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A DEMONSTRATION OF WETLAND VEGETATION MAPPING IN FLORIDA FROM COMPUTER-PROCESSED SATELLITE AND AIRCRAFT MULTISPECTRAL SCANNER DATA

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A DEMONSTRATION OF WETLAND VEGETATION MAPPING IN FLORIDA FROM COMPUTER-PROCESSED SATELLITE AND AIRCRAFT MULTISPECTRAL SCANNER DATA

by

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ABSTRACT

The Environmental Protection Agency (EPA) and the National Aeronautics and Space Administration (NASA) coordinated a project to assess the usefulness of satellite and aircraft multispectral scanner data for wetland vegetation inventory on the southwest coast of Florida. A semiautomated, computerized technique was implemented to process multispectral scanner digital data. The cost-effectiveness of the classified vegetation maps were evaluated. Results indicated that mangrove communities were classified most cost-effectively by the Landsat technique, with an accuracy of approximately 87% and at a cost of about $ .03 per hectare vs. $47.00 per hectare for conventional mapping methods.

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INTRODUCTION

The Environmental Protection Agency (EPA) and the National Aeronautics and Space Administration (NASA) launched a cooperative project to test the use of remote sensing to inventory a part of the Florida wetlands in the fall of 1975. Vegetative classifications were derived from satellite and aircraft multispectral scanner (MSS) data by a technique developed at the NASA Earth Resources Laboratory (ERL), located in Slidell, LA. All data processing was carried out at ERL. Region IV of the EPA, located in Athens, GA, engages in the environmental analysis and surveillance of the U. S. southeast, and participated in the initial planning, ground truth, and evaluation of the final results.

The study area encompassed a section of the southwest coast of Florida below 26°N latitude, including a part of Big Cypress Swamp, where subtropical vegetation blends into the natural landscape. The vegetation ranges from the upland fresh water system of cypress, swamp hardwoods, wet prairie and pine/palm hammocks to the transitional zone of marsh grasses which grades into the mixed mangrove forest fringing the coastline.

The EPA especially emphasized their need to remotely identify the mangrove communities, which are extremely difficult to survey on foot. The agency also was interested in remotely monitoring the invasion of melaleuca, a tropical tree, into disturbed Florida cypress swamps and the proliferation of Australian pine (not a true pine), an exotic tree escaped from cultivation.

The swamps of Florida are typical of those found in other locations; however, the presence of royal palm in communities of pine and/or hardwoods is unique to this state. The formation of pine/palm hammocks is a curious yet identifiable feature related to the calcareous soil of this area. Mangroves, although growing along portions of the Texas, Louisiana, and Mississippi coasts, thrive best along the Florida coast below 25°N latitude where they may reach a height of 30m (100 feet). Since the EPA was particularly interested in remotely identifying the mangrove forests within this study area, these species will be described below in more detail and reason for the interest explained.

Three different species comprise the 1,758 sq. km. (675 square miles) of mangrove communities of all Florida estuaries, where the brackish waters represent the best growth conditions (ref. 1). According to Kuenzler, one of the best mangrove developments is in the Ten Thousand Islands region, included in the study area of this project. Here the mangrove forests extend inland for 26 or more kilometers (18 miles) along the water courses. Red mangrove, Rhizophora mangle, considered the pioneer species, roots into the marl soil below low tide level. The young plants require quieter water and a more stable substrate than the mature trees (ref. 2). Matured red mangrove takes over the slightly higher intertidal peat soil inundated by high tide, forming impenetrable forests with its maze of prop roots. Black mangrove, Avicennia germinans, occupies flat areas inundated by higher tides. White mangrove, Laguncularia racemosa, appears less frequently than the other two species, but favors a more inland environment, overlapping with the habitat of black mangrove and grading into the inland marsh.

The three species do not grow in habitats exclusive of one another. On the contrary, most of the mangrove forest in the Ten Thousand Islands appears as mixed associations of all three types. Pure red mangrove occurs only as a narrow band (less than 50m wide) interfacing coastal waters. In the inland situation, black mangrove is the only species that dominates in large communities to the exclusion of the other two species.

As residential and commercial development expands into these pristine mangrove forests, the mangrove ecosystem and its high natural productivity are threatened. In the overall scheme, the environmental balance is at stake because the mangroves, an important link in the food chain, may be removed or at least disturbed, causing a decrease in nutrient resources available to marine organisms. Therefore, an inventory of the mangroves, to the species level if possible, would serve as essential information required by the EPA to make management decisions concerning the Florida environment.

PURPOSE

The purpose of this project was to produce vegetation maps of a section of the southwest coast of Florida derived from computer-processed MSS data acquired by both Landsat and aircraft. Then the EPA would assess the usefulness of the remotely sensed maps and related technique to:

(a) inventory vegetation communities and land use,

(b) monitor wetlands for stress and changes as a function of time from man-made and natural causes, and

(c) define wetland boundaries in the Florida coastal zone study area.

According to the EPA/Region IV, an inventory of marine wetlands would serve to:

"...define areas where permits must be adequately protective of uniquely sensitive and productive environments.

...define areas where non-point source controls should be adequately maintained to protect these environments.

...define areas where dredge-and-fill activities (especially finger canal development) must be very carefully controlled.

...define areas where construction grants for sewers in upland areas of the drainage basin must be diverted to other basins to protect the critical environment in the lower part of the basin."

Evaluation of the cost-effectiveness of the technique was also a prime objective. Consideration of the classification accuracies of the map products, their usefulness, and the cost to complete them constituted the criteria for evaluation.

APPROACH

Delineation of Study Area

The project study area was selected for its high-density mangrove forests fringing the coastline and its diversity of inland wetland vegetation. The area includes three urban centers. Ft. Meyers marks the northwest corner, Naples occurs at the center west edge, and Marco Island appears at the southwest. The land to the east is relatively undeveloped but urbanization is anticipated, which is why a regulatory agency such as the EPA is interested in acquiring a practical technique for baseline inventory.

Training Sample Selection from Photography

As a first step in the remote sensing technique applied in this project, aerial, color-infrared photography obtained by the state of Florida in 1971-72 was used to produce a mosaic of the study area shown in figure 1. This photographic representation helped to discriminate the different vegetative types existing in the study area, based on color tones and textures. These plant types were then marked on the photography for possible use as training samples in the computer processing of the Landsat and aircraft MSS data. The aerial photography also served as a "field map" to locate the training samples during the ground truth mission.

Samples used for the classification of the Landsat data measured at least 300m x 300m (1000 ft. x 1000 ft.), while those used for the aircraft data classification measured at least 40m x 40m (120 ft. x 120 ft.). The minimum size of the training samples relates to the resolution capability of the respective scanners and the need to assure statistical validity.

Ground Truth Mission

After the participating NASA and EPA investigators selected training samples to represent the full range of plant communities inhabiting the study area, they planned a ground truth mission to observe each sample by helicopter. One hundred sixty-three training samples were covered in five days of helicopter work, September 15-19, 1975. The field team recorded a description of each sample with the following observations made while hovering over the sample:

(a) percent mud or water and its spatial distribution,

(b) percent total vegetation,

(c) percent of each species in the total vegetation and the spatial distribution of each,

(d) percent crown closure, if forested,

(e) percent of each species in the canopy, if forested.

Aircraft and Satellite Multispectral Scanner Data Acquisition

The Earth Resources Laboratory aircraft acquired the MSS data on September 18, 1975, at an altitude of 3.5 km (10,000 ft.) over two overlapping, parallel flight lines, each 24 km (15 miles) in length. The coverage appears in figure 1. The flight mission was scheduled to coincide as closely as possible to the ground truth mission so that field observations correctly described the vegetation at the time of MSS data acquisition.

The flight lines covered the full distribution of vegetation types in a portion of the study area designated by the EPA to require finer resolution for the vegetational analysis. The aircraft deliberately flew at a time when the sun's rays were parallel to the flight path, thus minimizing distortion of the MSS data due to an oblique sun angle. The atmosphere was clear at the time of the flight.

