NASA CONTRACTOR REPORT NASA CR-62099

(NASA-CR-62099) THE USE OF COLOR INFRARED AERIAL PHOTOGRAPHY IN DETERMINING SALT MARSH VEGETATION AND DELIMITING MAN-MADE STRUCTURES (Old Dominion Univ., Norfolk, Va.) 51 p HC $5.75 CSCL 08H G3/13 N74-31855 Unclas 46854

THE USE OF COLOR INFRARED AERIAL PHOTOGRAPHY IN DETERMINING SALT MARSH VEGETATION AND DELIMITING MAN-MADE STRUCTURES OF LYNNHAVEN BAY, VIRGINIA

by Robert E. Holman III

Prepared under NASA Grant No. NGL-47-003-067 by
Department of Biology
Old Dominion University
Norfolk, Virginia 23508

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS FLIGHT CENTER
WALLOPS ISLAND, VIRGINIA 23337

JUNE 1974

THE USE OF COLOR INFRARED AERIAL PHOTOGRAPHY IN DETERMINING SALT MARSH VEGETATION AND DELIMITING MAN-MADE STRUCTURES OF LYNNHAVEN BAY, VIRGINIA

Robert E. Holman III
Thesis for a Masters of Science Degree
Department of Biology
Old Dominion University
Norfolk, Virginia 23508

ACKNOWLEDGEMENTS

The author wishes to express thanks to Dr. G.F. Levy and the other members of the graduate committee, Drs. P.W. Kirk, H.G. Marshall and R.N. Blais for their time and assistance with this manuscript. Appreciation is also expressed to Dr. E.C. Kindle for his help with NASA liaison and Dr. L.J. Musselman for aid in identification of wetland plants.

This project was in part supported by NASA Grant No. NGL-47-003-067 and University Graduate Student Research Funds.

Further appreciation must also be expressed to Ms. Ruth Whitman (National Aeronautics and Space Administration, Langley Research Center), Ms. Virginia Carter (United States Geological Survey), and Dr. R.R. Anderson (American University, Washington, D.C.) for their professonal assistance in the research.

Special appreciation is expressed to Mr. Jeffrey Messmore and Mr. Edward Layton for providing a flight over the study area and to Mr. Gary Hilton for his advice concerning the research. Technical assistance was generously provided by Ms. Margaret Daniels.

ABSTRACT

Color infrared aerial photography was found to be superior to color aerial photography in an ecological study of Lynnhaven Bay, Virginia. The research was divided into three phases: 1) determination of the feasibility of correlating color infrared aerial photography with saline wetland species composition and zonation patterns, 2) determination of the accuracy of the aerial interpretation and problems related to the aerial method used, and 3) comparison of developed with undeveloped areas along Lynnhaven Bay's shoreline.

Wetland species composition and plant community zonation bands were compared with aerial infrared photography and resulted in a high degree of correlation. Problems existed with changing physical conditions; time of day, aircraft angle and sun angle, making it necessary to use several different characteristics in wetland species identification. The main characteristics used were known zonation patterns, textural signatures and color tones. Lynnhaven Bay's shoreline was 61.5 percent developed.

INTRODUCTION

The objective of this study was to examine saline wetlands species composition and plant community zonation bands, examine the accuracy and problems related to the sensing means and examine undeveloped and developed areas of Lynnhaven Bay, Virginia. Color infrared aerial photography was used as a remote sensing tool in this research.

Bays and estuarine wetland studies are important because many marine organisms depend on these areas during at least one stage of their life cycle (Anderson, 1968 and Wass and Wright, 1969). Numerous organisms use these wetlands as breeding grounds, nurseries and nutrient sources. Within saline wetlands are salt marsh plants which contribute a great deal to the existence of this habitat. These plants are one of the main primary producers of the food web that prevails here; they trap sediment, regulate the tidal exchanges through the marsh, and upon decomposition supply nutrients to the marsh and surrounding estuary. Many invertebrate organisms such as Uca spp. and Littorina sp. make their homes on or near the bases of these halophytes (Kerwin, 1971-1972).

Marsh communities occur in bands which appear to be related to salinity and inundation (Adams, 1963). Species and the communities they occupy are indicators of conditions existing in a particular marsh. Destruction of these halophytes by development of wetlands can only mean a reduction in the numbers of higher forms of marine organisms. The shoreline of bays and estuaries, however, is being filled and developed rapidly without a full realization of the consequences of this destruction. Human expansion has affected 90 percent of the original acreage of tidewater wetlands along the Atlantic Coast from Maine to Virginia (Shaw, et al., 1971). This is why a closer examination of the rate of development in relation to wetlands shoreline in these areas is important.

This research was conducted in Lynnhaven Bay which is located five miles west of Fort Story in Virginia Beach and ten miles east of Norfolk, Virginia. The bay's location in relation to the Tidewater Virginia Area is shown on Figure 1. It is shallow with a mean tidal range of 61 centimeters (U.S.G.S., 1973).

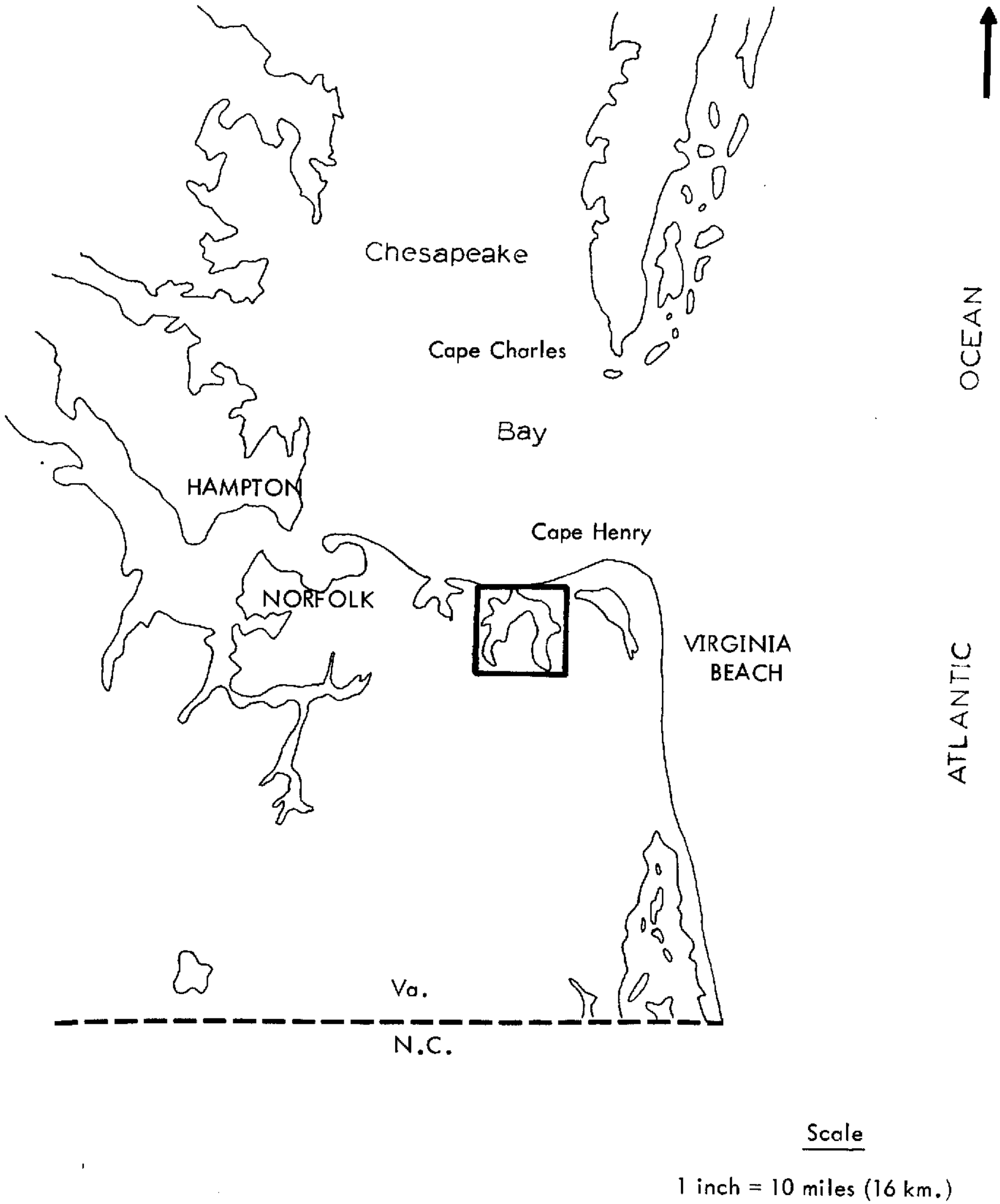


Figure 1. Lynnhaven Bay in relation to the Tidewater Virginia Area. The study area is delimited by bold lines.

The approximately 195 kilometers of shoreline is constantly shifting. This vacillation, at least in part, is due to the silting and dredging operation conducted in this busy waterway. A population in excess of 10,000 people living in this drainage area place a severe strain on this habitat (Chipman, 1948).

The examination of bay and estuary ecosystems has been in progress for more than sixty years. One of the early investigations was that of Harshberger (1909) who identified three types of marsh in his studies of the halophytes of the Northern New Jersey Coast. Nichols (1920) examined the vegetation along the coast of Connecticut and surmised that the vertical distribution of the seaside plants was mainly caused by tidal amplitude. Reed (1947) studied zones in two salt marshes near Beaufort, North Carolina, and found these zones were related to edaphic factors. Three marsh zones in the San Francisco Bay area were identified by Hinde (1954). Odum (1961) investigated the role of tidal marshes in estuary production and changed the concept of salt marshes from isolated communities to complete ecosystems. A study of coastal wetlands in Virginia with a consideration of the value of wetlands to man and his environment was conducted by Wass and Wright (1969).

The use of aerial photography began more than a century ago with the first aerial photographs taken from a camera supported by a string of kites in 1858. A few years later, in 1862, military use of this type of photography was applied over Richmond, Virginia (Howard, 1970). The modern potential of aerial photography was suggested by Thomas in 1920. The same year these techniques were first used for forest surveys in Canada (Wilson, 1920). Infrared aerial photography first came into use during World War II for camouflage detection. Wood (1953) applied these then new film techniques to an aerial forest survey and obtained better results than with color film.

The last decade has been marked by increased use of remote sensing by ecologists. Researchers today use many types of sensing in order to survey great expanses of the environment (Colwell, 1968). Infrared photography is being used as a remote sensing tool in agricultural, forest, and wetland studies.

Infrared photography's application in wetlands ia a new concept and has made great progress in the last few years. Anderson (1968) investigated the uses of infrared photography in marshlands, and concluded that color infrared was superior to natural color in differentiation of vegetative types within an estuary. Stroud and Cooper (1969) applied color infrared photography in determining species composition and zonation for net productivity in a North Carolina salt marsh. Anderson and Carter (1972) used infrared photography in delimiting wetlands by spectral signatures and their legal implication. Infrared photography was utilized in mapping coastal salt marsh of Georgia by Gallagher et al. (1972). They used these photographs to estimate the net productivity of Spartina alterniflora. Klemas et al. (1973) mapped the total coastal vegetation of Delaware by employing infrared photography as a surveying tool. Anderson and Wobber (1973) used color infrared photography in mapping and inventorying the saline wetlands along the coast of New Jersey. This was conducted under the New Jersey Wetland Act of 1970 in order that this important natural resource be properly protected. A similar study was conducted in Maryland by Garvin and Wheeler (1973) to find the extent of this natural resource for the Maryland State Government.

Infrared color film is sensitive to wavelengths (450-875 nm) slightly longer than visible color film (400-700 nm). Infrared film has three image layers that are sensitive to green, red, and infrared, instead of blue, green, and red as in the case of visible color film (Kodak, 1970). The manner in which infrared film forms color images is illustrated in Figure 2. The visible component combined with the infrared recording produces a modified color referred to as "false color". With this type of photography, contrast between plant species appear to be greater than with visible color photography.

