Spectral Reflectance Characteristics and
Automated Data Reduction Techniques which
Identify Wetland and Water Quality Conditions in the
Chesapeake Bay

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Introduction

This report presents progress on research designed to test the usability of multispectral, high altitude, remotely sensed data to analyze ecological and hydrological conditions in estuarine environments. Emphasis will be placed on data acquired by NASA aircraft during fiscal year 1 July 1969 to 1 July 1970 over the Patuxent River Chesapeake Bay Test Site, No. 168. Fig. 1 is a map of the test site.

Mission Nos. 103 (Aircraft RB57F) and 104 (C130 aircraft) were conducted over the Chesapeake Bay during September, 1969. Mission 103 was a high altitude flight (18,460 m) and 104 a low altitude flight (3,070 m). Table 1 shows the types and quality of data received from these missions.

The hypothesis being tested in this phase of the research was that remote sensing techniques found successful in earlier ecological studies of the Patuxent River, Maryland (Missions 74 and 79), would be usable in other, more complex ecosystems (the Chesapeake Bay) and at higher altitudes than previously flown. The principle objectives of Missions 103 and 104 were the following:

1. To determine feasibility of identifying source and extent of water pollution problems in Baltimore Harbor, Chesapeake Bay and major tributaries utilizing high altitude, ERTS analogous remote sensing data.

2. To determine the feasibility of mapping species composition

and general ecological condition of Chesapeake Bay wet-
lands, utilizing high altitude, ERTS analogous data.

3. To correlate ground spectral reflectance characteristics

   of wetland plant species with tonal characteristics on

   multispectral photography.

4. To determine usefulness of high altitude thermal imagery

   in delineating isotherms and current patterns in the

   Chesapeake Bay.

5. To investigate automated data interpretive techniques which

   may be usable on high altitude, ERTS analogous data.

The Chesapeake Bay Test Site

The Chesapeake Bay is the largest estuary on the Atlantic Coast of
the United States. With its some 50 major and minor tributaries it con-
stitutes one of the largest estuarine systems in the world. While the
surface area of the Bay is large (2,200 square miles) the mean depth is
only 28 feet, indicating it is extremely susceptible to physical and
biological changes. Increasing urban development along the tributaries
of the Bay system will bring inevitable changes in water quality and
shoreline aquatic ecosystems. Because of the size of the estuary and
the many diverse problems of an ecological nature it presents a unique
opportunity for evaluation of ERTS and ERTS analogous imagery in
identification and solution of these problems.

Successful management of water resources and attendant biological
communities requires coordinated efforts on the part of federal, state,
and local authorities. This is particularly necessary in a resource

such as the Chesapeake Bay where four states, the District of Columbia and numerous regional, county and city authorities may at times make independent decisions regarding utilization of the resources of the Bay.

Remote sensing from aircraft and satellite presents a unique method by which the Bay may be observed and studied as whole rather than in piecemeal fashion. Remotely obtained hydrological and ecological data present a focal point around which coordinated physical and biological studies may be feasible and attractive to many diverse groups now doing research in the Chesapeake Bay.

Results and Discussion

A. Water Quality

Results of previous water quality studies, including correlation of ground truth data with spectral signatures on film, have been published and will not be reiterated here except in summary form (1), (2). The following general aspects of water quality conditions in the Patuxent River had been determined in previous studies.

(1) Estimation of water salinity through color IR interpretation of plant species in wetlands.

(2) Sources of sediment addition to the estuary.

(3) Rough quantitative estimate of sediment content in the estuary through tonal quality on color IR film.

(4) Areas in the estuary where siltation and mudflat development present potential boat navigation problems.

(5) Sources of ground water inflow into the estuary through thermal IR imagery.

(6)   Sources of nutrient additions to the estuary through color

IR photography of algae blooms.

Water quality studies in Chesapeake Bay have been confined to
Baltimore Harbor. There are a number of industrial and municipal
effluents which empty into the Harbor; therefore, it is an ideal test
area for both low and high altitude ERTS analogous multispectral water
quality conditions.

As shown in Table 1, both low and high altitude multispectral data
were obtained over the test site. The prime reason for requesting the
low altitude imagery was to compare spectral signature of water quality
conditions with that on high altitude imagery and to determine magni-
tude of information loss with increase in altitude of the aircraft.
Of particular interest was comparison of color and color IR photography
since the latter had been found more useful in low altitude studies
on the Patuxent River. Unfortunately, much of the color IR data received
from these missions were not usable due to underexposure of the film.
Therefore, comparison with natural color was not possible.

Ektachrome color photography from both low and high altitude
missions was good and it was possible to evaluate loss of information
with altitude. Fig. 2 shows a low altitude photograph of Baltimore
Harbor. Comparisons with high altitude photographs indicate that
more detailed analysis of water quality conditions could be done from
low altitude. However, high altitude photography has the advantages of
smaller scale and larger areal coverage. General water quality con-
ditions may be ascertained as well as point sources of several effluents

which degrade water quality in Baltimore Harbor.

Algae blooms are excellent, indirect indicators of water quality in bodies of water. Nutrients discharged from municipal sewage effluents, septic tanks and farm runoff all provide conditions for algae blooming during certain times of the year. Problem areas may be quickly identified through these excessive aquatic plant growths. Color IR photography has been shown to be useful from low altitude for delineating algae blooms. Fig. 3 is a high altitude color IR photograph of the Potomac River near Washington, D. C., showing severe algae blooming. Other minor blooms were also evident from the high altitude photography of several tributaries of the Chesapeake Bay. This indicates that areas where entrophication is a problem may be located from high flying aircraft.

Automated data interpretive techniques for assessing water quality conditions will be discussed later in this paper.

B. Wetlands Studies

Results of previous wetlands studies have been published (2) and will not be repeated here, except in summary form. The following general aspects of wetland ecology have been determined in the Patuxent River, Maryland:

(1) Infrared spectral reflectances by wetland plants are unique for given species and communities. This results in tonal signatures which are readily discernable and separable on color IR film.

(2) Changes in plant species composition and vigor from spring to fall in wetlands, results in changes in tonal quality

on color IR film.

(3) Production of a key for wetland vegetation species utilizing
color (shades of pink) alone is apparently not possible
due to variations in the quality of color IR film from one
roll to the next. However, plant species and communities
may be classified according to tone brightness. One will
find the same sequence of species tone brightness, from
dark to light, regardless of the particular color exhibited
on a given roll of color IR film.

