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M. Kristine Butera

Lyndon B. Johnson Space Center
Houston, Texas

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16 Abstract

Vegetation in selected study areas on the Louisiana coast was mapped using low-altitude aircraft and satellite (Landsat) multispectral scanner data. Fresh, brackish, and saline marshes were then determined from the remotely sensed presence of dominant indicator plant associations. Such vegetational classifications were achieved from data processed through a standard pattern-recognition computer program. The marsh salinity zone maps from the aircraft and satellite data compared favorably within the broad salinity regimes. The salinity zone boundaries determined by remote sensing compared favorably with those interpolated from line-transect field observations from an earlier year. The advantage of the remotely sensed determination of zones is that it offers a greater confidence in product accuracy because of total area coverage with shorter time period for data collection and analysis. A vegetation map produced from remotely sensed data can be used not only to determine salinity zones but also to derive productivity and wildlife habitat maps for management practices and to detect changes.

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A TECHNIQUE FOR THE DETERMINATION OF LOUISIANA MARSH SALINITY ZONES FROM VEGETATION MAPPED BY MULTISPECTRAL SCANNER DATA: A COMPARISON OF SATELLITE AND AIRCRAFT DATA

By M. Kristine Butera
Lyndon B. Johnson Space Center*

SUMMARY

The objective of this investigation was to map the vegetation growing in selected study areas on the Louisiana coast using low-altitude aircraft and satellite (Landsat) multispectral scanner data and then to determine the fresh, brackish, and saline marshes from the remotely sensed presence of dominant indicator plant associations. Such vegetational classifications were achieved from data processed through a standard pattern-recognition computer program. The marsh salinity zone maps from the aircraft and satellite data compared favorably within the broad salinity regimes. The salinity zone boundaries determined by remote sensing compared favorably with those interpolated from line-transect field observations from an earlier year. However, the advantage of the remotely sensed determination of zones is that it offers a greater confidence in product accuracy because of total area coverage with a shorter time period for data collection and analysis. A vegetation map produced from remotely sensed data can be used as a baseline not only to determine salinity zones but also to derive productivity and wildlife habitat maps for management practices and to detect changes.

INTRODUCTION

The coastal marsh of Louisiana is characterized as nonforested wetland that originated as a deltaic plain. This plain was formed by sediment deposition from the changing courses of the Red, Atchafalaya, and Mississippi Rivers as they made their way to the Gulf Coast from very early times.

The sediments discharged to the Gulf of Mexico were swept westward and parallel to the coastline to form the chenier plain, the oldest substrate in coastal Louisiana and what is now the western edge of the state. The coastal midsection of the state, termed the inactive delta, succeeds the chenier plain

*Coastal Applications Group, Earth Resources Laboratory at the Slidell Computer Complex, Slidell, Louisiana 70458.

in development and was formed by the compaction and subsidence of old river sediments, which ultimately created the floating marshes, or canouche, of principally the Lafourche and Terrebonne parishes. Such flotage deceptively manifests a firm surface where, in actuality, the hard clay pan lies as much as 4.6 meters (15 feet) below. The active delta, the southeastern portion of coastal Louisiana, represents the youngest substrate and is still being formed by the present Mississippi River system.

The coastal marshes of Louisiana cover approximately 1.7×10^{10} square meters (4.2×10^{6} acres) of wetland vegetated mostly by sedges, grasses, and other herbaceous types (ref. 1). The value of these marshes lies in their ecological, commercial, and recreational contributions to the people and wildlife that this kind of land supports. Besides providing vast feeding grounds for game and waterfowl, the Louisiana coastal area offers breeding waters in its bayous and protected estuaries for commercially valuable shrimp, oysters, crabs, and menhaden (ref. 2). Portions of the Louisiana wetland have been drained for cultivation of rice and sugarcane; other portions are potential agricultural sites. Such abundant resources demonstrate the need for careful management of the extensive Louisiana marsh to ensure its renewability and value. Because the type of vegetation growing in a given area is an expression of its environment (e.g., soil, hydrological, and climatic factors), monitoring the flora provides a clue to the status of the environment and thus is an aid to marsh management.

The use of the multispectral scanner (MSS) to identify vegetation is a practical technique because this sensor can provide total coverage over an extensive area. The multispectral data can be semiautomatically analyzed for vegetation identification and mapping. Specifically, the technique can be applied to the problem of salinity intrusion that threatens the ecological balance in the Louisiana marsh. This salinity intrusion jeopardizes the delicately balanced, brackish-water nursery grounds for commercial fish and shellfish. It can also cause vegetation die-off, which results in erosion and land loss and diminishes potential agricultural acreage.

Salinity generally refers to the measurement of total soluble salts, mostly those of sodium and magnesium, and is correlated with the exchangeability of the cation and solution conductivity. The presence of certain associations of plant species has been recognized as an indicator of surface water salinity and soil salinity levels in the Louisiana marsh. In Penfound and Hathaway's comprehensive study of the Louisiana marsh in 1938 (ref. 3), the distribution of marsh vegetation was correlated with the salinity of soil water, or free subsurface water associated with the soil. The conclusion was that there was a "gradual transition from the nearly fresh to the saline marsh type, with broad ecotones, often several square miles in extent, connecting them." On the basis of soil-water salinity and the salt tolerance of each species, Penfound and Hathaway arranged their swamp and marsh dominants into four salinity zones: strictly fresh, nearly fresh, brackish, and saline. In 1949, O'Neil (ref. 4) used the same concept of vegetation correlated with salinity to map fresh, brackish, and saline marsh zones along the entire Louisiana coastline.

Chapman, a leading figure in the study of salt-tolerant and obligate vegetation, disputes the idea that salinity is the major determinant of vegetation type in the marsh (ref. 5). He contends such factors as tidal phenomena, soil type, vertical and horizontal salinity gradients in the soil, rainfall, and temperature influence the growth of certain marsh plant species to the exclusion of others. He also points out that because tidal effects extend inland, the roots of plants in all coastal zones must tolerate high salinity for at least a short period of time, irrespective of the distance inland from the coast.

The controversy of whether salinity is the greatest, or only, factor in determining vegetation type in the marsh will not be addressed in this report. This study assumes there is a positive correlation between salinity and vegetation in the Louisiana marsh, based on the other investigations described.

Chabreck et al. (ref. 6) prepared a vegetative type map in 1968 that defines four salinity zones on the Louisiana coast: fresh, intermediate, brackish, and saline (fig. 1). Their zones were determined by field observations made along 39 parallel transect lines spaced 12 kilometers (7.5 miles) apart and averaging approximately 64 kilometers (40 miles) in length, oriented north to south across the entire Louisiana coast. Plant species were identified at spot locations every 400 meters (0.25 mile) along each transect line. From these field data, Chabreck et al. interpolated the zonal boundaries, using Penfound and Hathaway's vegetational associations as salinity indicators. The completed map has become a reference source for state and federal agencies (e.g., U.S. Corps of Engineers, Louisiana Wildlife and Fisheries Commission) whose activities relate to the management of the Louisiana coastal marshes.

The feasibility of applying a computer-implemented multispectral remote-sensing technique to similarly obtain a marsh salinity zone map was proposed for this study. The advantages of a remotely sensed product compared to a map prepared in the manner of Chabreck et al. would be (1) total area coverage, which implies greater accuracy and a capability to detect smaller, anomalous areas within a broad zone, and (2) greater efficiency, derived from nearly instantaneous data acquisition and automated data processing. Past work of other investigators (refs. 7 and 8) has indicated a capability to analyze satellite data for coastal wetland plant community mapping.

Thus, this report outlines the development of a technique at the NASA Earth Resources Laboratory (ERL), Slidell, Louisiana, to use multispectral remotely sensed data, acquired by aircraft and satellite, to produce a map defining marsh salinity zones on a portion of the Louisiana coast. The technique is based on the remote identification of vegetational associations. It is believed that this technique may also be extended to vegetation mapping and salinity zone determination in other coastal areas because, as quoted from reference 9, "There is an amazing uniformity of marsh succession from Nova Scotia to Mexico where water is the equalizer and sodium chloride is the limiter."

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

OBJECTIVE

The objective of this experiment was to develop a computer-implemented multispectral remote-sensing technique to map the vegetation growing in selected study areas on the Louisiana coast from which marsh salinity zones could be inferred. Techniques using both aircraft and satellite data were to be developed, and the products from each technique were to be compared.

DESCRIPTION OF STUDY AREAS

Two areas on the Louisiana coast were selected for study. One location included the Lake Borgne and Mississippi River Gulf Outlet, and the other included an area intersected by Bayou Lafourche and bounded by Caminada and Timbalier Bays (fig. 2). Each area covered approximately 3500 square kilometers. Both study areas are believed to be experiencing an increase in salinity levels caused by saltwater intrusion from the Gulf of Mexico. This intrusion has been enhanced by canals dredged for petroleum production and mosquito control and by the loss of annual freshwater flooding from the Mississippi River due to the imposed levee system.

DATA ACQUISITION

Multispectral scanner and photographic data were acquired over the two study areas by the NASA NP3A aircraft in a 13-flight-line design set (fig. 2) on October 2, 1974. A modular multiband scanner capable of detecting 11 discrete bandwidths of data was used. Flight data were recorded in the mission 287/104 log (table I). An explanation for the orientation of the flight lines is given in the section entitled "Discussion." Computer-compatible tapes of satellite multispectral data from a Landsat-1 pass on October 8, 1974, were acquired for processing. These data (frames 1807-15505 and 1807-15512) covered the study areas. A comparison of channel widths for the aircraft and satellite scanners with a graph of general green-leaf reflectivity is shown in figure 3.

Ground-truth fieldwork was conducted in August and September of 1974 to locate and identify training samples of the dominant vegetative types for each salinity zone. The training samples were used in the pattern-recognition method for classification of both types of scanner data. Because the marsh is nearly inaccessible by car and extensive observations by boat are constrained, observations were made from a 47G Bell helicopter. Aerial photographs of the training fields were taken with a Hasselblad camera mounted on the helicopter. Information regarding the identity and percentage of each species within the training sample, its stage and vigor, the amount of dead biomass, and the percentage of exposed surface material such as mud or water was recorded verbally on tape and later transcribed onto field cards to which contact prints of the photographs taken from the helicopter were attached. A sample card is shown in figure 4. If plant identity could not be established by aerial observation alone, the helicopter was landed for infield scrutiny of the vegetation. If a species still could not be readily identified, a specimen was collected for more thorough study and confirmation of identification in the laboratory.

The training samples to be investigated by helicopter were located on color-infrared aerial photographs from a 1973 NASA mission. The samples were chosen to represent areas of vegetation that displayed a unique combination of texture and color. Each sample was assigned a number. Black-and-white expanded reproductions of the color-infrared photographs, on which the training samples were plotted and numbered, were used as field "maps." The training samples were also plotted on a 1:250 000-scale U.S. Geological Survey (USGS) map to depict their relative locations. Approximately 200 samples were considered for the ground-truth phase. Each training sample used for the aircraft classification measured at least 85 by 85 meters. This area was derived from a statistical requirement of 25 samples for a normal distribution within the training field population, where each sample measured 17 meters square based on the resolution cell size of the aircraft scanner data at an altitude of 6.7 kilometers. Training samples for satellite data measured at least 3 by 3 cells, based on a resolution cell size of 56 by 79 meters.

DATA PROCESSING

Both the aircraft and satellite MSS devices work on the principle of detecting and recording, in discrete wavelengths, energy reflected and emitted from surface material. This information was recorded for each resolution cell, or instantaneous field of view, as the scanner swept across an area on the ground perpendicular to the line of flight. Computerized multispectral "signatures" were developed for the ground cover identified in the training samples. The signatures were then used to identify each cell of the raw scanner data having reflectivity responses with best fit to those of a given training sample. In this way, the raw data were classified into ground-cover types.