The ERL multispectral scanner simulates the Landsat 1 and 2 scanners in the bandwidths of detected radiance. The instruments record energy in wavelengths of .5-.6μ, .6-.7μ, .7-.8μ, and .8-1.1μ. The aircraft scanner resolves at 2.5 milliradians, which means the instantaneous field of view, or pixel, measured 7.6m (25 ft.) at 3.5 km altitude. The instrument scans a swath perpendicular to the line of flight and $\pm 50^{\circ}$ of nadir.

The Earth Resources Laboratory obtained computer-compatible tapes of satellite MSS data from a Landsat 1 pass on November 2, 1975 (frame 5197-14383), which covered the study area. Cloud contamination prevented the use of any pass acquired earlier in the summer/fall period. Spectral data collected during the peak of the summer growing season, before senescence, would have been desirable.

The Landsat scanner detects energy in the four bandwidths mentioned previously. The resolution cell size measures 56m x 79m (185 ft. x 260 ft.), approximately an acre, as the instrument passes over the earth at an altitude of 920 km (570 miles) with a scanning swath of $\pm$ almost 6° of nadir.

Computer Processing of MSS Data

Because both the aircraft and Landsat MSS data existed in digital format, they could be classified quickly by computer via a pattern recognition technique developed at the ERL (ref. 3). In the initial step, the computer produced multispectral "signatures" for the training samples and used them to identify each cell of the raw scanner data. Specifically, the program determined the mean reflectivity response and standard deviation for each of the four bandwidths of data representing each sample. Samples of the same vegetation type were statistically grouped to produce a final mean reflectivity and variation about the mean.

After the program computed the spectral signatures for all classes, it used them to classify each digital element based on maximum likelihood theory. In multidimensional space, each spectral mean and standard deviation defined a volume of space representing that class type. Some classes intersected in space. The program then fitted each element of the entire data set against the multidimensional limits of each class. The element fitted with one of the classes when the likelihood (probability) was maximum that it belonged to that class. In this manner, most elements were classified. When the reflectivity responses of an element did not fit any of the spectral signatures developed from the training samples, the element remained unclassified. The Landsat and aircraft classifications were produced similarly--but independently--of one another.

Accuracy Verification Procedure

The accuracy of previous Landsat classifications derived from MSS data with the ERL technique has approximated at least 80% (ref. 4). However, accuracy varies with diversity, spatial arrangement, type of ground cover, and the verification procedure. The diversity of vegetation and the limited areal extent of plant communities, except for the mangroves, within the Florida study area suggested that a highly accurate classification might be difficult to obtain. Consequently, a test was designed to evaluate the accuracy of the Landsat wetlands classification.

First, a computer program designated verification test fields by unstratified, random sampling. In effect, the computer randomly selected about 100 elements from the Landsat classification, without regard to class identity. Each one of these elements became the center of a 5 x 5 digit element box, or 25-element square test field. The computer outlined these test fields on the final classification and on a digitized, high contrast image of the raw data. A film recorder reproduced the color-coded classification and raw data image. The latter was used as a map for navigation to each test field by helicopter. The test fields were plotted on an unrectified image so that the evaluation of classification accuracy would not include any resampling error possibly introduced in georeferencing the Landsat MSS data.

During the verification mission, the helicopter, at an altitude of 50-150m (165-495 ft.), approached each test field outlined on the filmed image from its southern boundary. Thus, the same orientation for observations served each test field. The field team diagrammed the arrangement of the ground cover and identified it on a sheet of paper with a 5 x 5 unit grid representing the 5 x 5 classified elements, or 25-acre test field. Later, EPA investigators compared the observations recorded on the gridded sheet to the computer classification within each 5 x 5 element box. They measured by planimeter the area drawn to represent each plant community and calculated it in terms of equivalent units of the 25-unit grid. Thus, one could directly compare the classified data in the 25-element box to the field observation of that site recorded in the 25-unit grid.

Cost Analysis of the Remotely Sensed Technique

NASA determined an approximate cost for the remotely sensed method of inventory of the study area. The determination included the costs for acquisition, processing, analysis and presentation of the aircraft and Landsat data. This cost analysis covered the classification of approximately 10,000 scan lines of aircraft data over approximately 400 sq. km. (150 square miles) and two computer-compatible tapes of Landsat data over about 4,000 sq. km. (1,500 square miles). The results do not imply a cost figure per scan line or per tape. The classification of additional aircraft or Landsat data would not increase costs proportionately since many of the items, once accounted, would not be repeated in the classification of additional data. The analysis derived the costs for materials, services, and travel and lodging expenses within the project area from receipts or catalog prices. Transportation expenses to and from the site were excluded. The project records and support contractor job orders dictated labor costs. Where possible, project costs reflected separately those associated with aircraft data and those associated with Landsat data.

RESULTS

Description of Training Samples

This report provides brief descriptions of the training samples in table I which were ground-truthed by helicopter September 15-19, 1975. The ground truth team actually visited 163 samples, of which 27 represented variations in water.

Aircraft MSS Classification

Within the area covered by the two flight lines of MSS data, 45 training samples were ground-truthed and then incorporated in the pattern recognition software. Training sample statistics defined the multispectral "signatures" for all vegetative types. The processing of the scanner data through the ERL classification software was standard except that a separate computer search classified water based on two channels of data, one in the visible and one in the near-infrared. The computer used all four channels to identify all other classes. Only the data within the middle 90° of each flight line were accepted for classification, though the full scan width was 100°. The map product resulted from the mosaicking of the classified data from the two flight lines originally recorded at an approximate scale of 1:24,000, but reduced here for reproduction in figure 2.

The map legend describes the final classification. Within most of the mangrove forest, the black, red and white species: *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa*, occurred in such evenly mixed stands that they could not be multispectrally separated and were coded dark green. However, in some cases, black mangrove grew in areas large and pure enough to be distinctly classified and was coded light green. Though red mangrove frequently grew along the swamp periphery interfacing with the coast, it occurred in such narrow bands that the scanner could not resolve it. The areas coded light brown and designated as Spartina marsh represented marsh dominated by either cord grass, *Spartina spartinae*, or black rush, *Juncus roemerianus*, as these two species had a low probability of separability from one another. Salt grass marsh, coded gold, represented areas dominated by *Distichlis spicata* with *Salicornia* spp. and *Batis maritima* as subdominants.

The pink color indicated the presence of cypress swamp and represented a somewhat variable ecological condition from areas of 100% cypress, *Taxodium distichum*, of differing crown closures to areas of cypress co-dominated or subdominated by lowland hardwood species: live oak, *Quercus virginiana*, wax myrtle, *Myrica cerifera*; sweet bay, *Magnolia virginiana*; palmetto, *Sabal*. spp; pine, *Pinus elliottii*. Since barren and urban areas and clouds have similarly high reflectivities, the computer classified them all as one class. It was coded white. Brazilian pepper trees, *Schinus terebenthifolius*, were recorded as pale blue. The forest category, coded red, included areas dominated by live oak and wax myrtle and subdominated by sweet bay and palmetto. Dark blue designated areas classified as pure cattail marsh, *Typha latifolia*.

Black identified all unclassified surface features. This included shadows created by overhead clouds, as well as all other vegetation and areas of water for which representative training samples were lacking.

The vegetation classification displays the natural gradation of mangrove forest adjacent to the coast, through the more inland saline marsh, which interfaces the cypress swamp and lowland hardwood forest. The known natural trend of the vegetation supports, in general, the trend presented by the classified map. One source of confusion occurred as an "edge effect" where the growth of mangrove peripheral to either coastal beach and water or to marsh grass, in some cases, resembled the multispectral signature for cypress swamp.

Landsat MSS Classification

The Landsat 1 frame 5197-14583 of November 2, 1975, the first nearly cloud-free pass of the summer-fall growing season, was selected for classification. Only tapes 3 and 4 (of a 4-tape set) were used, which constitutes the eastern half of the frame. A computer program initially corrected the raw data for a repetitive sixth scan line interference (attributed to the satellite scanner system) by replacing the relative reflectivity count values in every sixth scan line with the average count for each of the four channels in the preceding set of five scan lines. The computer generated a visual display tape for each band of data; however, the display tape for band 6 was used more than any other for the process of geographically locating the training samples onto the Landsat data. The locations of the training samples were transferred from the aerial color-infrared photography to the multispectral bulk data according to scan lines and element numbers. One hundred thirty-four of the vegetative training samples which had been ground-truthed in September and 20 more water samples were transferred to the Landsat display data.