Wetlands studies were extended to the Chesapeake Bay due to the
presence of plant communities and species not found in the Patuxent
River. Also, the larger sized wetlands in the Chesapeake Bay make it
feasible to study them from high altitude ERTS analogous aircraft data.

Of particular interest are the 240,000 acres of wetlands along the
lower eastern shore of the Chesapeake Bay. They range in type from
shallow fresh marsh to salt marsh, with the latter type predominating.
The value of these areas to maintenance of good water quality conditions
in estuaries, preservation of wildlife habitat, etc., is now widely
accepted. High altitude aircraft and satelite data could provide the
following information on wetland ecology:

(1) General species composition of major plant communities;

(2) Evaluation of different wetland types for importance to
certain wildlife populations;

(3) Rates at which wetlands areas are being lost due to natural
and man-made activities.

Missions 103 and 104 were designed to determine loss of information in wetlands (species composition, etc.) with increase in altitude and to determine film and filter combinations which would best delineate wetland plant communites from high altitude (Table 1). Unfortunately, much of the high altitude color IR photography was underexposed. Color IR photography from the Hasselblad cameras (1:240,000 scale, filters 15-G and 25-A) and Zeiss camera (1:60,000 scale, "D" filter) was usable. Fig. 4 is a low (1:20,000) and high altitude (1:60,000) photograph of a wetland area. As can be seen, little information on species composition is lost with this reduction in scale. Interpretation becomes more difficult on the 1:240,000 Hasselblad photography. Plant community zonation lines are blurred and determination of general species composition is considerably more difficult, particularly in fresh water wetlands where there is a large variety of species present.

It appears that photographic interpretation of wetlands on smaller scales will best be done with automated techniques such as density slicing. This will be discussed later in the report.

C. Spectral reflectance characteristics of wetland species

Remotely sensed photographic and imaging data are dependent in most cases upon differences in reflected or emitted electromagnetic radiation from surfaces. It became important in this study to know how plant leaf reflectance differs from species to species, what role season and plant age play in the quantitative and qualitative aspects of this reflectance, and the amount of intraspecies variation that can be expected.

A total of ten marsh plant species have been investigated for spectral reflectance characteristics. Fig. 5 is a comparison of three of the curves derived from the study. All spectral data were collected with an ISCO Model SR Spectroradiometer equipped with an extension probe for field work. Readings were made between 0.4 and 1.35 micrometers using incident sunlight as a reference. Approximately ten individuals of each species were studied to determine intraspecies variation.

The spectral reflectance curves for all plant species are similar in shape, but differ in magnitude (Fig. 5). In the visible range the curves show low reflectivity (1-6%) between 0.4 and 0.5 micrometers, a peak at 0.55 micrometers (6.2-9.1%), a drop to a minimum at 0.675 micrometers (3.3-6.7%). Beyond 0.7 micrometers, the curves rise steeply to a peak at 0.8, 0.85, or 0.9 micrometers in the infrared (30.5-46.6%). Beyond the peaks in the infrared, the reflectance falls gradually with a pronounced dip at 0.95 and 1.24 micrometers. Yellow water lily shows the highest reflectance in the infrared and salt marsh grass, the lowest. In the visible range, wild rice and yellow water lily have the highest reflectance at 0.55 micrometers and salt marsh grass the lowest. Between 0.7 and 0.9 micrometers (the spectral range in which the infrared emulsion layer of Kodak Ektachrome Infrared Aero Film is sensitive) the plants rank in order of decreasing total reflectance: yellow water lily, pickerelweed, sweet flag, wild rice, cattail, reed, rush and salt marsh grass. Fig. 6 shows tonal signatures of some of the above species on color IR film.

Table 2 shows the relationship between spectral reflectance and tonal "signatures" on color IR film. As can be seen by these data,

there is not a complete correlation between tone brightness and per-cent reflectance in this portion of the IR spectrum. Species such as cattail and salt marsh grass need to be restudied to determine if characteristics such as leaf orientation, leaf stacking, etc. have a significant effect on I R reflectance.

Comparison of spectral reflectance curves indicates that narrow bandwidths around 0.9 and 1.1 micrometers would be best for separation or delineation of all species studied. At 0.9 micrometers, only reed and wild rice cannot be separated. If it is desirable to separate sweet flag, pickerelweed, wild rice and reed, all of which have medium reflectance, 0.75, 0.85 and 1.1 micrometers are good wavelengths at which to work. Low reflectors such as cattail, rush and salt marsh grass separate well at a number of wavelengths -- 0.55, 0.675, 0.75, 0.8, 0.85, 0.9, and 1.3 micrometers. Strong reflectors, yellow water lily and arrow arrum should be easily delimited at 0.75, 0.8, 0.9 and 1.1 micrometers. Film-filter combinations can be chosen to select out narrow bandwidths around these optimum wavelengths or some type of multiband sensor may be used to collect data.

Comparison of spectral reflectance curves for reed (Phragmites) made in July and October shows a seasonal change in reflectance (Fig. 7). Color infrared photographs taken of a marsh in late June and late September show a change in color signature from bright pink to dark red or blueish red (Fig. 8). Ground observation in October showed vegetation in area II to consist entirely of mature growth with dry, brittle, grey-spotted leaves. Area I contained a percentage of young growth and the leaves appeared less brittle and discolored. Spectral reflectance in the near IR varies accordingly, being highest for leaves

of reed in July, lower in leaves from area I and lower still in leaves from area II measured in October. There was a large intra-species difference in October which points up one of the difficulties of collecting data near the end of the growing season.

Since season influences the reflectance characteristic of vegetation (aging, disease at the end of the growing season; change in internal structure of the growing leaf at the beginning of the growing season), spectral reflectance curves should be available for spring, summer, and fall.

Measurements of spectral reflectivity have been made primarily on agricultural crops and forest species. Marshlands and estuaries are valuable natural resources which provide nursery grounds for young fish and marine invertebrates as well as feeding areas for wildfowl. For this reason, it will prove desirable to monitor these areas by remote sensing on a regular basis for protection from man-made reductions in productivity. Shifts in vegetative distribution and density exceeding what normally occurs as a result of plant succession may indicate changes in drainage patterns, salinity, siltation and pollution levels. Changes in reflectance as a result of disease, drought, nutrient deficiency, or pollution can be detected quickly by remote sensing and remedial procedures applied.