Both the aircraft and satellite MSS data were processed through a pattern-recognition technique developed at ERL (ref. 11). A generalized flow chart of the processing is shown in figure 5. All data processing was accomplished at the data analysis station (DAS) at ERL. The DAS consists of the following equipment.

1. An instrumentation tape reproducer/recorder used to read the aircraft MSS data

2. A high-speed general-purpose digital minicomputer

3. A high-speed line printer

4. Two 380-cm/sec (150-in/sec) digital tape recorders/reproducers used to read the Landsat MSS magnetic tapes

5. A color screen display used to provide fast presentations of sensor data for evaluation by the system operator and equipped with a light-pen cursor to delineate data areas of interest

6. A camera system capable of recording data presentations on 24-cm-wide strip film in color or black and white

7. An interactive operator control console to provide operator-processor communication and control

A variable degree of noise was apparent in all the operating channels of the aircraft MSS; therefore, the four channels recording the "cleanest" data were selected for use in the pattern-recognition program. These were channels 5, 6, 8, and 9. (See fig. 3 for wavelengths). The aircraft MSS channels sensing the shorter wavelengths were eliminated from the processing because of the more noticeable atmospheric interference. Landsat bands 4, 5, 6, and 7 were used in processing the satellite data.

Results of the classifications of the training samples, called "scorecards," were extracted with an ERL computer program. The classified products derived from aircraft data were rectified during film recording to improve geometric fidelity over a scan width ±45° from nadir. Data beyond the ±45° scan range were discarded as unreliable. The satellite sensor generates minimal distortion because of its narrow scan angle of ±6°. Satellite data can also be rectified.

Because ponds, lakes, and bayous (as well as larger coastal waters) are major wetland components, their discrimination is essential to a definitive marsh classification. Water in this investigation was underclassified using standard, four-channel pattern recognition; therefore, a "water search" program was implemented on one set of aircraft data to separate water from all other classes. "Water search" is an ERL-developed technique that considers training-sample data based on two negatively correlated channels.

MARSH SALINITY ANALYSIS

Although Chabreck emphasized that associations of species, rather than individual species, best represented the various marsh salinity zones, success with the MSS technique required the sensing of dominant (most frequently occurring) plants. Chabreck's intermediate marsh zone was not considered in the MSS classification because of the arbitrary nature of its definition. For this investigation, the marsh salinity zones were identified by the presence of the following dominant species, which sometimes existed as codominants that could be remotely sensed.

Fresh marsh	Sagittaria falcata, Panicum hemitomon, Eichhornia crassipes
Brackish marsh	Spartina patens, Scirpus species, Phragmites communis
Saline marsh	Spartina alterniflora, Juncus roemerianus, Distichlis spicata, Avicennia nitida

FIELD VERIFICATION OF THE CLASSIFICATIONS

The field verification of the classifications was relatively simple. The test fields were points of approximately equal distance apart and were selected from the classified maps for identification of the vegetation at the same ground points. The field check was conducted by helicopter. The ratio of those test fields correctly classified to the total number of verified test fields represented the classification accuracy.

RESULTS

Locations and descriptions of the dominant vegetational species and exposed surface material observed for each training sample used in the classifications of aircraft and satellite data are given in the appendix. The specific training samples incorporated in each classification are also listed. Generally, the training samples selected for the classifications were homogeneous; i.e., each sample was dominated by one species (usually greater than 75 percent), although other species may have been associated with it in a lesser quantity. Some samples of mixed dominants had to be included to represent frequently occurring natural associations of codomination. Some of the training samples contained a relatively high percentage of surface water, a natural wetland condition that must be considered in developing multispectral signatures. Descriptions and reproductions of the filmed, classified products are given in the following sections.

Aircraft MSS Classification of Marsh Vegetational Species, Flight Line 3

The initial species classification of MSS data from flight line 3 is shown in figure 6 and represents the identification of Sagittaria falcata with Panicum hemitomon, Myrica cerifera with Panicum hemitomon, Spartina patens, Spartina alterniflora, Spartina alterniflora with Avicennia nitida, and water. A transition from fresh marsh species (Panicum hemitomon, Sagittaria falcata, Myrica cerifera) at the northern end of the flight line through brackish marsh species (predominantly Spartina patens) to the saline marsh species (Spartina alterniflora and Avicennia nitida) closer to the coast was detected by the aircraft multispectral scanner. The salinity zone delineations were geographically similar to those of Chabreck's map (fig. 1). However, contrary to

Chabreck, an intermediate zone was not considered for classification because it was believed that its vegetational components could be merged into either the fresh or brackish categories. Because this investigation concentrated on wetlands, training samples for urban, barren, and agricultural areas were not incorporated in the pattern-recognition program (though they can routinely be processed) and thus account for much of the unclassified data. Areas of unclassified data known to be water still remained. Minor misclassification occurred between fresh marsh species and what was known to be agricultural fields.

Aircraft MSS Classification of Marsh Salinity Zones for the Terrebonne Bay Area, Flight Lines 2 to 5

A mosaic of data from four parallel aircraft flight lines is shown in figure 7(a) and represents a vegetational species classification color-coded for the three marsh salinity zones. All pixels classifying as either a codominant association of *Sagittaria falcata* with *Panicum hemitomon* or of *Myrica cerifera* with *Panicum hemitomon* were coded green for fresh marsh. All pixels classifying as either *Spartina patens*, *Scirpus* species, or an association of *Spartina patens* and *Spartina alterniflora* were coded yellow for brackish marsh. Those pixels classifying as *Spartina alterniflora* or an association of *Avicennia nitida* and *Spartina alterniflora* were coded pink for saline marsh. A preliminary classification of these flight lines indicated there was a high percentage of known bodies of water that were left unclassified. A subsequent classification using the water-search program to identify water visibly improved classification accuracy of water by at least 20 percent. A scaled representation of Chabreck's salinity zone delineations for the same area is provided for comparison in figure 7(b). His intermediate zone is irrelevant to this work, and one may assume that the remotely sensed fresh/brackish interface lies somewhere within his intermediate category. The major difference between the results of Chabreck's map and the results of this investigation is that the brackish zone appears more extensive in the latter. The accuracy of this classification was approximately 66 percent.

Landsat MSS Classification of Marsh Salinity Zones for the Lake Borgne Area

A mosaic of two tapes from Landsat frame 1807-15512 is shown in figure 8(a) and represents a delineation of the marsh salinity zones derived similarly to those in figure 7. It covers approximately the same study area. The remaining categories were developed for an ERL related project. A qualitative comparison between this product and the mosaicked aircraft classification indicates the boundaries for the marsh salinity zones were approximately the same.

For comparison, Chabreck's 1968 salinity zone determinations are presented in figure 8(b) at a scale to match this classification. This MSS classification had an accuracy of 83 percent.

Aircraft MSS Classification of Marsh Salinity Zones for the Lake Borgne Area, Flight Lines 8 to 15

A mosaic of MSS data from eight parallel flight lines is shown in figure 9. This mosaic was produced similarly to the aircraft classification in figure 7. However, the fresh marsh zone has been omitted because of the scarcity of fresh marsh species in this area. The brackish water of Lake Borgne and the probable salt intrusion of the Mississippi River Gulf Outlet contribute to the infrequency of the fresh marsh species.

From the species classification, all pixels identified as either *Phragmites communis* or *Spartina patens* were coded dark pink for brackish marsh, whereas those pixels identified as either *Spartina alterniflora* or *Juncus roemerianus* were coded light pink for saline marsh. A slight gradient, which is poorly represented because of color-filming problems, appears in the marsh zones as the saline components dominate the coastal edge. Forested areas composed largely of *Magnolia virginiana*, *Quercus nigra*, and *Liquidambar styraciflua* were coded green and appeared in dense concentration along the banks of the Mississippi River and major inland bayous. Forested wetlands characterized by *Taxodium distichum*, *Salix nigra*, *Baccharis halimifolia*, and palmetto were coded light blue and were identified as a fringe element between the forest and the marsh; they also appeared along small bayous and in isolated areas (some presumably old streambeds) closer to the coast. Because the water-search program was not used, some bodies of water, particularly turbid ones such as the Mississippi River, were left unclassified.

The appearance of random, horizontal banding was a function of instrumental noise and created bands of misclassified data where it existed, amounting to as much as 50-percent data interference in some areas. The classification was approximately 85-percent accurate.

Landsat MSS Classification of Marsh Salinity Zones for the Terrebonne Bay Area

A mosaic of two tapes of Landsat frame 1807-15505 is shown in figure 10(a) and represents a delineation of the marsh salinity zones derived similarly to those in figure 9. It encompasses the same study area. As in figure 9, only the brackish and saline zones occur significantly in this coastal area, probably because of the interface of this area with the brackish water of Lake Borgne, the salinity intrusion of the Mississippi River Gulf Outlet, and the absence of river water influence due to the levee system. A qualitative comparison between figure 10(a) and figure 9 indicates the same trend occurs in both; i.e., the more saline areas are closer to the coastal water. Chabreck's 1968 zones are provided in figure 10(b) for comparison of the results of the two different methods. The accuracy for this classification was approximately 80 percent.

TRAINING SAMPLE CLASSIFICATIONS

The training sample classifications for the aircraft MSS data sets are arranged in tables II, III, and IV to show the percent occurrences by class name. These tables represent "scorecard" analyses, or a computer record of the classifications for the composition of each training sample, indicating its degree of homogeneity. The purity of most of the classified training samples was generally high; many exceeded 90 percent. Where there was a low percent occurrence of class "x" within the training sample for class "x," relatively high percent occurrences of other classes known to associate naturally with class "x" were recorded for the training sample. For instance, table III indicates class SA material constitutes 53.87 percent of training sample SA 59, but also 19.93 percent of the training sample classified as SPSA. Because SPSA is a natural species association and SA is common to both classes, it is reasonable to expect some pixels of training sample 59 to classify as SA and others as SPSA. The same situation may exist when there is some overlap in the multispectral signatures developed for the classes.

FIELD VERIFICATION AND CLASSIFICATION ACCURACY

A comparison of the verified test fields with the final classifications provided accuracy information for the Terrebonne Bay (table V) and Lake Borgne (table VI) products. In the case of Terrebonne Bay, field verification of 18 systematically random test fields indicated the Landsat classification was considerably more accurate than the aircraft classification. However, a field verification of the Lake Borgne classifications, using 15 systematically random test fields, indicated comparable accuracies within the 80-percent range for both the aircraft and the satellite data.

DISCUSSION

The orientation of the aircraft with respect to the Sun affects the recorded reflectivity responses. Optimally, the aircraftborne scanner should be flown parallel with the Sun's azimuth so that the Sun's rays are either to the back or to the front of the plane to minimize shadows. The effects of shadows on the MSS data are most pronounced when the Sun is oblique to the aircraft. Consequently, the flight lines for this investigation were oriented parallel to the Sun's rays for the scheduled time of data acquisition.

The late summer/early fall time frame has been cited as optimum for MSS separation of marsh species because the species are mature and in flower or fruit. Previous work by other investigators (ref. 13) indicates that good spectral separation of coastal wetland species occurs in October. Thus, both aircraft and Landsat MSS data were acquired in October for this investigation. Ground truth for aircraft data training samples geographically located within or including a band of noise was rejected for use in the pattern-recognition program. However, the entire data set was classified so that the banding was still visible in the final aircraft classifications (figs. 7 and 9).

The difficulty in the classification of water was more apparent in the aircraft MSS data than in the Landsat, probably because of the difference in resolution. The spectral diversity of water in some channels may account for the classification problem using the ERL four-channel classifier. Clear seawater absorbs at a maximum in the infrared and at a minimum in the green, whereas the more turbid river water absorbs at a maximum in the blue-violet and at a minimum in the yellow-orange (ref. 14). Even when the number of water training samples was increased, classification accuracy was improved only slightly. Grouping the training samples to generate an average mean and standard deviation did not substantially improve the water classification either. However, application of the water-search program appeared to effect a good classification; many areas that were known to be water but had been unclassified in the previous attempts were added. Examination of the coastal water at the bottom of the right strip in figure 6 and of the same geographical area in figure 7 shows an obvious improvement in the classification of the latter using the water-search method.

