species, and the range of crown colors for each species were noted (See Table 7).

Most of the oaks on the ground truth map exhibited a variety of yellow-brown natural crown colors on flight 32 and most of the sour gums were already leafless. Only two beech were canopy trees and therefore included in the ground truth map, and only one of these could be correlated. The range of crown coloration for all species of oaks did not permit a reliable separation of species by coloration, either with natural or infrared colors. Since the natural colors within each species showed less variation for individual trees than did the infrared colors, the natural colors were chosen as a basis for possible extrapolations.

Of the eight sour gums listed in Table 7, two were leafless. The rest exhibited the same range of color as oaks, but this was probably because leafless gums were being masked by other species. Since observations of autumn phenology (See Table 8 ) show that sour gum leaves turn red quite early in the autumn and then fall off, it was considered safe to assume that any such trees showing this characteristic on Hog Island would probably be sour gums. The only other local species having this distinctive autumn phenology is the flowering dogwood, but neither the ground truth data nor an examination of flight 57 (taken in May when the dogwoods were in flower) revealed the presence of any dogwoods on the island. The possible confusion of leafless sour gums with dead trees was eliminated by comparison with the ground truth data and flight 73 (taken in July).

Extrapolations were attempted for 49 trees which had been described from flight 32 at the 1:1200 scale but which did not match any trunks on the field map. The descriptions of their crowns were first compared at the 1:1200 scale and the 1:800 enlargement to get additional correlation data, but many of the crowns which had appeared single on the smaller scale proved to consist of two to five crowns, often differently identified, on the larger scale. This situation eliminated 26 trees (as described on the smaller scale) from further attempts at extrapolation. Tentative identifications of the remaining 23 trees were made by comparing the descriptions of their crown coloration in natural and infrared color with those of trees already identified in Table 7. Of these 23 trees, 7 had already been identified from other flights. The remaining 16 were added to the map (Figure 3).

TABLE 7

SPECIES OF TREES CORRELATED WITH LATE AUTUMN CROWN COLORATION

| Species | No. on field map | No. on photo | Infrared Color | Natural Color |
|---|---|---|---|---|
| White oak | 3 | 65 | Lavender-gray | Medium yellow-tan |
| (Quercus alba) | 13 | 130 | Lavender-gray | Pale yellow-tan |
| | 24 | 66 | Lavender-gray | Pale yellow-tan |
| | 40 | 76 | Lavender-gray | Medium yellow-tan |
| | 48 | 99 | Rust red-orange | Pale greenish brown |
| | 54 | 77 | Pale purple-pink | Medium yellow-tan |
| | 55 | 45 | Pale purple-pink | Pale green-yellow |
| | 57, 162 | 45 | Pale purple-pink | Medium yellow-tan |
| | 58 | 80 | Lavender-gray | Pale yellow-tan |
| | 63 | 52 | Pale purple-pink | Pale yellow-tan |
| | 64 | 35 | Pale yellow | Dull yellow-tan |
| | 68 | 115 | Pale purple-pink | pale yellow-tan |
| | 73 | 122 | Lavender-gray | Rust yellow-tan |
| | 80 | 33 | Pale yellow | Pale rust brown |
| | 113 | 64 | Lavender-gray | Yellow-tan (yellow-pink brown) |
| | 118, 119 | 96 | Lavender-gray | " |
| | 143 | 67 | Lavender-gray | " |
| | 150-151 | 62 | Pale purple-pink | Pale brown yellow-gre |
| | 158 | 57 | Pale purple-pink | Pale brown yellow-gree |
| | 160 | 27 | Yellow-green | Pale rust |
| Red & Black Oak | 31 | 77 | Lavender-gray | Medium yellow-tan |
| (Quercus rubra) | 30 | 118 | Lavender-gray | Pale yellow-tan |
| (Q. velutina) | 56 | 78 | Pale purple-pink | Pale brown yellow-gree |
| | 70 | 117 | Red-orange | Rust yellow-tan-green |
| | 72 | 81 | Lavender-gray | dull yellow-tan |
| | 76 | 39 | Red-orange | Brown yellow-green |
| | 47 | 68 | --- | Leafless |
| | 86 | 80 | Lavender-gray | Yellow-tan (yellow-pink Brown) |
| | 94 | 28 | Yellow-green | Dark rust |
| | 132 | 37 | Pale yellow | Pink-brown-yellow |
| | 142 | 112 | Red-rust-orange | Pale yellow-green |
| | 169 | 21 | Bright yellow-orange | Rust |
| | 174 | 67 | Lavender-gray | Yellow-tan (yellow-pink brown) |

Table 7 (Continued)

| Species | No. on field map | No. on photo | Infrared Color | Natural Color |
|---|---|---|---|---|
| Spanish Oak (Quercus falcata) | 10 | 59 | Pale purple-pink | Pale green yellow |
| | 38 | 49 | Pale purple-pink | Pale green yellow |
| | 28 | 51 | Purple rust | Pale green yellow |
| | 74 | 123 | Yellow-green | Pale rust brown |
| | 75 | 39 | Red-rust-orange | Pale brown-green |
| | 77 | 108 | | Rust brown |
| | 78 | 56 | Pale purple-pink | Pale brown-yellow |
| | 81 | 54 | Pale purple-pink | Pale brown-yellow |
| | 103 | 91 | Lavender-gray | Yellow-tan (yellow pink-brown) |
| | 152 | 62 | Pale purple-pink | Pale brown yellow green |
| | 168 | 127 | Lavender-gray | Yellow-tan (yellow pink-brown) |
| | 176 | 92 | Lavender-gray | Yellow-tan (yellow pink-brown) |
| | 177 | 34 | Pale yellow | Pinkish brown-yellow |
| Chestnut Oak (Quercus prinus) | 15 | --- | | Medium yellow-tan |
| | 23 | --- | Blue-green | Pale brown |
| | 115 | 58 | Pale purple-pink | Pale brown-green |
| Post Oak (Quercus stéllata) | 59 | 79 | Lavender-gray | Yellow-tan (yellow pink-brown) |
| Beech (Fagus grandifolia) | 27 | 65 | Lavender-gray | Yellow-tan (yellow pink-brown) |
| Sour Gum (Nyssa sylvatica) | 41, 43 | 68 | Blue-gray | Yellow-tan |
| | 42 | --- | Blue-gray | Leafless |
| | 60 | 107 | Lavender-gray | Yellow-tan |
| | 69 | 72 | Blue-gray | Leafless |
| | 88 | 124 | Yellow-green | Pale Rust |
| | 130 | 103 | Lavender-gray | Yellow-tan |
| | 153 | 70 | --- | Leafless |

# PHENOLOGY

Observations of the phenology or seasonal changes of plants (i.e., leaf development, flowering, fruiting, leaf color change, and leaf fall) are often valuable for determining species, and indirectly the effects of weather, in conjunction with remote sensing. Sayn-Wittgenstein (1961), in his studies of mixed mesophytic forest in southeastern Canada, stresses the importance of both dates and descriptions of phenological changes for correct species identification.

These criteria have been used in recording the spring and autumn phenology of forest, salt marsh, and cultivated species in Rhode River watershed as a photointerpretation aid. Forest and salt marsh observations were made primarily at the CBCES; observations of cultivated species were made throughout the watershed.

Natural color photographs were taken at three intervals during critical color changes in the autumn of 1971. A hand-held camera was used to record forest and abandoned field vegetation around the horizon from the top of a 40-foot silo. Ground truth identifications were made for many of the trees thus photographed. The data are still being analyzed.

Attempts to standardize observed autumn leaf colors by correlating individual leaves with a set of Munsell color chips were not successful;

there was too much variation in leaf coloration within each species or even within individual trees (also noted by Northrop and Johnson, 1970). Moreover, there is no assurance that the close range reflectance of an individual leaf will represent the long range reflectance from an entire crown (Knipling, 1969-70). Weather conditions also influence leaf colors and rates of change. For example, heavy rainfall and moderate temperatures in the autumn of 1971 (September and October), followed by a brief cold spell and high winds (December) produced muted coloration, followed by rapid browning and leaf fall.

An autumn phenology table (Table 8) illustrates the variability in rates of leaf color change between species of trees and among individuals of the same species, especially in different habitats. Individual genetic characteristics, exposure and dryness, and age were all found to influence autumn phenology.

Sweetgum (Liquidambar styraciflua) and sassafras (Sassafras albidum) exhibit a mixture of reds and yellows. In 1970, red maple (Acer rubrum) did the same. The influence of habitat was marked in sour gum (Nyssa sylvatica), which changed color faster on the islands in Rhode River than on the adjacent mainland, apparently because the islands are drier and more exposed. Sweetgum and white oak (Quercus alba) also changed color faster in exposed locations.

Examples of the effects of weather on forest phenology in the autumn of 1971 were the unusually late color change of red maple, the unusually early change of Spanish oak (Quercus falcata), and the duller coloration of tuliptree (Liriodendron tulipifera) leaves. All these phenomena are in contrast to those observed in 1970.

