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Inventory of Delaware's Wetlands

Combining visual and multispectral photoanalysis is a cost-effective and rapid mapping method.

Abstract: *Overlay maps of Delaware's wetlands have been prepared, showing the dominant species or group of species of vegetation present. Five such categories of vegetation were used indicating marshes dominated by specific groups of species. In addition, major secondary species were indicated where appropriate. Small, representative areas of each of the major marsh regions were analyzed and enhanced to show detailed growth patterns not shown on the small-scale maps. The mapping technique utilized the General Electric Multispectral Data Processing System (GEMSDPS) to analyze NASA RB-57 color-infrared imagery. The GEMSDPS is a hybrid analogue-digital system designed as an analysis tool to be used by an operator whose own judgement and knowledge of ground truth can be incorporated at any time into the analyzing process. The result is a high-speed, cost-effective method for producing enhanced photomaps showing a number of spectral classes.*

Introduction

The commitments to environmentally sound coastal land management that have been generated in federal and state governments over the past few years have produced a demand for accurate and complete bodies of scientific data on which to base policy decisions. Coastal wetlands in particular have been the subject of much controversy and litigation and the lack of survey-type information over broad areas of wetland is apparent. For this reason a baseline inventorying project was undertaken in Delaware's coastal wetlands as a prelude to an evaluation of the relative value of different parcels of marsh and the setting of priorities for use of these marshes.

In view of severe limitations of time and manpower, the adopted mapping approach relied heavily on aerial photographs and multispectral analysis, utilizing conventional ground reconnaissance only to aid and check the photo-interpretation. Work such as that of Kolipinski[1], Garvin[2], Wobber[3], Anderson[3], Reimold[4] and others has shown that multispectral image analysis can significantly help, yet not replace, the human interpreter. Suitable imagery from NASA and USDA was available, and access to General Electric's Multispectral Data Processing System was acquired.

Coastal wetlands of the type found along the entire east coast of the United States are well suited to remote sensing techniques, particularly multispectral analysis. The uniform flatness of marsh topography eliminates variations in reflectance due to sloping surfaces and shadows. The most common marsh plant species are few in number, thus simplifying photo-interpretation. Environmental changes generally take place over large horizontal distances in the marsh. Therefore, zones of relatively uniform vegetation are usually large enough to be discernible, even on very high-altitude imagery. Finally, the major plant species are different enough in their morphologies to have distinct reflectance characteristics, particularly in the near-infrared portion of the spectrum. The net result is that multispectral imagery can be used to make detailed wetlands maps showing vegetation growth patterns which are related to local environmental factors.

Description of Delaware's Wetlands

There are approximately 115,000 acres of tidal wetland in the state of Delaware forming an almost continuous band along the western shore of Delaware Bay from Cape Henlopen north to Wilmington.[5] The width of this band varies from a few hundred yards to three to four miles with an average width on the order of one mile. In addition, there are small fringes of marsh associated with the barrier beach-lagoon complexes along the Atlantic shore in the southern portion of the state. The most abundant plant species found in the marshes are salt marsh cord grass *(Spartina alterniflora)*, salt marsh hay *(Spartina patens)*, spike grass *(Distichlis spicata)*, reed grass *(Phragmites communis)*, high tide bush *(Iva frutescens)*, and sea myrtle *(Baccharis halimifolia)*. There are, of course, many other species present, but in most instances their occurrence is limited to small patches scattered within areas dominated by one or more of the above mentioned primary species.