Plants absorb a larger percent of visible solar radiation than infrared, but reflect back more radiation in the infrared rather than the visible region of the spectrum, thus making infrared photography ideal for plant studies (Howard, 1970). This high reflectance in the infrared region is due to the discontinuities of the internal cellular mesophyll layers (air space and cell wall interface) of plant

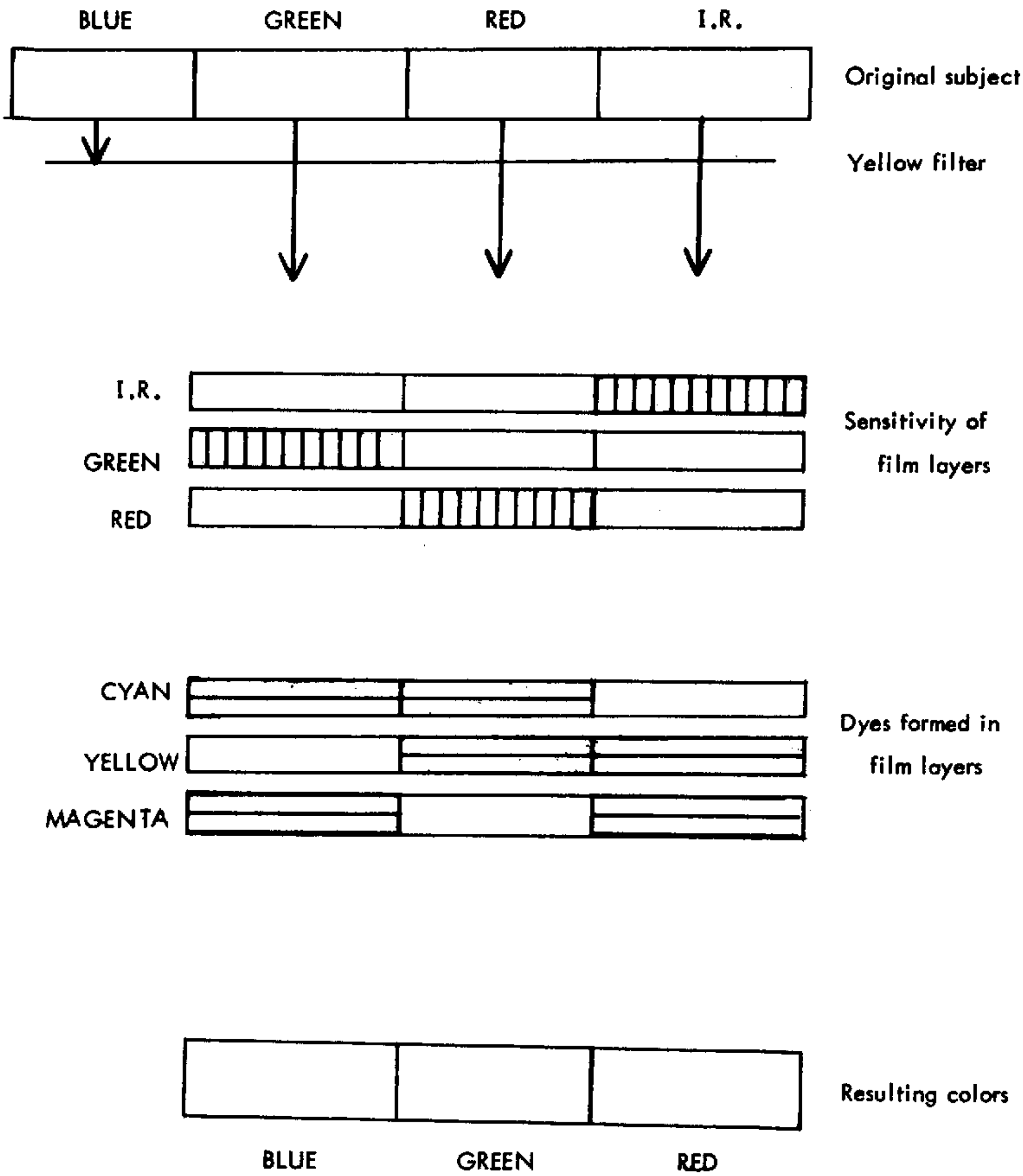


Figure 2. The manner in which color formation occurs in infrared film (revised from Kodak, 1970).

leaves (Gausman, 1974). Agricultural crops in the infrared region appear to have a high reflectance of solar radiation while narrow leaf emergence marsh plants appear to have a low reflectance of infrared solar radiation (Anderson, 1970). This makes the discrimination of wetlands much easier because there is less light reflected from them in the infrared region than there is from upland plant species. Gates (1964), Knipling (1970), and Penny et al. (1973) have shown that individual species have different reflectance due to shape, size, pigmentation, density and height.

METHODS

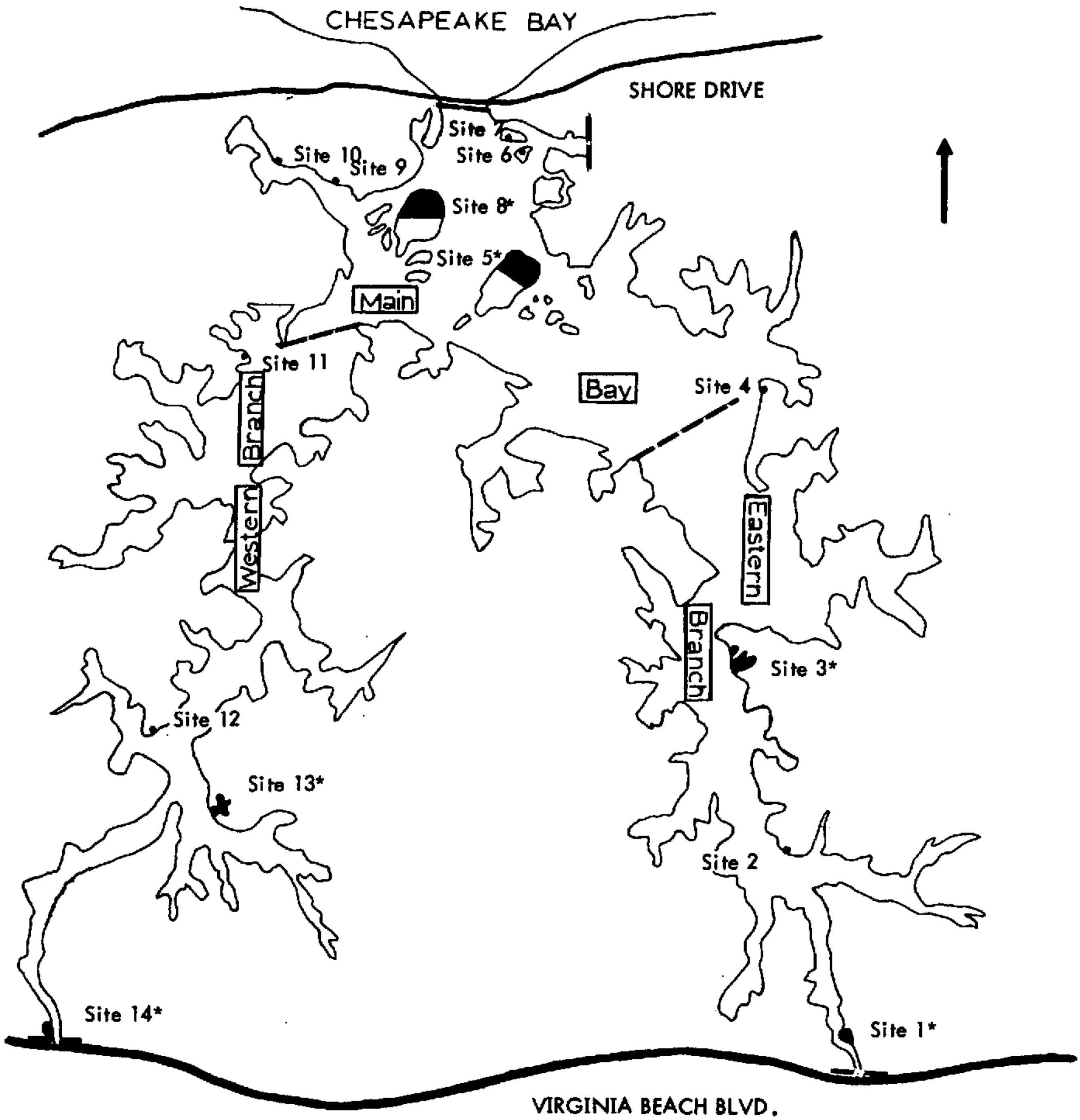
Figure 3 shows a color infrared aerial photograph of Lynnhaven Bay. The 14 sites studied are shown in Figure 4. Three sites (1,3,5) were designated as control areas with their composition verified by "ground truth" studies. The same number of experimental sites (8, 13, 14) were then photographed and the photographs interpreted on the basis of the results of the control studies. The first photographic mission used Ektachrome Aerographic 2448 film with a CAV filter and Aerochrome Infrared 2443 film with 12-AV and CC-10M filters. Photographs were taken of Lynnhaven Bay at an altitude of 944.88 meters (3,100 feet) by The Wallops Island Station of the National Aeronautics and Space Administration. Large scale images were used because of the bay's irregular shape and small wetland areas. These photographs were examined in order to determine representative areas of wetlands and developed versus undeveloped shoreline in Lynnhaven Bay. Representative sites of salt marsh were rephotographed in more detail in order to locate the six major study sites. The second and third photographic missions were personally conducted from an altitude of 914.40 meters (3,000 feet). Photographs were taken with Ektachrome Infrared IE 135:20 film with a Wratten No. 12 filter (Kodak, 1971). A summary of the remote sensing parameters is shown in Table 1.

Field studies were conducted in the three controlled sites to correlate the photograph's color and texture pattern with the vegetation. Three experimental sites having the same wetland types as the control areas were examined on the imagery. After the experimental locations had been studied through photography, ground examinations were performed to verify the interpretations and the degree of accuracy.

Ground examinations were conducted in these six sites using one-meter belt transects and spot sampling. Belt transects were run through areas showing the greatest diversity of color patterns on the photographs. The number of transects used at each site was determined by the extent of variation (color pattern, tone, and texture) revealed in the imagery. Spot sampling was performed in each of the six major study sites outside of the transects in order to confirm the remaining portion of the site's vegetation. In each transect, species composition, zone limits, and height were measured.

Figure 3. A color infrared aerial photograph of Lynnhaven Bay. The scale is 1:65,000. 1 Nov. 1973.

(Original in color)



* indicates one of the six major study sites

Scale

1 inch = 0.71 miles (1.1km.)

Figure 4. Lynnhaven Bay study area showing the three sections the bay was divided into and the location of ground truth verification sites.

I. Sensor complement

Flight	Sensor number	Type	Film	Format	Focal length	Filter	Date
1	1	T-11	MS-2448	9"X9"	152 mm.	Color correction	5/18/73
1	2	T-11	IR-2443	9"X9"	152 mm.	Color correction Wratten No. 12	5/18/73
2	1	C-ST	IE-135:20	1.5"X1.0"	200 mm.	Wratten No. 12	10/5/73
3	1	C-ST	IE-135:20	1.5"X1.0"	200 mm.	Wratten No. 12	10/5/73

II. Data identification

Flight	Plane	Altitude (meters)	Time (EDST)	Frames	Weather	Tide (high)	Date
1	C-54	944.88	9:52-10:36 am.	197	cloudy	9:36 am.	5/18/73
2	C-150	914.40	2:01-2:28 pm.	20	haze	3:23 pm.	10/5/73
3	C-150	914.40	1:36-2:33 pm.	40	sunny	10:52 pm.	10/15/73

Table 1. A comparison of remote sensing parameters utilized in this study.

Density was estimated by taking a stem count along a quarter meter in the outside, middle and inside sections of each zone along the transect line. All three sample points were in reference to uplands being on the inside. General visual observations of surface conditions including apparent elevation changes were also made.

All botanical classification was conducted using one reference. This key was Gray's Manual of Botany.

The degree of accuracy of the photographic interpretation was determined by first measuring the total area of a given site, using a gird overlay on a scale drawing. Then the misinterpreted area was subtracted from the total area and the difference expressed as a percentage. Misinterpretations occur because of faulty deciphering or the inability to decipher certain areas of the photographs.