## TABLE 8

## FALL PHENOLOGY

| Date | Species | Description | Area |
|---|---|---|---|
| 8/24/71 | Nyssa sylvatica | Some lvs. turning color | Hog Island |
| 8/30/71 | Liquidambar styraciflua | Some top lvs. turning reddish | Roadsides and old field of RR. watershed |
| | Robinia pseudoacacia | Some roadside lvs.brown-red | |
| | Prunus serotina | Some top lvs. reddish | |
| 9/20/71 | Nyssa sylvatica | Many dark, coppery red crowns<br>Some bright red crowns | Hog Is., Big Is., and Muddy Creek |
| | Baccharus halimifolia | White silky flowers | Muddy Creek, Fox Pt., Hog Is. |
| | Cornus florida | Some turning red | |
| | Liquidambar styraciflua | Some turning part red | |
| 10/4/71 | Liriodendron tulipifera | Many still all green, some with lvs. ochre-green | View from west silo |
| | Parthenocissus quinquefolia | Bright red | View from west silo |
| | Liquidambar styraciflua | Most a medium green<br>Some light green with red-orange | View from west silo |
| | Sassafras albidum | Yellow-green, lower lvs. on branches often orange-red | View from west silo |
| | Quercus falcata | dull orange, yellow, light green or shiny dark green | View from west silo |
| | Diospyros virginiana | Coppery green with dark, yellowish fruits | View from west silo |
| | Prunus serotina | Mostly darkish green or pale pink-green | View from west silo |
| | Salix nigra | Pale green with faint brownish-red | View from west silo |
| | Celtis occidentalis | Pale green, some yellow-green lvs. | Road to Western |
| | Quercus palustris | Brown and pale green | Java Forest |
| | Cornus florida | pale pink-green | " |
| | Platanus occidentalis | Brown (dying)-green and yellow-green lvs. | " |

Table 8 (Continued)

| Date | Species | Description | Area |
|---|---|---|---|
| 10/5/71 | Robinia pseudoacacia | Yellow and green lvs., dull, glaucous | Roadside of Route |
| | Cornus florida | Bright red | Roadside of Route |
| | Liquidambar styraciflua | Small trees, tops dark or bright red, lower 2/3 green | Roadside of Route |
| | Sassafras albidum | Green and bright red | Powerline cut off |
| | Ulmus americana | Green with brown and yellow | Route 2 |
| | Nyssa sylvatica | Bright red and losing lvs., some green | Route 2 |
| | Carpinus caroliniana | green with brown and yellow | Route 2 |
| | Liquidambar styraciflua | Many all green; small trees red on top 1/3, green below | Route 2 |
| | Fagus grandifolia | Green with brown and yellow lvs. | Route 2 |
| | Carya sp. | Green, sometimes with brown-yellow lvs. | Powerline cut off |
| | Celtis occidentalis | Green, some brown | Route 2, cont. |
| 10/13/71 | Liriodendron tulipfera | Lvs. brown, dull yellow and green; some bright yellow with green | Road to Western Java Forest |
| | Quercus falcata | Dark Green | " |
| | Carya sp. | Green with brown and yellow lvs. or brown-yellow lvs. | " |
| | Ulmus americana | 70% dropped, remaining light yellow | " |
| | Cornus florida | Reddish-green lvs. | " |
| | Acer rubrum | Light green lvs. | " |
| | Carya glabra | Green lvs. | " |
| | Quercus alba | Green lvs. | " |
| | Nyssa sylvatica | Reddish-green and bright red, dropping lvs. | " |
| | Platanus occidentalis | Brown-green lvs., falling | " |
| | Fagus grandifolia | Green lvs. | " |
| | Liquidambar styraciflua | Light green lvs. | " |
| | Nyssa sylvatica | Bright maroon lvs. | Kirkpatrick marsh |
| | Scirpus Olneyi | Green, top 1/2 brown-yellow | vicinity |
| | Phragmites communis | heads pale pink-brown, stems blue-green, sometimes light yellow | Kirkpatrick marsh vicinity |
| | Quercus phellos | Green with some yellow and brown lvs. | Kirkpatrick marsh vicinity |

Table 8 (Continued)

| Date | Species | Description | Area |
|---|---|---|---|
| | Quercus palustris | Light orange-green lvs. | Kirkpatrick marsh vicinity |
| | Quercus falcata | Shiny dark olive green lvs. | Kirkpatrick marsh vicinity |
| | Quercus alba | Dark green lvs. vicinity | Kirkpatrick marsh |
| | Juglans nigra | Leafless | Contees Wharf Rd. |
| | Mimosa pudica | Dull glaucous green, brown pods | Contees Wharf Rd. |
| | Pueraria lobata | Bright green | Route 2 |
| 10/14/71 | Prunus serotina | Some green, some reddish-green | Fox Point Road |
| | Sassafras albidum | Orange, some green | Fox Point Road |
| | Quercus phellos | Green with some yellow and brown lvs. | Fox Point Road |
| | Liquidambar styraciflua | some green, some reddish | Fox Point Road |
| | Quercus rubra/velutina | Yellow-pink-brown-green, green, and green with assorted colors | Fox Point |
| | Quercus alba | green | Fox Point |
| | Quercus falcata | Shiny brown-green or shiny green | Fox Point |
| | Fagus grandifolia | green, slightly yellow | Fox Point |
| | Quercus prinus | Light green, some with yellow-brown boughs | Fox Point |
| | Liquidambar styraciflua | Green with yellow | Fox Point |
| | Robinia pseudoacacia | Glaucous dull green lvs. | Fox Point |
| | Nyssa sylvatica | Light red, dropping lvs. | Fox Point |
| | Cornus florida | reddish-green lvs. | Fox Point |
| | Diospyros virginiana | dark green lvs. | Fox Point |
| | Ulmus americana | pale yellow lvs. | Fox Point |
| | Prunus serotina | green lvs. | Fox Point |
| 10/19/71 | Quercus rubra/velutina | Green or reddish-brown lvs. | Road to Western Java Forest |
| | Platanus occidentalis | Green, yellow, and brown on lvs., some still green | " |
| | Quercus alba | green lvs. | " |
| | Liquidambar styraciflua | Green, some yellow-green lvs. | " |
| | Liriodendron tulipifera | Golden yellow or green lvs. | " |
| | Fagus grandifolia | Green, some with yellow lvs. | " |
| | Acer rubrum | Green lvs. | " |
| | Carya tomentosa | Golden brown lvs. | " |
| | Ulmus americana | Part grayish green, part yellow lvs., shiny and pale | " |

| Date | Species | Description | Area |
|---|---|---|---|
| | Nyssa sylvatica | Some still green, most dropped lvs. | Java Forest |
| 10/20/71 | Platanus occidentalis | Green with brown and yellow lvs. | From CBCES dock |
| | Robinia pseudoacacia | Glaucous gray-green | From CBCES dock |
| | Zea mays, standing | Stalks light brown | From CBCES dock |
| | Quercus falcata | Bright green | From CBCES dock |
| 10/26/71 | Carya spp. | Yellow and dropping lvs. | Western Java Fore |
| | Fagus grandifolia | Golden brown, some green with brown | Western Java Fore |
| | Quercus alba | Greenish-yellow or green | Western Java Fore |
| 10/29/71 | Morus rubra | Light Green | Fox Point Road |
| | Liquidambar styraciflua | Some all green, most have yellow and/or red and/or maroon | Fox Point Road |
| | Acer negundo | Light green lvs., silvery-gold samaras hanging below | Fox Point Road |
| | Quercus palustris | Green and ochre brown, losing lvs. | Fox Point Road |
| | Prunus serotina | Many almost leafless, others yellow and green lvs. | Fox Point Road |
| | Sassafras albidum | Some flame orange-yellow, one bright red, some green on top, yellow below | Fox Point Road |
| | Diospyros virginiana | Leafless or bright yellow lvs., bright or dull orange fruit | Fox Point Road |
| | Liriodendron tulipifera | Yellow with brown and green | Fox Point Road |
| | Acer rubrum | green | Fox Point Road |
| | Campsis radicans | Very pale yellow | Fox Point Road |
| | Parthenocissus quinquefolia | in trees, bright red | Fox Point Road |
| | Quercus falcata | Shiny-green or brown-green-yellow-orange lvs. | Fox Point Road |
| | Quercus phellos | Spotty green/yellow/brown | Fox Point Road |
| | Robinia pseudoacacia | Light green with yellow lvs., glaucous | Fox Point Road |
| | Quercus alba | Ochre and light olive green, some very light green with brown and yellow | Fox Point Road |
| | Quercus rubra/velutina | Maroon-brown with green and yellow lvs. dropping | Fox Point Road |
| | Quercus prinus | Light, bright green lvs. with brown edges | Fox Point Road |
| | Nyssa sylvatica | Lvs. red and falling | Fox Point Road |
| | Carya tomentosa | Red-brown and yellow, dropping lvs. | Fox Point Road |