As figures 7 and 9 illustrate, mosaicking the aircraft flight lines of data detracts from the overall representation. Also, confidence in classification accuracy decreases at the edges of each flight line because of the atmospheric interference in the reflective path length, which is longest at the edges of the scan and shortest at nadir.

Regarding the verification of classification accuracy, the inaccessibility of the marsh limited the number of test fields that could be checked and resulted in a number that was not statistically optimum. This may have been responsible, in particular, for the lower Terrebonne Bay aircraft classification accuracy. Nevertheless, other ERL wetlands investigations confirm a relatively high average accuracy that places confidence in the computer-implemented MSS technique.

A degree of error was probably built into the verification procedure by the difficulty in georeferencing each test field on the classified map of aircraft data to the ground. The stability of the satellite platform and the narrow scan angle of the Landsat scanner promote accuracy in georeferencing Landsat MSS data, whereas the roll, pitch, and yaw of an aircraft system and the large sensor scan angle constrain the geographical accuracy of aircraft MSS data. A georeference program for the Landsat data has been developed at ERL. There is an advantage, then, to the use of georeferenced satellite data over the aircraft data when change detection becomes an objective. Multitemporal classifications can be geographically registered with greater confidence.

A comparison of Chabreck's marsh salinity zones with those derived from this investigation is interesting but not strictly valid because of two outstanding variables. First, there is a 6-year gap between the data sets, and second, the methods of data collection and analysis are different. Consequently, a detection of true vegetational changes caused by salinity level fluctuations from 1968 to 1974 cannot be assumed by this investigation. However, the remotely sensed 1974 classifications can be used as baseline data for a succeeding investigation implementing the same technique to classify vegetational data for future change detection.

An outcome of this experiment was the comparison of the effect of resolution cell size on the accuracy of the final salinity zone boundaries derived from aircraft MSS or satellite MSS data. An aircraft resolution of approximately 15 meters produced a classification accuracy of 66 percent for the Terrebonne Bay area, which was considerably less than the Landsat classification accuracy of 83 percent. For the Lake Borgne area, the aircraft sensor produced an accuracy of 85 percent, slightly better than the Landsat classification accuracy of 80 percent. However, the aircraft results were generated from inherently "noisy" data and may not reflect results that might be obtained from an optimum data set. Nevertheless, these results, and other ERL wetland classification attempts, seem to indicate that Landsat resolution is adequate for salinity zone determinations in the Louisiana marsh.

The Landsat and aircraft classifications differed significantly in the extent of brackish-classified marsh. The amount and location of brackish marsh in the Landsat classification compared more closely to the Chabreck map than did the aircraft classification, which classified a larger area as brackish. This difference may be traced to the different grouping of training samples for each classification and specifically to the inclusion of a mixed _Spartina alterniflora_ and _Spartina patens_ class that was represented by the brackish color code in the aircraft data.

The inherent difference between the remote-sensing and Chabreck methods may explain some of the discrepancies observed in comparing the MSS remotely sensed maps with the Chabreck map. The former were derived from discrete, but adjacent, data points describing the entire study area, where each pixel of the ground material was translated into a salinity zone. The Chabreck map was derived from an interpolation between discrete, but nonadjacent, data points representing the salinity zones by boundaries.

TECHNIQUE APPLICATION

A remotely sensed map of wetland vegetational species can be used for many applications, only one of which is the salinity zone determinations. Another feasible application is the indirect measurement of wetland productivity. For instance, _Spartina alterniflora_ contributes greatly to marsh primary productivity. The canes disintegrate to provide vitamins and amino acids for the ecological food chain (refs. 15 to 17). The areal extent for this marsh species could be computed from a remotely sensed vegetation map and a productivity sum derived from a nutritive value for each square meter.

Remote sensing of wetland vegetation can also be used to identify potential wildlife habitats and contribute to wildlife management practices. For example, three-cornered grass, _Scirpus olneyi_, is an excellent wildlife food producer, but its habitat is commonly encroached by wiregrass, _Spartina patens_, and saltmarsh grass, _Distichlis spicata_ (ref. 18). This investigation has demonstrated that both three-cornered grass and wiregrass can be remotely identified. Therefore, by detecting and locating the encroaching species, management measures can be undertaken to promote the growth of the desired grass.

Because most marsh species tolerate only a given range of tide levels, this relationship may be used to deduce a tide-level/elevation map from remotely sensed vegetation maps. Other wetland investigators (ref. 19) claim the upper wetland coastal boundary can be positioned within 3 or 4.5 meters (10 or 15 feet) horizontally by field inspection, given the plant species and tidal cycle. They also claim the task can be accomplished from identification of vegetation from remotely acquired, color-infrared photographs. One might then speculate that the same task could be achieved using the MSS technique.

The remote MSS technique can also be used to detect changes in coastal areas. The comparison of marsh vegetation and other coastal features from two or more different time frames can give clues to the direction and strength of various coastal pressures. Change detection itself can encompass all the applications previously mentioned by providing the multitemporal vegetation maps that may reveal changes in marsh salinity, productivity, and elevation.

CONCLUSIONS AND RECOMMENDATIONS

A computer-implemented technique has been developed to map marsh vegetation in coastal Louisiana with multispectral scanner digital data acquired by aircraft and satellite. The technique was used to delineate marsh salinity zones based on the relationship that certain associations of plant species act as indicators for fresh, brackish, and saline zones. Fieldwork was conducted to acquire training samples for the vegetation classification of the digital multispectral data, acquired in October 1974, through a pattern-recognition program.

The results of the aircraft and satellite vegetation classifications and marsh salinity zone delineations support the following conclusions.

1. Many marsh plant species, if they dominate an area of a size compatible with sensor resolution, can be identified from both aircraft and satellite multispectral scanners with an accuracy that is high enough to warrant use of the technique for vegetation identification and marsh salinity zone determinations.

2. Louisiana marsh salinity zone boundaries derived from both the aircraft and the satellite data compared well, which indicates that satellite (Landsat) resolution is sufficient to accomplish broad-boundary salinity zone definition in the Louisiana marsh.

3. The remotely sensed marsh salinity zone maps described boundaries that compared well with those outlined on a 1968 map produced by a line-transect method of sampling and then interpolating.

4. Additional applications of the multispectral remotely sensed vegetation mapping technique can provide other environmental information about an area based on plant species inferences. Productivity measurements, tide-level/elevation, wildlife habitat, and change-detection data can be extracted from the use of such a technique.

The results of this investigation support the following procedural recommendations.

1. To classify water, a two-channel search using one visible and one near-infrared channel, rather than the four-channel standard pattern-recognition program, should be implemented. The improvement in the accuracy of the classification of water using the water-search program seems to be related to sensor resolution. The water-search program improved the classification of water from the aircraft data more than it did from satellite data.

2. For aircraft-acquired data in the marsh, flight lines should be flown optimally with 50-percent overlap to account for atmospheric interference, which increases laterally from nadir across the scan path.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, April 5, 1977
177-52-83-07-72

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TABLE I.- FLIGHT LOG FOR NASA AIRCRAFT MISSION 287/104,

OCTOBER 2, 1974

Flight line	Time (CST) start/stop, hr:min:sec	Groundspeed, km/hr	Altitude, km	Scan rate, rps	Latitude (N) start/stop, deg:min:sec	Longitude (W) start/stop, deg:min:sec
8	8:41:55 8:48:25	658	6.096	13	30:13:09 29:55:00	89:50:05 89:12:01
9	8:51:55 9:00:25	519	6.096	10	29:51:02 30:11:05	89:12:05 89:53:01
10	9:05:25 9:11:05	641	6.096	12	30:08:01 29:48:06	89:55:04 89:16:01
11	9:17:35 9:25:50	523	6.096	10	29:44:08 30:04:02	89:17:06 89:56:05
12	9:29:20 9:35:40	656	6.096	12	30:01:04 29:42:04	89:58:07 89:20:09
13	9:42:05 9:50:15	528	6.096	10	29:38:08 29:58:00	89:21:09 90:00:08
14	9:55:10 10:01:40	658	6.096	12	29:55:03 29:35:09	90:03:04 89:24:08
15	10:07:45 10:15:45	547	6.096	10	29:32:03 29:51:07	89:25:08 90:05:00
1	10:29:45 10:37:25	563	6.096	10	29:02:09 29:41:07	90:04:07 90:05:00
2	10:41:40 10:48:25	647	6.096	12	29:42:05 29:03:06	90:09:03 90:09:01
3	11:20:00 11:26:30	647	6.096	10	29:41:07 29:04:00	90:13:06 90:13:06
4	11:30:25 11:38:15	565	6.096	12	29:02:06 29:42:04	90:17:09 90:19:03
5	11:45:00 11:51:30	658	6.096	10	29:42:04 29:04:00	90:21:08 90:21:08

TABLE II.- AIRCRAFT MSS CLASSIFICATION OF TRAINING SAMPLES FOR FLIGHT LINE 3

Class name (a)	Training sample no.	Class name percent occurrence									
		1 SFPA	2 SP	3 SP	4 MCPA	5 SPCY	6 WAT	7 SP	8 SA	9 ANSA	0 UNCL
SFPA	3	91.67	2.63	0	0.44	0	0	0	0	0.22	5.04
SP	11	2.63	89.25	1.97	1.10	0	0	0	0	1.10	3.95
SP	178	0	2.80	89.32	0	0.53	0	1.23	0	0	6.12
MCPA	9	.51	.25	0	95.96	0	0	0	0	0	3.28
SPCY	5	.29	2.30	1.01	0	68.68	3.16	.14	0	0	24.42
WAT		0	0	0	0	0	95.25	0	0.56	0	4.19
SP	179	.26	0	0	0	0	0	76.30	0	.26	23.18
SA	75	0	0	0	0	.16	.49	1.79	92.67	0	4.89
ANSA	78	0	1.79	0	0	0	0	0	0	94.64	3.57

[a] SFPA = *Sagittaria falcata/Panicum hemitomon*
SP = *Spartina patens*
MCPA = *Myrica cerifera/Panicum hemitomon*
SPCY = *Spartina patens/Cyperus* species
WAT = Water
SA = *Spartina alterniflora*
ANSA = *Avicennia nitida/Spartina alterniflora*
UNCL = Unclassified

TABLE III.- AIRCRAFT MSS CLASSIFICATION OF TRAINING SAMPLES FOR THE TERREBONNE BAY AREA

Class name (a)	Training sample no.	Class name percent occurrence											
		1 SFPA	2 MCPA	3 SCIR	4 SP	5 SP1	6 SP2	7 SPSA	8 SA	9 SA1	10 ANSA	11 WAT	0 UNCL
SFPA	18	84.33	2.08	5.31	0	0.33	0	0.42	0.30	0	0.01	0	7.22
MCPA	9	.53	96.52	0	0	0	0	0	0	0	0	0	2.95
SCIR	165	1.65	.83	91.74	0	0	0	0	0	0	0	0	5.78
SP	179	0	0	.26	87.76	0	0	1.56	1.30	1.82	0	0	7.30
	11	0	.88	.44	.22	13.38	1.75	42.98	4.39	0	.22	0	35.76
	182	3.45	2.39	1.59	.80	44.30	2.65	3.45	2.92	0	0	1.33	37.12
	178	0	0	0	1.10	4.23	82.54	4.60	.92	.18	0	2.76	3.67
SP1	87	0	0	0	57.58	4.04	1.01	1.01	10.10	2.02	0	3.03	21.21
SP2	58	.83	0	0	61.98	0	0	.83	11.57	9.09	0	0	15.70
SPSA	86	0	0	0	0	1.82	1.82	78.18	0	0	0	0	18.18
	57	0	0	0	2.48	.83	0	23.14	66.94	0	0	0	6.61
	46	0	5.23	0	.65	3.27	0	75.16	0	0	0	0	15.69
SA	60	0	0	0	6.67	0	0	.74	83.70	.74	0	0	8.15
	59	0	0	0	1.48	1.11	0	19.93	53.87	5.17	2.21	1.11	15.12
SA1	75	0	0	0	3.66	0	0	.70	11.50	77.53	0	0	6.61
ANSA	78	0	0	0	0	0	0	0	0	0	91.07	0	8.93