The six major sites were divided into three saline marsh types according to Shaw et al. (1971). Sites 1 and 14 were selected because they represented coastal salt meadow. Shaw defined this type as waterlogged during the growing season, but not covered with tidewater. Vegetation included salt meadow cordgrass, saltgrass, blackrush and in fresher parts salt marsh fleabanes. Sites 3 and 13 formed regular flooded salt marsh. This type was interpreted by Shaw as covered with water during high tide in the growing season. Plant species was mainly salt marsh cordgrass. The third pair, sites 5 and 8, were island environments forming coastal salt flats. Shaw defined this type as waterlogged during the growing season and covered regularly with a few inches of water at high tide. Vegetation consisted of saltflat grass and saltwort. The types of saline wetlands defined by Shaw tended to overlap each other and some vegetation was excluded. The author modified Shaw's classification by including these omitted plant species in the three types of wetlands found in Lynnhaven Bay.

Lynnhaven Bay was then separated into three sections to simplify data organization for comparison of developed areas within each section. The three sections consisted of Eastern Branch, Main Bay and Western Branch. Figure 4 shows the three sections of the bay and the ground sites involved.

The Eastern Branch had as its northern boundary a line drawn from Poorhouse Cove to the northern tip of Forest Hills. This section continued south to Virginia Beach Boulevard, at London Bridge, as the southern boundary. The Western Branch's northern boundary was a line from Hill Point to the point just above Bayville Circle. This section extended south to Virginia Beach Boulevard, at Thalia Bridge, the southern boundary. The Main Bay had as its southern boundary the two northern boundaries of the Eastern and Western Branches. The northern boundary of the Main Bay was its intersection with Shore Drive, at Lesner Bridge, while its eastern boundary was a line extending from Virginia Beach City Marina to Inlet Road.

The shoreline was divided into two main types, developed and undeveloped; the former was further differentiated into bulkheaded, cleared and residential subtypes. Bulkheaded areas were those which had man-made barriers parallel to the shoreline at high tide to prevent erosion. This zone included marinas and residential shore front property. Residential zones were defined as those areas having houses on waterfront property within 200 meters of the shoreline. The third subtype, consisted of cleared zones; areas lacking vegetation and often having exposed soil. This included exposed zones down to the shoreline where a home, business or bridge construction had been conducted. The second type, undeveloped areas, was divided into two subtypes; fringe marsh and meadow marsh. Fringe marsh included wetland vegetation that was found along the shoreline with wooded or lake boundaries behind. The wetland did not extend back from the shoreline more than 60 meters. Meadow marsh was defined as areas found on points, in coves and along exposed shoreline with an area exceeding 60 meters from the shoreline to the uplands.

Islands that were found in Lynnhaven Bay were not included as shoreline but put into a separate category. They were measured in the same manner for comparison but separated because most of the shoreline of the islands was submerged during high tide and thus not true shoreline.

The length of Lynnhaven's shoreline was determined by tracing the water-land or water-marsh interface on the 9 inch by 9 inch transparencies just after peak high tide. Uneven shoreline was traced with a Dietzgen Plan Measure Model No. 1718. The two units of measurement were centimeters and inches. Smaller units, millimeters and fractions of an inch, were also estimated on the plan measure instrument. This measurement only gave a linear distance of the total shoreline, with area not included. The shoreline was measured twice, once in centimeters and then in inches. The data from both attempts were combined and average of the two figures was obtained.

Actual ground distances were reduced on the photographs to scale. Altitude and focal length of the camera were the two critical factors involved with the scale. The same focal length was used throughout the flight leaving only the altitude in question. A change in altitude would have probably occurred when the plane turned for its next pass. This was the reason that positive scale was determined by measuring roadway widths at the beginning and end of the eight flight paths in the NASA imagery. A fifty-meter change at this low altitude would have made a considerable difference in the scale distance.

Roadways were measured between the two white lines, on either side of the road, representing the width. The roadway distances on the photographs varied only one-tenth millimeter or less and thus indicated that altitude did not vary significantly. With the roadway differences in mind, an error factor was determined at one-tenth of a millimeter or 0.625 meters on the scale used.

The map scale was derived from mean ground to aerial photography ratios of roadways. The scale was one millimeter to 6.25 meters.

Field surveys in the form of spot observations were conducted at the remaining eight scattered sites around the bay to verify the different types and subtypes. Figure 4 shows the location of each of these sites. Ground truth data for dominant marsh vegetation and ground references for scale determination were collected. Table 2 shows the dominant saline marsh plant species in each type of marsh. Marsh plants that dominated were determined by observations of species that formed easily recognizable zones in the different wetland types.

I. Fringe Marsh (Regular flooded salt marsh)

<u>Spartina alterniflora</u>

<u>Juncus roemerianus</u>

* <u>Iva frutescens</u>

* <u>Baccharis halimifolia</u>

II. Meadow Marsh (Coastal salt meadow)

<u>Spartina alterniflora</u>

<u>Spartina patens</u>

<u>Distichlis spicata</u>

* <u>Spartina cynosuroides</u>

<u>Juncus roemerianus</u>

* <u>Phragmites communis</u>

* <u>Iva frutescens</u>

* <u>Baccharis halimifolia</u>

III. Island Marsh (Coastal salt flats)

<u>Spartina alterniflora</u>

* <u>Juncus roemerianus</u>

* species not found in Shaw's classification of saline wetlands.

Table 2. Dominant plant species found growing in the three wetland types. Revised from Shaw <u>et al.</u> (1971) wetlands classification.

RESULTS AND DISCUSSION

Salt Marshes

Salt marsh plants of Lynnhaven Bay were found to exhibit a typical salt marsh zonation pattern found in Virginia wetlands (Marcellus, 1972). A typical marsh is divided into four major zones. Spartina alterniflora occupies zone one, having a tall form at the water's edge and a shorter form inland on the lower marsh. This is the dominant grass of the United States eastern coastal saline wetlands. A second zone is dominated by Juncus roemerianus. This species is usually found behind Spartina alterniflora and has a single rounded stem with no leaves. A third zone, found at higher elevations, is dominated by Spartina patens and Distichlis spicata (Adams, 1963). These short, thin stemmed halophytes form dense mats and are inundated only during storm tides. Other scattered marsh plants, Salicornia sp. and Pluchea camphorata also occupy this zone (Wass and Wright, 1969). Finally, zone four, the upper marsh, is dominated by two salt bush species. These plants, Iva frutescens and Baccharis halimifolia are both low shrubs and sometimes found in zone three. Their furthest landward extent usually separates the marshland from higher ground. One further species, Phragmites communis grows in a variety of habitats and is sometimes found in patches on mounds of the upper marsh. Figure 5 shows a typical Virginia salt marsh zonation pattern in detail.

Major Sites Ground Studies

Extensive ground truth studies were conducted in the three controlled sites to familiarize the interpreter with certain zonation patterns, textural signatures and color tones transmitted by each species existing there. Without the use of ground studies little aerial interpretation could have been accurately accomplished.

An inverse relationship between height and density became apparent from the ground studies. When height increased, a decrease in density occurred. This was readily seen in the three sizes of Spartina alterniflora. A summary of height versus density for Spartina alterniflora can be found in Table 3.

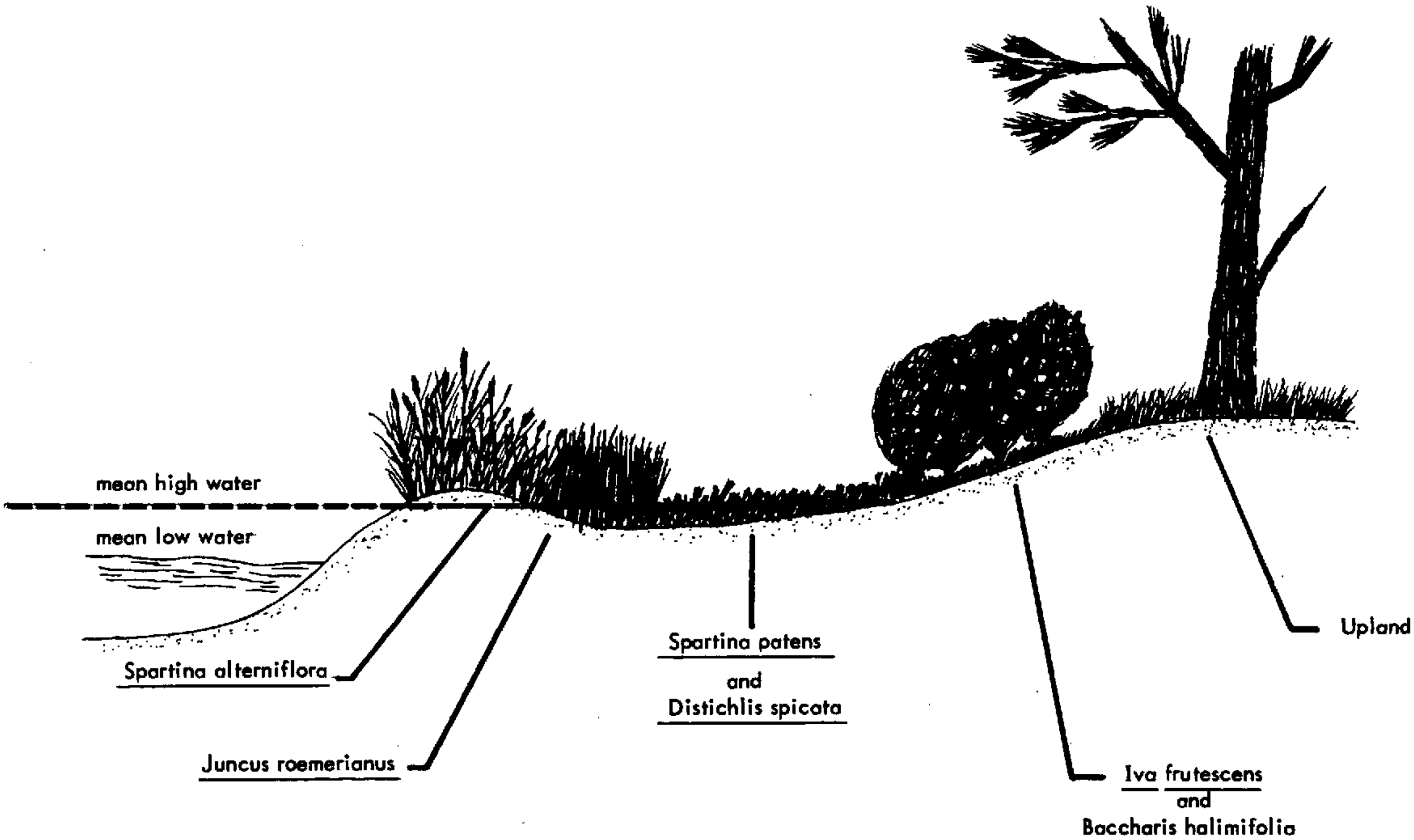


Figure 5. Zones of a typical salt marsh in Virginia (revised from Marcellus, 1972).

Species		Height (cm.)	Density (¼ meter stem count)
-Major-			
Spartina alterniflora	short	50-99	12-20
	medium	100-149	6-15
	tall	150-199	4-8
Spartina patens and Distichlis spicata		50-87	45-87
Juncus roemerianus		110-180	7-30
Iva frutescens and Baccharis halimifolia		180-250	1-3
-Minor-			
Phragmites communis		280	--- *
Spartina cynosuroides		180	--- *
Salicornia bigelovii		30	--- *
Borrichia frutescens		30	--- *
Aster tenuifolius		50	--- *
Pluchea camphorata		70	--- *

* only taken for major species types.

Table 3. Major species heights and densities measured in the study area.

Key Characters

Certain characters were found to be helpful in the identification of the three wetland habitats on color infrared photography. The zonation patterns established from ground truth studies were useful in providing the interpreter with an idea of what species should and should not have been present in similar habitats. Texture patterns also helped in determining species composition (Whitman, 1973). Marsh grasses and some rushes have a fairly smooth texture pattern. A few species, mainly shrubs, gave a coarse texture pattern seen as clumps. The color tone varied among halophytes and usually was the key to species identification, but errors did result when color tone was used alone for identification (Penny *et al.*, 1973). All three characters are important for proper species and distribution determination.