As previously stated, the major species display distinct morphologies allowing them to be distinguished from one another on the basis of reflectance characteristics. A brief description of the preferred environments, morphology and resulting reflectance of each species category follows.[6]

Major Categories

Spartina alterniflora (Salt marsh cord grass). The dominant marsh grass species of the Eastern United States. *S. alterniflora* occupies the low or wettest portion of the marsh. Two ecotypes are distinguished in Delaware: a tall form which inhabits the relatively high, narrow, natural levees that line the tidal creeks, and a short form found over the remaining low marsh areas. The narrow stalks and leaves of *Spartina alterniflora* provide a relatively sparse reflecting surface if viewed from above with the result that this species appears darker than the other major species in color-infrared imagery (see Figure 1a). The tall form pro-

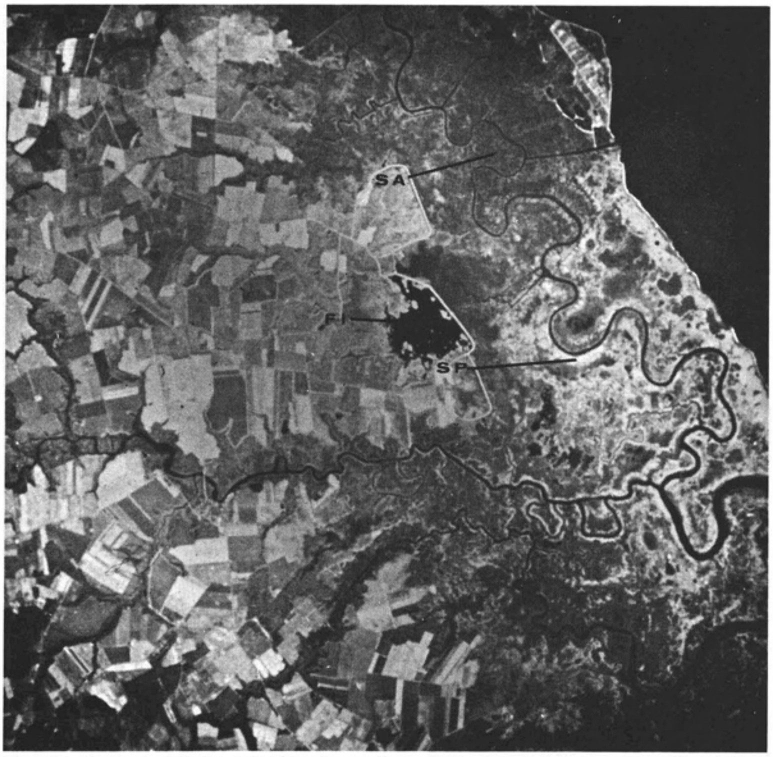

FIG. 1A. Sample NASA RB-57 color-infrared photograph (reproduced in black and white) including portions of area shown in Figure 4. Original size, 9 by 9 inches. Original scale, 1:60,000. *SA, Spartina alterniflora; SP, Spartina patens; FI,* fresh water impoundment.

vides a slightly more dense reflecting surface than the short form allowing discrimination of the two ecotypes.

Spartina patens and *Distichlis spicata* (Salt marsh hay and spike grass). These two species occupy areas of marsh topographically higher than those occupied by *Spartina alterniflora*. Although short with thin stems, both species grow in a very dense mat which produces high reflectance in the infrared (see Figure 1a). Often, but not always, the two species are found together and are indistinguishable on color-infrared imagery. Because they seem to occupy very similar environmental niches, the two species are lumped together into one category.

Phragmites communis (Reed grass). Naturally found in small patches on mounds and other topographic highs within the marsh, *Phragmites* now occupies extensive areas where artificial filling or drainage has produced a suitable environment. Growing up to 10 feet high with broad leaves, *Phragmites* has the highest reflectance of any of the marsh grasses and thus appears lightest on the photos.

Iva frutescens and *Baccharis halimifolia* (High-tide bush and sea myrtle). These low shrubs are generally found in a narrow band just above the reach of the highest tides. They are almost always found together and their broad leaves and sparse growth pattern combine to give them distinct reflectance characteristics in the infrared.

Fresh water impoundments—Built to attract ducks and other waterfowl, these are generally identified by their straight, artificial boundaries and the continuous presence of standing water (see Figure 1a). They contain many fresh water plants including species of *Peltandra* (Arrow arum), *Typha* (Cattail), *Pontederia*, and *Sagittaria* (Arrowhead).