[a]SFPA = *Sagittaria falcata/Panicum hemitomon*
MCPA = *Myrica cerifera/Panicum hemitomon*
SCIR = *Scirpus* species
SP = *Spartina patens*
SPSA = *Spartina patens/Spartina alterniflora*
SA = *Spartina alterniflora*
ANSA = *Avicennia nitida/Spartina alterniflora*
WAT = Water
UNCL = Unclassified

TABLE IV.- AIRCRAFT MSS CLASSIFICATION OF TRAINING SAMPLES FOR

THE LAKE BORGNE AREA

Class name (a)	Training sample no.	Class name percent occurrence									
		1 SWA	2 SP	3 SP1	4 SA	5 JR	6 BH	7 PC	8 FOR	9 WAT	0 UNCl
SWA	128	97.08	0	0	0	0	0	0	0	0	2.92
SP	94	0	89.74	1.71	0	0	0	1.71	0	0	6.84
	97	0	80.38	0	0.38	0	1.15	1.92	0	0	16.17
	96	0	98.68	0	0	0	0	0	0	0	1.32
	133	0	56.44	12.04	6.30	0	4.38	2.47	1.64	0	16.73
	130	0	94.20	.48	0	.48	0	0	.97	0	3.87
SP1	151	0	11.54	68.75	0	0	8.17	.48	.48	0	10.58
	149	0	93.94	1.52	0	0	0	0	0	0	4.54
SA	215	0	17.19	0	57.81	3.13	10.94	0	0	0	10.93
	136	0	0	0	96.47	3.53	0	0	0	0	0
	141	.42	.84	2.52	89.92	1.26	0	0	0	0.84	4.20
JR	214	0	2.82	0	28.17	60.56	0	0	0	0	8.45
	212	0	7.27	0	18.18	43.64	1.82	0	3.64	0	25.45
	137	0	0	0	.97	95.65	0	0	0	0	3.38
BH	92	0	4.47	12.73	0	0	48.97	0	0	0	25.11
PC	196	0	8.57	1.43	4.29	0	1.43	72.86	0	0	11.42
FOR	104	0	7.77	.25	.13	.51	10.70	.51	69.68	0	10.45
	121	0	2.14	3.70	0	2.14	42.61	0	32.68	0	16.73
	124	0	0	0	0	0	0	.08	98.91	0	1.01
WAT	125	0	0	0	0	0	0	0	0	99.26	.74

[a] SWA = swamp
SP = *Spartina patens*
SA = *Spartina alterniflora*
JR = *Juncus roemerianus*
BH = *Baccharis halimifolia*
PC = *Phragmites communis*
FOR = lowland hardwood forest
WAT = water
UNCL = unclassified

TABLE V.- ACCURACY VERIFICATION TEST FOR

TERREBONNE BAY MSS CLASSIFICATIONS

Test field	Field observation	Landsat agreement with classified product (a)	Aircraft agreement with classified product (b)
YC 68	Fresh	Yes	Not on product
YC 58	Fresh/swamp	Yes	No (brackish-saline)
YC 78	Fresh	No (brackish)	Not applicable - scanline banding
YC 88	Fresh	No (no plurality)	Not on product
YC 57	Fresh	Yes	Yes
YC 67	Agriculture	No (fresh)	Not on product
YC 56	Brackish	Yes	Yes
YC 66	Fresh	Yes	Yes
YC 76	Fresh	Yes	No (brackish)
YC 86	Brackish/saline	Yes	Not on product
YC 55	Saline	Yes	Yes
YC 65	Saline	Yes	No (brackish)
YC 75	Brackish	Yes	Yes
YC 85	Brackish/saline	Yes	Yes
YC 74	Saline	Yes	No (brackish)
YC 84	Saline	Yes	Yes
YC 73	Saline	Yes	Yes
YC 83	Brackish/saline	Yes	Not applicable - scanline banding

[a]Landsat classification accuracy = 15/18 = 83 percent.

[b]Aircraft classification accuracy = 8/12 = 67 percent.

TABLE VI.- ACCURACY VERIFICATION TEST FOR

LAKE BORGNE MSS CLASSIFICATIONS

Test field	Field observation	Landsat agreement with classified product (a)	Aircraft agreement with classified product (b)
BJ 11	Agriculture	Yes	Not on product
BJ 21	Forest	No (no plurality)	Yes
BJ 31	Saline	Yes	Yes
BJ 51	Saline	Yes	No (brackish)
BJ 61	Brackish/saline	Yes	Yes
BJ 71	Saline	Yes	Yes
BJ 70	Saline	Yes	Yes
BJ 60	Saline	Yes	Yes
BJ 50	Barren/saline	No (barren)	Indefinite location
BJ 40	Brackish	Yes	No (saline)
BJ 30	Brackish	No (saline)	Yes
BJ 20	Brackish/saline	Yes	Yes
BJ 49	Brackish/saline	Yes	Yes
BJ 59	Saline	Yes	Yes
BJ 69	Saline	Yes	Yes

[a]Landsat classification accuracy = 12/15 = 80 percent.

[b]Aircraft classification accuracy = 11/13 = 85 percent.

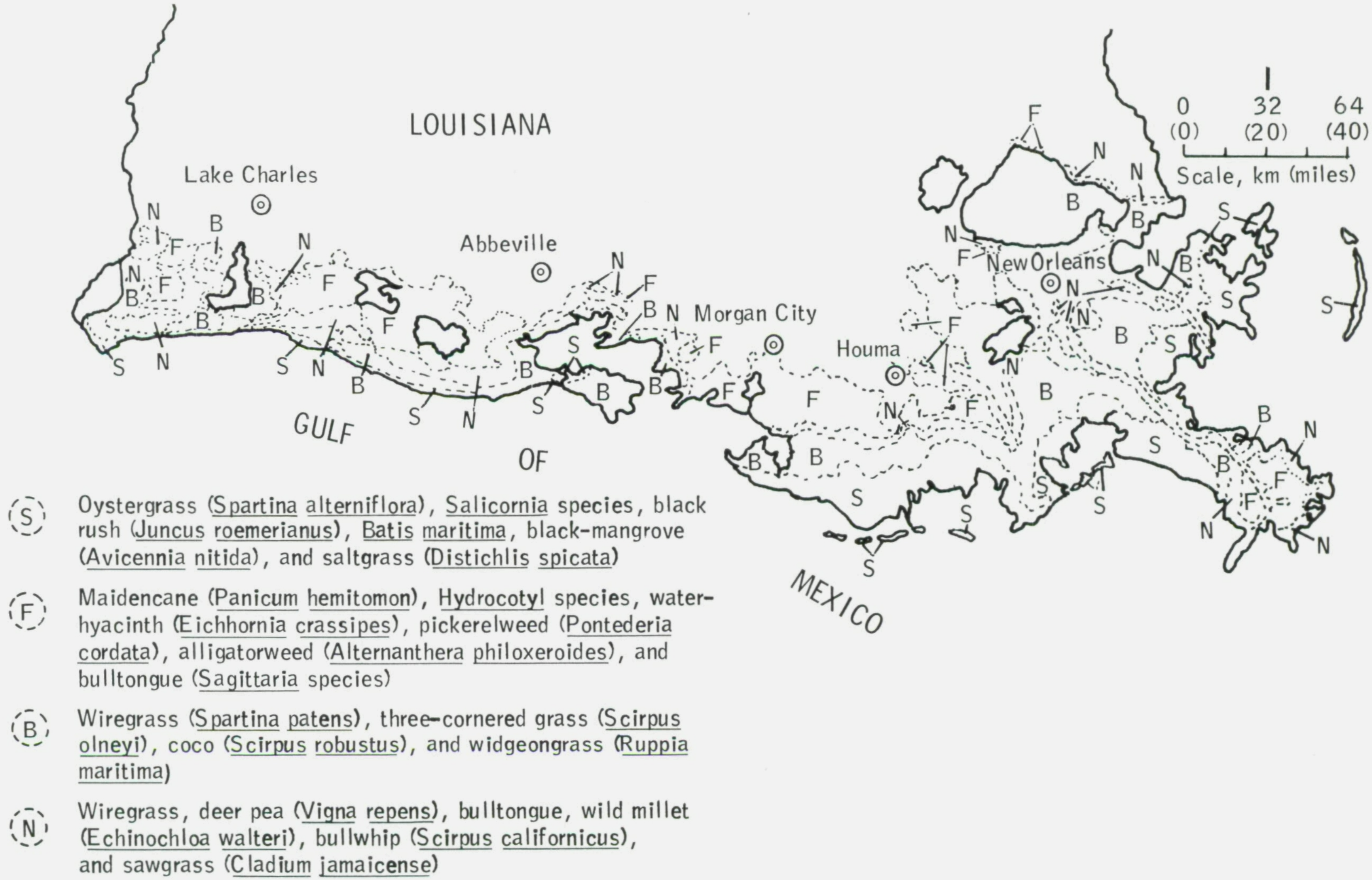

Figure 1.- Vegetative-type map of the Louisiana coastal marshes (from ref. 6).

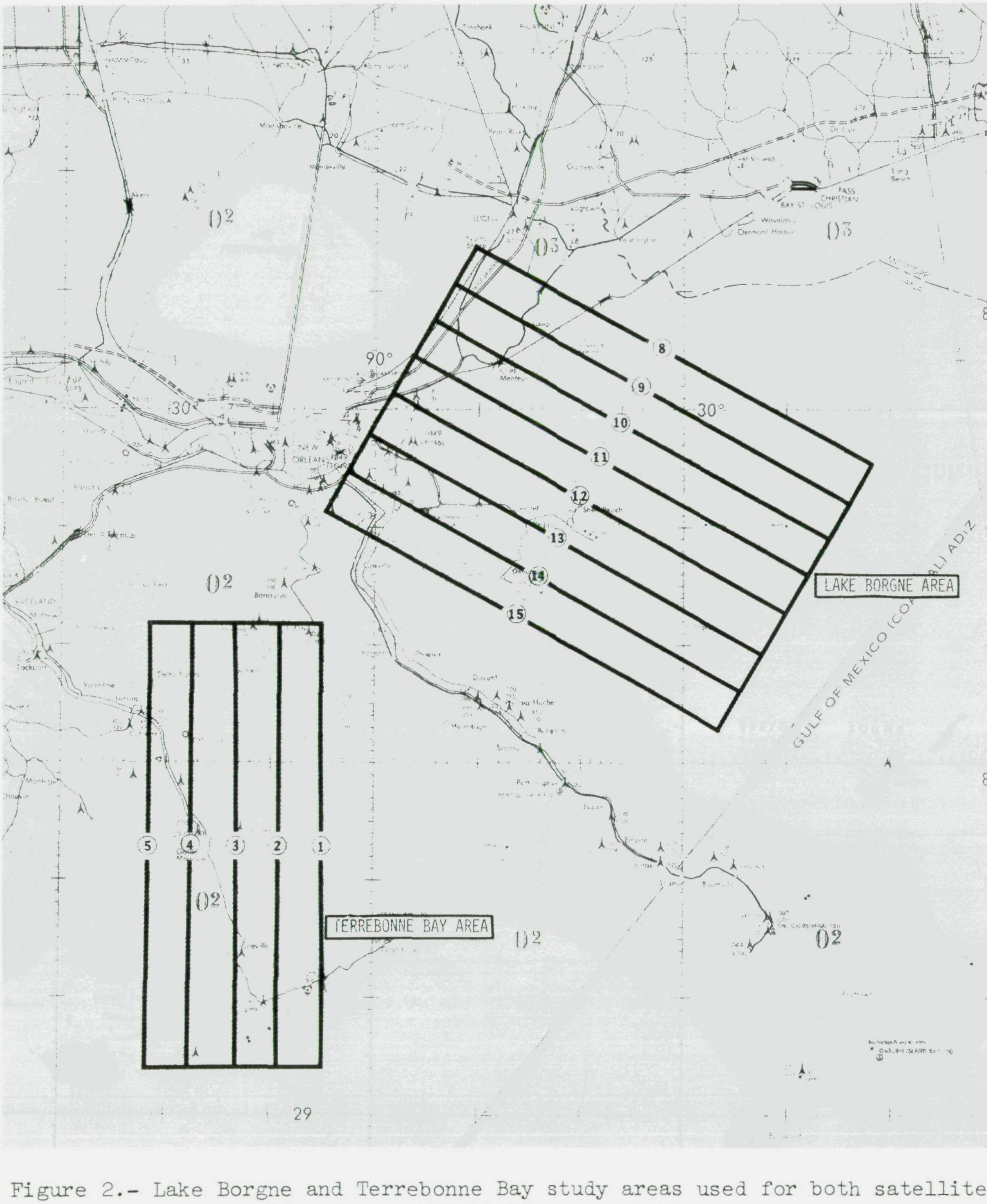

Figure 2.- Lake Borgne and Terrebonne Bay study areas used for both satellite and aircraft investigations. Flight lines are indicated for the aircraft mission.