Plant Signatures in October

Most of the wetlands interpretation was conducted in October with Ektachrome Infrared IE 135:20 film. However, Thompson *et al.* (1973) found that during a seasonal study of coastal wetlands, July and August appeared to have the brightest color tones and greatest textural differences. October had duller color tones and less distinct textural differences. The land-water interface was easily separated even in imagery of the salt marsh, as previous workers had found (Anderson, 1968). *Spartina alterniflora* seemed to be associated with three color patterns mainly in sites 5 and 8 of the coastal salt flat type. The color patterns appeared to be correlated with height difference. Tall *Spartina alterniflora*, greater than 150 cm., varied from pink to gray on the photographs; medium *Spartina alterniflora*, between 100 and 150 cm., appeared blue to deep green and short Spartina alterniflora, below 100 cm., was a medium blue. The deep green color reflected by medium *Spartina alterniflora* could have been partly due to epiphitic algae growing on the stems and leaves. Short *Spartina alterniflora's* blue color was caused by the low density and the wet soil background. *Juncus roemerianus* was present in all sites with color varying from deep green to deep brown. This species was always easily distinguished from other halophytes by its unusual stem pattern. *Spartina cynosuroides* occurred only in sites 1 and 14 with a medium green color that was impossible to distinguish from medium height Spartina alterniflora. This could have been caused by both species' heights and leaf patterns being similar. The Spartina cynosuroide zone was only a few meters wide and always adjacent to the Spartina alterniflora zone. Spartina patens and Distichlis spicata were impossible to separate in the photographs and thus lumped together. Their reflectance was white to light blue and had a scattered color pattern, probably due to the similar habitat the two species occupied (Klemas, et al., 1973). The only site where Spartina patens and Distichlis spicata could not be distinguished was site 14. This probably was due to the high azimuth angle distorting the ground cover reflectance. The salt bushes of the upper marsh, Iva frutescens and Baccharis halimifolia, were present in all sites. They could not be seen in the aerial photograph of sites 3 and 13 due to the surrounding trees blocking their reflectance. The color pattern for Iva frutescens was green to dark green, while that of Baccharis halimifolia was white, due to its blooming state (Garvin and Wheeler, 1973). This was verified by ground studies and color tones reflected in the color infrared photography conducted in May and October for the two species. Table 4 shows the color difference due to Baccharis halimifolia blooming stage. Both plants are shrubs and could be easily separated from other species by their texture pattern, which appeared clump-like, quite distinct from the grass texture signature. Another high marsh species, Phragmites communis, was found on the image with a pinkish-red color tone. This plant could not be distinguished in most of site 14 because the trees behind Phragmites interfered with its reflectance.

Identification of species composition in the three experimental sites had a high degree of accuracy when interpretation of aerial photographs was compared with ground truth studies. Table 5 shows the area measurements and percent accuracy in the control and experimental sites. Two plant species Spartina cynosuroides and Phragmites communis could not be delineated due to similar species found with Spartina cynosuroides and trees blocking Phragmities reflectance. This reduced the accuracy in site 14 to 89 percent. Site 13 had Spartina patens and Distichlis spicata with a white color tone not seen in the other sites. These plants could not be identified properly and resulted in a 95 percent accuracy. Species composition in site 8 was easier to interpret because Spartina alterniflora was the dominant species.

Plant Species	I. Aerochrome Infrared: Type 2443 (taken in May '73)	II. Ektachrome Infrared: Type 135:20 (taken in Oct. '73)
Spartina alterniflora	red-blue	pinkish-blue-green
Spartina patens and *Distichlis spicata*	bright red	white-light blue
Juncus roemerianus	brown	deep green-deep brown
Iva frutescens	bright red	green-dark green
Baccharis halimifolia	bright red	white (bloom)

Table 4 . Major plant species color tones found on the two types of infrared film used.

I. Controlled sites	Site number	Area (sq. meter)
London Bridge	1	11,687
Trants Point Cove	3	34,800
Pleasure House Island	8	47,580

II. Experimental sites	Site number	Area (sq. meter)	Percent accuracy of species identification
Thalia Bridge	14	10,584	89
Buchanan Creek Mouth	13	1,000	95
Humes Island	5	62,436	96

Table 5. Parameters of controlled and experimental sites.

Problems arising from interpreting the upper marsh species resulted in accuracy of 96 percent. The summary of data concerning Site 1 can be found in table 6.

All three tested sites had a high overall accuracy proving that aerial photography can be a good tool for delineating species composition and zonation patterns in salt marsh plant communities.

Reflectance of Vegetation

When color infrared photography was used, image tones varied with species type. Gates (1964) and Penny et al. (1973) suggested that changes in color tones were related to elevation, species height and leaf pattern. Spartina alterniflora revealed three color tones that seemed to be related to relative height. Leaf patterns altered with species type, evident in the photograph of Juncus roemerianus patch surrounded by Spartina alterniflora. Both plants had identical heights, but Juncus roemerianus color tone was deep brown, while Spartina alterniflora reflected a deep green.

The color infrared photograph of Site I, when compared to the vegetation map of Site I, shows many observable patterns. Spartina alterniflora forms the easily seen outer zone of Site I. Two color tones are visible in this zone; pinkish and green. These two colors represent two of the height classes of Spartina alterniflora. Landward, a white to light blue zone representing the Spartina patens and Distichlis spicata association occurs. Within this zone occurs scattered patches of Spartina alterniflora, Iva frutescens, Juncus roemarianus, and Plucha campherata. These other minor species color tones add to the reflectance of this zone and modify the color tones seen. Small scattered dark green Juncus patches occur in the upper left hand corner of this second zone. Ground studies revealed the Juncus was growing around pools of open water. The water which appears black, enhances the color tones, making this area quite distinct. A third zone can be discerned bordering the apartment complex in the upper left hand comer. This zone is dominated by Iva frutescens and Baccharis halimifolia. These salt marsh bushes appear clumped and color tones vary from dark green for Iva frutescens to white for Baccharis halimifolia. The top of the photograph, between the apartment buildings, a bright pinkish-red patch of Phragmites communis is visible. This species is sometimes found in the upper marsh and is often associated with disturbance.

A. Site: (1) London Bridge [control]
B. Area: 11,687 sq. meters
C. Date: 10/15/73
D. Transect Number: 3
E. Direction of Transect: (1,2,3), N.E. [330°]
F. Tide: Ebb 3:06 pm.
G. Time: 1:40 pm.

TRANSECT NO.1

Zone	Species (* dominant species)	Surface Conditions	Zone Distance (meters)	Dominant Species height(cm.) Out	Middle	In	density (¼ meter) Out	Middle	In
1	* Spartina alterniflora (med.) Spartina cynosuroides	Plant stems in water	4	130	120	140	8	10	6
2	* Spartina patens and Distichlis spicata S. alterniflora Pluchea campherata Iva frutescens Solidago sempervirens	Stems above water	75	+70	60	45	40	60	45
3	* I. frutescens Baccharis halimifolia	Highest elevation of transect	3	-	210	-	-	2	-

* dominance was determined by species with the largest number of plants in a particular zone.
\+ not taken for S. patens because of high stem count (too time consuming).

Table 6. Ground truth data collected at site 1.

Table 6 continued:

Zone	Species (* dominant species)	Surface Conditions	Zone Distance (meters)	Dominant Species height (cm.) O	M	I	density (¼ meter) O	M	I
4	*S. patens and D. spicata S. alterniflora	Wind blown in cowlicks	11	+-	-	-	-	-	-
5	* I. frutescens B. halimifolia	Stems in water	4	-	220	-	-	5	-

TRANSECT NO.2

Zone	Species (* dominant species)	Surface Conditions	Zone Distance (meters)	Dominant Species height (cm.) O	M	I	density (¼ meter) O	M	I
1	* Spartina alterniflora (tall & med.)	Stems in water	10	170	-	220	15	-	8
2	* Spartina patens and Distichlis spicata S. alterniflora Pluchea camphorata	Scattered Pluchea	20	60	-	60	80	-	80
3	* S. alterniflora (med.) S. patens and D. spicata P. camphorata	Found at border of pools	20	140	–	80	6	–	7
4	* S. patens and D. spicata S. alterniflora	Wind blown in cowlicks	22	65	–	40	-	-	-
5	* Juncus roemerianus S. alterniflora Iva frutescens	Open water	4	- -	150 140	- -	- -	30 6	- -
6	* S. patens and D. spicata	Wind blown in cowlicks	4	-	50	-	–	-	-

Table 6 continued:

Zone	Species (* dominant species)	Surface Conditions	Zone Distance (meters)	Dominant Species height (cm.) O	M	I	density (¼ meter) O	M	I
7	* S. alterniflora	Open water	12	–	160	–	–	5	–
	J. roemerianus			–	150	–	–	30	–
8	* S. patens and D. spicata	Stems below water	13	–	60	–			
	S. alterniflora			–	80	–			
	P. camphorata			–	70	–			
9	* I. frutescens	Stems in water	1	–	150	–	–	2	–
	Baccharis halimifolia								
	TRANSECT NO.3								
1	* Spartina alterniflora (tall, med.) short	Mixed stand	6	–	140	–	–	9	–
	Spartina patens and								
	Distichlis spicata								
	Scirpus robustus								
2	* S. patens and D. spicata	Wind blown	33	50	–	60	–	–	–
3	* S. alterniflora (med.)	Left of transect	14	120	–	140	6	–	5
	S. patens and D. spicata	Juncus stand							

H. Spot Sampling: Phragmites communis

In Sites 3 and 14 Iva frutescens was always associated with the upper marsh transition zone. On the coastal salt flats (Sites 5 and 10), the three height categories of Spartina alterniflora were found to be associated with three different color tones. The upper marsh species, occupying the island environment, were not unindated during high tide. On Site 13, a small zone of Spartina patens and Distichlis spictata was associated with coastal salt meadow instead of regular flooded salt marsh. The rest of Site 13, however, seemed to correspond to the regular flooded salt marsh vegetation types described in the literature. Coastal salt meadow (Site 14) contained plant species not occurring in Site 1. Spartina cynosuroides was associated with Spartina alterniflora and a common fresh water species, Typha latifolia, was found in the upper extent of this site. Phragmites communis was also found in the upper marsh region in half of the site. This part of the site had been disturbed during the construction of a waste treatment plant. Figures 6-12 compare an infrared aerial photograph with actual ground mapping.

Problems with Sensing Type

Aerial infrared photography, like other sensing techniques, has certain limitations. With this technique, agricultural crops reflect a high percent of solar radiation while narrow leaf emergence marsh plants reflect a low percent of solar radiation (Anderson, 1970). This low reflectance usually has the advantage of easily discriminating saline wetlands but has the liability of the luminescence being greatly reduced which can make the interpretation of species composition difficult. One major complication with infrared photography is the change in color hue within a particular salt marsh species. Hue inconsistencies will result from aerial platform angle variations in relation to sun angle and ground plane (Steiner and Holfner, 1965 and Suits, 1972). Some of the viewing geometry involved with the use of remote sensing can be seen on Figure 13. When the author compared photographs of a particular site, the photograph that was taken in a more perpendicular position resulted in less distortion in actual ground distances. Best color tone differences between marsh species was found when the aircraft was heading directly away from the sun and maintaining a parallel position in relation to the ground site.

Figure 6. Color infrared aerial photograph of Site 1.
The scale is 1:1 140. 15 Oct. 1973.