| Date | Species | Description | Area |
|---|---|---|---|
| 11/2/71 | Carya spp. | Bright yellow lvs. | Contees Wharf Ro[illegible] |
| | Liriodendron tulipifera | Bright yellow, pale yellow, yellow green, brown yellow, and leafless | Contees Wharf Ro[illegible] |
| | Mimosa pudica | Glaucous green with yellow pods | Contees Wharf R[illegible] |
| | Pueraria lobata | Green | Contees Wharf Ro[illegible] |
| | Liquidambar styraciflua | All variations of green and red | Muddy Creek Road |
| | Robinia pseudoacacia | glaucous dull green | Muddy Creek Road |
| | Platanus occidentalis | Each leaf with brown, green, & yellow | Muddy Creek Road |
| | Acer rubrum | Green | Kirkpatrick Marsh vicinity |
| | Quercus phellos | Mostly green; green and yellow | Kirkpatrick Marsh vicinity |
| | Quercus Alba | Green and brown | |
| | Liquidambar styraciflua | Green | Kirkpatrick Marsh vicinity |
| | Quercus palustris | Green with yellow, losing lvs. | |
| | Prunus serotina | Some still green | Kirkpatrick Marsh vicinity |
| 11/8/71 | Liriodendron tulipifera | some yellow, most leafless | Muddy Creek Road |
| | Fagus grandifolia | Many leafless, others green & yellow | Muddy Creek Road |
| | Robinia pseudoacacia | Glaucous dull green | Muddy Creek Road |
| | Liquidambar styraciflua | Some green, some yellow-green and almost leafless; small ones red on top 1/3, green on lower 2/3 | Muddy Creek Road |
| | Acer rubrum | Green | Muddy Creek Road |
| | Quercus prinus | Yellow-green with brown | Muddy Creek Road |
| | Carya spp. | Leafless | Muddy Creek Road |
| 11/10/71 | Acer rubrum | Green | Western Java For[illegible] |
| | Quercus falcata | Green-yellow, olive, or leafless | Western Java For[illegible] |
| | Quercus rubra/velutina | Green with brown and falling lvs. | Western Java For[illegible] |
| | Quercus alba | Green, brown, or leafless | Western Java For[illegible] |
| | Fagus grandifolia | Leafless or green and brown lvs. | Western Java For[illegible] |
| | Liriodendron tulipifera | Leafless or orange-yellow and brown lvs. | Western Java For[illegible] |
| | Nyssa sylvatica | Leafless | Western Java For[illegible] |
| | Liquidambar styraciflua | Some green, most leafless | Fox Point Road |
| | Acer rubrum | Green | Fox Point Road |

Table 8 (Continued)

| Date | Species | Description | Area |
|---|---|---|---|
| | Prunus serotina | Green | Fox Point Road |
| | Quercus prinus | Yellow-brown lvs. | Fox Point Road |
| 11/11/71 | Platanus occidentalis | Leafless or brown and green lvs. | Road to Western |
| | Quercus alba | Most with green lvs. | Java Forest |
| | Fagus grandifolia | Most leafless, some with copper lvs. | Road to Western Java Forest |
| | Carya spp. | Leafless | Road to Western |
| | Liquidambar styraciflua | Green or leafless | Java Forest |
| | Acer rubrum | Green | Road to Western |
| | Liriodendron tulipifera | Leafless or with yellow-brown lvs. | Java Forest Road to Western |
| | Quercus falcata | Some leafless, some with a few olive-green lvs., some with many olive-green lvs. | Java Forest Road to Western Java Forest |
| | Quercus rubra/velutina | Mostly green | Road to Western |
| | Quercus stellata | Mostly green | Java Forest |
| 11/18/71 | Acer rubrum | Various; green/yellow/brown-yellow/ochre/olivegreen/orange-brown | Muddy Creek Road |
| | Quercus falcata | Olive-green or brownish lvs. | Muddy Creek Road |
| | Pueraria lobata | dead, therefore gray | Muddy Creek Road |
| | Robinia pseudoacacia | gray-green, lvs. falling | Muddy Creek Road |
| 11/24/71 | Quercus alba | Some brownish lvs. still on, some leafless | Muddy Creek Road |
| | Quercus falcata | Some brownish lvs. still on, some leafless | Muddy Creek Road |
| | Liquidambar styraciflua | Some trees red on top 1/3, most leafless | Muddy Creek Road |
| | Acer rubrum | Orange-brown and yellow-orange lvs. | Muddy Creek Road |
| | Lonicera japonica | Still green and shiny | Muddy Creek Road |
| | Fagus grandifolia | Most leafless with a few copper lvs. | Muddy Creek Road |
| | Other species | Mostly leafless | Muddy Creek Road |
| 12/4/71 | Prunus avium | Green lvs. turning yellow | Contees Wharf Roa |
| | Quercus alba | with some brown lvs. on | Contees Wharf Ro |
| | Quercus stellata | with some brown lvs. on | Contees Wharf Roa |
| | Quercus rubra/velutina | with some brown lvs. on | Contees Wharf Roa |
| | Quercus falcata | with some brown lvs. on | Contees wharf Roa |
| | Liquidambar styraciflua | Some maroon lvs. on | Contees Wharf Ro |

Additional studies of spring and autumn phenology are planned in order to develop useful generalizations for photointerpretation in the Rhode River watershed. An earlier analysis of phenological characteristics, crown structure, and habitat influence on forest species in the neighboring South River watershed by O'Neill et al.(1950) is expected to provide much useful data. Phenological characters have already proved valuable for photointerpretation of the forest at Hog Island on the CBCES (described in another section of this report).

## EVALUATION OF SALT MARSH PHOTOINTERPRETATION

Salt marsh vegetation was mapped in detail to further the understanding of the Rhode River ecosystem and to determine the effectiveness of remote sensing data for interpreting marsh cover types. The two largest marshes in the watershed, Hog Island Marsh and Kirkpatrick Marsh, both at the mouth of Muddy Creek (see Figure 1) were chosen for their accessibility and broad range of vegetation types. The Hog Island Marsh was studied first, then the data from that study were used to predict the vegetation in the Kirkpatrick Marsh, which was later verified by ground truth. This exercise determined the facility of extrapolating photointerpretive techniques to other salt marshes.

A detailed ground truth survey was made in Hog Island Marsh and correlated with a natural color transparency taken in April at 1200 feet altitude (scale 1:2400). This transparency and ground truth data were then compared with a transparency of the Kirkpatrick Marsh taken in July at 2500 feet altitude (scale 1:5000). A print was made of this latter transparency (Figure 4).

The two investigators who had determined vegetation types in the Hog Island Marsh made independent comparisons between the transparencies of Hog Island and Kirkpatrick Marshes, basing their predictions of the Kirkpatrick Marsh vegetation upon similarities of color,

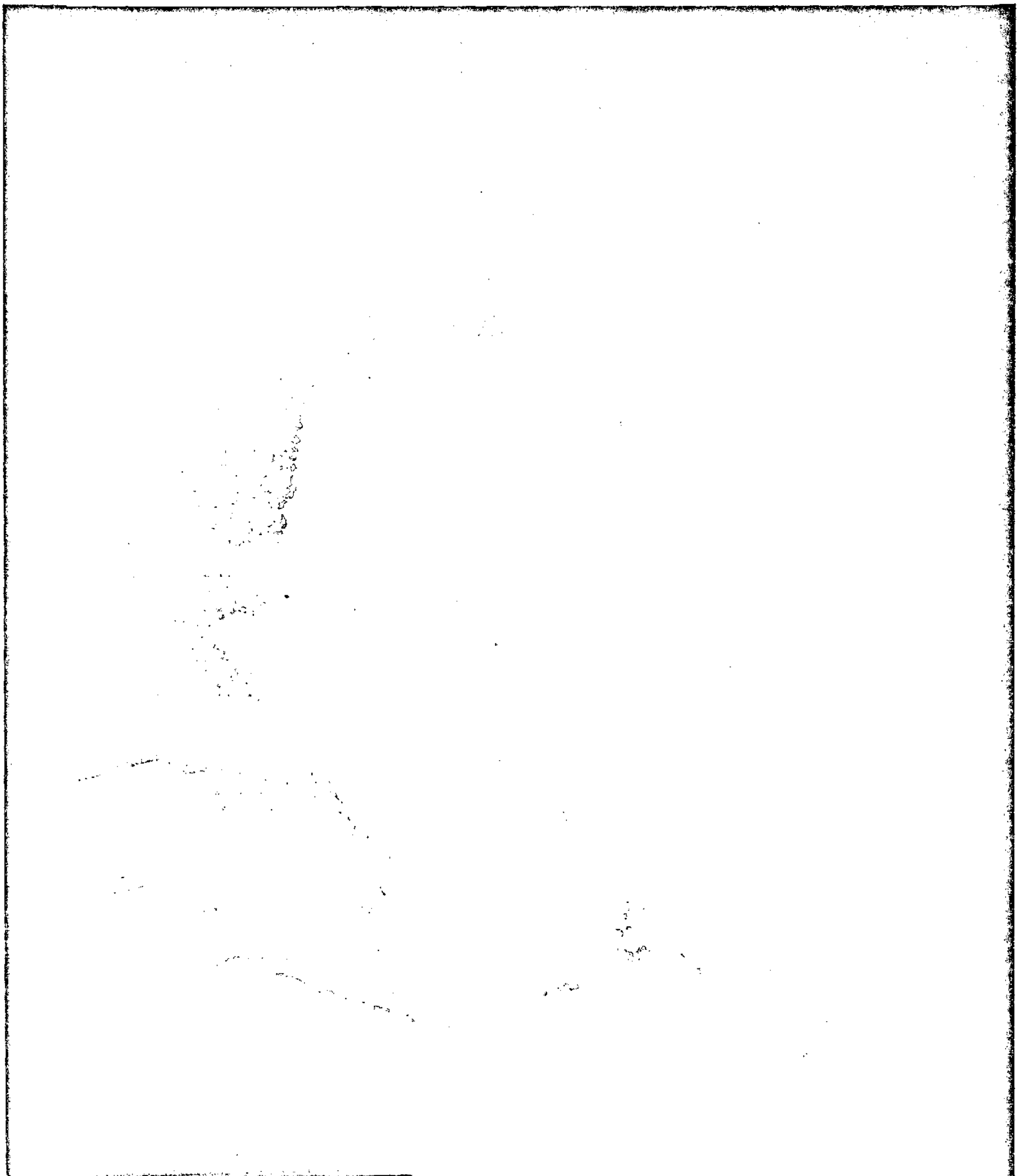


Figure 4
PRINT OF AERIAL NATURAL COLOR TRANSPARENCY OF KIRKPATRICK SALT MARSH USED FOR PHOTOINTERPRETATION

texture, and habitat. Variations in color and/or texture of the Kirkpatrick Marsh vegetation were outlined and numbered on an acetate overlay of the transparency (reproduced on paper - Figure 5). This overlay was taken to the Kirkpatrick Marsh where the species composition of each numbered area was verified by ground truth.