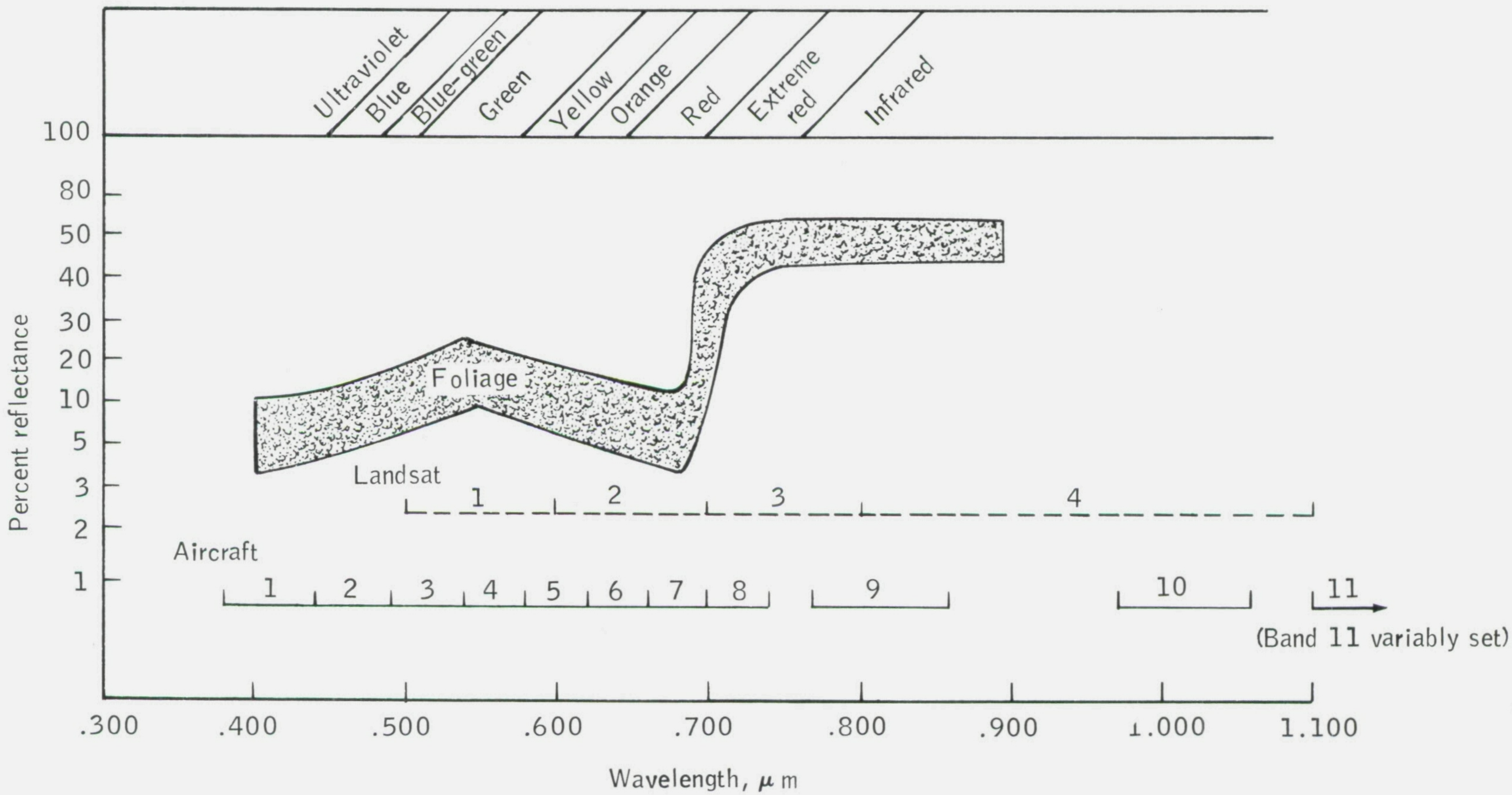

Figure 3.- Diagram of Landsat and aircraft scanner bandwidths compared to the general reflectance curve for deciduous foliage (percent reflectance plotted against wavelength, ref. 10).

SITE NAME: SAMPLE NO.:

IMAGERY: Mx. No.______, Roll No._____, Frame No._____

GROUND TRUTH PHOTOGRAPH: Mx. No.______ Data Lab No. L-_____, Roll___Frame____.

SITE LOCATION:

____

% mud or water____________, % total vegetation__________________.
% of each species in the total vegetation:

______________________________ ________% ______________________________ ________%
______________________________ ________% ______________________________ ________%
______________________________ ________% ______________________________ ________%

COMMENTS:

GENERAL OBSERVATION:

DATE: VISITED BY:

Figure 4.- Sample card used for recording field observations of each training field.

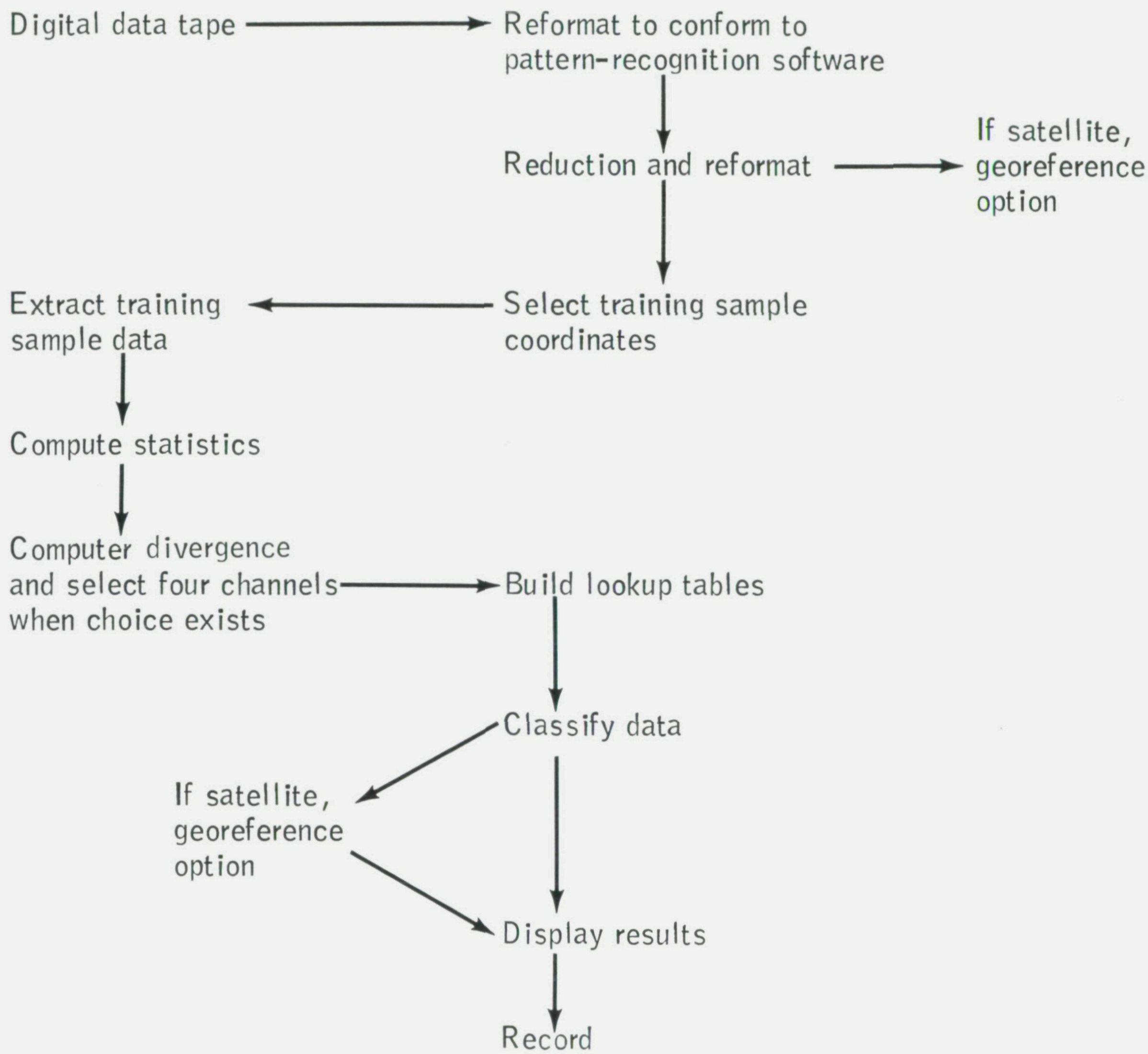

Figure 5.- Functions of pattern-recognition technique for computer classification of aircraft and satellite MSS data.