Training samples were then either accepted or rejected based on the generated statistics of mean, standard deviation and covariance matrix for each band of data for each training sample. The pattern recognition program relied on those training samples approaching normal distributions to classify the remaining data. It was desirable, although not always possible, to formulate training statistics for a given class using at least two or three samples. The relative probability of separating one class from another, or "interclass pairwise divergence," predicted possible conflicts in separation for some of the classes which will be explained in the following text.

The initial classification attempted to identify nearly all cover types, even those that occurred in areas of a size that might have been stretching the limit of Landsat resolution. The later verification data suggested a broader level of classification was a more realistic goal. Consequently, of an original 17 classes, some were grouped to produce a second and final classification of 11 classes listed in figure 3.

The map legend explains the color representation for the various classes. The water class, coded dark blue, included clear coastal water, as well as shallow, sediment-laden areas. The satellite scanner could not resolve red mangrove, which fringed the coastline in a narrow band. Large, interior, homogeneous areas of black mangrove, coded light green, were discriminated from mixed mangrove associations, coded dark green. Since, even in a pure stand of black mangrove, there was some contamination by the other species, the spectral signatures for the two mangrove classes were similar. This contributed to a classification accuracy that was lower for the two individual classes, but higher when the two classes were considered together.

The salt grass category was coded orange and was dominated by the presence of Distichlis spicata growing with sea-blite, grasswort and batis just behind the mangrove swamp. Cord grass and black rush, both salt marsh species, and wet prairie, composed of freshwater grasses and sedges, were collectively termed wetland grasses and coded turquoise. The naturally-occurring communities of mixed wet prairie grasses distributed under sparsely-grown cypress were difficult to categorize.

Brazilian pepper, a shrub unique to the Florida peninsula, was coded violet and appeared as an isolated, but prominent, 1-2 hectare (3-5 acre) stand north of Everglades City. Inland stands dominated by palm with lesser amounts of buckbrush and wax myrtle were coded lime-green.

The mixed cypress swamp was a major inland community, coded yellow, and included cypress, cypress/mixed lowland hardwoods, cypress/slash pine and/or willow in varying proportions. A major conflict occurred between spectrally similar mangrove stands and what was thought to be particularly dense stands of mixed lowland hardwoods codominant with cypress. Because the habitats of mangroves and fresh swamp are nearly mutually exclusive, a program to automatically correct the problem areas was implemented to improve the classification.

Areas of Australian pine, slash pine, and pine/palm hammocks were coded brown and occurred adjacent to the fresh swamp and wet prairie groups. The slash pine in the study area was observed to grow sparsely, perhaps 20-30% crown closure, with exposed understory grasses and sometimes palm. Melaleuca, a cultivated species lately introduced to the area but now escaped, was coded white.

Unclassified areas were coded black and represented phenomena for which no training samples were selected, as in the case of urban, agricultural, and barren areas and the potholes and clouds and cloud shadows to the north. They also represented areas where the reflectivities varied greatly from the statistical acceptance curves developed from the training samples.

As an overview, the Landsat technique distinguished the important ecosystems of the area. The Fahkahatchee Strand, a cypress, hardwoods, mixed pine and palm swamp, shows up prominently inland in figure 3. The classification identified water as a significant component of the Strand. The Corkscrew Swamp, a mixed cypress ecotype east of Naples, is visible on the map. The greater density of pine forest and shrubs/palmetto, indicative of higher topography and drier soil, appeared as expected in the northern region of the scene. Generally, the predominant classes of fresh swamp, pine, grasses, water, and mangrove separated well from one another except for the conflict between fresh swamp and mangrove. Their mutual exclusion in habitats of these two classes resolved the conflict.

Verification of the Florida Wetlands Landsat Classification Accuracy

Computer software randomly selected the verification test fields and outlined them on a high contrast Landsat image derived from bands 2 and 4, given in figure 4. By scaling-off significant features on this image, the helicopter team gauged the approximate location of each field.

The accuracy evaluation ultimately included only those fields located within the area for which the computer was "trained." Thus, the check consisted of 104 fields. The EPA initiated the verification mission approximately one year after the date of the Landsat pass.

The computer printed out a character plot giving the classification of each of the 25 elements within each field outlined on the Landsat classification. An alphabetical letter represented each one of the 23 classes in the character plot. However, similar classes were combined for the evaluation to give the following groups in table II: (1) water, (2) mangroves, (3) salt grass, (4) wetland grasses, (5) Brazilian pepper,

(6) shrubs/palmetto, (7) cypress swamp, (8) pine, (9) melaleuca, and (10) unclassified. Using these groups, the classification was compared to the actual ground data grid with its accompanying evaluation for a typical test field, indicated in figure 5.

To explain the evaluation, let G represent the 25-unit grid on which the ground data were recorded during the helicopter verification mission. Let P represent the 25-digital element character plot of the classified Landsat data for the same test field. First, the data on G were identified and grouped in the same way as the data on P, so that the same vegetation categories could be compared. The number of equivalent units taken up by each group on G was calculated from planimeter measurements. The number of units of a group on G was compared to the number of elements indicated for that same group on P. That number which was coincident to both G and P was recorded for each group. These numbers were summed for all groups in each field. If the sum represented a majority of the elements within the test field, then the test field was counted correctly classified. The EPA performed the identifications, measurements and calculations for all verified test fields.

Assuming the above criteria, the average accuracy of the Landsat classification for all classes was 74%, given in table III. Mangrove, the special interest category, had a Landsat classification accuracy of 87%. The aircraft classification was 68% accurate for all classes.

Cost Analysis Results Provided by NASA/ERL

Table IV summarizes total costs for the demonstration project, initiated in late 1975 and completed in late 1976, except for costs incurred by the EPA analysis of the verification mission. Tables V - VIII detail itemized costs for project planning, data acquisition, data processing, and verification, respectively. The costs do not reflect inflation that has occurred since the completion of the project.

Separation of some of the costs for Landsat and aircraft project planning, data acquisition, and processing was not done at the time when costs were actually incurred. For instance, the project investigators did not convene separate planning for Landsat and aircraft data processing. In view of this, many of these costs reflect only estimates. Table IX summarizes the data in tables IV - VIII and compares the estimated costs of this project had only aircraft or satellite data been used.

Cost-Effectiveness Evaluation Provided by the EPA[1]

Product requirements versus accuracy and cost determined the cost-effectiveness of this remotely sensed mapping technique. The remote identification of mangroves was the primary requirement, with other wetland communities of secondary interest.

The EPA determined the hypothetical cost to produce the vegetation classifications by conventional survey methods, which

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[1]This section is a condensed version of the EPA's independent evaluation of the cost-effectiveness of this demonstration project.

was then compared to the cost of duplicating them by the remotely sensed technique (based on the cost analysis results). However, the EPA stated they could not provide an accuracy for the conventional type of classification because they had never been required to perform an accuracy test. Thus, an accuracy comparison was not possible.

Tables X and XI give an itemized account of costs for conventionally mapping 80 ha. (200 acres) of a Spartina marsh and mixed mangrove forest, respectively.

Table XII provides the costs comparison of both methods using the Spartina marsh and mangrove forest as examples. While a Landsat map of either category costs three cents per ha. to produce, a conventional mangrove map costs approximately 1550 times more and for Spartina, about 550 times more.

According to the EPA, "Mapping a Spartina marsh with conventional techniques would probably be more cost-effective for less than 80 ha. Larger areas of Spartina and any significant areas of mangroves would require remote sensing to be cost-effective." The mangrove forest itself is nearly impenetrable by conventional ground survey.

DISCUSSION

As stated earlier, this project was conceived jointly by the EPA and NASA to test the success of remotely mapping some of the wetland vegetation of Florida. With an inventory map, such as the one derived in this project, the classification that most accurately describes the real land cover situation is desired. However, what determines success is whether the classification results meet certain criteria, one of which should be a defined minimum accuracy. Another is affordable costs. Thus, the "user" has to identify his requirements.