The ground truth showed that the predictions by the two investigators had a mean accuracy of 50% totally correct identifications of the areas in Figure 5, and a mean accuracy of 72% partially (at least 25%) correct identifications. The actual correctly identified area of the marsh was much greater than 50%, however, since most of the incorrectly identified areas were quite small.

Accuracy of prediction was adversely affected by: (1) the occurrence of vegetation types in the Kirkpatrick Marsh which had no counterparts in the Hog Island Marsh; (2) phenological differences between plants of the same species photographed in April and in July; (3) textural differences between similar vegetation types because of the 2:1 reduction in scale between the April and July photos; (4) the presence of standing water in the Kirkpatrick Marsh, which formed confusing dark blotches in some vegetation types.

The ground truth data were used to construct vegetation type maps for Hog Island Marsh (Figure 6) and Kirkpatrick Marsh (Figure 7). Comparison of the latter with Figure 5 shows that many small variations detected on Figure 4 proved insignificant in the field.

FIGURE 5

AERIAL COLOR/TEXTURE VARIATIONS IN

KIRKPATRICK SALT MARSH VEGETATION

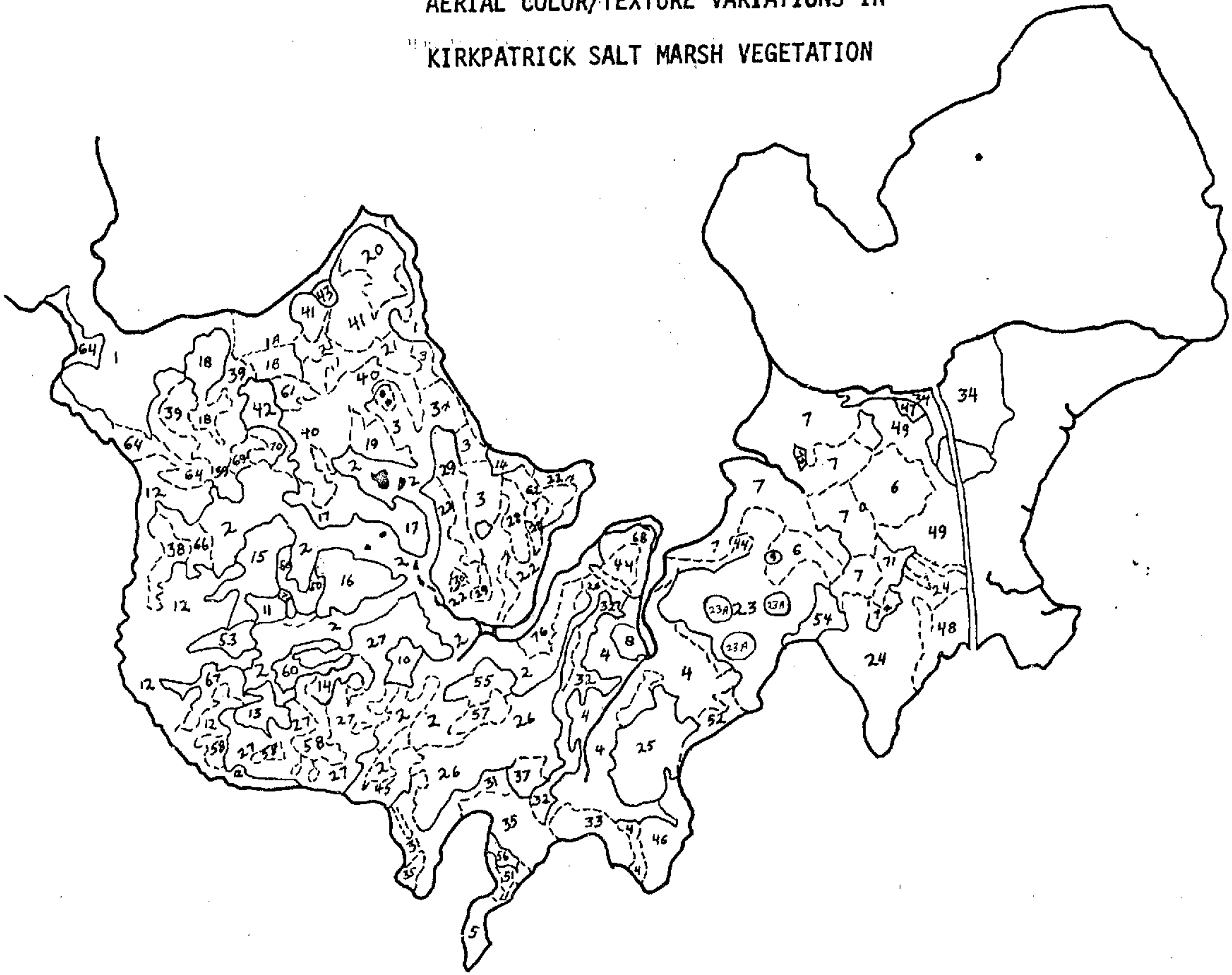


FIGURE 6

HOG ISLAND MARSH VEGETATION TYPES

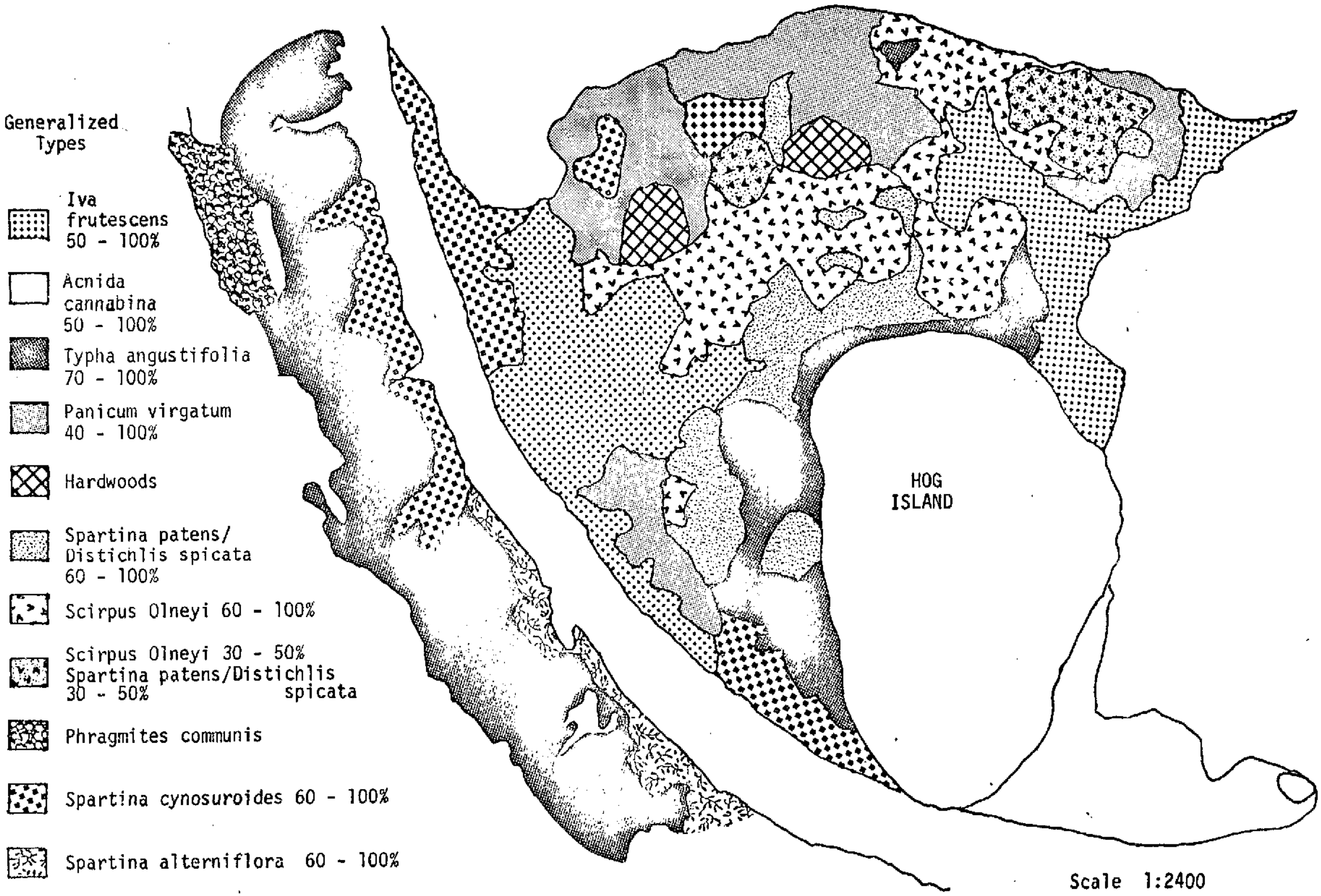
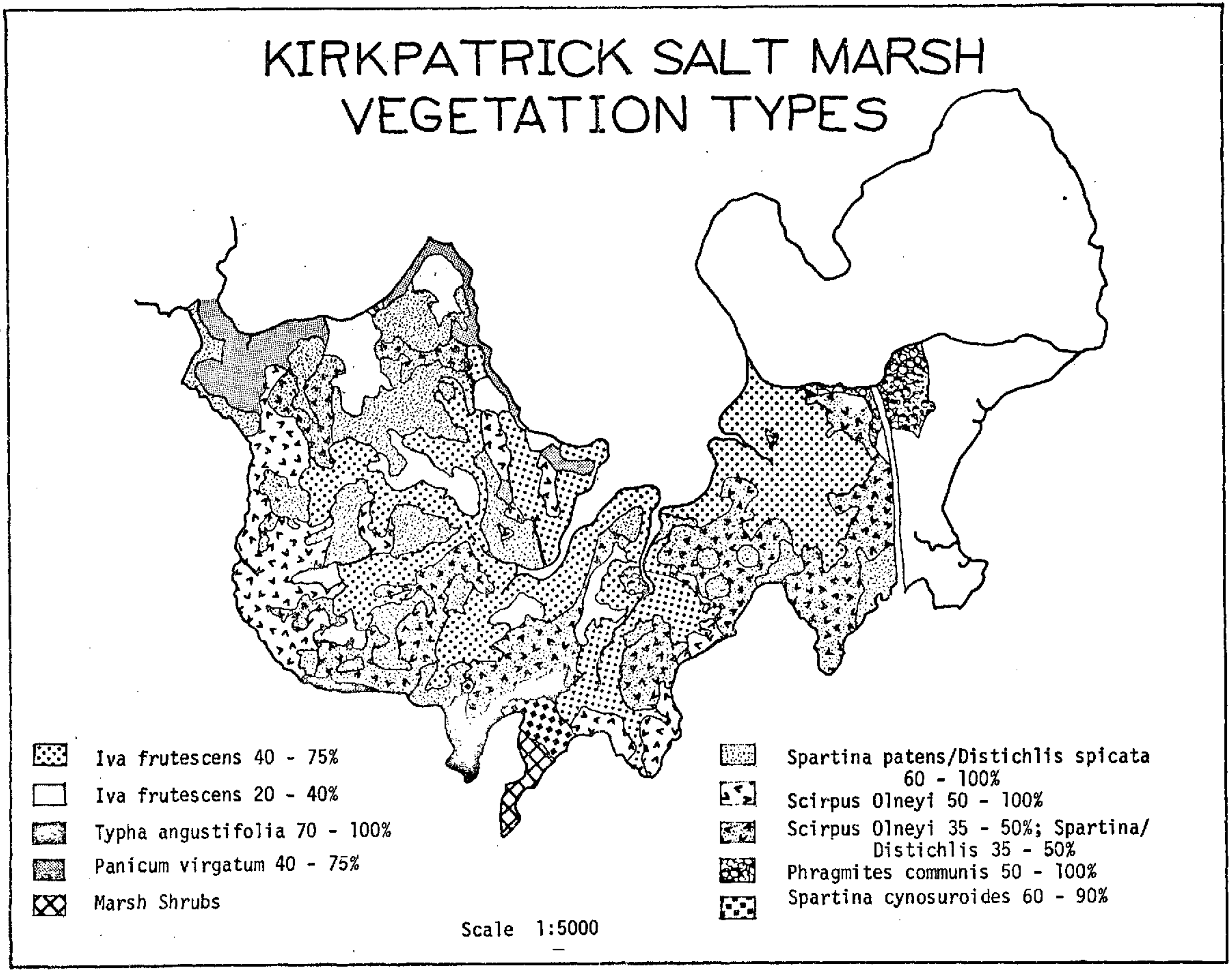


FIGURE 7


KIRKPATRICK SALT MARSH
VEGETATION TYPES
Iva frutescens 40 - 75%
Iva frutescens 20 - 40%
Typha angustifolia 70 - 100%
Panicum virgatum 40 - 75%
Marsh Shrubs
Spartina patens/Distichlis spicata 60 - 100%
Scirpus Olneyi 50 - 100%
Scirpus Olneyi 35 - 50%; Spartina/Distichlis 35 - 50%
Phragmites communis 50 - 100%
Spartina cynosuroides 60 - 90%
Scale 1:5000

Additional photointerpretive exercises are planned, involving other salt marshes in Rhode River. Prediction accuracy is expected to increase considerably when marshes photographed on the same flight are compared. Comparison of the effects of increasing altitude on recognition of marsh vegetation will also be made (see Olson, 1964).

## RECOGNITION OF LATE SUMMER CROPS

Aerial photography was used to identify late summer crops on Rhode River watershed and the validity of these identifications was tested to evaluate photointerpretive capability. A field survey of agricultural crops the summer of 1971 was completed about a month before the NASA, Wallops flight dated 8/24/71 which was taken at an altitude of 3500 feet with both natural color and color infrared film. Using the field survey and photographic data, a photointerpretation test was given to workers at the CBCES to (1) determine the ease with which the major crops, pasture, and weedy fields could be distinguished from each other and (2) compare the two film types for ease of photo-interpretability. The test required interpretation of 97 fields with natural color film and 194 fields with color infrared film. The results of interpretation of the major field types are given below.

| Participant | A | | B | |
|---|---|---|---|---|
| Film Type | Natural Color | Color IR | Natural Color | Color IR |
| Correct identification of corn, tobacco, grass, and grass-weed fields | 80 per cent | 85 per cent | 76 per cent | 78 per cent |

Identification of the field types was fairly good. Criteria used for recognizing the three major types are given in Table 9. Although testees preferred to use natural color film, a slight increase in accuracy resulted from use of color infrared film. This increase may be due to in-test training since natural color film was viewed first. A larger sample size will be needed to verify this difference.

TABLE 9

| Parameter | Corn | Tobacco | Grass<br>Grass and Weeds |
|---|---|---|---|
| Growth and harvest patterns | Rows distinguishable, harvested many rows at a time | Rows distinguishable, harvested by individual plants | Rows usually not distinguishable but evidence of previous cultivation (row lines) sometimes present |