D. Thermal imaging of estuarine systems

Fig. 1, a map of the Chesapeake Bay, shows the presently operating and planned thermal electrical generating plants in this area. As can be seen there are already areas under thermal stress (Baltimore Harbor) and the potential for stress in the larger system is very real as

greater demands for electricity are made on the industry.

It is extremely important that the baseline studies on thermal characteristics of the Bay be done now. Thermal imaging from aircraft, with concomittant ground truth, presents a rapid means for doing this baseline study. Unfortunately, the thermal imagers aboard the C130 and RB57F aircrafts were not operational during these missions. Data of these types will be requested in future missions.

E.   Automated data interpretive techniques

With the advent of ERTS-A and a significant increase in remotely sensed data, it is important to establish automated techniques for data reduction. The sheer bulk of information available from satellites will make eyeball interpretation impractical and obsolete. For this reason data interpretive techniques such as color coded microdensitometry, color additive procedures and density slicing are being investigated for use in wetland and water pollution studies.

One of the more promising techniques being explored at the present time is Datacolor density slicing available through Spatial Data Corporation. Through use of a television camera and up to 32 different colors (actually 8 colors and 4 tones for each color) densities on black and white transparencies are separated and color imaged on a television screen. The machine is capable of separating a maximum of 32 different densities.

Fig. 9 is a print of an image generated by analysis of a black and white Hasselblad photograph (Filter #58), showing distribution of sediment from a stream. The color coded densities representing dispersement of sediment into the Bay are easily separable. Quantitative

values of sediment content could easily be assigned to each density value.

Fig. 10 shows a print of a black and white Hasselblad transparency (scale 1:240,000, Filter No. 58) and a print of the color image generated as a result of density analysis by the Datacolor machine. Sixteen densities were counted in the wetland, indicating that plant species composition may be determined rapidly using small scale black and white photography. It will be necessary to field check the wetland to determine if each density represents a single plant species or community type.

As a part of the wetland study, the author has been cooperating with the Department of Natural Resources, State of Maryland. A new wetland law enacted July 1, 1970, requires the state to delineate state-owned wetlands from those that are privately-owned. The state is claiming ownership to all wetlands that are inundated by each tide. The problem here is to accurately draw a line which separates the two in many wetland areas.

Fig. 11 is a high altitude color IR photograph showing how this delineation is accomplished. Bright tones are interpreted as high marsh (privately-owned) and darker tones as low marsh (state-owned). Fig. 12 shows how this interpretation may be accomplished utilizing an automated technique such as the Datacolor system.

Summary

This paper reports progress in analysis of data received from Missions 103 and 104, September 1969, Site 168, Chesapeake Bay. This was the first flight over the expanded test site and it presented an

opportunity to become familiar with the general topographic and hydro-

logic features of the Chesapeake Bay as well as to begin ERTS analogous

studies of a large, complex estuarine system.

Must of the data received was good; however, a considerable portion

of the color IR photography was not usable. This prevented comparison

of high altitude natural color with color IR for use in water pollution

and wetland investigations. The following general conclusions are a

summary of interpretive results.

1. General water pollution conditions in Baltimore Harbor may

    be inferred from high altitude, small scale, RC-8 color

    photography. Point source effluents and dispersement of

    pollutants are imaged on the film.

2. Species composition and general ecological conditions of

    wetlands may be interpreted from high altitude RC-8 color

    and Zeiss color IR photography. Little information is

    lost with increase in altitude.

3. Water quality and wetland studies are more difficult on

    small scale Hasselblad photography. It appears that

    automated data reduction techniques may be necessary for

    adequate interpretation.

4. Spectral reflectance properties of several marsh plant

    species have been established. Attempts at matching

    reflectance with tone brightness on color IR photography

    have yielded mixed results, with little or no correlation

    observed on two species.

5. Automated data interpretive techniques have been investigated
    and appear to work well with black and white, small scale
    photography.

3

Literature Cited

1. Anderson, R. R. 1968 Remote Sensing of Marshlands and Estuaries
    Using Color Infrared Photography. NASA, Earth Resources Aircraft
    Program Status Review, Vo. III: 26-1 to 26-23.

2. Anderson, R. R. 1969 The Use of Color Infrared Photography and
    Thermal Imagery in Marshland and Estuarine Studies. NASA, Second
    Annual Earth Resources Aircraft Program Status Review, Vo. III:
    40-1 to 40-29.

Table 1 Types and quality of data received from Missions 103 and
104, Chesapeake Bay Test Site, September 1969.

Mission No.	Data Type	Quality
103, RB 57 F,	RC-8 Ektachrome Color	Good
18,460 m altitude.	RC-8 Ektachrome Color IR	Poor, Underexposed
	Hasselblad B & W, Filter #58	Good
	Hasselblad B & W, Filter #25A	Good
	Hasselblad Ektachrome Color	Not useable
	Hasselblad Color IR, Bilter #15G	Good
	Hasselblad Color IR, Filter #25A	Good
	Zeiss, Color IR, "D" Filter	Good
104, C130 B,	RC-8 Color IR Soll7, Filter #15	Poor, Underexposed
3,070m altitude.	RC-8 Ektachrome Color	Good
	Hasselblad, B & W, Filter #58	Good
	Hasselblad, B & W, Filter #25A	Partially underexposed

Table 2 Relationship between spectral reflectance and tonal
signature on color IR film of selected marsh plant
species.