Table XII clearly demonstrates the cost-saving benefit of using the remotely sensed technique. The EPA felt that an accuracy level of approximately 80% was required for a useful classification, and favorably acknowledged the 87% obtained for the mangrove class (table III). In fact, the EPA used the Landsat classification to locate black mangrove basins for a research study of nutrient exchange between black mangroves and the surrounding estuaries and offshore areas. Also, based on the results of this study, the EPA has initiated an inventory of the mangroves along the entire coast of Florida (about 14,000 sq. km.) using the Landsat technique.

The classifications produced from this project were the result of a "first attempt" in processing MSS data of the study area from only a single date, and could be refined. The following text presents possible ways to improve the technique, sources of error, and specific problems encountered in the investigation.

The time of MSS data collection deserves consideration. The September date of the aircraft mission was still within the time frame of vigorous vegetative growth for most species, providing good data for spectral separation. However, the late

November date of the Landsat pass may not have been good for spectral separation. By late fall, the annual leaf drop of some deciduous trees and the annual dying-back of marsh grasses, if they had been extensive, could have constrained the development of distinct and representative spectral signatures.

The "edge effect," referred to in the RESULTS section of this paper, created an initial misclassification in both the aircraft and Landsat processed data. A computer program corrected these areas of misclassification by automatically changing the designated pixels from the class in error to the appropriate class. In other words, the pixels that were initially classified as cypress along the boundary of much of the mangroves were then changed to mangrove. However, this is not a completely accurate fix. Each changed pixel actually represented the integrated spectral response of two cover types, the average of which happened to approximate the spectral response of a third cover type - cypress, in this case.

The "edge effect" is a universal problem in the processing of digital data. It is manifested in the delineation of agricultural fields and urban areas, in particular. The need exists to develop software to (1) identify each edge pixel and (2) classify it according to the identity of the cover type occurring in the highest proportion within the pixel.

The aircraft and Landsat data were classified into similar categories. However, the aircraft classification, which includes the coastal Ten Thousand Islands area, represented only a section of the entire Landsat study area. Some of the training samples incorporated in the aircraft classification, when they met the minimum resolution size requirements of Landsat, were also incorporated in the satellite classification. However, other training samples necessarily were selected to represent other vegetative types growing within the Landsat coverage but not included in the aircraft study area. Since the use of a set of training samples common to both classifications was not feasible, a one-to-one comparison of each class for the two classifications was not possible. The higher resolution of the aircraft scanner provided more detail in the classification of the vegetative communities and other surface features, but the resolution of the Landsat classification was considered adequate for the identification of the majority of the classes.

Australian pine and melaleuca, two exotic species gone wild in the Florida landscape, were not successfully identified with the Landsat technique. The melaleuca has invaded the cypress and hardwood swamps and seems to be competing so successfully that it seriously endangers that ecosystem. It was hoped that Landsat data could be used to monitor the presence of melaleuca as the initial step in controlling its distribution. However, after the field verification, it became apparent that although the melaleuca was widespread, it existed in communities too small to develop a signature for Landsat classification. The technique successfully classified Austrialian pine only when it occurred in extensive areas, which was infrequent. So it was grouped with pine. Neither melaleuca nor Australian pine grew in the aircraft study area. In 1981, when NASA launches Landsat D with its thematic mapper of 30m. resolution, the spatial limitations of the present technique will be reduced.

The final design of the accuracy verification test combined practical and statistical considerations. The percentage of the budget set aside for the verification mission dictated the number of test fields that could be verified by helicopter, considering the rental fee. Even with the budget restrictions, approximately 100 fields (25 elements each) provided an adequate number for statistical analysis.

Geographic uncertainty was a potential source of error in the verification test. If, in verifying a test field that spatially represented a square of 25 digital elements, the position of the hovering helicopter was offset by one element in one direction, the potential misclassification was interpreted as 5/25 or 20%. If offset by one element in both the forward and lateral directions, the interpreted misclassification for the test field was 9/25 or 36%. This would be due to positional uncertainty at the time of verification, and might have caused the conclusion of a lower classification accuracy. The study area did not have many surface features to ease site identification.

A suggested refinement in the verification method, viewed in retrospect, involves the diagramming of the ground cover in each test field based on helicopter observations. With flight time at a premium, each ground diagram was completed as quickly as possible. This amounted to a rather rough sketch in some cases. The areas within the sketched boundaries were then measured by planimeter. In essence, the method of measurement was unnecessarily precise for data that were collected in a less precise way. The results could be improved with more accurate diagrams.

CONCLUSIONS

In a cooperative project, the NASA/Earth Resources Laboratory and the EPA/Region IV applied a NASA remote-sensing technique to meet an EPA objective to inventory the Florida wetlands. The study area took in a part of Big Cypress Swamp and the Ten Thousand Islands, an untouched area dominated almost exclusively by mangroves and pressured by developers. The EPA evaluated the technique for its utility in monitoring the mangroves, in particular. The agency also assessed the cost-effectiveness of the technique. The following conclusions address classification results and the EPA evaluation, respectively.

The conclusions below refer to technical aspects of the Landsat and aircraft MSS classifications:

(1) The major vegetative classes identified by the remote-sensing technique were cypress swamp, pine, wetland grasses, salt grass, mixed mangrove, black mangrove and Brazilian pepper.

(2) Australian pine and melaleuca were not satisfactorily classified from Landsat. These escaped species, though of high

environmental interest, only infrequently occurred in stands large enough to be detected with the data used for this project.

(3) The aircraft scanner provided better resolution resulting in a classification of finer surface detail. However, Landsat scanner resolution was considered adequate for most of the classes of interest.

(4) With both Landsat and aircraft-acquired data, the mangroves were sucessfully identified.

(5) An "edge-effect," created by the integration of diverse spectral responses within boundary elements of digital data, affected the wetlands classification. A solution to the "edge-effect," which occurs in other surface classifications, as well, should be investigated.

(6) The aircraft classification accuracy, averaged for all classes and based on 16 test fields over the 400 sq. km. study area, was 68%.

(7) The average accuracy of the Landsat classification for all classes was 74%, based on 104 test fields over a 4,000 sq. km. project area. Mangroves classified at an accuracy of 87%.

The conclusions below refer to the evaluation of the usefulness and cost-effectiveness of the remote-sensing technique in view of the EPA requirements:

(1) In comparing costs, inventory by the Landsat technique proved far cheaper than by conventional ground survey. Based on the 1,500 sq. km. study area, a mangrove map would cost about $ .03/ha. using the Landsat technique. The same map would cost $46.50/ha. using a conventional method.

(2) For small areas less than 80 ha. that require wetlands inventory, Landsat resolution is too low. In this case, the EPA recommended the use of the aircraft scanner technique or conventional ground survey to produce a surface classification.

(3) The EPA considered adequate the overall Landsat classification accuracy and the accuracy for the mangrove class. The EPA had no data from which they could compute an average accuracy for inventory via conventional method.

(4) The application of a technique is a measure of its usefulness. The EPA used the classification results to locate black mangrove basins in a separate study of nutrient exchange between this species and the surrounding estuaries. Further, the EPA has initiated an inventory of the mangroves along the entire coast of Florida implementing the Landsat remote-sensing technique outlined in this report.

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ACKNOWLEDGMENTS

The EPA participation in this project provided an evaluation of the remote-sensing technique from a "user's" viewpoint. Such outside efforts will lead to the tailored usefulness and relevancy of the NASA-developed technique to individual environmental concerns, both public and private.

The author wishes to thank EPA/Region IV for their cooperation, particularly Delbert Hicks and Hoke Howard, scientists assisting in the project.

The author also thanks the contractor personnel of Lockheed Electronics Co., Inc., for their conscientious efforts in supporting the project. In particular, the expertise of Chris Gauthier, biologist, and Larry Duplessis and Noel Williams, data processors, was appreciated.

TABLE I.- FLORIDA TRAINING SAMPLE DATA GROUPED ACCORDING TO SIMILAR COMPOSITION (Each number identified an individual sample and its location for record-keeping)

Mixed *Avicennia germinans, Laguncularia racemosa, Rhizophora mangle*
1, 3, 5, 6, 33, 34, 36, 37, 65, 66, 69, 71, 96, 97, 100, 102, 103

Mixed *Laguncularia racemosa, Rhizophora mangle*
2

Mixed *Rhizophora mangle, Avicennia germinans*
95, 133, 134

Mixed *Rhizophora mangle, Avicennia germinans*
4

Mixed *Avicennia germinans, Laguncularia racemosa*
101, 122

Avicennia germinans > 70%
35, 38, 63, 64, 65, 70, 121

Rhizophora mangle
125

Distichlis spicata > 60%
7, 43, 44, 68, 105, 107, 115, 120

Spartina spartinae > 60%
8, 9, 10, 11, 13, 19, 118

Juncus roemerianus
104, 106, 112 (?)