| Density | Very dense, ground usually not visible | Quite dense, can sometimes see ground between plants | Fairly thin, often uneven density |
| Growth form and texture | Tall vegetation, individuals not distinguishable, fairly coarse and uniform texture | Moderately tall, individuals distinguishable, texture very coarse and uniform | Low vegetation, individuals not distinguishable, fine texture. If weeds present, texture coarser, often irregular. |
| Color<br>Natural | Greenish brown (due to tasselling of corn) | Bright green | Green to dull pale green, Brown or green mottling due to soil, moisture, and dist. of vegetation |
| IR | Reddish brown, Often yellowish | Bright magenta | Red, pink, or reddish-brown, pink, red, or brown mottling |

## APPLICATIONS OF REMOTE SENSING TO RHODE RIVER ESTUARY

Remote sensing techniques have been found highly useful in this study in tracing patterns of siltation and current flow, particularly in shallow water. They are expected to prove valuable for monitoring changes in the outlines of the shore. Their value in mapping the distribution of submersed aquatic vegetation has not been demonstrated in Rhode River, because of a dearth of such vegetation during the growing season of 1971. However, a temporary concentration of floating plants (probably alga) was discovered with the aid of aerial photographs.

The best type of film examined to date for tracing siltation, changes in depth, and current flow is natural color film at a scale of 1:10,000. Infrared color film has been much less satisfactory; it shows the heaviest silt plumes but masks the minor details. The data taken by Rome Air Force Base on 4/7/71 with a thermal infrared scanner at 2000 feet show great detail of surface water patterns, but since the scanner penetrated only the top 0-2 millimeter of water, it is hard to conclude how significant these patterns are. A scale of 1:10,000 is sufficient to show the whole picture of water movements over a fairly large area or along a shoreline. A smaller scale (down to 1:20,000) would be a useful supplement, since it would show most of the estuary on one frame, and any loss of detail could be corrected by referring to the 1:10,000 scale. Scales larger than 1:5,000 cover too small an area, and the additional detail on them has been found unnecessary for tracing siltation and current flow.

Films of the estuary were examined at all seasons to determine the optimum seasons for detecting different phenomena. Water clarity was best during the winter months, probably because of reduced sediment loads entering the estuary. Due to suspended sediment, however, clarity was significant in very shallow water only. Sediment plumes were clearly visible in the estuary from May to November 1971, especially after a rainy period in October (Figure 8) which evidently caused unusually heavy stream siltation. The development of submersed aquatic vegetation could not be noted because its distribution was too sparse, but observations on the ground revealed small patches of Eurasian water-milfoil (Myriophyllum spicatum, currently the predominant species in Rhode River) from May to October. A temporary concentration of what is believed to have been floating algae was discovered in August. No planktonic blooms or "red tides" were detected on the photographs, but a CBCES limnologist thinks they should be visible if present. A "red tide" was detected by ground observations late in the autumn.

Specific applications of remote sensing to the estuary which have been explored to date are: monitoring of siltation patterns at the mouth of Muddy Creek and along the shore of Cheston Peninsula, monitoring of shore erosion at Cheston Peninsula, determination of bottom contours in Muddy Creek, and mapping of rooted submersed aquatic vegetation.