(Original in color)

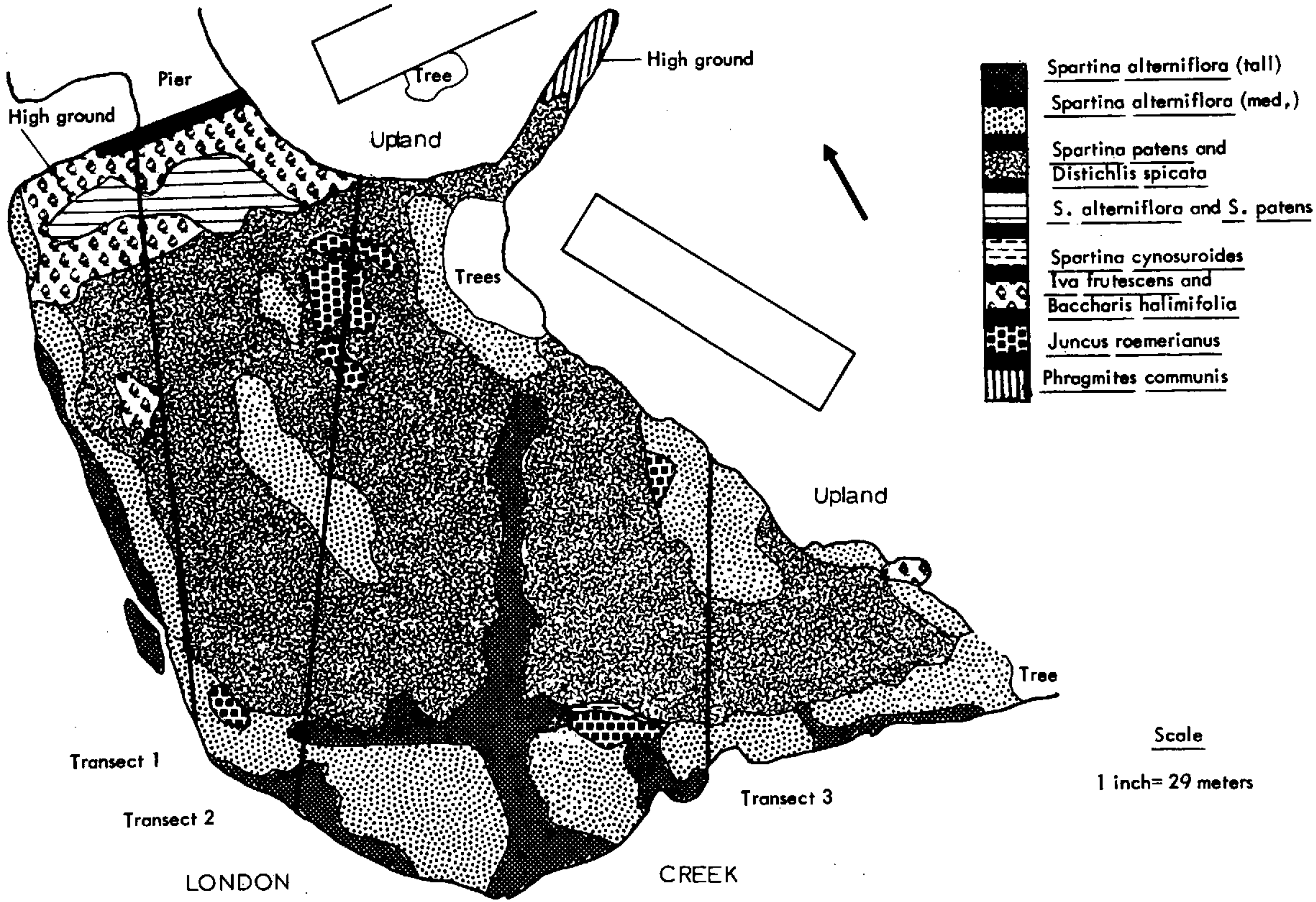


Figure 7. Species composition and zonation patterns of Site 1.

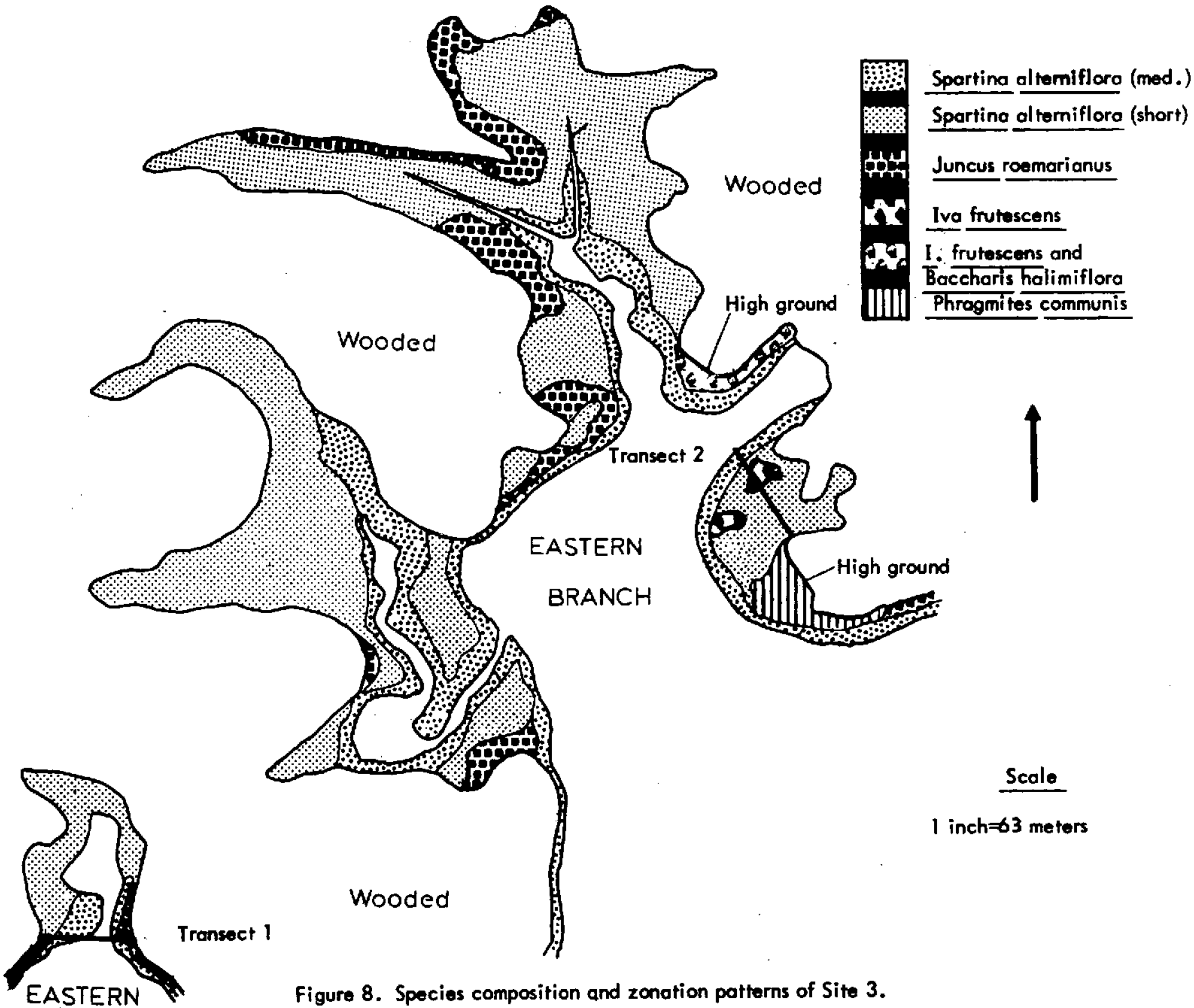


Figure 8. Species composition and zonation patterns of Site 3.

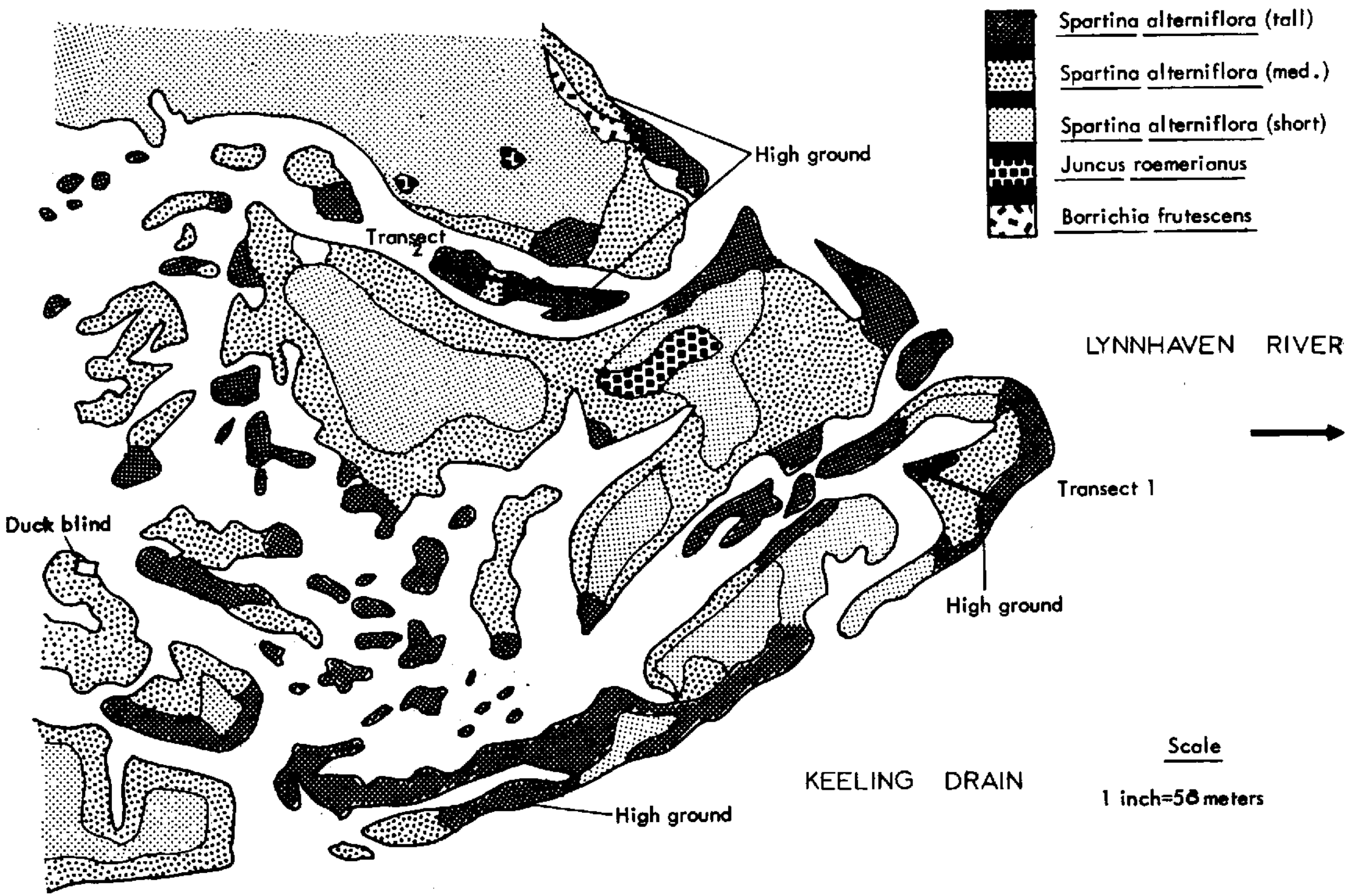


Figure 9. Species composition and zonation patterns of Site 5.