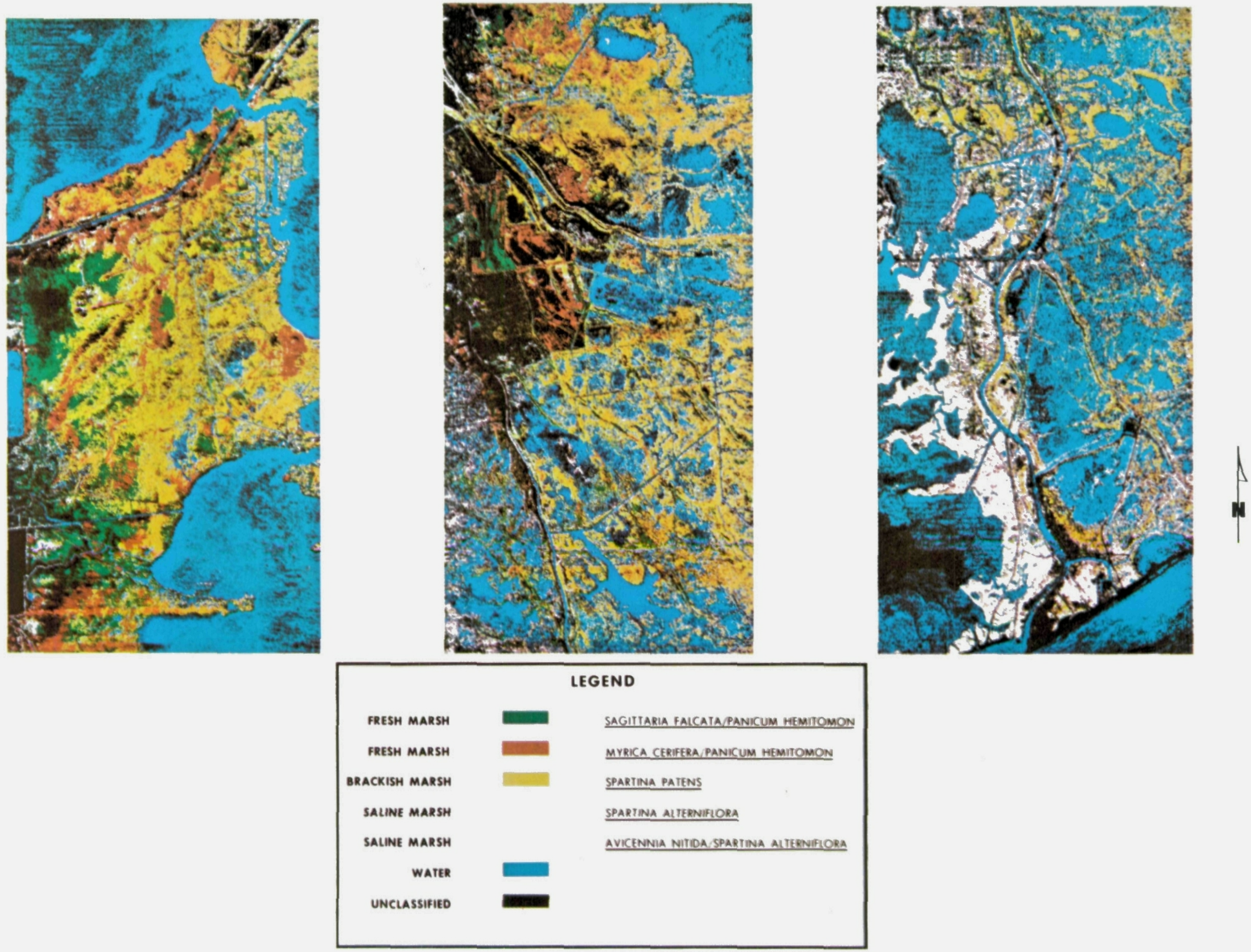

Figure 6.- The MSS classifications of major species associations of marsh vegetation October 1974 (from ref. 12).

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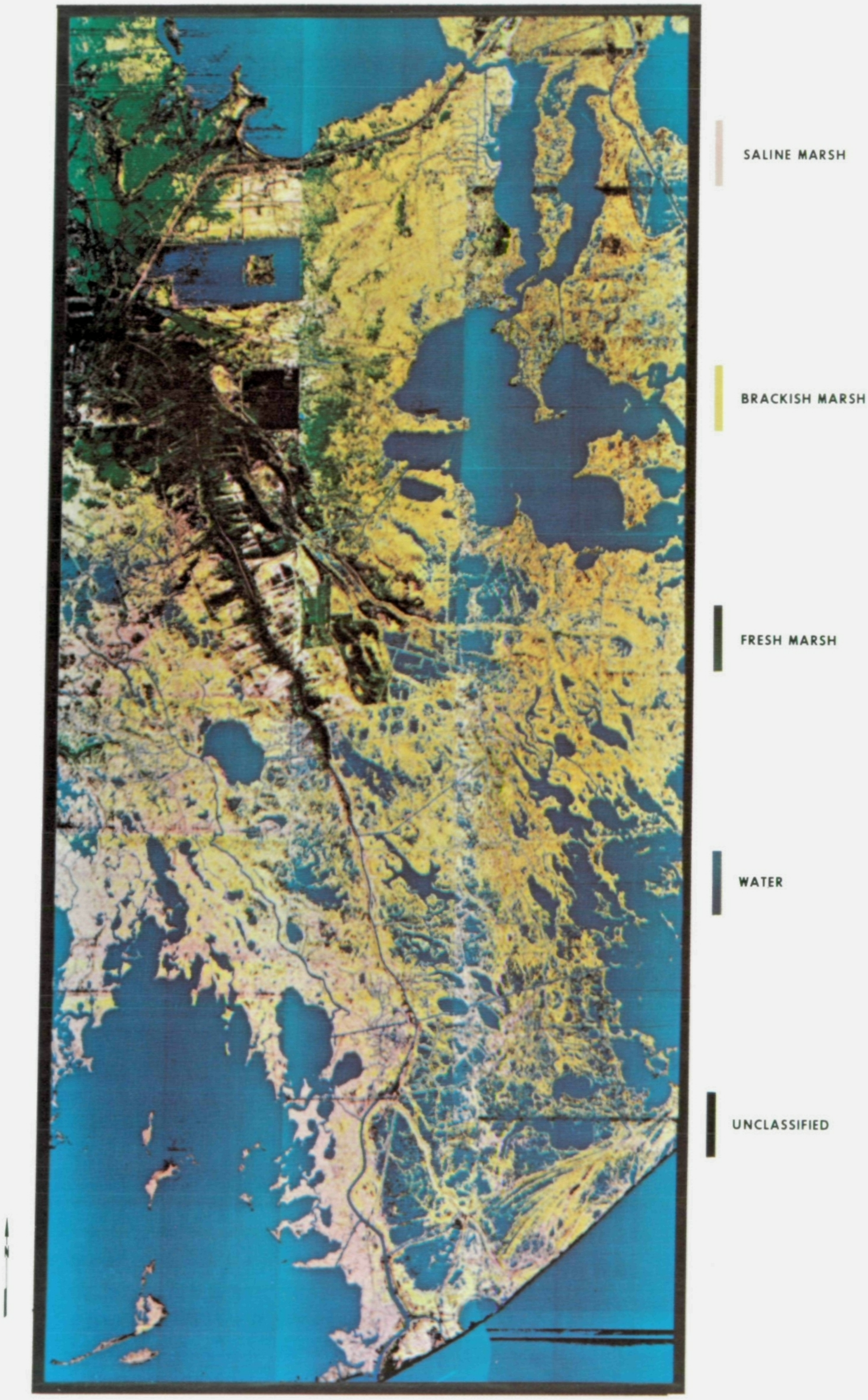
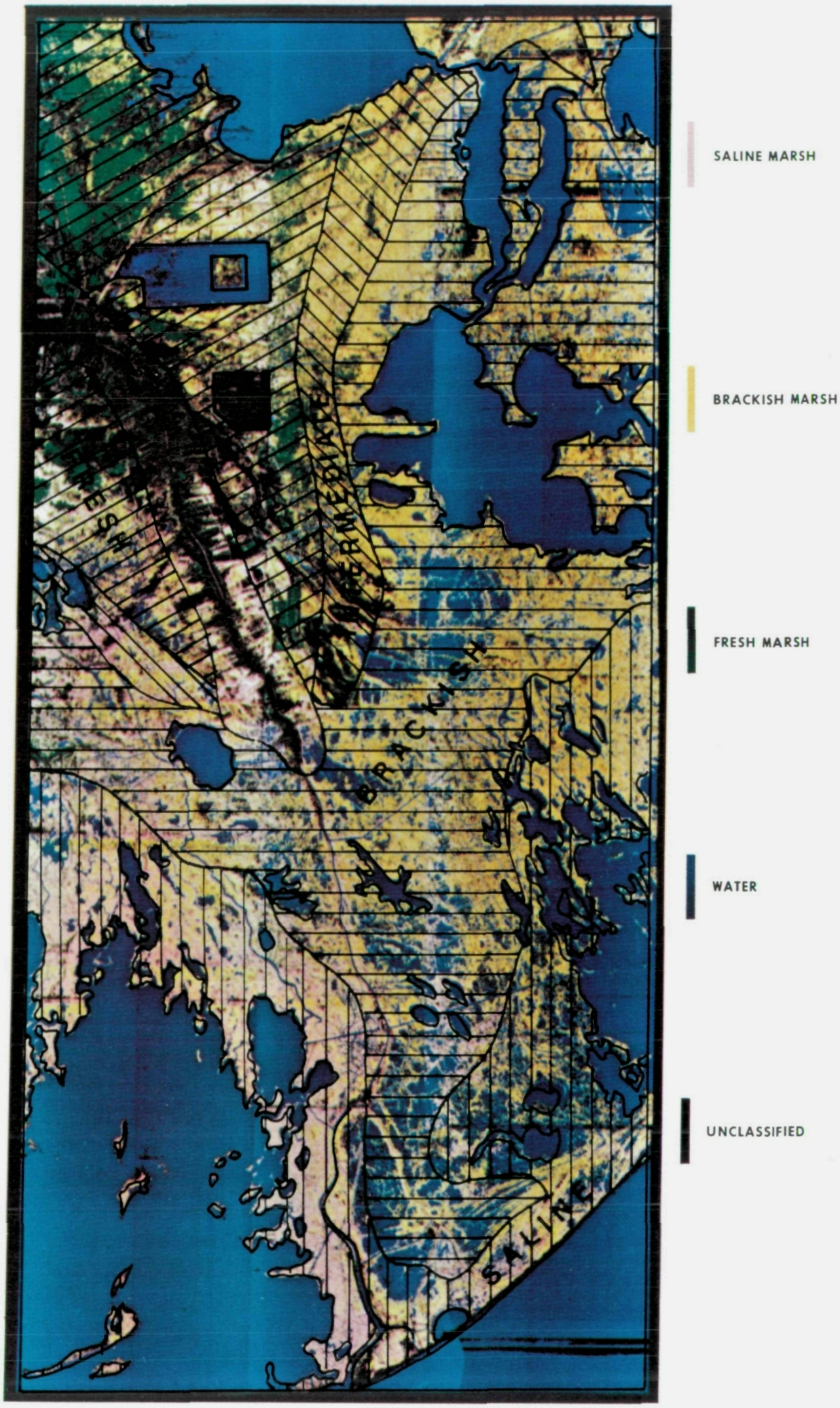