Mixed marsh grasses: codominants: *Spartina* sp. *Juncus roemerianus, Eleocharis microcarpa, Distichlis spicata*
32, 48, 68, 73, 114

Wet prairie - Saw blade sedge (unidentified)
14, 22, 25, 39, 52

Sagittaria sp. > 50%
92

Typha latifolia
31, 113

Native grasses and *Taxodium distichum* sparsely distributed:
80

Taxodium distichum > 50%
20, 28, 40 (?), 46, 49, 50, 67, 72, 78, 89, 90, 111, 117

TABLE I - Concluded

<u>Mixed lowland hardwoods with *Taxodium distichum* < 50%</u>
17, 18, 21, 23, 27, 29, 45, 62, 85, 86, 116, 119

<u>Lowland hardwoods: Codominants: *Quercus virginiana, Magnolia, Acer rubrum, Sabal, Myrica cerifera*</u>
16, 27

<u>Mixed *Pinus elliottii, Taxodium distichum* < 50%, and/or palms:</u>
26, 27, 42, 47, 55, 57, 59, 60, 75, 78, 81, 88, 98, 99

<u>Marsh grass and *Pinus elliottii* sparsely distributed:</u>
123

<u>Mixed palms > 50%</u>
51, 56, 82

<u>Mixed *Sabal* and *Taxodium distichum* < 50%</u>
24, 27, 29, 42, 45, 47, 54, 62

<u>Mixed palms and *Pinus elliottii*</u>
53, 58, 61, 77, 79, 82, 83, 110, 124

<u>*Salix nigra* > 50%</u>
84, 91, 93

<u>*Melaleuca*</u>
130

<u>Brazilian pepper = 80%</u>
12

<u>*Casuarina equisetifolia* > 60%</u>
131, 132

<u>Submergent vegetation</u>
76

<u>Water</u>
126, 127, 128, 129, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 155 - 163.

<u>Barren areas</u>
153, 154

TABLE II.- FLORIDA WETLANDS LANDSAT CLASSES COMBINED FOR EVALUATION

	Major Group	Combined Landsat Classes	Landsat Classification Alphabetical Code*
1.	Mixed Mangroves	Red Mangrove	D
		Black Mangrove	E, F
		Mixed Mangrove	G
2.	Salt Grass	Salt Grass	H
3.	Wetland Grasses	Spartina/Juncus	I
		Typha/Eleocharis	J
		Wet Prairie	K
		Sagittaria	V
4.	Brazilian Pepper	Brazilian Pepper	L
5.	Shrubs/Palmetto	Shrubs/Palmetto	M
6.	Cypress	Cypress	N
		Mixed Cypress	O
		Pine/Mixed Cypress	P
		Willow	W
7.	Pine	Pine/Palm	Q
		Mixed Pine	R
		Pine	S
		Australian Pine	U
8.	Melaleuca	Melaleuca	T
9.	Water	Water	A, B, C

*used in character plot shown in figure 5

TABLE III.- LANDSAT AND AIRCRAFT MSS CLASSIFICATION ACCURACIES FOR THE FLORIDA WETLANDS

	No. of Verified Test Fields	No. of Test Fields Accepted As Correctly Classified	Classification Accuracy
Landsat			
All Classes	104	77	74%
Mangrove Class	31	27	87%
Aircraft			
All Classes	16	11	68%

TABLE IV.- TOTAL COSTS FOR THE EPA/NASA FLORIDA WETLANDS REMOTE SENSING PROJECT

Project Planning and Preparation	4,125
Data Acquisition	9,483
Data Processing	7,850
Verification	1,460
TOTAL	$22,918

TABLE V. - ITEMIZED COSTS FOR PROJECT PLANNING AND PREPARATION

Activity:	COSTS Actual Landsat & Aircraft Project	Projected Landsat Project Only	Projected Aircraft Project Only
Planning, Supervision and Coordination			
NASA Civil Service - 80 Manhours	$800.	$500.	$300.
Support Contractor - 40 Manhours	400.	250.	150.
EPA - 40 Manhours	400.	300.	100.
Mission Preparation			
Labor (ERL Support Contractor)			
Photomosaic preparation - 50 Manhours	500.	0*	0*
Selection of Training Samples - 49 Manhours	490.	475.	157.
Mission Package Preparation - 20 Manhours	200.	80.	200.
Literature Search - 80 Manhours	800.	0**	0**
Materials			
Reference Book (Univ. of Miami)	24.	0**	0**
Color IR Prints (Mark Hurd Co.)	500.	500.	500.
Black & White Prints (USPI)	3.	0	3.
Maps & Graphic Supplies (Support Contractor Stock)	8.	8.	8.
TOTAL	$4,125.	$2,113.	$1,418.

NOTES:

*Photomosaic not considered necessary for general/production (Non R&D) remote sensing exercises.
**Not considered necessary when field personnel are thoroughly familiar with test site.

TABLE VI.- ITEMIZED COSTS FOR DATA ACQUISITION

Type of Data:	COSTS Actual Landsat & Aircraft Project	Projected Landsat Project Only	Projected Aircraft Project Only
Satellite Data			
Landsat Tape	$200.	$200.	0
Aircraft Data			
Magnetic Tape for RS-18 MSS	260.	0	260.
Aircraft fuel and oil	383.	0	383.
9" color infrared film	261.	0	261.
Support Contractor			
Salaries - 242 Manhours	2,430.	0	2,430.
Expenses (food, lodging, transportation)	1,216.	0	1,216.
Ground Truth Data			
Support Contractor			
Salaries - 40 Manhours	400.	388.	128.
Expenses (food, lodging, transportation)	184.	178.	59.
NASA Civil Service			
Salaries - 40 Manhours	400.	388.	128.
Expenses (food, lodging, transportation)	184.	178.	59.
EPA			
Salaries - 80 Manhours	800.	776.	256.
Expenses (food, lodging, transportation)	368.	356.	118.
Materials and Services			
Helicopter Rental			
Support Contractor	493.	478.	158.
EPA	884.	857.	283.

TABLE VI.- Concluded

	COSTS		
	Actual Landsat & Aircraft Project	Projected Landsat Project Only	Projected Aircraft Project Only
Cataloguing			
Preparation of Herbarium samples and integration of data cards and ground truth forms into file system. 100 manhours	1,000.	970.	320.
TOTAL	$9,483	$4,788.	$6,065.

TABLE VII. - ITEMIZED COSTS FOR DATA PROCESSING[a]

Type of Data:	COSTS Actual Landsat & Aircraft Project	Projected Landsat Project Only	Projected Aircraft Project Only
Landsat Data			
Computer Classification of Data			
NASA Civil Service - 80 Manhours	$800.	$800.	0
Support Contractor - 200 Manhours	2,000	2,000	0
Product Preparation			
Photographic Laboratory	175.	175.	0
Graphics Support - 20 Manhours	200.	200.	0
Aircraft Data			
Computer Classification of Data			
NASA Civil Service - 80 Manhours	800.	0	800.
Support Contractor - 350 Manhours	3,500.	0	3,500
Product Preparation			
Photographic Laboratory	175.	0	175.
Graphics Support - 20 Manhours	200.	0	200.
TOTAL	$7,850	$3,175	$4,675

TABLE VIII.- ITEMIZED COSTS FOR ACCURACY VERIFICATION

Site Visitation by EPA	
Salaries - 48 Manhours	$480.
Expenses (food, lodging, transportation)	300.
Helicopter Rental	680.
TOTAL	$1,460

NOTES:

[a]This effort is not considered necessary if the accuracy for the technique has been previously established by the user to his satisfaction.