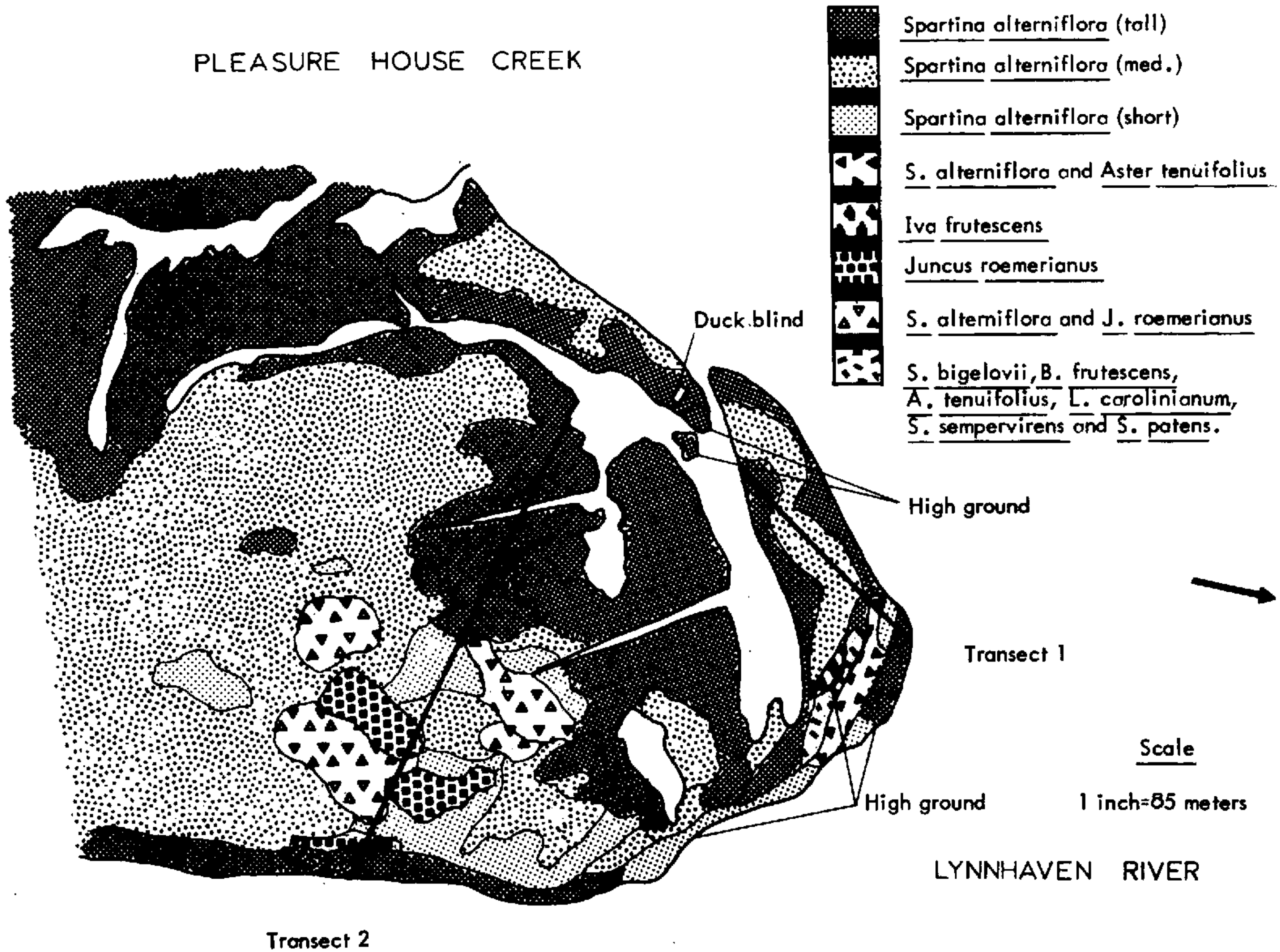


Figure 10. Species composition and zonation patterns of Site 8.

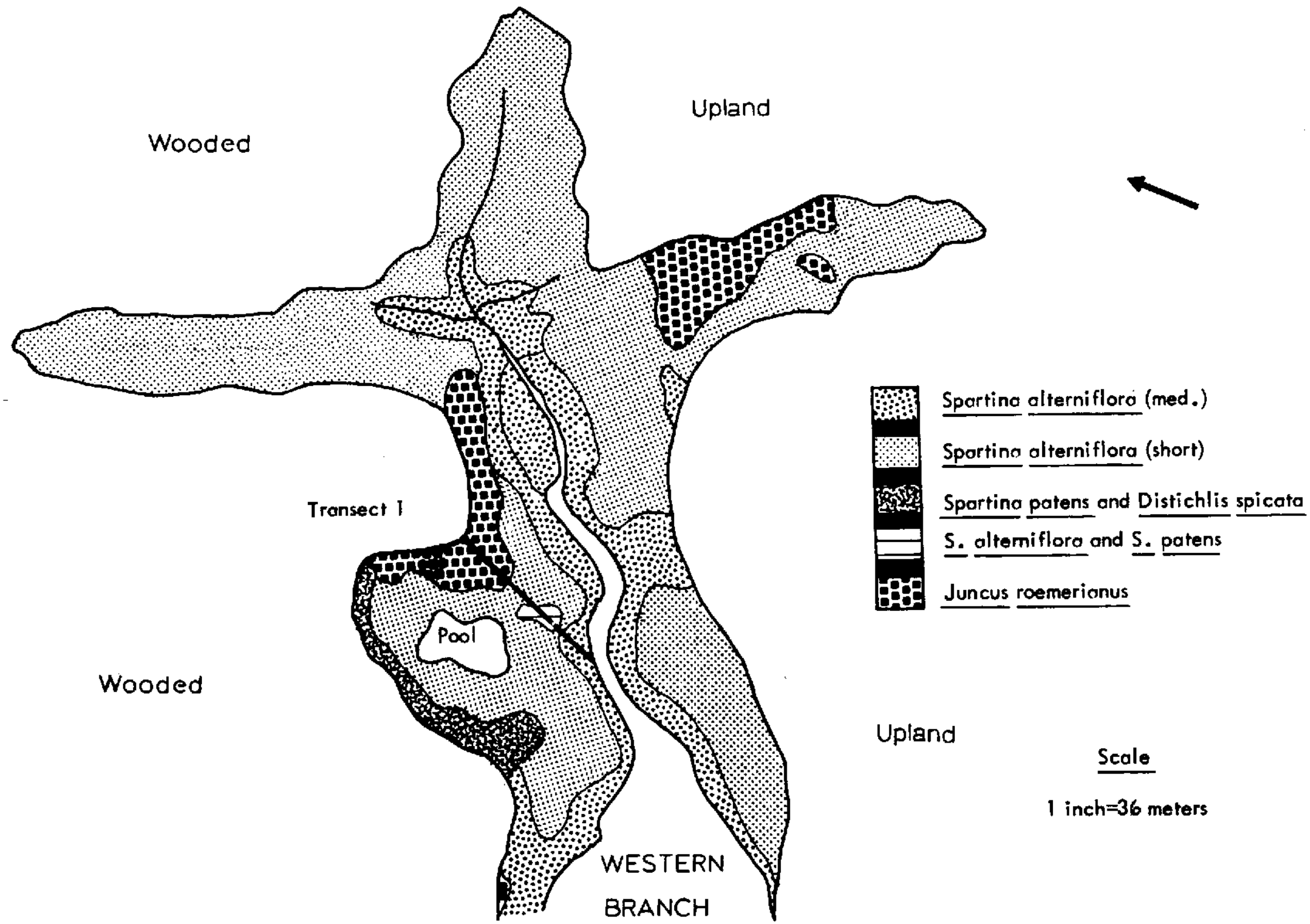


Figure 11. Species composition and zonation patterns of Site 13.

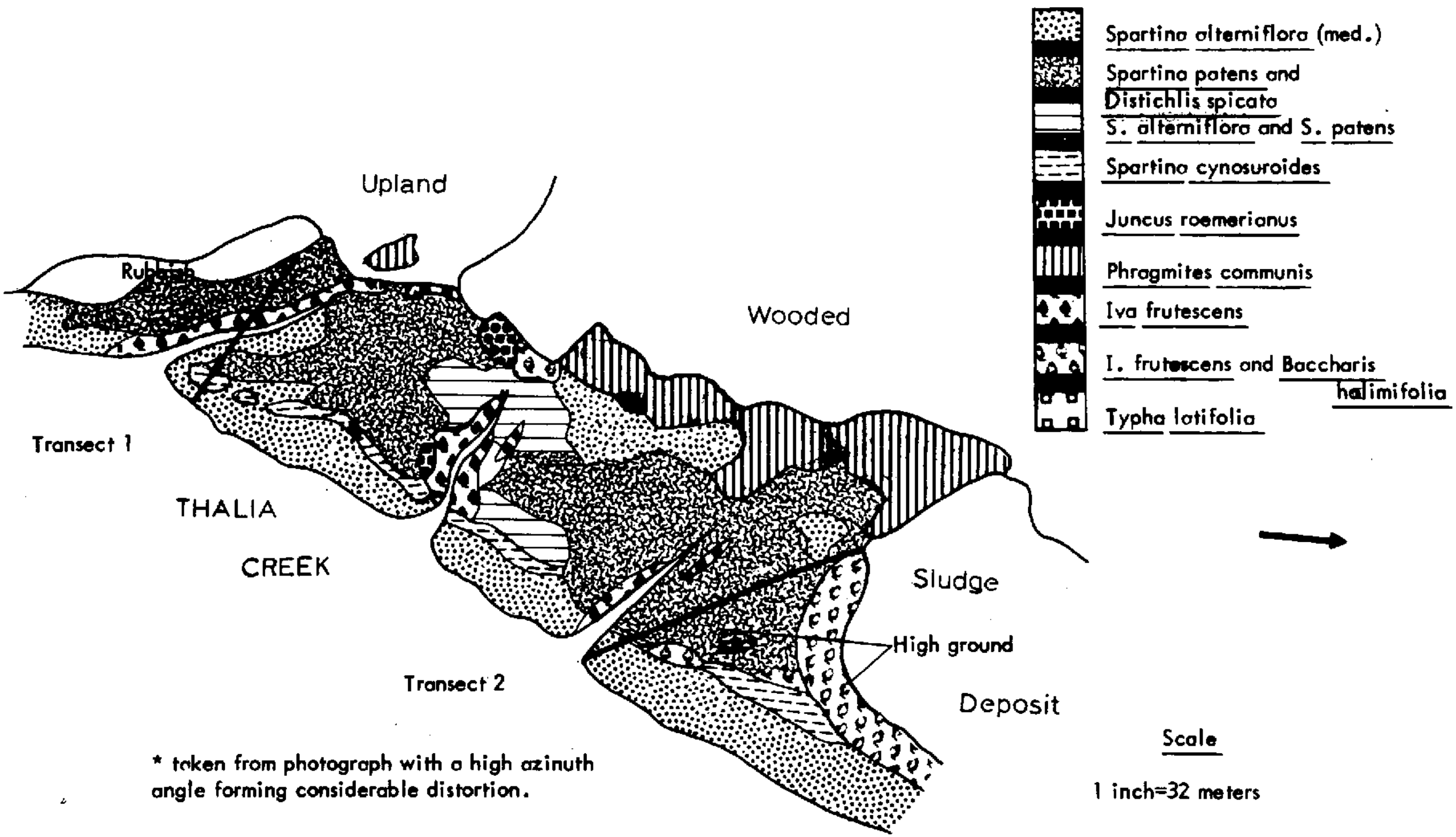


Figure 12. Species composition and zonation patterns of Site 14.