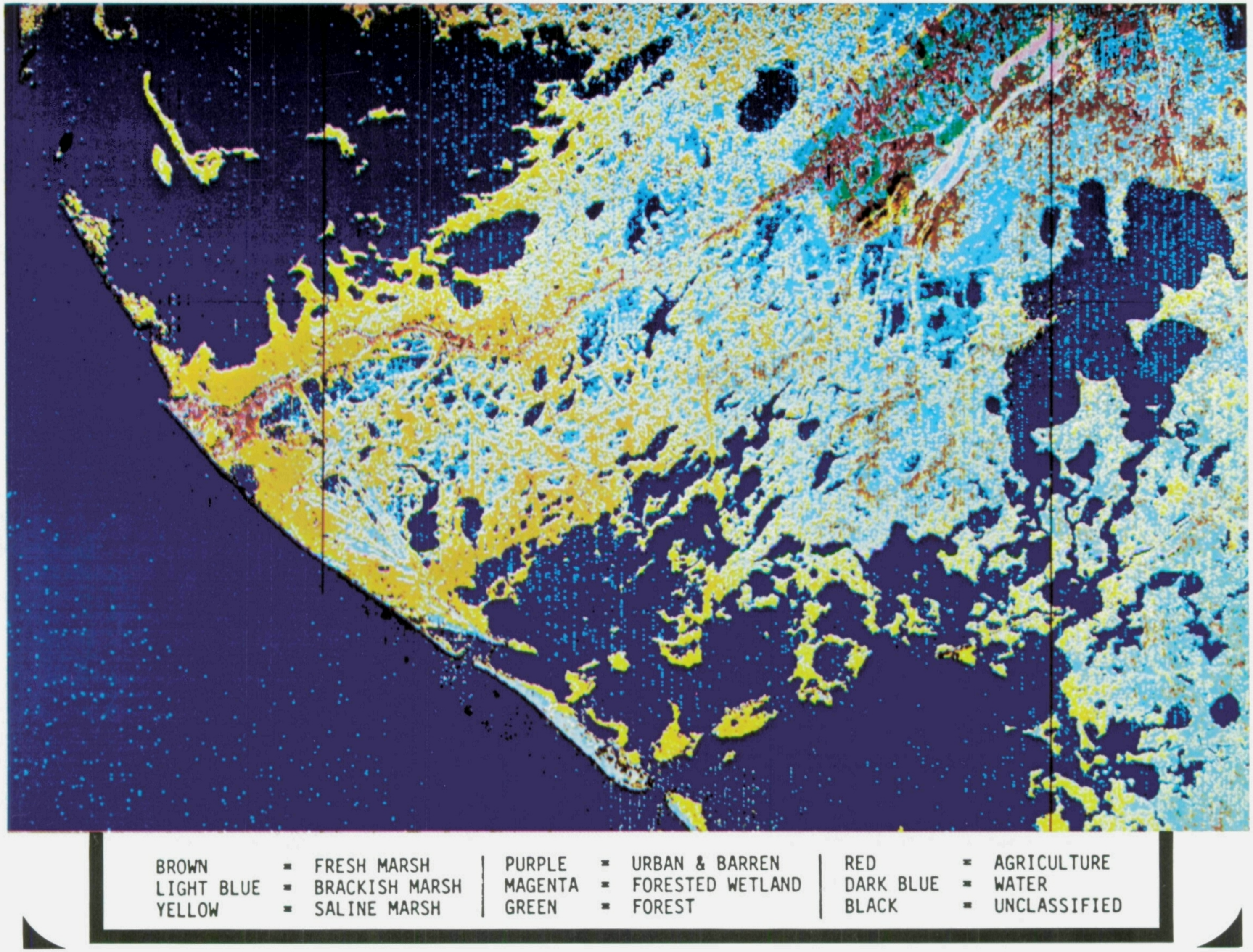
(a) Aircraft MSS classifications.

Figure 7.- Marsh salinity zones for the Terrebonne Bay area (October 1974).



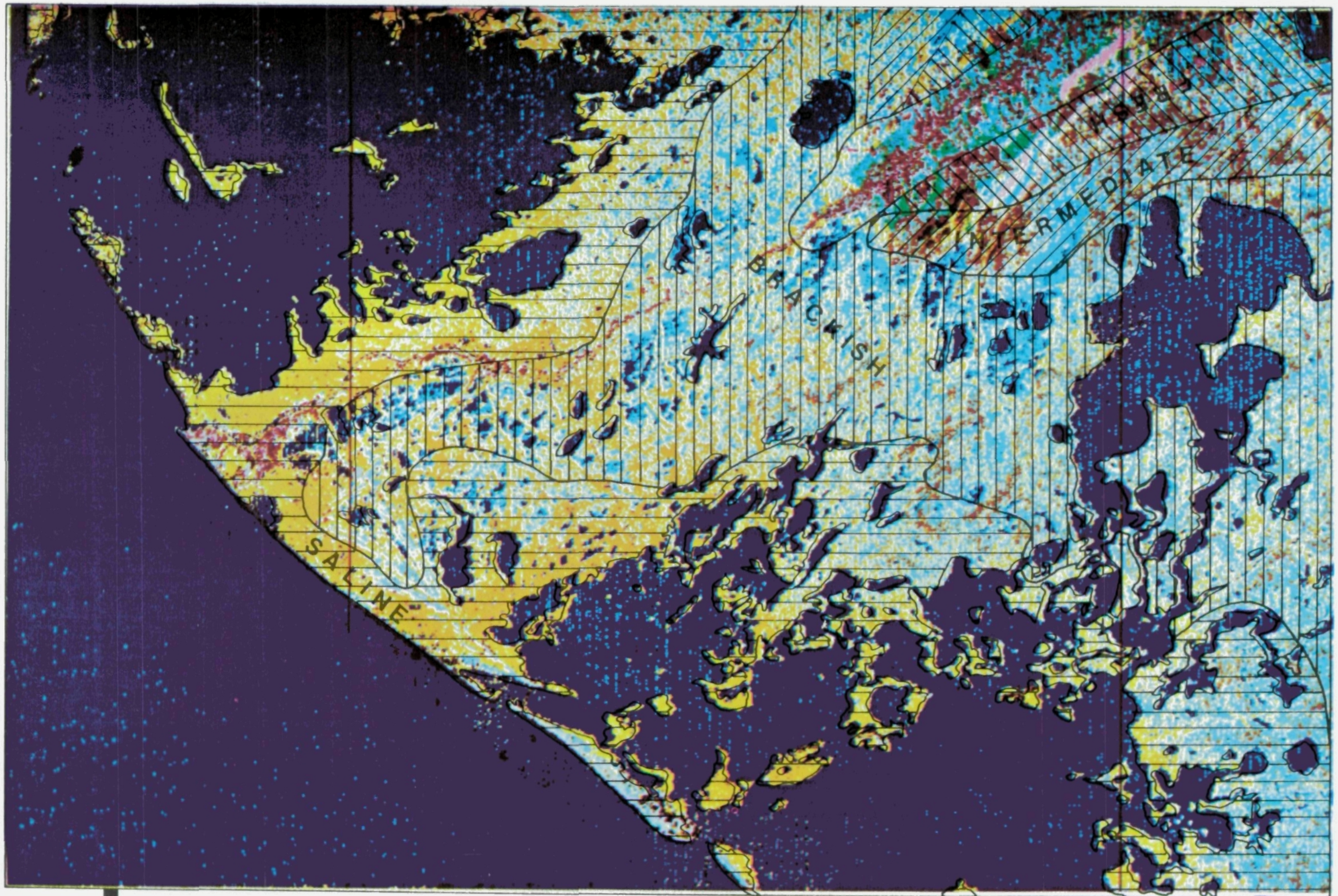
(b) Chabreck's classification overlain on the aircraft MSS classifications (from ref. 6).

Figure 7.- Concluded.



(a) Landsat MSS classifications

Figure 8.- Marsh salinity zones for the Terrebonne Bay area (October 1974).



BROWN	= FRESH MARSH	PURPLE	= URBAN & BARREN	RED	= AGRICULTURE
LIGHT BLUE	= BRACKISH MARSH	MAGENTA	= FORESTED WETLAND	DARK BLUE	= WATER
YELLOW	= SALINE MARSH	GREEN	= FOREST	BLACK	= UNCLASSIFIED

(b) Chabreck's classifications overlain on the Landsat MSS classifications (from ref. 6).

Figure 8.- Concluded.

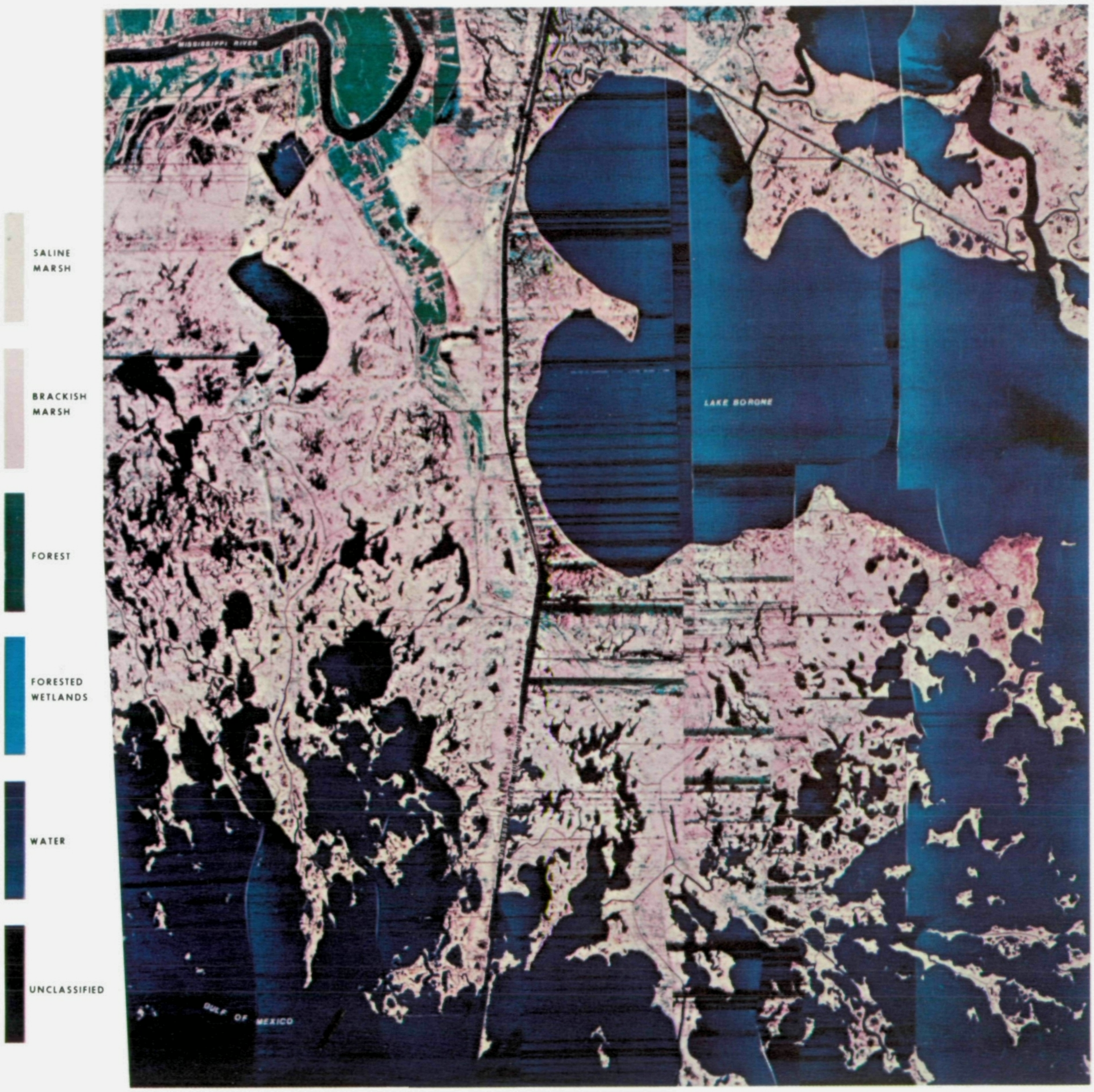


Figure 9.- Aircraft MSS classifications of marsh salinity zones for the Lake Borgne area (October 1974).