Plant	Tonal "Signature" on Color IR Film	Average % Reflectance 0.7-0.9 Micrometers
Cattail	Dark	29.2
Pickerelweed		31.1
Sweet Flag		29.7
Wild Rice		29.4
Salt Marsh Grass		23.9
Yellow Water Lily	Light	32.3
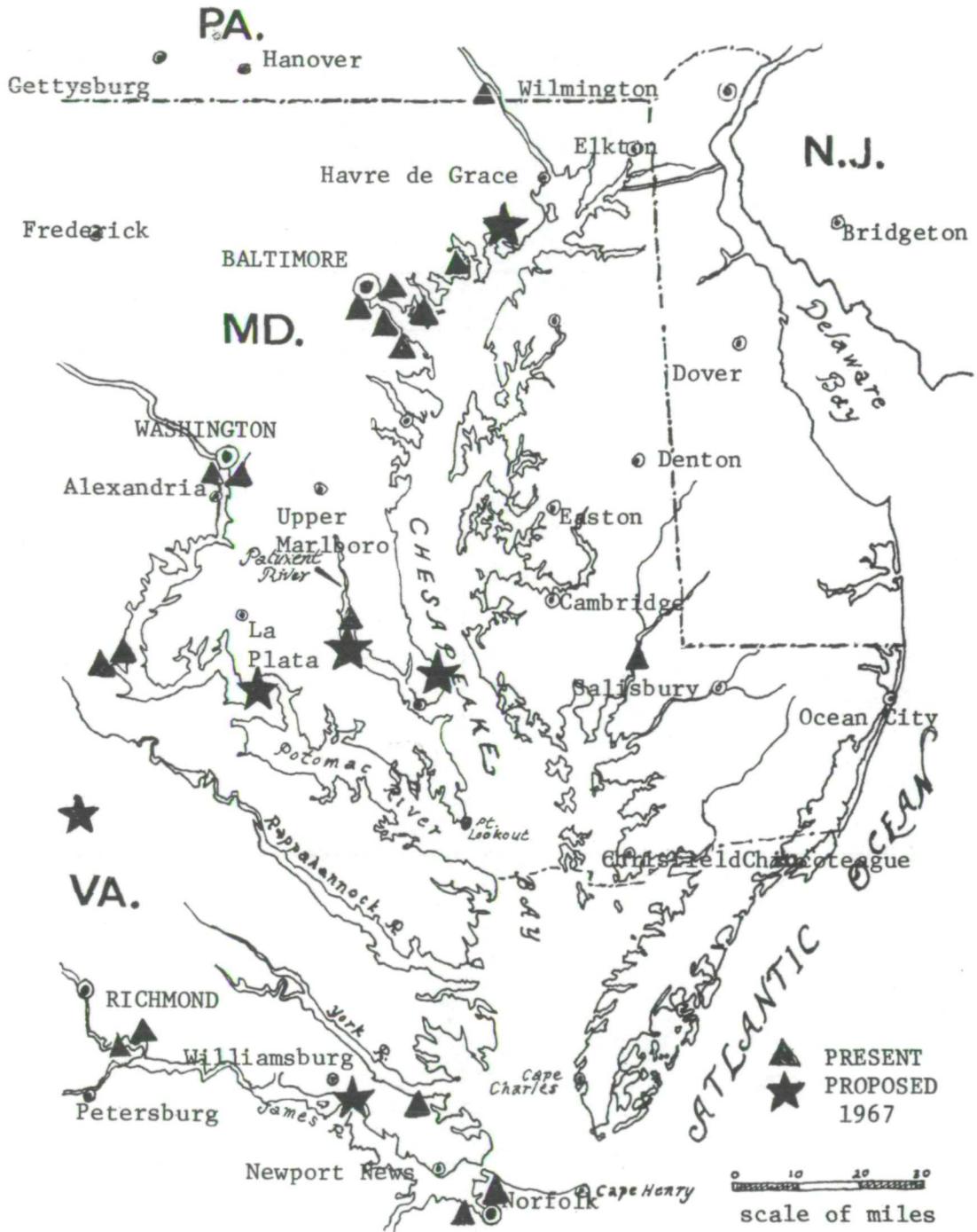
Fig. 1 Map of the Chesapeake Bay showing extent of study area and status of thermal electric power plant development.