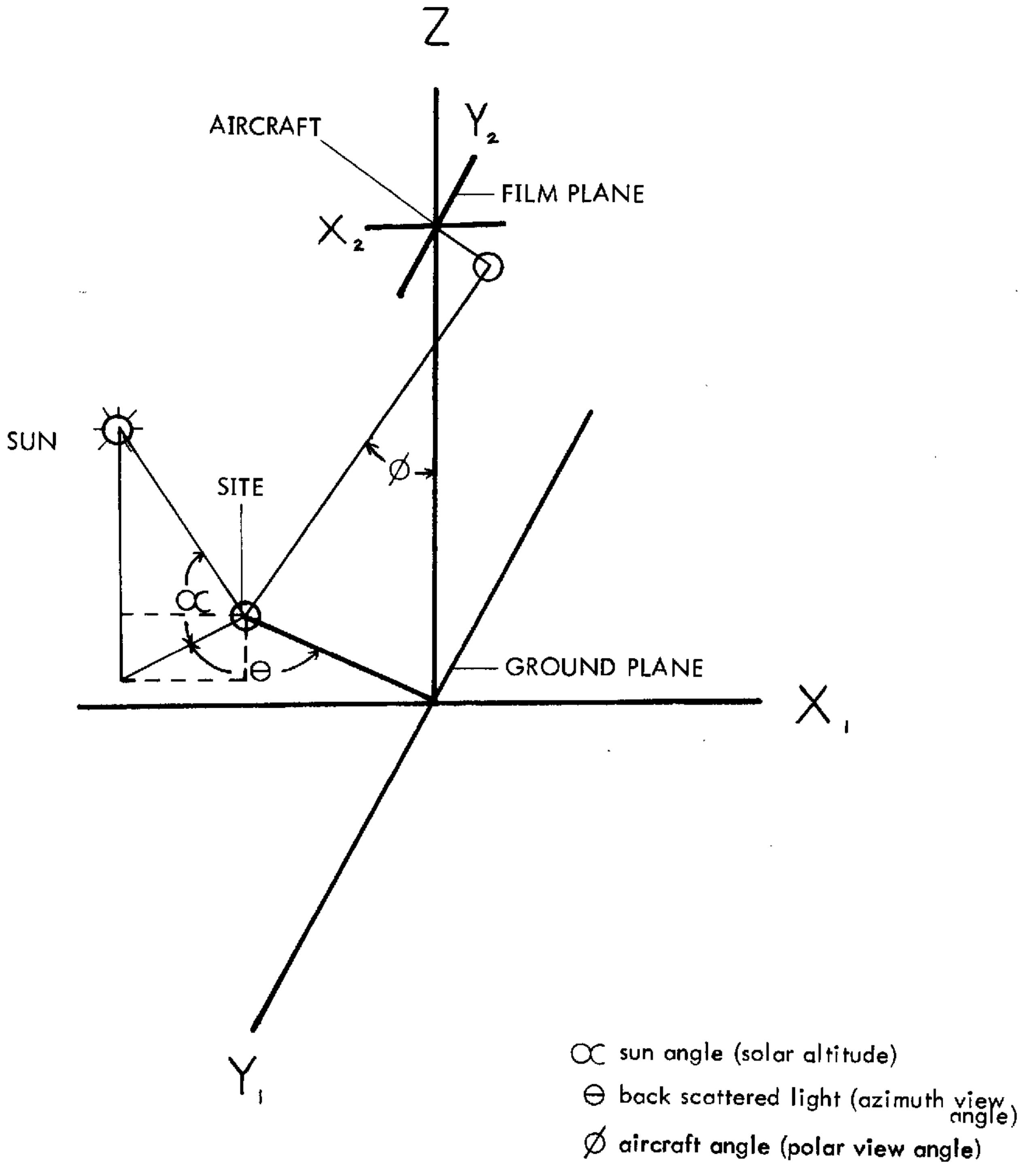


Figure 13. The viewing geometry involved with aerial photography (revised from Steiner and Haefner, 1965).

Howard (1970) states that color tone changes will occur with changing atmospheric conditions, film-filter combinations, lens quality and processing methods. These factors combine to form complex patterns difficult to interpret. The more physical conditions that can be duplicated from one flight to another, the easier it is to interpret the spectral signatures returned from the vegetation.

Total Ground Studies

The fourteen sites of ground truth surveying revealed that most of the shoreline marsh of Lynnhaven Bay was regular flooded salt marsh, as expanded from Shaw's classification. This usually consisted to two dominant zones, one of Spartina alterniflora and the other Juncus roemerianus, Iva frutescens and Baccharis halimifolia also formed a scattered zone behind Juncus roemerianus but they were never mentioned in Shaw's classification for any saline wetland. These salt bushes were not always seen on the imagery due to the upland trees blocking their appearance. The second category of coastal salt meadows was mostly found in the main branches and coves around the bay. Four dominant plant zones consisted of Spartina alterniflora, Juncus roemerianus, Spartina patens mixed with Distichlis spicata and Iva frutescens with scattered Baccharis halimiflora. Small zones of Spartina cynosuroides and Phragmites communis, not seen in Shaw's classification, were occasionally found in the upper reaches of the marsh. Wetland plant species found in Lynnhaven Bay are listed in Table 7.

Photography of Developed Versus Undeveloped Areas

Both color and color infrared aerial photographs were taken of the bay by NASA on May 18, 1973. Infrared photography was found to be superior for interpreting the five categories of shoreline. The sharp contrast between the land and water made the shoreline easy to define. This was due to water absorbing most infrared radiation and appearing dark blue to black while land had varying high degrees of reflectance (Anderson, 1968). Figure 14 shows the difference between color and infrared photography. Most saline wetland types had less reflectance than from the higher reflectances of upland vegetation. The two types could be separated by the extent

I. Major

Spartina alterniflora - smooth cordgrass

Spartina patens - salt meadow grass

Distichlis spicata - spike grass

Juncus roemerianus - black needlerush

Iva frutescens - marsh elder

Baccharis halimifolia - groundsel tree

II. Minor

Phragmites communis - marsh reed

Spartina cynosuroides - big cordgrass

Salicornia bigelovii - glasswort

Borrichia frutescens - sea ox-eye

Limonium carolinianum - sea lavender

Aster tenuifolius - aster

Solidago sempervirens - golden rod

Typha latifolia - common cattail

Pluchea camphorata - marsh fleabane

Scirpus robustus - big bulrush

Scirpus americanus - small bulrush

Sabatia stellaris - sea-pink

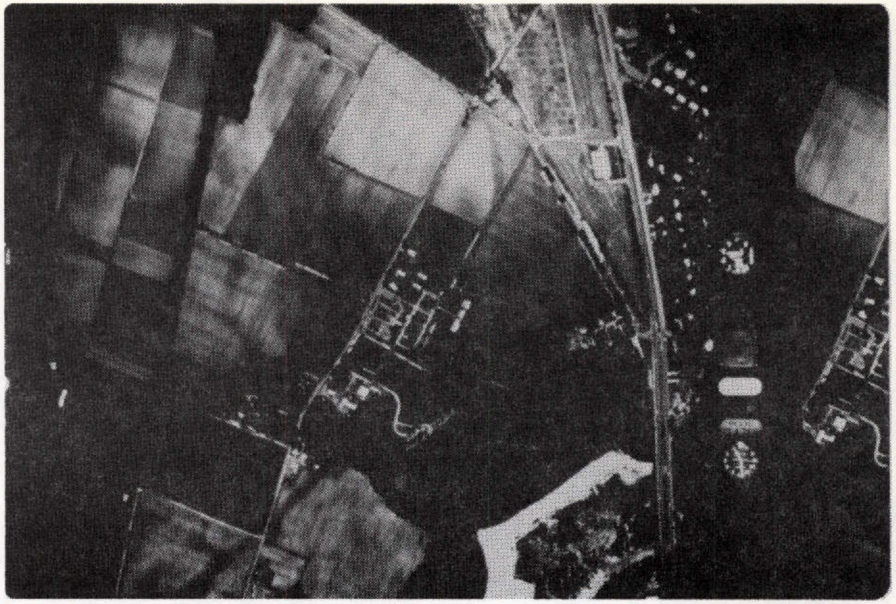
Hibiscus militaris - rose-mallow

Phytolacca americana - pokeweed

Asparagus officinalis - asparagus

Table 7. Species list of dominant and minor marsh plants found in the ground truth varification sites.

Color



Color Infrared

Figure 14. Comparing color with color infrared photograph of a portion of Lynnhaven Bay. The scale is 1:3,100. 18 May 1973. Some subdivisions can be seen on the photograph such as: A. fringe marsh B. residental and C. cleared areas. (Original in color)

of plant growth perpendicular to the shoreline. Different colors on the photographs were usually indicators of separate species type (Gallagher, 1972) and also used to subdivide the two types of wetlands. The color differences can be seen on Figure 15 which shows color infrared photographs of the three wetland types. Developed areas also could be sepatated on the photographs. Residential zones were usually determined by partially cleared wooded areas with houses evident between trees. Bulkhead zones, in most cases, were found within the residential zones. They were observed as thin lines running parallel with the shoreline. The marinas were the only other location where bulkhead zones were situated. Cleared zones were the easiest of all to locate. They usually were composed of sand, having a high reflectance, and appeared white on the photographs.

Islands were also included in the aerial survey. This type of wetland is defined by Shaw *et al.* (1971) as coastal salt flats. Islands color hues and luminescence compared closely with the two wetland types found along the shoreline. The dominant plant species was *Spartina alterniflora* with scattered clumps of *Juncus roemerianus* occasionally present but not found in Shaw's classification.

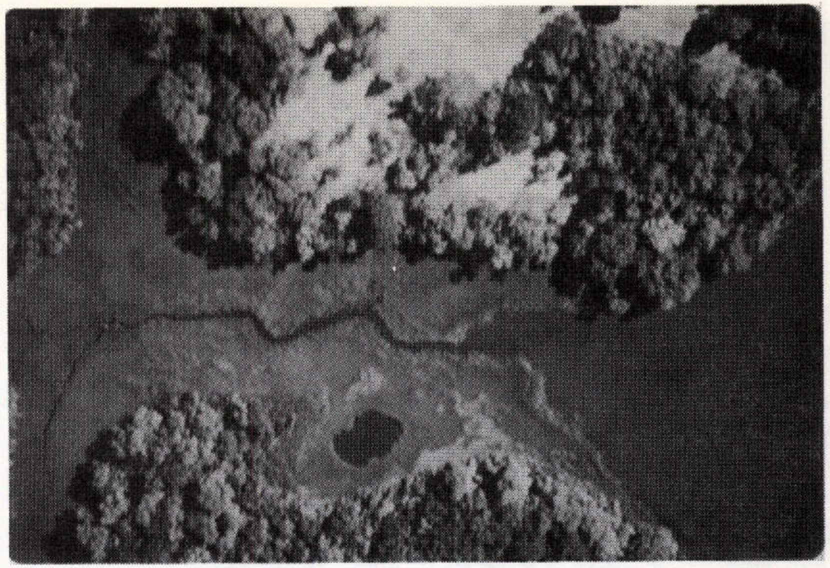
Plant Signatures in May

Dominant plants in the wetlands produced different color tones on the aerial photographs in relation to their species. Table 4 lists the species with their color tones for the two types of infrared film. *Spartina alterniflora* appeared red to blue on the infrared film. *Spartina patens* and *Distichlis spicata* grow together, and their color was viewed a bright red. A brown color was characteristic of *Juncus roemerianus*. *Iva frutescens* and *Baccharis halimifolia*, salt marsh shrubs, both appeared with a bright red color. Two distinct scattered zones of *Spartina cynosuroides* and *Phragmites communis* were characterized by a red color while the color of Phragmites communis approached pink. May was too early in the growing season for good species identification (Thompson, *et al.*, 1973).

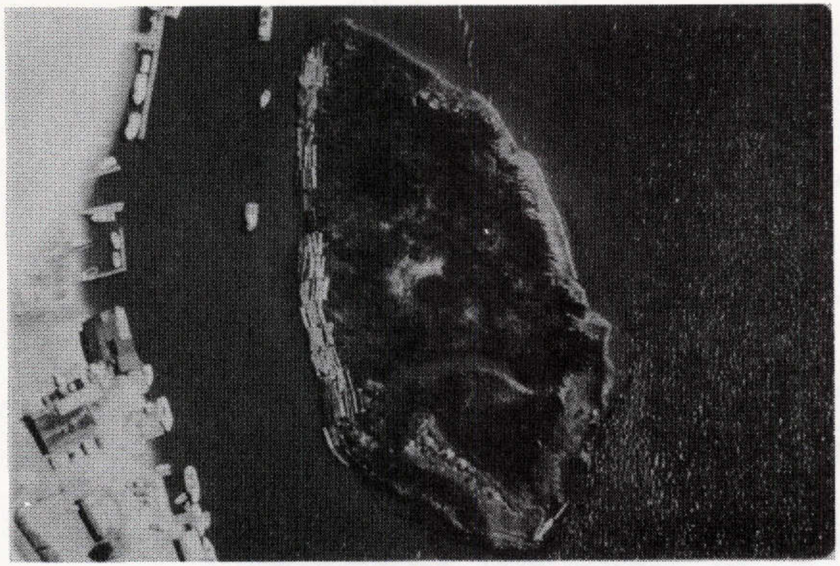
Shoreline Categories

The Main Bay with a shoreline distance of 44.2 kilometers had the shortest shoreline of the three divisions of Lynnhaven Bay. Developed subtypes were bulkheads 3.5 kilometers (8 percent), residential 20.0 kilometers (45.1 percent) and cleared

Coastal salt meadow
as seen in Site 1.



Regular flooded salt marsh
as seen in Site 13.



Coastal salt flat
as seen in Site 7.

Figure 15. The three types of wetland found in Lynnhaven Bay shown in infrared photography.

Scale is 1:3,100. 15 Oct. 1973. (Original in color) areas 4.9 kilometers (11 percent). Undeveloped subtypes were 12.8 kilometers (29 percent) fringe marsh and 3.1 kilometers (7 percent) meadow marsh areas. The data revealed that residential areas exceeded in distance any other category.