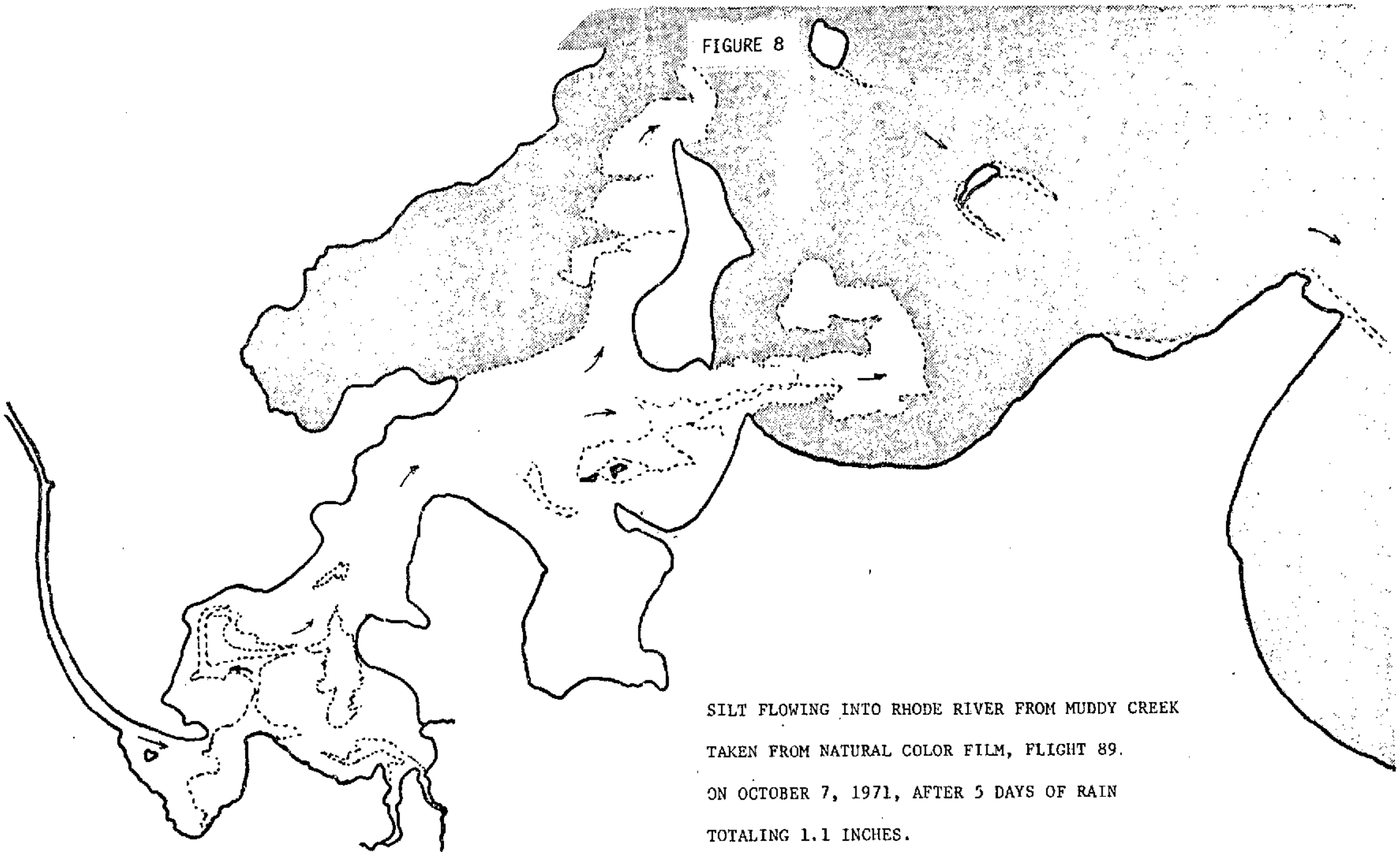
The first two applications were made entirely from examination of aerial photographs, while ground truth observations were used for the others.

The siltation patterns observed in Muddy Creek and along Cheston Peninsula are shown in Figures 8 and 9 respectively. Heavy, moderate, and light silt concentrations were readily distinguishable. In Figure 9, three views of Cheston Peninsula photographed at six-month intervals show variations in the siltation plume. An estimate of the rate of shore erosion at Cheston Point during 1971 was attempted by measuring the width of the point on photographs taken a year apart. This difference in width could not be detected with the instruments available, but a comparison with photographs taken in May 1968 showed that by October 1971 the shoreline had retreated approximately four meters.

Bottom contours were distinguishable only in very shallow water because of suspended sediments. Figure 10 shows the visible contours at the mouth of Muddy Creek at low tide. Several transects across the mouth were made with a skiff to verify the observed contours and collect some quantitative depth records, but the softness of the bottom and drifting of the skiff made this impractical.

The distribution of rooted submersed vegetation was observed periodically from a boat. Floating mats of Eurasian milfoil were noted along the upper tidal portion of Muddy Creek in the autumn of 1970, and other scattered mats appeared along the creek during the summer of 1971. The creek channel, however, is too narrow for many details to

FIGURE 8



SILT FLOWING INTO RHODE RIVER FROM MUDDY CREEK

TAKEN FROM NATURAL COLOR FILM, FLIGHT 89.

ON OCTOBER 7, 1971, AFTER 5 DAYS OF RAIN

TOTALING 1.1 INCHES.

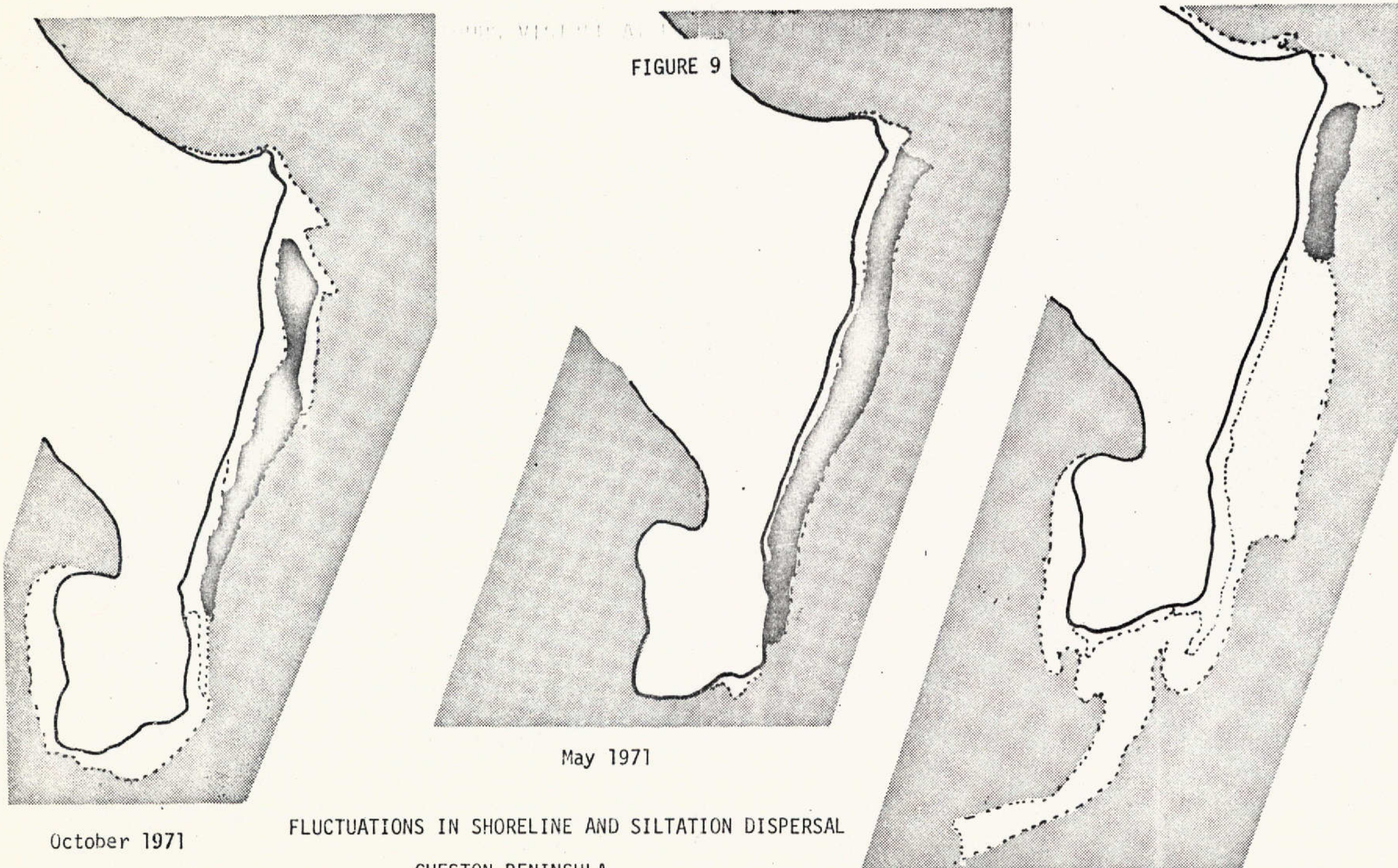
Legend

| | | |
|---|---|---|
| Light gray | - | heavily silted |
| Medium gray | - | moderately silted |
| Dark gray | - | relatively unsilted |