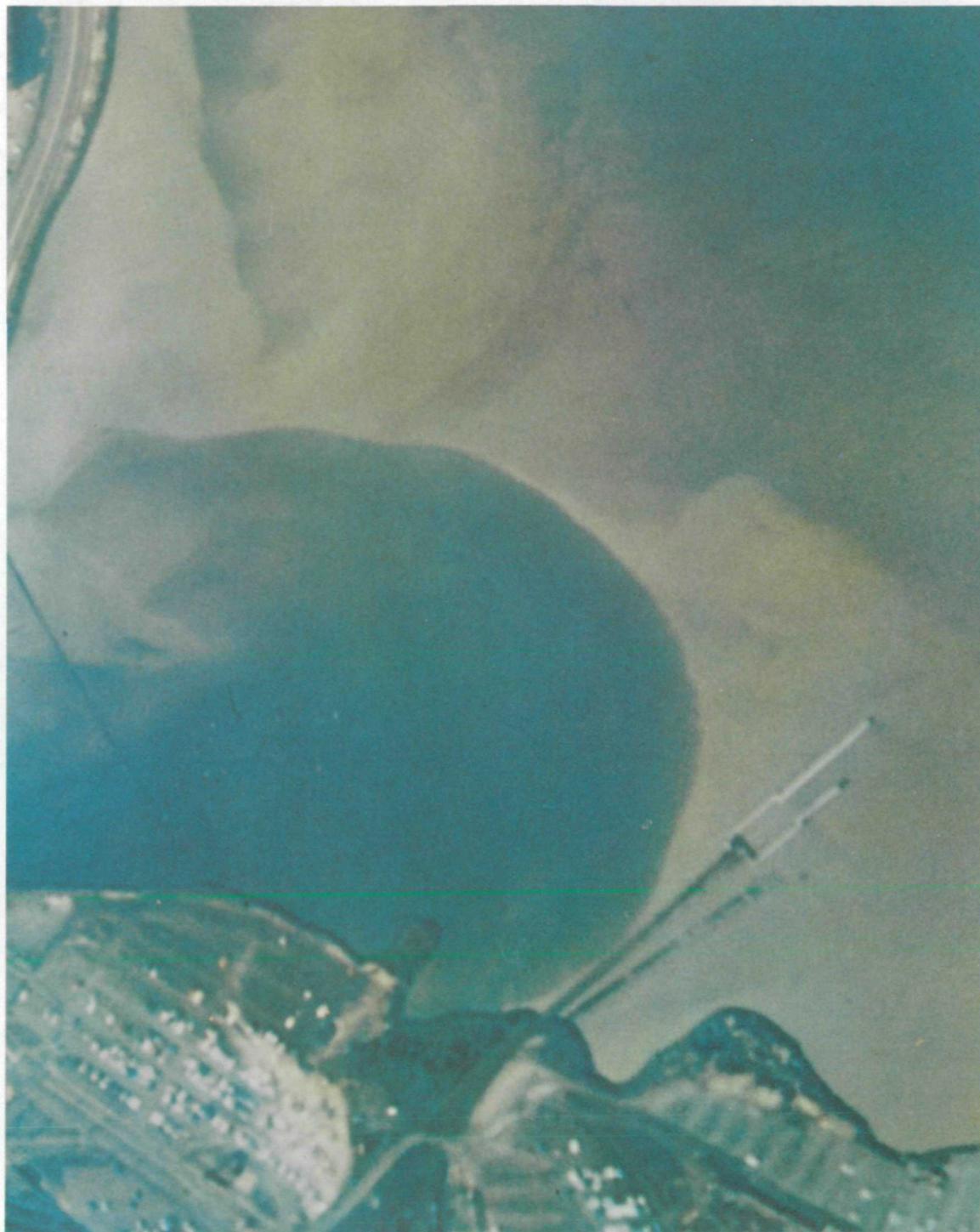
Fig. 2. Low altitude photograph of Baltimore Harbor showing one of
several industrial effluents. Ektachrome color. Scale,
1 cm = 55 meters.
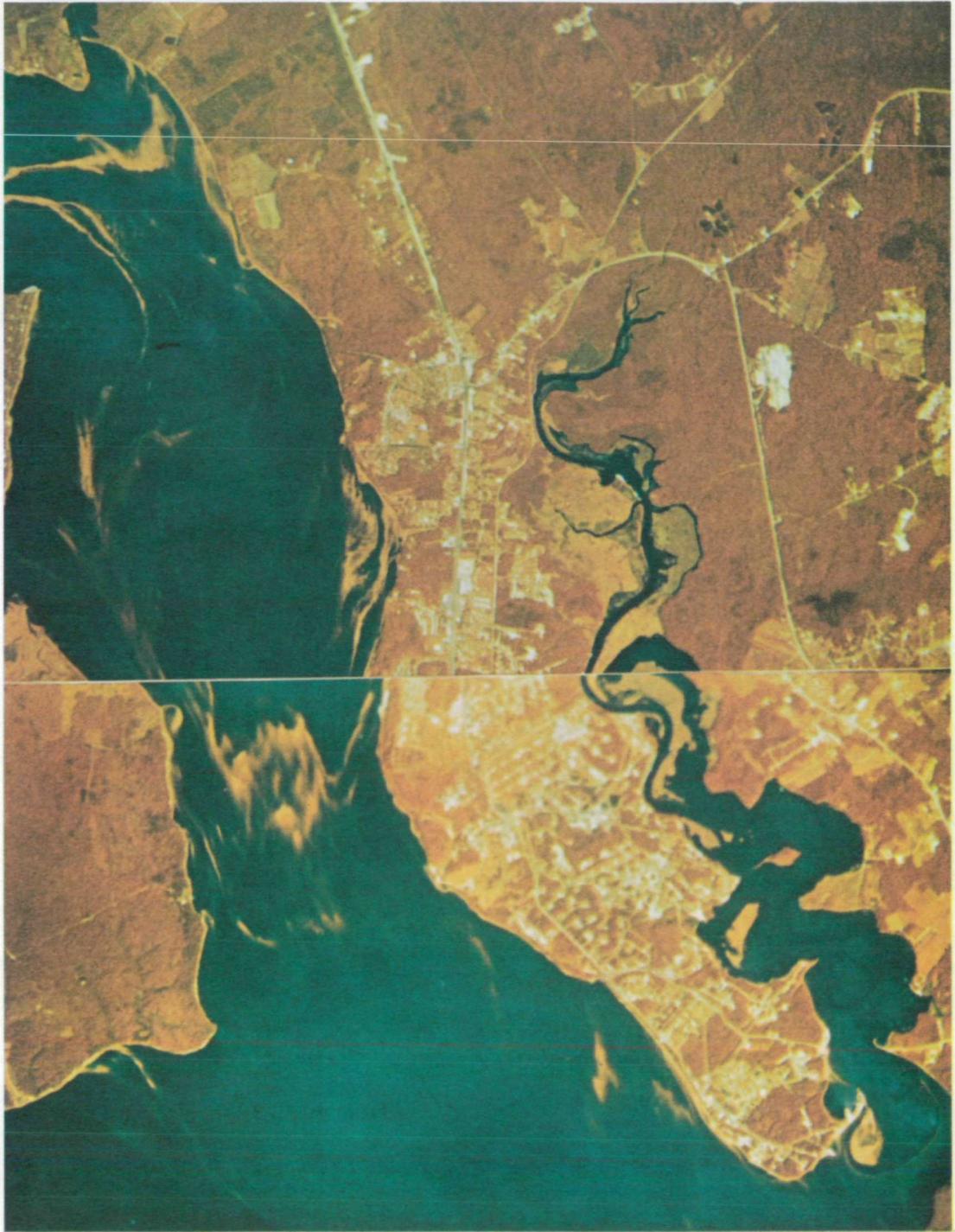
Fig. 3. High altitude photograph of the Potomac River near Washington, D.C., showing severe algae blooms in the water. Ektachrome color IR. Scale, 1 cm – 580 meters.