TABLE IX. - COMPARISON OF ESTIMATED COSTS FOR THE FLORIDA WETLANDS REMOTE SENSING PROJECT USING ONLY LANDSAT OR AIRCRAFT DATA[a]

ITEM	LANDSAT COST ESTIMATE[d]	AIRCRAFT COST ESTIMATE[e]
Project Planning and Preparation	$2,113.	$1,418.
Data Acquisition	4,788.	6,065.
Data Processing		
NASA Civil Service	800.	800.
Other Support Work[b]	2,375.	3,875.
SUBTOTAL	$10,076.	$12,158.
Accuracy Verification[c]	(1,460.)	(1,460.)
TOTAL	($11,536.)	($13,618.)

NOTES:

a. Estimated costs based on defined project test area size. The classification of additional airborne or Landsat data would not increase costs proportionately since many items, once accounted for, would not be repeated for additional data.

b. Data processing item is similar in content to the service obtainable from private industry.

c. This effort may not be necessary if the accuracy for the remote sensing technique has been previously established by the user to his satisfaction.

d. Estimate based on a land area size of approximately 1500 square miles.

e. Estimate based on a land area size of apvroximately 150 square miles.

TABLE X.- ESTIMATED COSTS FOR CONVENTIONAL MAPPING METHODS FOR A SPARTINA MARSH[a] (80 ha.)

Aerial Photo Duplicates	$50.00
Study Preparation (2 mandays)	146.00
Study (8 mandays)	584.00
Travel Expenses	106.00
Transportation GSA	50.00
Lab Work (6 mandays)	438.00
TOTAL	$1,324.00
Cost/ ha.	$16.50

Computed by the EPA

TABLE XI. - ESTIMATED COSTS OF CONVENTIONAL MAPPING METHODS FOR A MANGROVE FOREST[a] (80 ha.)

Aerial Photos	\$50.00
Study Preparation (4 mandays)	292.00
Study (10 mandays)	730.40
Travel Expenses (10 mandays)	350.00
Transportation GSA	100.00
Lab Work (20 mandays)	2,191.00
TOTAL	\$3,713.40
Cost/ ha.	\$46.50

[a] Computed by the EPA.

TABLE XII. - COST COMPARISON BETWEEN THE LANDSAT AND CONVENTIONAL CLASSIFICATION TECHNIQUES

Technique	Class Type: *Spartina* Marsh	Class Type: Mangrove Forest
Landsat	$ .03/ha.	$ .03/ha.
Conventional Survey	$16.50/ha.	$46.50/ha.

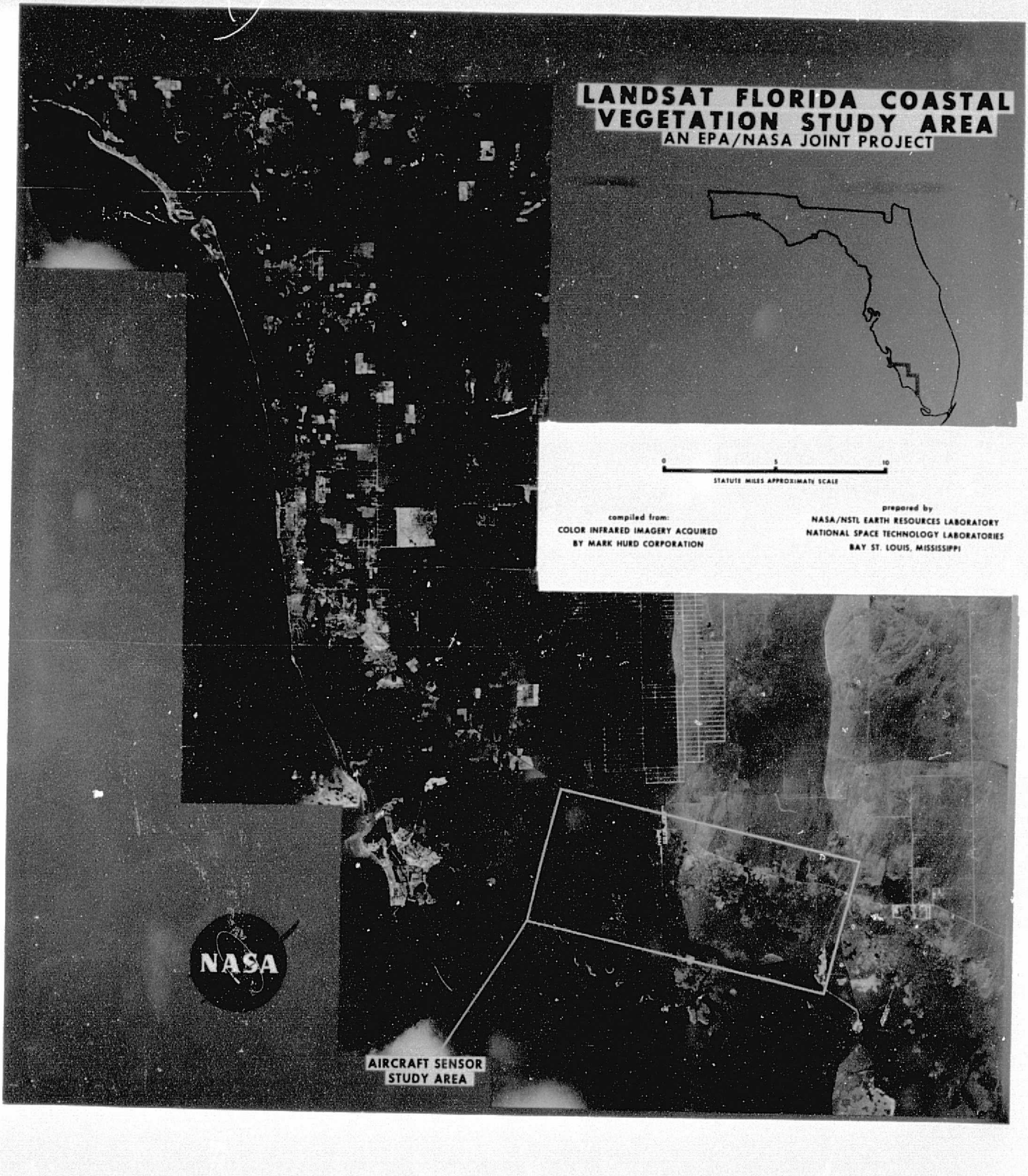


Figure 1. Mosaic of aerial color-infrared photography of the study area.