It should be noted that these groups were identified on the basis of reflectance in three color bands (green, red and infrared) and not simply in the infrared as might be inferred from the general description above.

The considerable morphological differences between the major species make it unlikely that transitory variations in reflectance would affect the interpretation. The imagery used for interpretation was obtained within two hours of a single day, eliminating significant variations in sun angle and weather conditions. The vegetation was photographed at its peak, in late September. Plant vigor is highly variable, particularly in *Spartina alterniflora*, and yet *S. alterniflora* was correctly identified growing at heights of from one to two meters down to 15 to 20 centimeters. This would seem to indicate that minor variations due to disease, etc., would not affect accuracy of identification. Field work indicated that the species distribution had not significantly changed during the two-year interval between aquisition of photographs and completion of the project with the exception of *Phragmites communis*. In instances where infestation of *P. communis* is particularly rapid, boundaries could be in error by as much as 60 feet (preliminary observations indicate that under certain conditions *P. communis* can propagate over horizontal distances of up to 30 feet per year). At the mapping scale of 1:24,000 this amounts to less than 1/30 of an inch on the maps. Such errors were considered acceptable considering the limitations of scale and photographic distortion incurred (see Mapping Approach Section).

Mapping Approach

The primary imagery used in compiling vegetation maps was obtained by a NASA RB-57 aircraft in September of 1970 (Mission 144, Site 244). Of the various types of imagery available from Mission 144, it was decided that nine-inch color-infrared photographs would provide optimal discrimination of vegetation types. Visual interpretation was performed on color-infrared prints obtained with Zeiss RMK 30/23 camera at a scale of 1:60,000 (see Figure 1a). For automated analysis it was found that color-infrared transparencies taken with a Wild Heerbrugg RC-8 camera at 1:120,000 scale had better light characteristics and thus yielded better results despite smaller scale (see Figure 1b). Resolution in these high-altitude photographs was sufficient to produce first-generation vegetation maps registered onto USGS topographic maps at a scale of 1:24,000 and for more detailed automated pattern recognition at considerably smaller scales. A more detailed second-generation set of maps is being compiled from low-altitude (6,000 ft) imagery obtained in October, 1973.

To collect ground truth for the interpretation of the NASA photographs, field sites were visited on foot and by small boat throughout the summer of 1972. In addition, low-altitude aerial photographs were obtained from light planes. Taken from altitudes of 500 to 2,000 feet, this imagery was sufficiently detailed for easy identification of major plant communities and thus provided ground truth over larger areas than it was possible to obtain on foot or by boat. In some areas detailed field work, including measured transects, was used as a check of automated pattern recognition capabilities.

The classification scheme used in mapping (see Figure 2 and 3) developed naturally from

FIG. 1B. Sample NASA RB-57 color-infrared photograph (reproduced in black and white) including portions of area shown in Figure 4. Original size, 9 by 9 inches; original scale, 1:120,000.

the structure of the marsh plant communities and from the discrimination capability of the imagery used. Therefore, the five major categories described not only represent the dominant species and communities present in the marshes in Delaware, but also are the vegetation types that are most readily discriminated in the imagery used for interpretation.

In areas where a significant amount of another species than that shown as predominant in the NASA imagery was present, this is noted on the maps by capital letters (see Figures 2, 3, and Table 1). The secondary species were identified by field observation, although further studies may show that some such associations can be identified from aerial imagery.