Fig. 4. Low altitude (top) and high altitude photographs illustrating only slight loss of information in wetland going from low to high altitude analysis. Ektachrome color IR. Scale, 1 cm = 120 meters (low) and 1 cm = 360 meters.
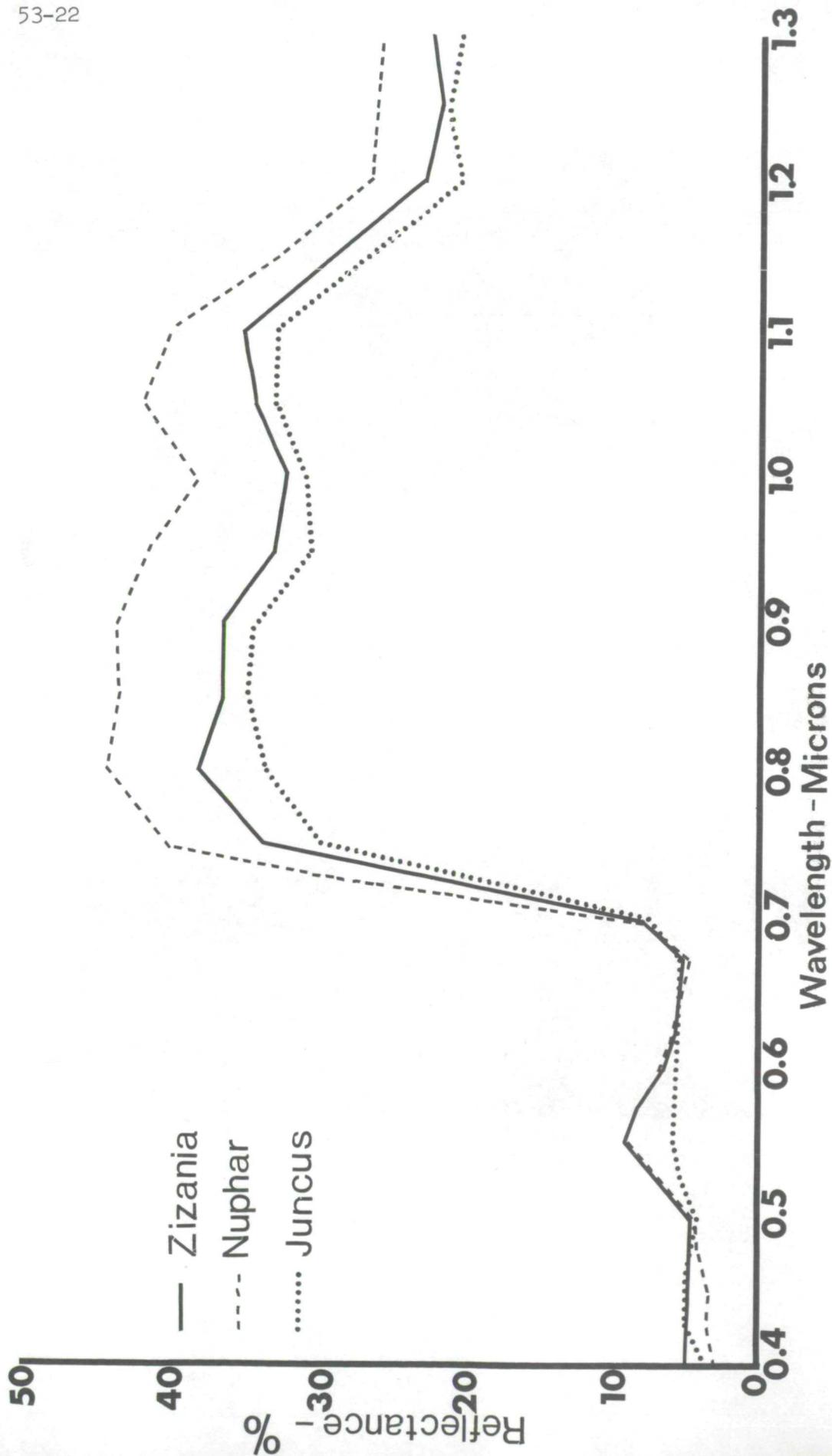
Fig. 5 Compares spectral reflectance characteristics, in the 0.4-1.3 micrometer range, of Zizania aquatica (wild rice), Nuphar advenum (water lily) and Juncus sp. (black rush).
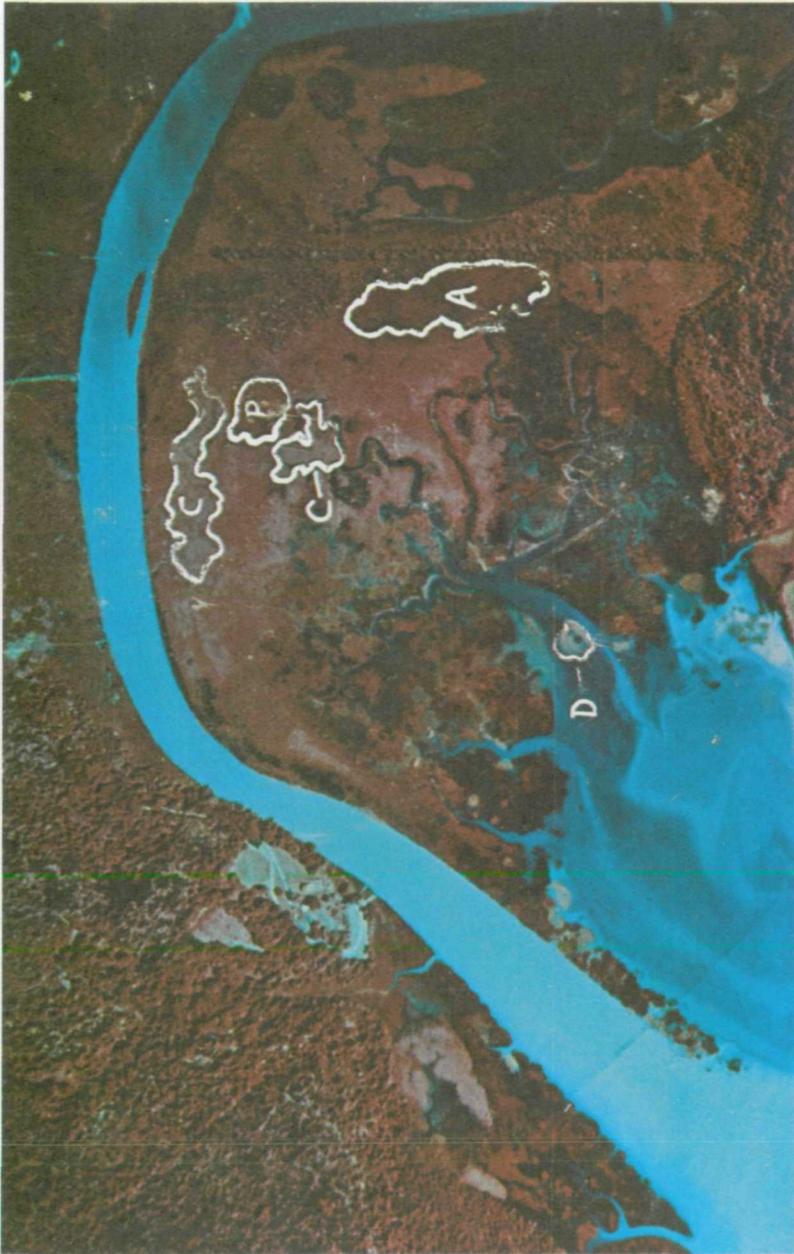
Fig. 6. Color IR photograph showing tonal quality of important wetland species. A – cattail; B – sweetflag; C – wild rice; D – water lily. Scale 1 cm = 120 meters.
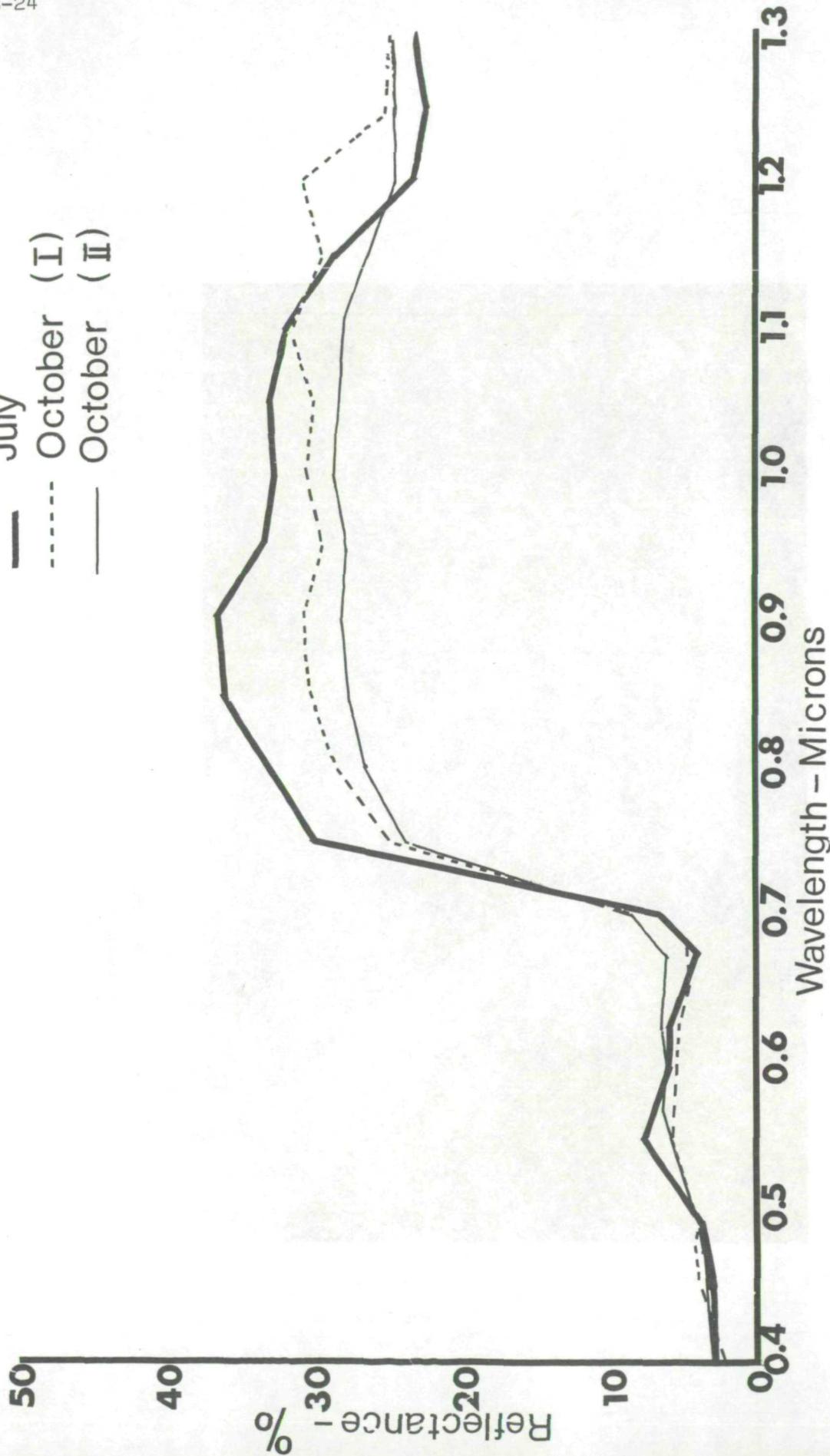
Figure 7. Spectral reflectance curves for Phragmites communis.
between 0.4 and 1.35 microns. Note the seasonal difference in
reflectance between leaves in July and leaves from adjacent
areas (I and II) on October 4, as well as the intraspecies
difference (I and II) toward the end of the growing season.