FLORIDA WETLANDS VEGETATION CLASSIFICATION

DERIVED FROM RS-18-MS SCANNER DATA ACQUIRED AT 3050 M FLYING HEIGHT

SEP. 18, 1975

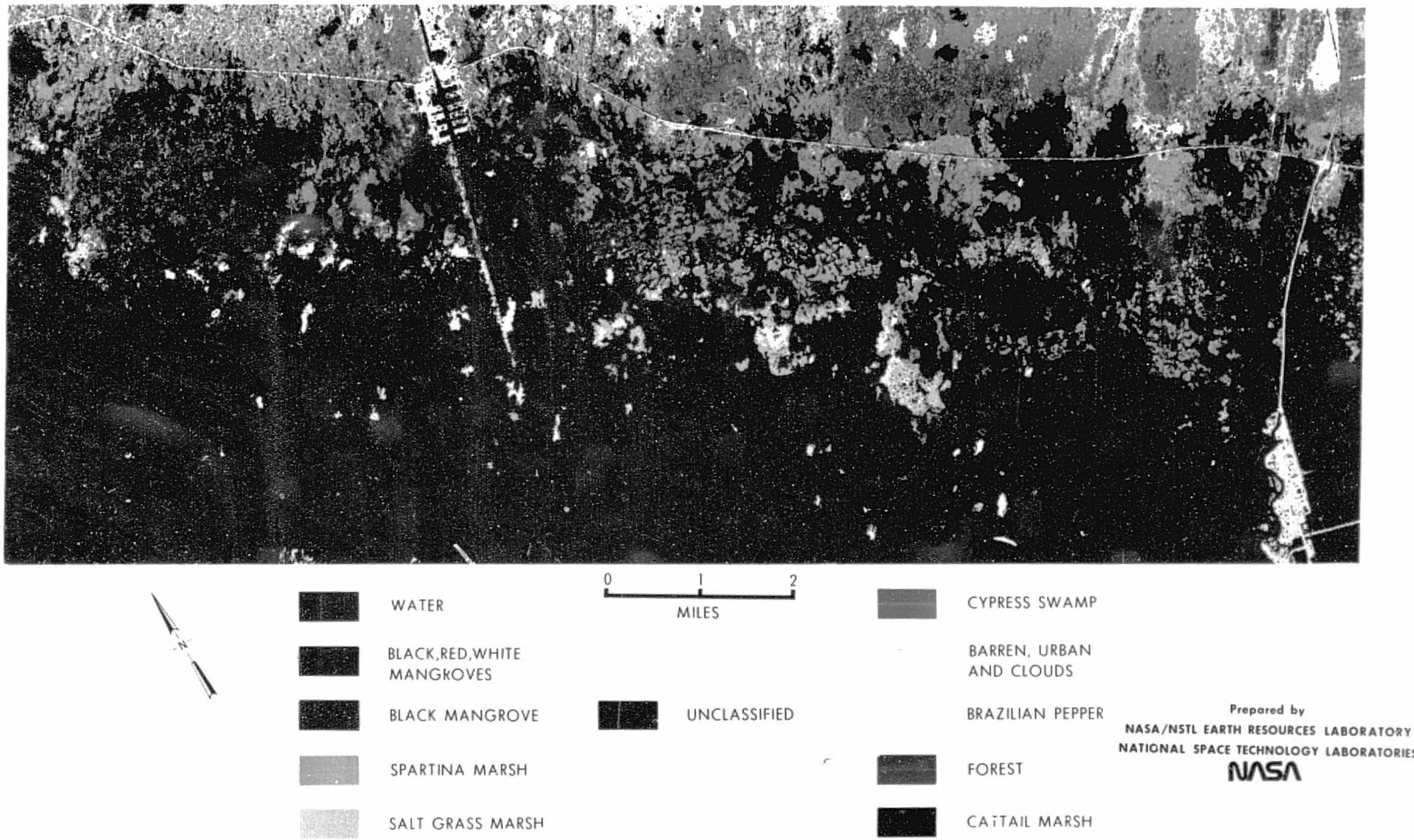


Figure 2. Aircraft MSS classification of the vegetation in the Ten Thousand Island area.

FLORIDA WETLANDS VEGETATION CLASSIFICATION DERIVED FROM LANDSAT I SCANNER DATA NOVEMBER 2, 1975

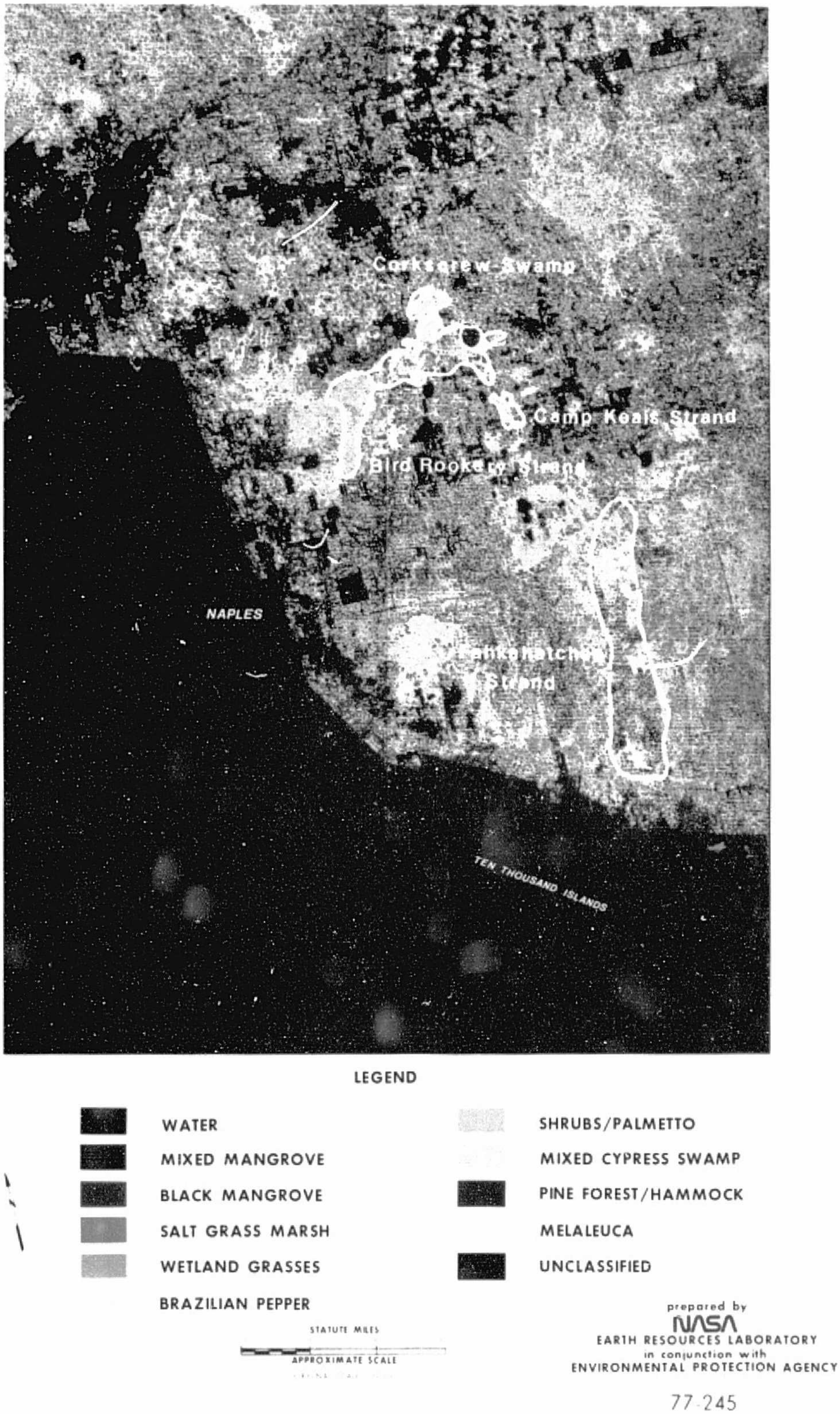


Figure 3. Landsat MSS classification of the study area indicating note-worthy cypress strands and swamps and their apparent composition.