As the primary objective of this study was to evaluate rapid discrimination and inventorying of plant species, horizontal control was not considered of critical importance. No attempt was made at geometric corrections other than locating boundaries by eye in relation to landmarks visible on both the photos and the topographic quads. Accu-

TABLE 1. KEY FOR CAPITAL LETTERS INDICATING SECONDARY SPECIES ON VEGETATION MAPPS

P	*Phragmites communis*
A	*Spartina alterniflora*
C	*Spartina cynosuroides*
H	Salt Hay *(Spartina patens* and *Distichlis spicata)*
I	Shrubs *(Iva frutescens* and *Baccharis halimifolia)*
S	*Scirpus* spp.
M	*Hibiscus* spp.
Z	*Zizania aquatica*
W	*Acnida cannabina*
F	Fresh Water Category *(Peltandra virginica, Pontedaria cordata, Typha* spp., *Sagittaria* spp.*)*

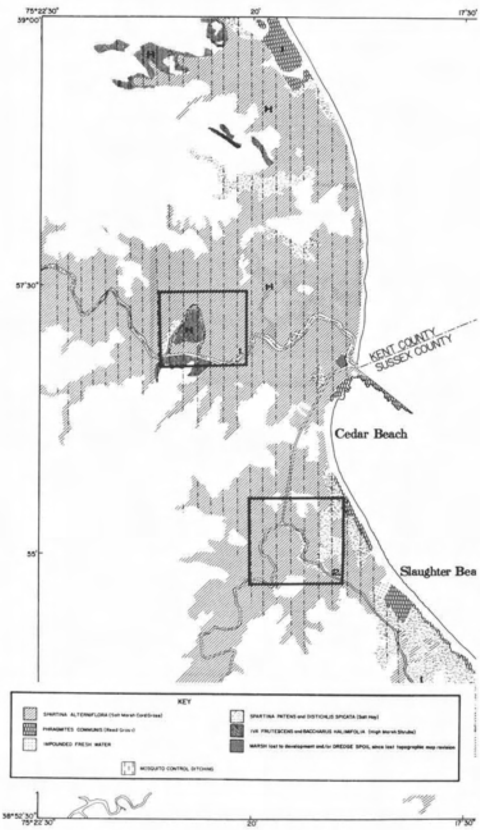

FIG. 2. Vegetation map.

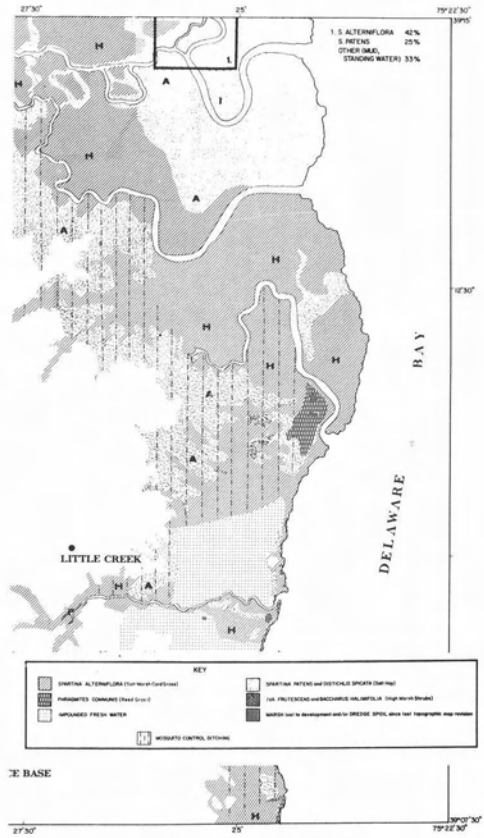

FIG. 3. Vegetation map.

racy of identification is more difficult to evaluate; however, a conservative estimate would put the probability of an interpreter correctly identifying the major plant species of an area at 90 percent. In field work completed subsequent to photointerpretation, no areas were found where the major plant species was incorrectly identified on the photos. Inaccuracies due to varying abundance of secondary species most likely do occur but are considered acceptable within the context of an inventory of this type.

Inventory categories were established for areas ditched for mosquito control and for marsh areas lost to dredgefill operations after the most recent revision of the USGS topographic maps. Marshes lost to development were easily identified on NASA imagery and USDA photos at a scale of 1:20,000 were used to delineate ditched areas.