Arrows show discernable current flow

SCALE 1:10000

FIGURE 9




FLUCTUATIONS IN SHORELINE AND SILTATION DISPERSAL

CHESTON PENINSULA

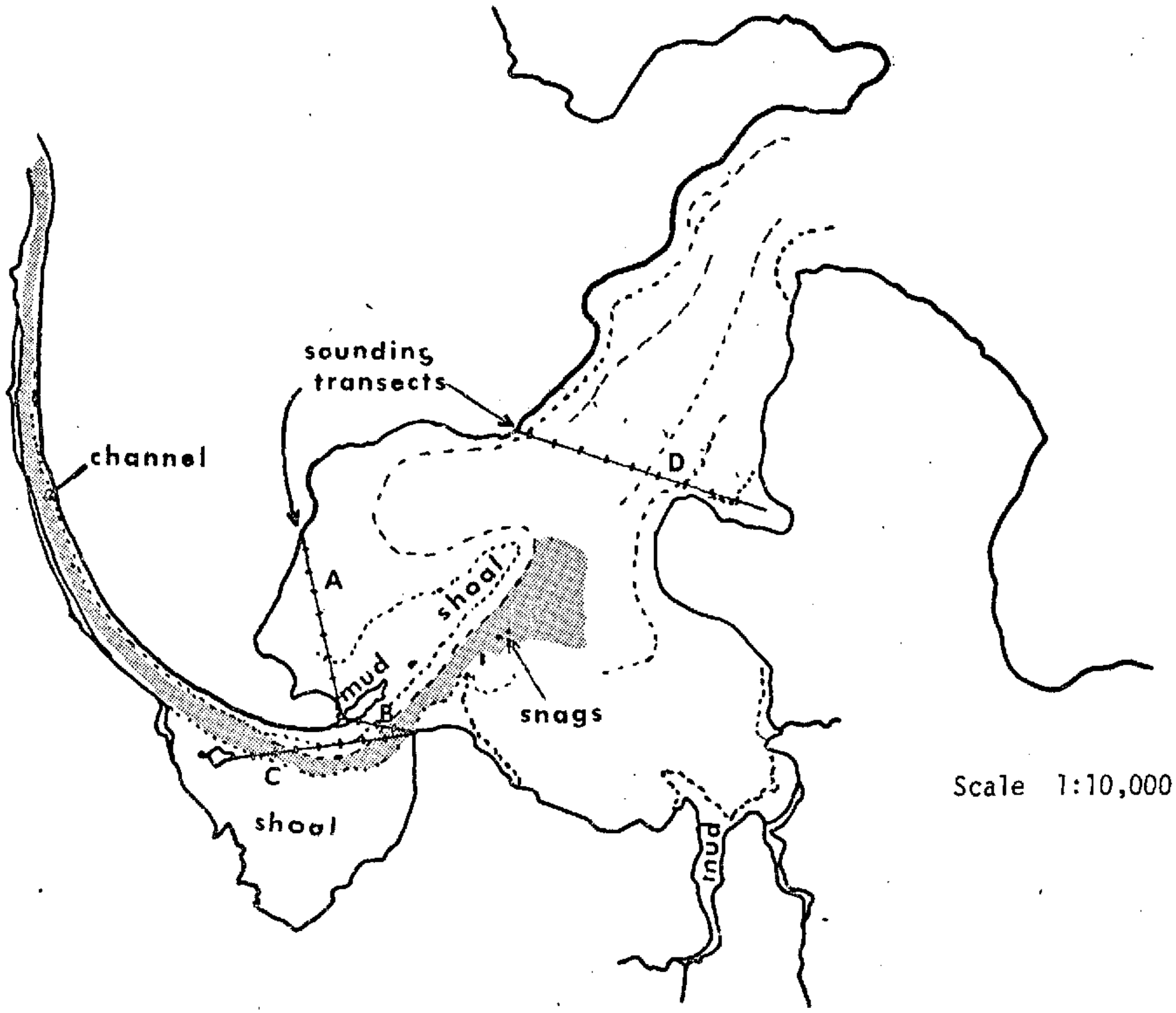
**SCALE 1:10000**

Legend

| | | | |
|---|---|---|---|
| light gray - - - | heavily silted | dark gray - - - | relatively unsilted |
| medium gray - - - | moderately silted | black - - - | dark water, probably upwelling |

FIGURE 10

BOTTOM CONTOURS VISIBLE AT LOW TIDE, MOUTH OF MUDDY CREEK



be observed from the air. Only individual plants were found in the estuary at the mouth of Muddy Creek and along the lower portion of Sellman Creek. These plants included widgeongrass (*Ruppia maritima*), horned pondweed (*Zannichellia palustris*), and redhead-grass (*Potamogeton perfoliatus*) as well as Eurasian milfoil.

# EVALUATION OF AUTOMATIC RECOGNITION WITH MULTISPECTRAL SCANNER IMAGERY

Automatic recognition techniques using multispectral imagery of Rhode River watershed were analyzed for reliability and accuracy of identification of ground truth categories including vegetation types, soil, and water. The University of Michigan's Willow Run Laboratory under the commission of NASA, Wallops, flew over part of Rhode River watershed and adjoining areas at an altitude of 5000 feet with an optical-mechanical multispectral scanner during the fall of 1970. After the multispectral data were processed and an image of the flight path developed on film, sample areas representative of various vegetation, soil, and water types were chosen as "training sets" to be fed into an analog computer known as SPARC. This computer then attempted to recognize all categories similar to the "training sets," a technique known as automatic recognition.

Sample areas were chosen from water, soil types, marsh types, hardwood forest types, conifer forest types, and pasture, agricultural fields, and abandoned fields. Choices were based on ground truth data and examination of filmstrips of the flight at different wavelengths. The following imagery was fed into the computer for recognition purposes: 0.41-0.43 $\mu$m, 0.43-0.45 $\mu$m, 0.54-0.58 $\mu$m, 0.63-0.68 $\mu$m, 0.68-0.74 $\mu$m, and 0.75-0.85 $\mu$m. Experimentation with automatic recognition of the chosen sample areas under different wavelengths resulted in selection of nine types for ozalid display: water, loblolly pine, salt marsh, vegetated fields, light bare soil, dark bare soil, pasture, mature mixed upland hardwoods, and immature mixed upland hardwoods.

Attempts were made to compute percent correct and incorrect SPARC identification for these types by planimetering the recognized, incompletely detected, and falsely detected areas of each type on the ozalid display. Several factors prevented this computation for all types. At the time of the flight, there was incomplete ground truth for tone of bare soil fields and for composition of vegetated fields and pasture, the latter because some of the fields in the flight line were off the watershed. In the case of light and dark soil tone, apparently a narrow band photo was used to determine training sites because no tone differences are apparent on the natural color and color infrared photos taken by NASA two days later. It was therefore impossible to obtain ground truth for soil tone from previous field observations or aerial photographs. Finally, the mature and immature mixed upland hardwoods were so diffusely displayed on the ozalid imagery that it was impossible to planimeter recognized, incompletely detected, and falsely detected areas for these types with any accuracy. Percentage correct recognition, incomplete detection, and false detection for water, salt marsh, and loblolly pine are given in Table 10 below while descriptions of the accuracy of the SPARC recognitions for all these types are given in Table 11.

Only 34 percent of the total flightline was recognized by the SPARC process. Of the recognized area, 24 percent comprised water. Land categories, therefore, comprised only 10 percent of the total flight-line. The recognition itself was technically imperfect, there being some overlap in areas recognized as light bare soil and dark bare soil and in areas recognized as pasture and mature upland hardwoods. Theoretically, there should be no overlap in the recognition.

In agreement with the report by the Willow Run Laboratories, it is suggested that better results would be obtained if imagery were taken at lower altitude, from 1000' - 2000', to obtain both better resolution of small vegetation types and larger test areas. The suggestion by Willow Run Laboratories that greater homogeneity within such heterogenous types as salt marsh, vegetated fields, pasture, and mature and immature mixed upland hardwoods, could be obtained by flying in summer or late spring is probably well-founded. If greater reliability could be placed on output from the automatic recognition technique, it would be an invaluable tool for mapping and monitoring the Chesapeake Bay region.

TABLE 10

SPARC IDENTIFICATION PERCENTAGES

| Recognition Category | Total area of Recognition category in S PARC field | Correct Recognition | Incomplete Detections | False Detections |
|---|---|---|---|---|
| Loblolly pine, mature, closed canopy | 13230 s.a.c.* | 11130 s.a.c. | 2050 s.a.c. | 50 |
| | 100% | 84% | 15% | |
| Deep water | 533060 s.a.c. | 470260 s.a.c. | 52800 s.a.c. | 0 |
| | 100% | 88% | 12% | 0 |
| Salt marsh (predominantly *Spartina*, with *Iva*, and *Distichlis* | 32090 s.a.c. | 1150 s.a.c. | 29500 s.a.c. | 1440 s.a.c. |
| | 100% | 3% | 92% | 5% |

* s.a.c. = SPARC area count, computed from planimeter area proportions in comparison to the s.a.c. for "Correct recognition."