Fig. 8. Spring (top) and fall photograph of a wetland area showing
seasonal change in reflectance of plant species. Ektachrome
color IR. Scale, 1 cm = 120 meters.

Fig. 9. Datacolor image showing possible analysis of sediment discharge with this system. "A" is mouth of creek and water with heaviest sediment load. "B", "C" and "D" show decreasing amounts of sediment as it disperses in the estuary. Scale, 1 cm = 100 meters.
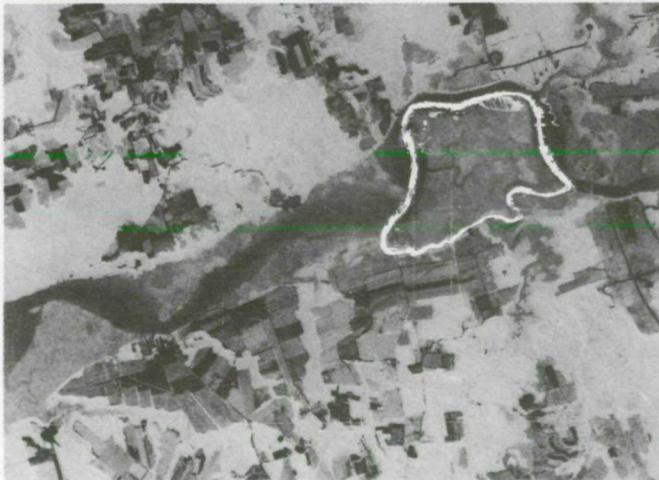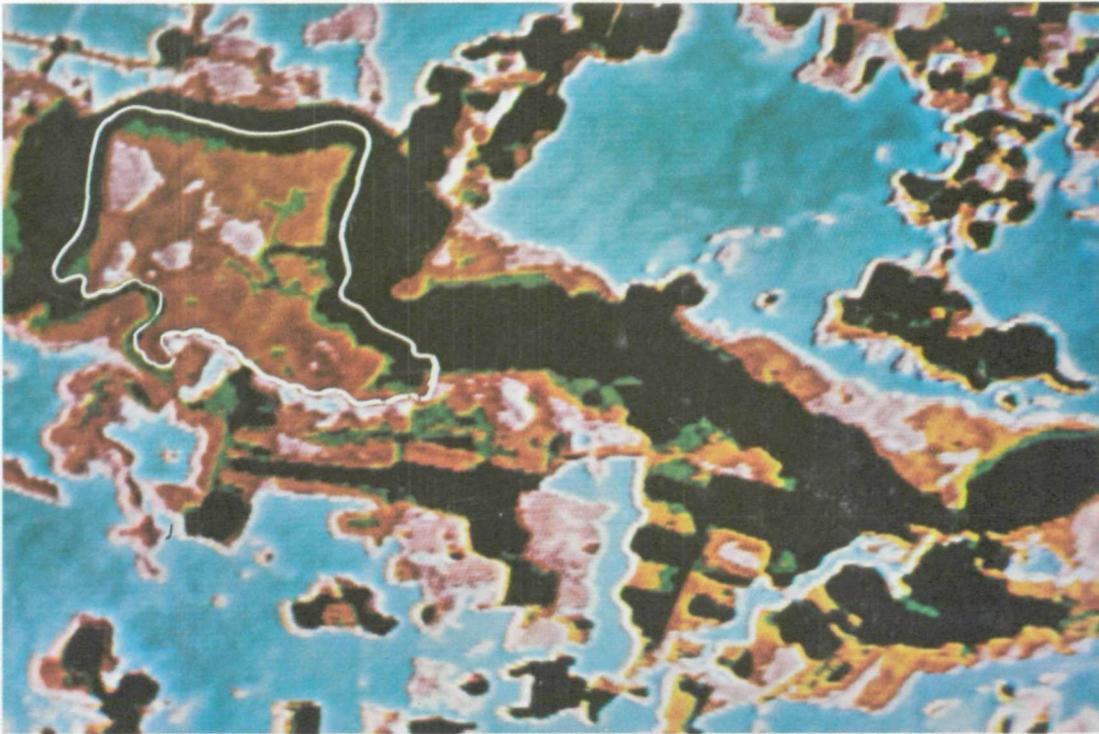
Fig. 10. Datacolor image (top) and black and white photograph from which image was generated. General delineation of species composition in the wetland (outlined area) can be done from high altitude photography. Scale, 1 cm = 800 meters.