MULTISPECTRAL ANALYSIS

Although the discrimination and mapping of gross vegetation features is most readily accomplished by a human interpreter, detailed interpretation can benefit from the use of automated multispectral analysis. Such automated analysis was performed utilizing the General Electric Multispectral Data Processing System ((GEMSDPS), which is an analogue-digital hybrid designed as an analysis tool to be used by a human operator and benefit from his observations. As shown in Figure 4, it consists of:

- "A modified color TV camera which scans and reads out radiometrically the data contained in either a set of three black-and-white multiband transparencies of a scene or a single-color transparency of that scene. The TV camera output consists of three registered video signals, each signal pertaining, respectively, to the scene as recorded photographically with a particular film-filter combination."
- "Analog, real-time electronic data processing equipment which operates upon the three spectral video signals. This includes the signature analyzer, spatial field-of-view gating, and a totalizer which indicates the percent area in the scene falling in a selected spectral signature class."
- "Electronic real-time displays and photo-

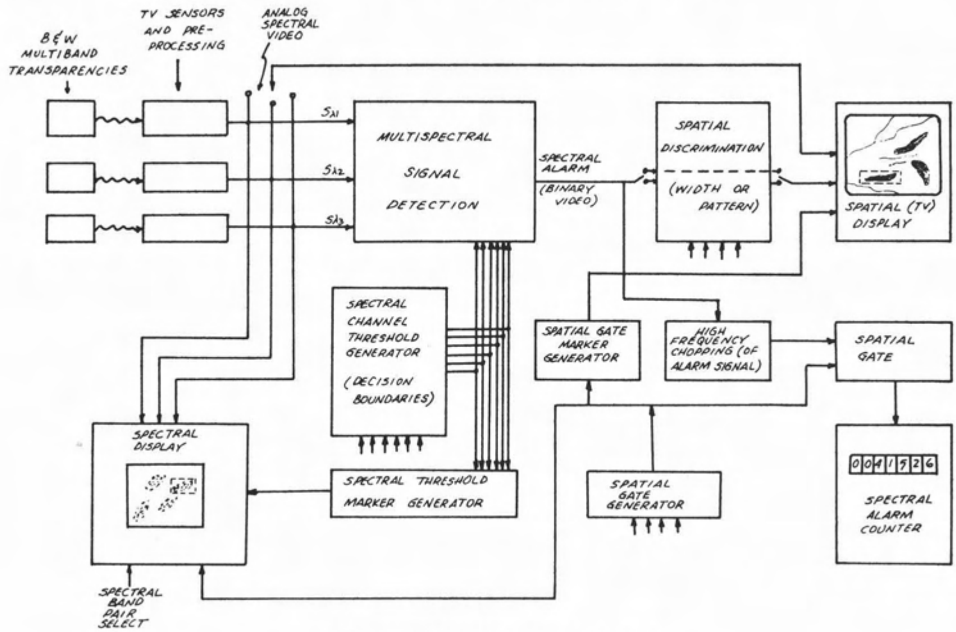

FIG. 4. Multispectral test system.

> graphic cameras to record those displays. The displays include a color TV monitor to present the scene with enhancement for selected spectral signature classes and a CRO display of two-band spectral signatures occurring within the scene."[7]

This accurate and highly flexible system has been designed to allow the operator to adjust the signature analyzer and other processing units for optimum discrimination and to see the results of these adjustments immediately. He can thus, very rapidly, combine his knowledge of the scene gained in the field with precise, unbiased, electronic analysis and thereby measure the spectral characteristics of a region of any size in the scene, search the scene for regions with similar characteristics and read out the percentage of the total scene occupied by areas with the specified spectral signature. By repeating the same procedure for other areas in the scene, the operator can quickly produce a composite photo-map enhancing all of the spectrally classified areas of interest. The final product can take a variety of forms—the operator can photographically preserve the enhanced TV image (see Figure 5); he can digitize the results, print out a digital map or a tabular representation of the different spectral signatures identified, and the percentage of the total scene each occupies; or he can combine any or all of the above display modes to produce a specific desired result.