TABLE 11

EVALUATION OF SPARC OUTPUT

| Recognition Category | Correct Recognitions | Incomplete Detections | False Detections |
|---|---|---|---|
| Loblolly pine, mature, closed canopy | Almost all of training site and adjacent parts of lob. pine stand | Small amount of training site area | Scattered Virginia pine near the CBCES |
| Deep water | Both test sites and almost all of category recognized | Non-recognition of shallow areas around mouth of Muddy Cr. and in southern part of flightline. The latter due to spectral reflectance. | None |
| Salt marsh (predominantly Spartina with Iva and Distichlis) | Very little of training site and adjoining marshes | Most of marshes not recognized | A few vegetated fields, scattered forest, and Typha marsh. |
| Vegetated fields | Almost all of training site recognized as well as parts of other vegetated fields | Spotty recognition of most vegetated fields | Spartina, Baccharis, and Typha marsh included |
| Light bare soil | Most of training site and dirt shoulders of Muddy Cr. Rd. | Not ascertainable | Some pasture, "dark bare soil, and light colored trees on Hog Is. |
| Dark bare soil | Almost all of training site detected and parts of shoulder on Muddy Cr. Rd. | Not ascertainable | Some pasture |
| Pasture | Most of training site, grass on banks of Muddy Cr. Rd. | Spotty recognition of other pastures | Vegetated fields |

Table II (Continued)

| Recognition Category | Correct Recognitions | Incomplete Detections | False Detections |
|---|---|---|---|
| Mature, mixed upland hardwoods | Training site partially recognized; mature trees along Muddy Cr. and on Corn Is. | Fox Pt., Hog Is., some of Corn Is. shadowed trees (due to topog. and sun angle) | Probably negligible |
| Immature mixed upland hardwoods | Training site poorly detected | Large tracts of immature forest, i.e., old fields along Fox Pt. road | Some vegetated fields |

## SUMMARY

The watershed of Rhode River, a small sub-estuary of the Chesapeake Bay, was selected by NASA, Wallops as a representative test area for a study of remote sensing imagery over the entire Bay. A broad program of ecological research was already underway on the watershed, at the Smithsonian Institution's Chesapeake Bay Center for Environmental Studies (CBCES). A joint NASA-CBCES project was developed with two basic objectives: to evaluate remote sensing data for the interpretation of ecological parameters, and to provide essential data for ongoing research at the CBCES. Different types of remote sensing have been used effectively in studying watershed drainage, natural and cultivated vegetation, and estuary sedimentation.

A total of 17 overflights were made, thirteen flights by NASA at low altitudes (1200-5000 feet), using a T-11 camera mounted in a helicopter. The low level flights used natural color and infrared color film developed as 9x9 inch positive transparencies. The remaining flights included one by NASA using an RB-57 at 60, 000 feet with natural and infrared color film; a flight by the University of Michigan using a C-47 at 5000 feet with film and a multispectral scanner; and two flights by Rome Air Force Base using a modified AM-AAS-18 MAIRS thermal scanner at 2000 feet, and an RC-8 sensor with natural color film at 3000 feet. The helicopter flights were made at all seasons, with greater

frequency in spring and autumn. Flight dates were arranged with ground truth personnel in response to vegetation conditions.

The most useful flight data for current research at the CBCES proved to be the 9x9 inch transparencies of natural color and infrared color film. Both film types were effective for interpreting natural and cultivated vegetation, but natural color was superior for distinguishing species if haze conditions were negligible. Infrared color was best for detecting drainage patterns and evergreen species in winter, while natural color was preferable for interpretation of estuarine conditions. The two films complemented each other well.

The multispectral scanner data from the University of Michigan flight were disappointingly low in resolution and prone to false detections. Only 34% of the total flightline was recognized, and 24% of this was water. Sample recognition areas were chosen from water, soil types, pasture, cropland, abandoned fields, salt marsh, and conifer hardwood forest. Percentages of correct and incorrect identification of water, salt marsh, and loblolly pine were obtained by planimetering the areas detected and comparing them with areas of the same categories on natural color film. The results were:

| | | | |
|---|---|---|---|
| Loblolly pine (mature canopy): | 84% correct, | 15% incomplete, | 1% false |
| Deep water: | 88% correct, | 12% incomplete, | 0% false |
| Salt marsh: | 3% correct, | 98% incomplete, | 5% false |

Percentage recognitions were unobtainable for light and dark bare soil because no corresponding tonal differences were visible on color film for comparison. The recognition for mixed hardwood forest proved too diffuse to be accurately determined.

Thermal infrared scanner data were taken at night and clearly showed temperature differences between pine and deciduous forest, bare and vegetated soil, pavement and soil, and surface temperatures in the estuary.

Applications for low level natural color and infrared color film included construction of a drainage map and vegetation map; photo-interpretation of deciduous forest vegetation, salt marsh vegetation, and cultivated fields; and detection of estuarine erosion and siltation patterns. The photointerpretive studies included correlations with ground truth and statistical analysis of the results. Observations of seasonal phenology facilitated these studies.

Drainage Map

A drainage map was drawn which shows all discernible streams, intermittent channels, and marshy or swampy areas. It was drawn from an uncontrolled mosaic of tracings from natural color film photographed in April, before the forest foliage developed. The tracings from natural color film were then compared to corresponding frames of infrared color film to determine the degree of accuracy obtainable from each film type. Natural color proved satisfactory except for detection of narrow stream courses and swampy areas. For these and all hydrographic purposes, infrared color was superior. Approximately 20% of the streams detected on natural color required correction after examination of infrared color photos.

Vegetation Maps

The vegetation map was drawn from the same uncontrolled mosaic as the drainage map, but was modified to show the distribution of deciduous and coniferous forest, cultivated and abandoned fields, freshwater and salt marshes, and residential areas. On both natural color and infrared color film, these features showed well, but the latter type was better for detecting evergreen subcanopy vegetation, and delineating marshes and stands of conifers. Species composition in the forest areas and abandoned fields was determined by extensive ground truth collection at over 500 stations. Dominant and sub-dominant species were defined on the basis of trunk diameter and abundance. The map represents dominant and sub-dominant canopy and understory species at each station by letters and symbols. Since most cover types in the deciduous forest grade into each other, it was impractical to draw boundaries for them.

Photointerpretation - Hardwood Forest

A detailed correlation of ground truth with aerial photographs was made at Hog Island, at the mouth of Muddy Creek. The 5-acre island supports an upland oak-sour gum forest with some Virginia pine and an oak-beech-mountain laurel understory and shrub layer. Techniques were obtained for fairly reliable identification of these species from natural color and infrared color photographs taken at different seasons.

A ground truth map of the positions of 182 canopy trees was constructed with surveying instruments. The trees were identified and their trunk diameters recorded to facilitate proper matching with crown images on the aerial photographs. Photographs were taken in late winter, spring, summer, mid-autumn, and late autumn. Natural color film proved satisfactory for identification of hardwoods at all seasons, while color infrared was most useful in the autumn. Both types were suitable for locating evergreen species, especially in winter. Reliable correlations between photographs and ground truth were hampered by photographic distortion and inaccuracies in surveying, both of them intensified by steep terrain around the sides of the island. Correlations were most accurate for large canopy trees near the center of the island.

A map of 260 tree crowns was drawn from an enlarged photograph, and 156 of these crowns were identified. Fifty-four identifications were made by ground truth, the remainder by photointerpretation of crown characteristics at different seasons.

Photointerpretation - Salt Marsh

Photointerpretive studies were made for the two large salt marshes at the mouth of Muddy Creek, known as the Hog Island and Kirkpatrick Marshes. Ground truth was collected in Hog Island Marsh and correlated with a photograph taken in April at 1200 feet altitude. These data were compared with a photograph of the Kirkpatrick Marsh taken in July at 2500 foot altitude. From this comparison, predictions were made of vegetative composition in the Kirkpatrick Marsh and later verified by ground truth. Predictions averaged 50 percent totally correct and 72 percent partial ones. Most errors involved relatively small areas of marsh resulting chiefly from dissimilarities in the vegetation of the types as shown on the two photos, and partial inundation of the Kirkpatrick Marsh.

## Crop Recognition

For recognition of summer crop types a field survey was made to locate fields of corn, tobacco, soy beans, grass (including hay, wheat, and sod), and mixed grass and weeds. A photointerpretation test to determine how easily the crops could be distinguished on both natural color and infrared color film was given to workers at the CBCES. The test required interpretation of 97 fields with natural color film and 194 fields with color infrared. Of the major field types, 76-85 percent were correctly identified. Although testees preferred natural color to color infrared, interpretation was 2-5 percent more accurate with the latter. This may have been a result of in-test training.

## Estuarine Applications

Natural color aerial photographs at a scale of 1:10, 000 were found highly useful for tracing patterns of estuarine siltation and current flow, especially in shallow water. At least three levels of sediment concentration were discernible. Bottom contours were traceable at low tide in shallow water. Infrared color photographs were virtually useless for these applications. Both film types were fairly good for detecting concentrations of floating aquatic vegetation, but a dearth of rooted aquatic plants in Rhode River in 1971 prevented extensive study or vegetation mapping. Recurrent photographs of an eroding shoreline proved useful for monitoring rates of erosion. A comparison in the width of a peninsula photographed in 1968 and 1971 revealed a loss of four meters of soil in the 2 1/2 year interval.

The photointerpretive techniques acquired in this study are being further developed and will be applied to progressively larger areas in the vicinity of the Rhode River watershed. Additional ground truth studies will be used to verify extrapolations on the composition of vegetation. Remote sensing techniques at progressively higher altitudes, eventually including those of the ERTS satellite, will be used to study other estuarine ecosystems around the Chesapeake Bay.

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THE END