LANDSAT PSEUDO-COLOR DISPLAY OF FLORIDA WETLANDS

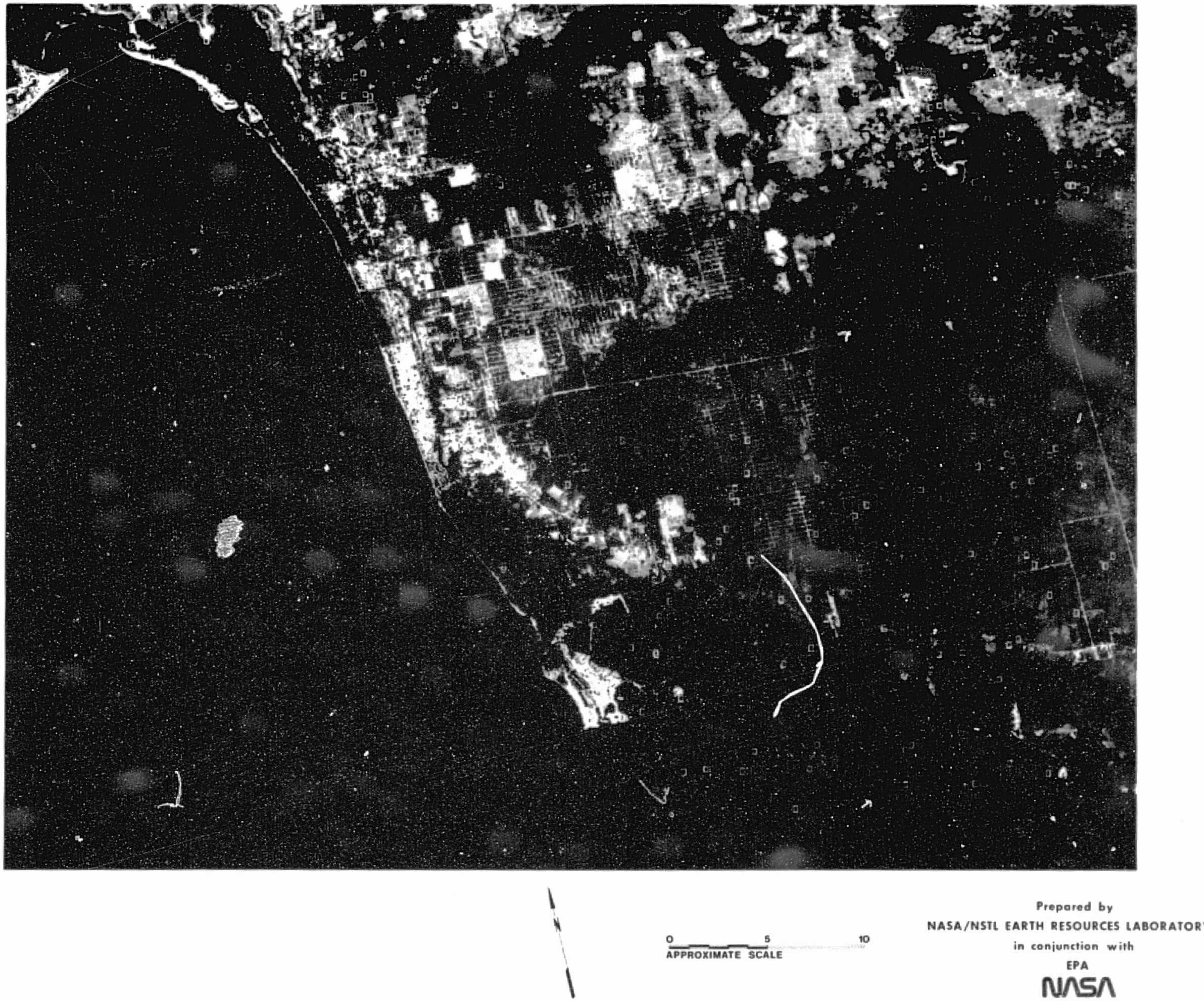
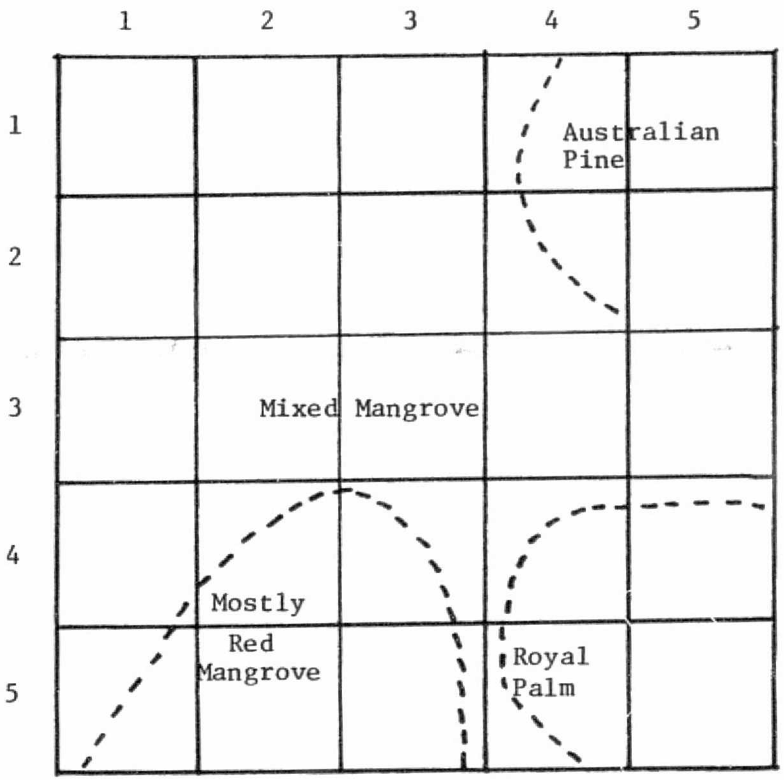


Figure 4. Landsat raw data display indicating locations of randomly selected verification test fields (yellow boxes).



Ground Data Grid G

	1	2	3	4	5
1	E	G	K	G	G
2	E	G	G	G	G
3	G	G	G	G	G
4	G	G	G	K	G
5	G	E	G	-	-

Landsat Character Plot P
(See Table II for Code)

	Observed (from G)	Landsat Classification (from P)	Correctly Classified
Black Mangrove (E,F)	0	3	
Mixed Mangrove (D,G)	19.75	18	18
Wet Prairie (K)	0	2	
Australian Pine	2.75	0	
Unclassified	2.50	2	2
Total	25	25	20

Figure 5.- Accuracy evaluation for test field no. 186. Red mangrove appearing on G was included in the mixed mangrove category. Since a royal palm class was not developed, it fell in the unclassified category.

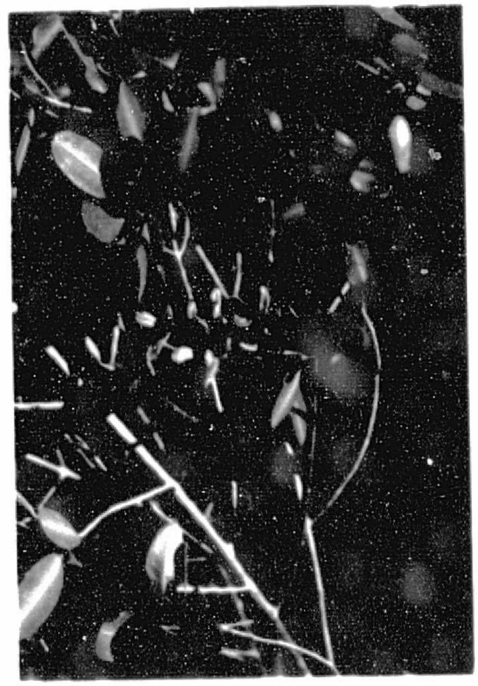
APPENDIX

This section includes (1) a list of the common names of the Florida plant species encountered in this project and their Latin names, and (2) representative photos of the mangroves.

TABLE XIII.- FLORIDA VEGETATIVE SPECIES REFERENCE

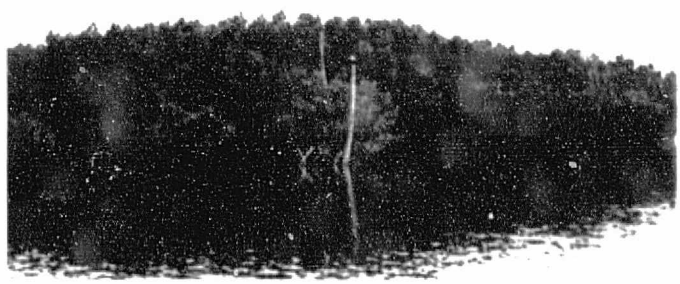
Common Name	Latin Name
red mangrove	*Rhizophora mangle*
black mangrove	*Avicennia germinans*
white mangrove	*Laguncularia racemosa*
salt grass	*Distichlis spicata*
cattail	*Typha latifolia*
wet prairie	mixed grasses & sedges *(Cyperus sp.)*
Brazilian pepper	*Schinus terebenthifolius*
palm	*Serenoa repens*
buckbrush	*Baccharis halimifolia*
cypress	*Taxodium distichum*
slash pine	*Pinus elliottii*
melaleuca	*Melaleuca quinquenervia*
Australian pine	*Casuarina equisetifolia*
bulltongue	*Sagittaria falcata*
willow	*Salix caroliniana*
black rush	*Juncus roemerianus*
cord grass	*Spartina spartinae*
glasswort	*Salicornia virginica*
sea-blite	*Suaeda linearia*
batis	*Batis maritima*
spike rush	*Eleocharis microcarpa*
mixed lowland hardwoods	
red maple	*Acer rubrum*
sweet bay	*Magnolia virginiana*
wax myrtle	*Myrica cerifera*
sweet gum	*Liquidambar styraciflua*
live oak	*Quercus virginiana*

Inner estuary of mixed mangroves.



White mangrove in fruit. Leathery leaves are common to all three mangrove species

Stand of red mangrove with prominent prop roots.



Dense mixed mangrove forest fringing a coastal inlet.

Figure 6. Photographs of Florida mangroves taken during the ground truth mission.