The GEMSDPS thus makes the accuracy and speed of electronic spectral analysis available to the non-technical operator, who may have extensive field experience, and allows him to interact with the automated process to any degree he desires in order to produce a result which is compatible with his specific knowledge of the area.

RESULTS

Fifteen overlay maps of Delaware's coastal zone were thus prepared, showing the dominant species or group of species of vegetation present. Five such categories of vegetation were used indicating marshes dominated by (1) salt marsh cord grass *(Spartina alterniflora)*, (2) salt marsh hay and spike grass *(Spartina patens* and *Distichlis spicata)*, (3) reed grass *(Phragmites communis)*, (4) high tide bush and sea myrtle *(Iva frutescens* and *Baccharis halimifolia)*, and (5) a group of fresh water species found in impounded areas built to attract waterfowl. In addition, major secondary species were indicated where appropriate. Multispectral analysis and enhancement were performed on selected areas considered to be representative of the relative species abundance and growth patterns present in the surrounding marsh. The enhancements themselves, then, are large-scale inserts designed to supplement the generalized vegetation maps by showing detailed growth patterns and the relative abundance, in percent, of each species present. Figure 5b, for example, is an enhancement of the area enclosed by box 1 on

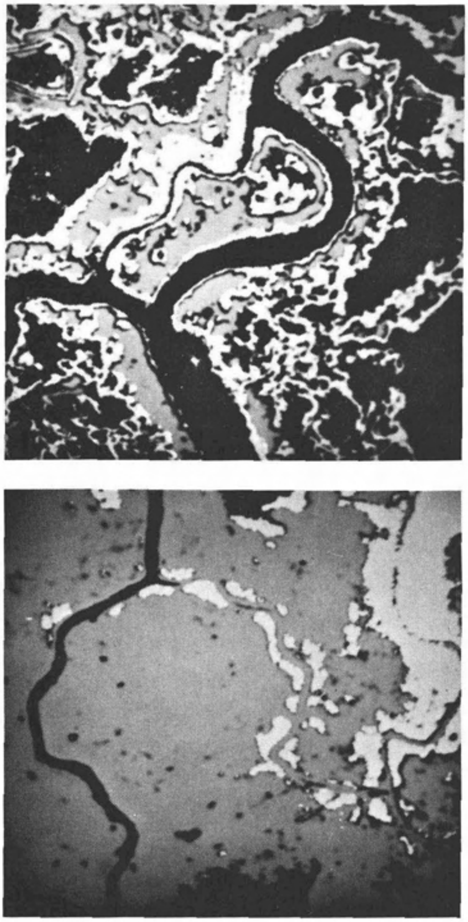

FIG. 5. *(Top)* Enhancement of Area 1 of Figure 3. Black represents water and mud, gray indicates *S. patens* and *D. spicata,* and white is *S. alterniflora. (Bottom)* Enhancement of Area 2 of Figure 2. Black represents water and forest, gray is *S. alterniflora,* and white is *S. patens.*

Figure 3. Detailed zonation of different vegetation species which could not be displayed on the small-scale map is shown, with *Spartina alterniflora* forming an outer fringe and *Spartina patens* occupying the higher, center portion of marsh. The final maps were at a scale of 1:24,000 registered to USGS topographic and soil maps. Inserts showed those areas which were automatically analyzed and the results of that analysis, providing a general picture of Delaware's coastal vegetation *and* a detailed description of selected marsh areas.

CONCLUSIONS

Multispectral analysis of aerial imagery was found to be a valuable tool in the mapping of Delaware's wetlands. The accuracy of analysis was limited primarily by the quality of the imagery used. The real-time operation of the analysis system allowed enhancement of selected species and assessment of their relative abundance in a fraction of the time required if the same study were performed using field reconnaissance manual photo-interpolation. In addition, the system output can be adjusted to accommodate a variety of display and analysis modes including digital storage, analysis and print-out. The ability of a small team to complete the mapping of the entire Delaware Coastal Zone within five months suggests that the approach described in this paper is a cost-effective and fast method of assessing the general community structure of large, inaccessible areas.

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