Fig. 11. High altitude photograph of a wetland showing distinctive features of high marsh (brightly colored) and low marsh (dull green color). Ektachrome color IR. Scale, 1 cm = 640 meters.
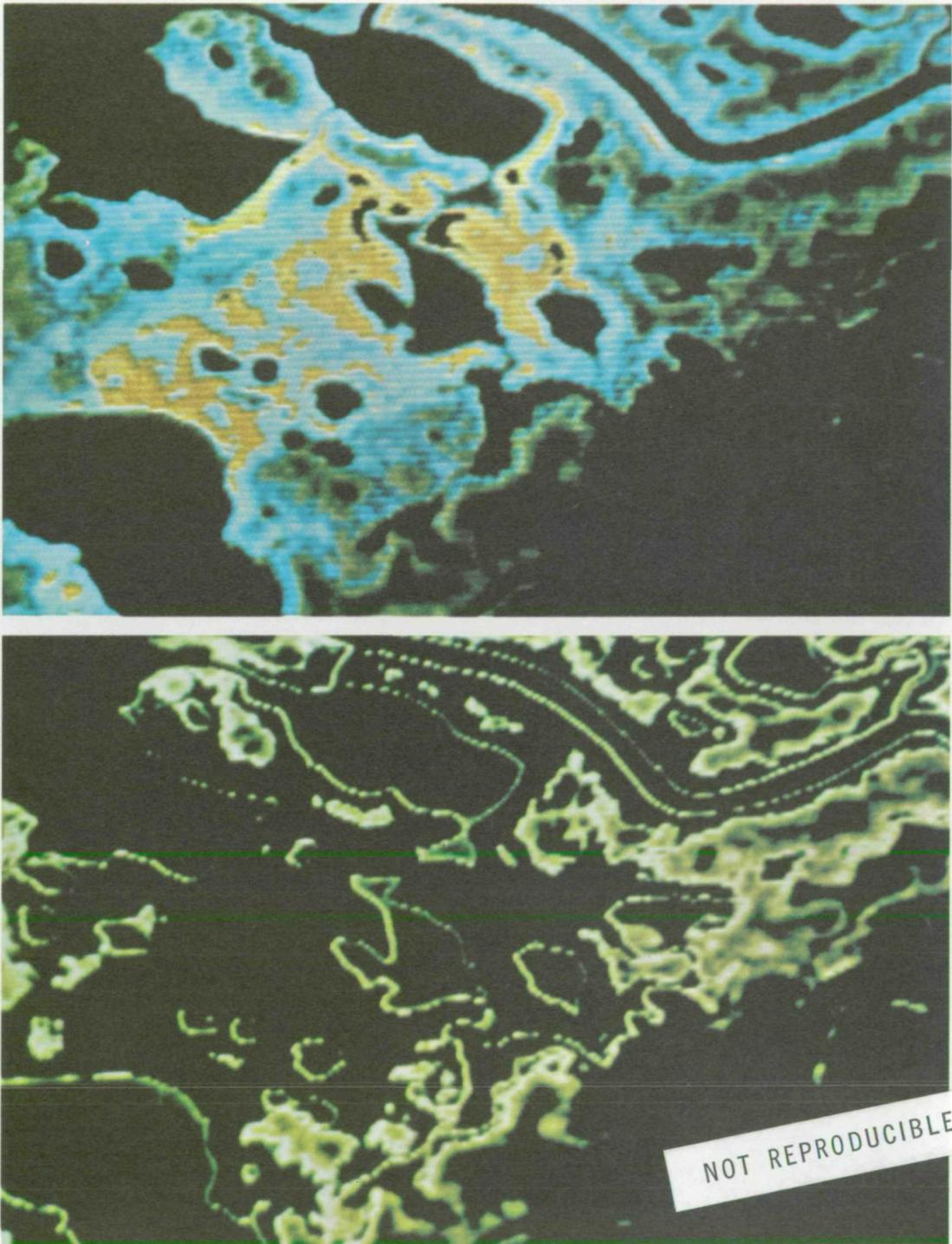
Fig. 12.   <u>Datacolor</u> image of wetland showing high marsh (yellow), low
marsh (blue) and shallow water (green).