The Western Branch had a shoreline distance of 79.2 kilometers. Undeveloped subtypes had 11.7 kilometers (14.8 percent) meadow marshes and 17.1 kilometers (21.6 percent) fringe marsh areas. Developed subtypes consisted to bulkhead 9.2 kilometers (11.6 percent), residential 40.0 kilometers (50.5 percent) and cleared areas 1.2 kilometers (1.6 percent). Again in this division residential areas dominated the shoreline.

Finally, the Eastern Branch had a shoreline of 72.1 kilometers. The developed subtypes had bulkhead 7.5 kilometers (8.3 percent), residential 36.3 kilometers (48.3 percent) and cleared areas 1.9 kilometers (2.7 percent). Undeveloped subtypes were fringe marsh 11.7 kilometers (16.2 percent) and meadow marsh areas 22.2 kilometers (30.7 percent). As in the other three types, this division had more residential shoreline than any other category.

Tables 8 and 9 show all data obtained from shoreline measurements of the three divisions. The Eastern and Western Branches of the bay had similar shoreline distances, with the Main Bay being the shortest. The total shoreline distances for each section were the Eastern Branch 72.1 kilometers (36.9 percent), Western Branch 79.2 kilometers (40.5 percent) and Main Bay with 44.2 kilometers (22.6 percent). This gave a total shoreline distance of 195.6 kilometers (121.5 miles) during high tide. Residential zones accounted for close to fifty percent of the total shoreline in each division. This shows a high demand for water front property around the bay, which will decrease the total wetlands. Meadow marsh zones appeared to be more prevalent in the Eastern Branch of the bay. This fact can be explained by the presence of more coves and branches in the Eastern Branch. Also, slightly more development was located in the Western Branch. All divisions, except for the Eastern Branch, showed fringe marsh dominant over meadow marsh by a ratio of 2:1. Cleared areas had the shortest amount of shoreline and this zone only represents the cleared areas along the shoreline. Bulkheads accounted for only about nine percent of the shoreline in each division but most of its shoreline is associated with residential areas.

I. Main Bay

Frames: 23,24,37-40,52-55,60,61,63,64,73-75,86-88

A. Average

		Miles	Kilometers
1. bulkhead		2.2	3.5
2. residential		12.4	20.0
3. cleared	TOTAL=44.2 km.	3.0	4.9
4. fringe marsh		8.0	12.8
5. meadow marsh		2.0	3.1

II. Western Branch

Frames: 14-22,26-34,39-44,46

A. Average

		Miles	Kilometers
1. bulkhead		5.7	9.2
2. residential		24.9	40.0
3. cleared	TOTAL=79.2 km.	0.8	1.2
4. fringe marsh		10.6	17.1
5. meadow marsh		7.3	11.7

III. Eastern Branch

Frames: 77-83,88,89 92-96, 100-107

A. Average

		Miles	Kilometers
1. bulkhead		4.7	7.5
2. residential		22.5	36.3
3. cleared	TOTAL=72.1	1.2	1.9
4. fringe marsh		7.3	11.7
5. meadow marsh		13.8	22.2

* IV. Island marsh

Frames: 17,20,24,33,38,43,50,61,69,80,84,88,90,92,94,96,100,101,105

A. Average

		Miles	Kilometers
1.	TOTAL=28.2 km.	17.5	28.2

* separate category, not part of the shoreline category because the majority of islands are submerged during high tide.

Table 8 . The division data for the three sections of the bay.

V. Total bay data

Category	Kilometers		Percent	Areas	
bulkhead	20.2		9.5	Developed	61.5 %
residential	96.3		48.4		
cleared	8.0		3.6		
fringe marsh	41.6		20.4	Undeveloped (wetlands)	38.5 %
meadow marsh	36.9		18.1		
* island marsh	28.2	(17.5 miles)	----		
TOTAL	195.6	(121.5 miles)			

* island marsh not considered part of the shoreline but given in kilometers for comparison.

Table 9 . The data for the total bay.

The largest deviation was in the residential areas. A twelve percent difference (6.6 kilometers) was observed in this category. This difference could be accounted for by varying distances the interpreter set for residential areas. The developed area around the house was the only factor that could be used for determining residential areas. Much of this was covered by trees, making it difficult to determine the exact distance in all cases.

All figures given in this report pertain to the shoreline as it existed at the time of the flight on May 18, 1973. The author had no knowledge of any other data that could have been used for verification of his data, so the figures given in this report of shoreline for each category are rough estimates taken during high tide.

All three divisions of the bay combined together give a good concept of the bay's condition. Development including 9.5 percent bulkhead, 48.4 percent residential and 3.6 percent cleared areas gives a total of 61.5 percent. Undeveloped subtypes in the form of wetlands account for 20.4 percent fringe marsh and 18.1 percent meadow marsh. Their totals reveal a 38.5 percent undeveloped shoreline in Lynnhaven Bay.

A further measurement of island shoreline in the bay was carried out. The islands were found mainly at the mouth, in the Main Bay, and near the southern boundary of the Eastern Branch. Their total shoreline at high tide was 28.2 kilometers (17.5 miles). Meadow marsh compares very closely with island marshland in kilometers of shoreline. Island habitats consisted mainly of Spartina alterniflora stands that are the highest primary producers in salt marshes (Odum, 1961, Teal, 1962 and Odum et al., 1972).

CONCLUSIONS

The ecological study of Lynnhaven Bay, Virginia was conducted to determine some of the uses of infrared photography and as a means of comparison for future projects conducted in this area. Rates of change and some idea of pressures on the environment could be easily determined from the results of this study. Previous data could also be used with this study to show the rates of change that have occurred in the bay.

Color infrared aerial photography was found to be superior to color aerial photography in this study of Lynnhaven Bay. Accurate vegetation maps of species composition and wetland boundaries of the three saline marsh types of the bay were constructed from infrared photographs.

Coastal salt flats of Lynnhaven Bay consisted mainly of *Spartina alterniflora* the highest biomass producer in the salt marsh, thus providing more nutrients for the bay and surrounding estuaries than coastal salt meadows which were composed of many dominant marsh species. This saline wetland type is just as susceptible to being filled and developed as regular flooded marsh and coastal salt flat types because of its close proximity to land.

Residential, developed, and undeveloped areas of the bay were separated and the shoreline of each was determined. All five categories of shoreline were much easier to define on the infrared imagery.

Color infrared aerial photography, as a remote sensing tool, was found to have a low overall cost and could be utilized to interpret large areas of bays and estuaries where ground studies would be time-consuming, if not impossible to conduct.

LITERATURE CITED

Adams, D.A. 1963. Factors influencing vascular plant zonation in North Carolina salt marsh. Ecology. 44: 445-465.

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

Anderson, R.R. 1969. The use of color infrared photography and thermal imagery in marshland and estuarine studies. Second Annual Earth Resources Program Status Review, Vol. III: 40-1 to 40-29.

Anderson, R.R. and V. Carter. 1972. Wetlands delineation by spectral signature analysis and legal implications. Fourth Annual Earth Resources Program Status Review. Vol. II: 78-1 to 78-9.

Anderson, R.R. and F.J. Wobber. 1973. Wetlands mapping in New Jersey. Photogrammetric Engineering. 39(3): 353-358.

Chipman, W.A. 1948. Conditions affecting shellfish production in Lynnhaven Bay Virginia and the possibility of improving them by increasing tidal flow. In Lynnhaven Inlet, Bay and Connecting Waters, Va., 87th Congress Sec. Session, House Document No. 580. 1962.

Colwell, R.N. 1968. Sensing of natural resources. Scientific American. 218(1): 54-69.

Eastman Kodak. 1970. Applied infrared photography. Publication M-28. Rochester, New York.

Eastman Kodak. 1971. Photography from lightplanes and helicopters. Publication M-5. Rochester, New York.

Fernald, M.L. 1950. Gray's Manual of Botany. Eighth Ed. American Book Co. New York. +1632 p.

Gallagher, J.L., R.J. Reimold and D.E. Thompson. 1972. Remote sensing and salt marsh productivity. In the Proceedings of the American Society of Photogrammetry, 38th Annual Meeting, Washington, D.C.

Garvin, L.E. and R.H. Wheeler. 1973. Coastal wetlands inventory in Maryland: In the Proceedings of the American Congress on Surveying and Mapping, 35th Annual Meeting, Washington, D.C.

Gausman, H.W. 1974. Leaf reflectance of near-infrared. Photogrammetric Engineering. 40(2): 183-191.

Harshberger, J.W. 1909. The vegetation of the marshes and of the salt and fresh water ponds of northern coastal New Jersey. Academy of Natural Science. Philadelphia, Proceedings No. 6: 373-400.

Hindle, H.P. 1954. The vertical distribution of salt marsh phanerogams in relation to tide levels. Ecological Monographs. 24(2): 209-225.

Howard, J.A. 1970. Aerial Photo-Ecology. American Elsevier Publishing Company New York. +240 p.

Kerwin, E.P. 1971. Distribution of the fiddler crab in relation to marsh plants within a Virginia estuary. Chesapeake Science. 12(4): 180-183.

Kerwin, E.P. 1972. Distribution of the salt marsh snail in relation to marsh plants in Paropotank River area. Chesapeake Science. 13(3): 150-153.

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

Knipling, E.B. 1970. Physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of the Environment. 1(3): 155-189.

Marcellus, K.L. 1972. Coastal Wetlands of Virginia. Interim Report No. 2 to the Governor and General Assembly, Virginia Institute of Marine Science. July 1972.

Nichols, G.E. 1920. The association of depositing areas along the seacoast. Torrey Biological Club Bulletion. 47: 511-548.

Odum, E.P. 1961. The role of tidal marshes in estuarine production. New York State Conservationist. 15(6): 12-15.

Odum, W.E., J.C. Zieman and E.J. Heald. 1972. The importance of vascular plant detritus to estuaries (A pre-print of a paper which will appear in the Proceedings of the Second Marsh and Estuary Management Symposium to be published by the Division of Continuing Education of the Louisiana State University, Baton Rouge).

Penney, M.E. and H.H. Gordon. 1973. Tonal variations in wetlands imagery. In the Proceedings of the American Society of Photogrammetry. Fall Convention Oct. 2-5, 1973.

Reed, J.F. 1947. The relation of the Spartinetum glabrae near Beaufort, North Carolina to certain edaphic factors. American Midland Naturalist. 38: 605-614.

Shaw, S.P. and C.G. Fredine. 1971. Wetlands of the United States: Their extent and their value to waterfowl and other wildlife. U.S. Department of the Interior, Fish and Wildlife Service, Office of River Basin Studies, Circular 39.

Steiner, D. and H. Haefner. 1965. Tone distortion for automated interpretation. Photogrammetric Engineering. 31(2).

Stroud, L.M. and A.W. Cooper. 1969. Color infrared aerial photographic interpretation and net production of a regularly flooded North Carolina salt marsh. Water Resources Institute of University of North Carolina, Report No. 14.

Suits, G.H. 1972. The causes of azimuthal variations in directional reflectance of vegetation canopies. Remote Sensing of Environment. 2(3): 175-182.

Teal, J.M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology. 43(4): 614-624.

Thomas, H.H. 1920. Aircraft photography in the service of science. Nature. 105(2641): 257-259.

Thompson, D.E., J.E. Ragsdale, R.J. Reimold and J.L. Gallagher. 1973. Seasonal aspects of remote sensing coastal resources. Remote Sensing of Earth Resources Vol. III, University of Tenn. Press. pp. 1201-1249.

United States Department of Commerce, National Oceanic and Atmospheric Administration, Coastal and Geodetic Survey. 1973. Tide Tables: North and South America.

Wass, M.L. and T.D. Wright. 1969. Coastal Wetlands of Virginia. Interim Report to the Governor and General Assembly, Virginia Institute of Marine Science. December 1969.

Whitman, R.I. and K.L. Marcellus. 1973. Textual signatures for wetland vegetation. In the Proceedings of the American Society of Photogrammetry, Fall Convention, Oct. 2-5 1973.

Wilson, E. 1920. Use of aircraft in forestry and logging. Canadian Forestry Magazine. 16(10): 439-444.

Wood, K.B. 1953. Photo-interpretation in forestry. Photogrammetric Engineering. 19(3): 477-480.