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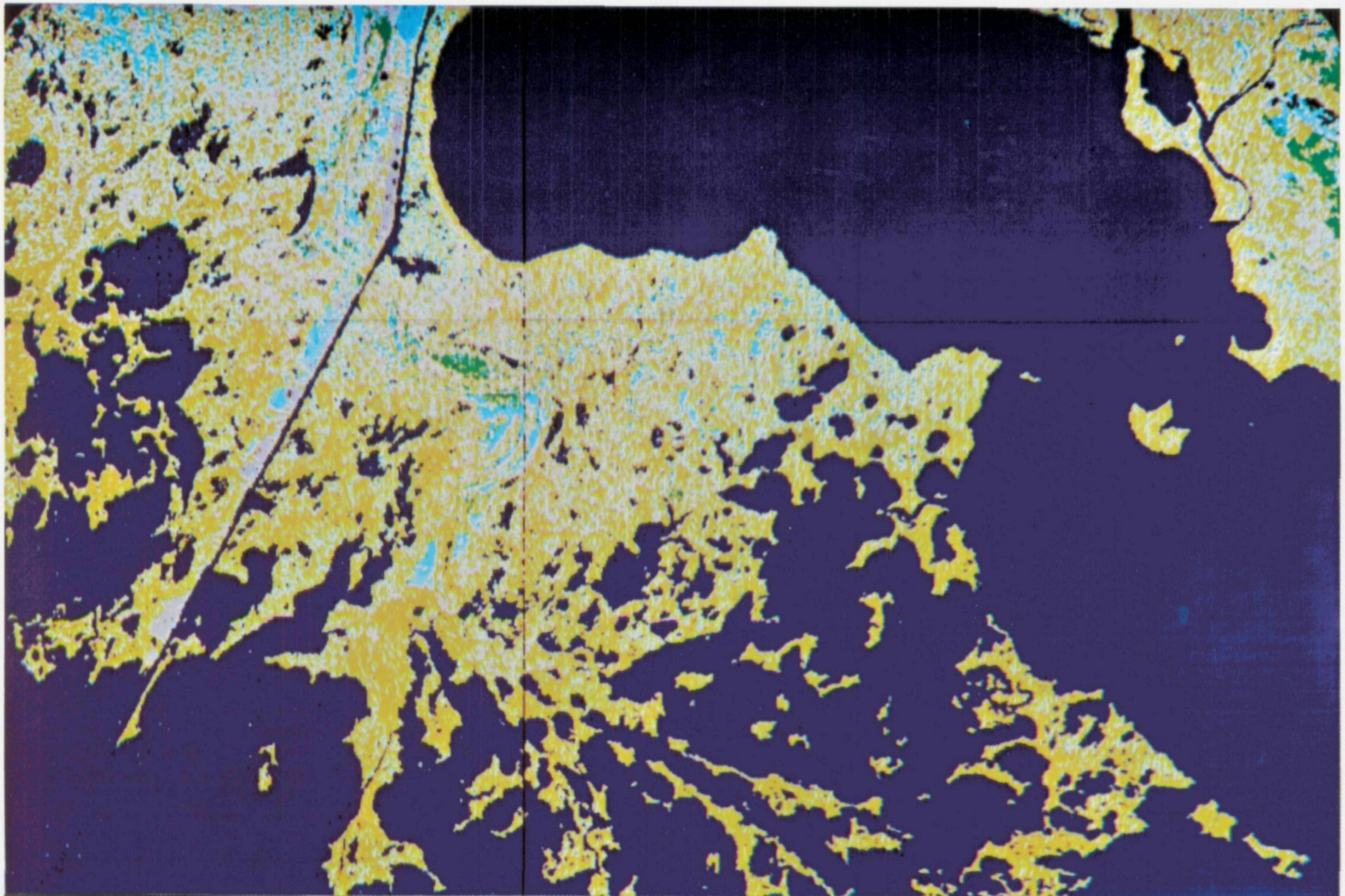
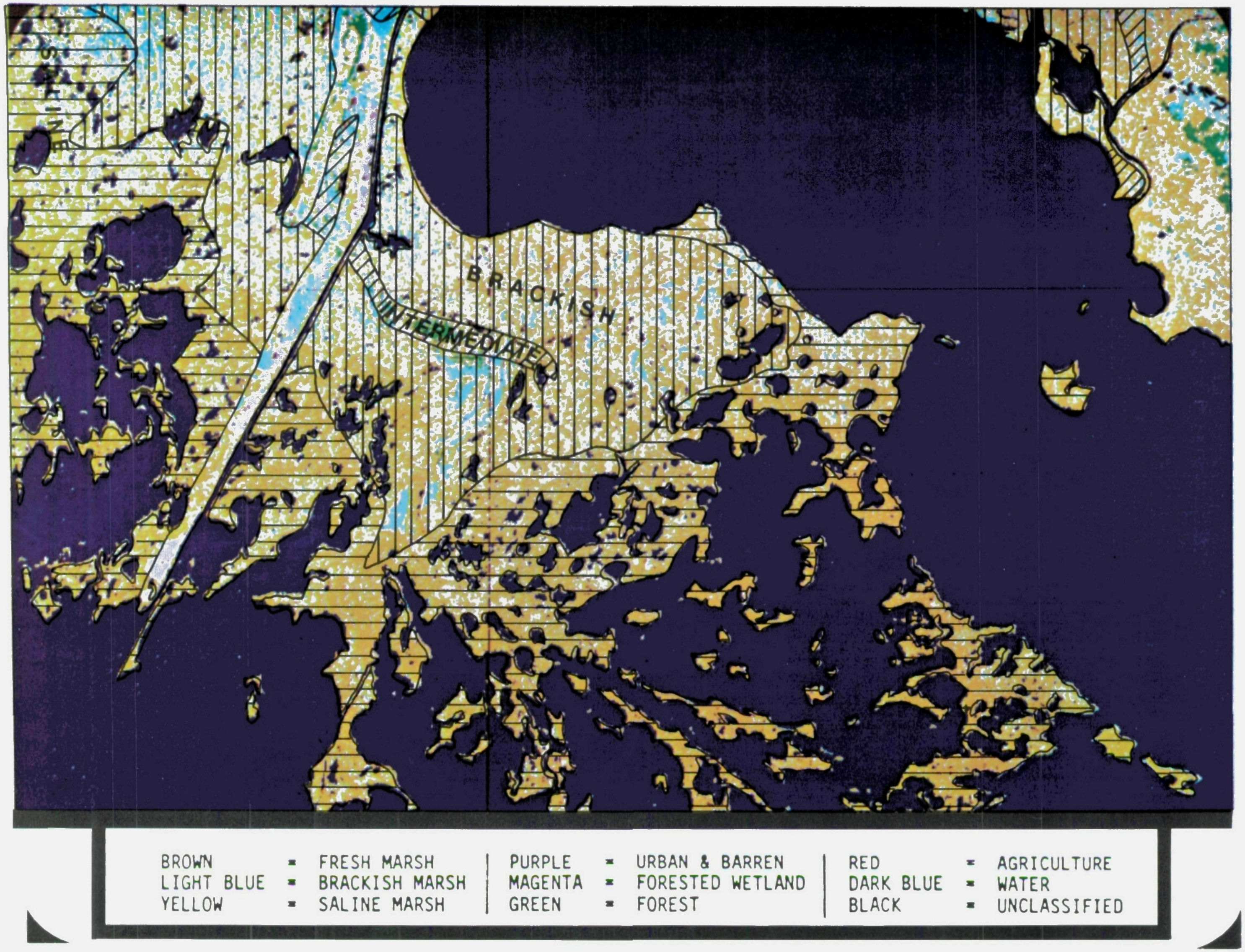


BROWN	= FRESH MARSH	PURPLE	= URBAN & BARREN	RED	= AGRICULTURE
LIGHT BLUE	= BRACKISH MARSH	MAGENTA	= FORESTED WETLAND	DARK BLUE	= WATER
YELLOW	= SALINE MARSH	GREEN	= FOREST	BLACK	= UNCLASSIFIED

(a) Landsat MSS classifications.

Figur 10.- Marsh salinity zones for the Lake Borgne area (October 1974).



(b) Chabreck's classifications overlain on the Landsat MSS classifications (from ref. 6).

Figure 10.- Concluded.

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APPENDIX

The following data are provided in this appendix.

1. Scientific and common names of marsh plants (table VII)

2. A brief description of the training samples according to number (table VIII)

3. A listing of the training samples used in each MSS classification (table IX)

4. A map indicating the approximate location of training fields (fig. 11)

5. Photographs of representative marsh vegetation (fig. 12)

TABLE VII.- COMMON NAMES OF MARSH PLANTS

Scientific name	Common name
<u>Alternanthera</u> <u>philoxeroides</u>	Alligatorweed
<u>Avicennia</u> <u>germinans</u>	
<u>Avicennia</u> <u>nitida</u>	Black-mangrove
<u>Baccharis</u> <u>halimifolia</u>	Groundsel-tree
<u>Bacopa</u> species	
<u>Batis</u> <u>maritima</u>	Batis, saltwort, or beachwort
<u>Borrichia</u> <u>frutescens</u>	Sea ox-eye
<u>Carya</u> species	Hickories and pecans
<u>Celtis</u> <u>laevigata</u>	Hackberry
<u>Cyperus</u> species	Sedges
<u>Distichlis</u> <u>spicata</u>	Saltmarsh grass
<u>Eichhornia</u> <u>crassipes</u>	Waterhyacinth
<u>Eleocharis</u> <u>microcarpa</u>	(Type of spikerush)
<u>Habenaria</u> species	Long spur orchids
<u>Hydrocotyl</u> species	(Includes marsh pennyworts)
<u>Ipomea</u> <u>sagittata</u>	(Type of morning glory)
<u>Juncus</u> <u>roemerianus</u>	Black rush
<u>Liquidambar</u> <u>styraciflua</u>	Sweet gum
<u>Lophotocarpos</u> species	
<u>Magnolia</u> <u>virginiana</u>	
<u>Myrica</u> <u>cerifera</u>	Wax myrtle
<u>Panicum</u> <u>hemitomon</u>	Maidencane
<u>Phragmites</u> <u>communis</u>	Roseau cane

TABLE VII.- Concluded

Scientific name	Common name
Polygonum species	(Includes knotweed)
Pluchea species	Marsh fleabanes
Pontederia cordata	Pickerelweed
Quercus nigra	
Quercus virginiana	Live oak
Sabal species	Palmettoes
Sagittaria falcata	Bulltongue
Salicornia species	Glassworts or saltworts
Salix nigra	Black willow or swamp willow
Scirpus olneyi	Three-cornered grass
Scirpus species	Bulrushes
Solidago species	Goldenrods
Spartina alterniflora	Oystergrass
Spartina patens	Wiregrass or saltmeadow grass
Taxodium distichum	Bald cypress
Tillandsia usneoides	Spanish moss
Typha species	Cattail
Ulmus americana	American elm
Zizaniopsis miliacea	(Includes marsh millet)

TABLE VIII.- TRAINING SAMPLES USED IN EACH MSS CLASSIFICATION

Figure	Aircraft or satellite	MSS classification type	Location	Training sample numbers
6	Aircraft	Marsh vegetation species	Terrebonne Bay (flight line 3)	3, 4, 5, 9, 11, 75, 78, 81, 171, 178, 179, 180
7	Aircraft	Marsh salinity zones	Terrebonne Bay (flight lines 2 to 5)	6, 7, 9, 10, 11, 18, 37, 40, 46, 57 to 60, 75, 78, 81, 83, 86, 87, 165, 177 to 180, 182, 198, 200 to 209
8	Landsat	Marsh salinity zones	Terrebonne Bay	3, 8, 9, 14, 15, 17, 19, 21, 22, 29, 43, 57, 58, 60, 64, 73, 75, 83, 86, 87, 167, 175, 178, 181, 182, 186
9	Aircraft	Marsh salinity zones	Lake Borgne (flight lines 8 to 15)	40, 81, 92, 94, 96, 97, 104, 121, 124, 125, 128, 130, 133, 136, 137, 141, 149, 151, 177, 180, 196, 199, 200, 202 to 209, 212, 214, 215
10	Landsat	Marsh salinity zones	Lake Borgne	96, 102, 104, 109, 121, 122, 124, 127, 128, 130, 132, 133, 135, 137, 139, 141, 148, 149, 210, 212 to 216

TABLE IX.- LOUISIANA 1974 MARSH TRAINING SAMPLE DATA

Training sample number	Species observed	Percentage	Remarks
3	Sagittaria falcata Panicum hemitomon Typha species Eleocharis microcarpa	40 40 5 5	Good fresh marsh, probably with extreme seasonal changes
4	--	--	Discard
5	Spartina patens Bacopa species Cyperus species	70 to 80 5 10	Discard
6	--	--	100-percent water
7	--	--	100-percent water
8	Spartina patens Juncus roemerianus Typha species Ipomea sagittata	80 -- -- --	
9	Panicum hemitomon Myrica cerifera Sagittaria falcata Hydrocotyl species	50 40 -- --	Fairly even distribution of clumps of Myrica cerifera
10	--	--	100-percent water
11	--	--	Discard
14	Taxodium distichum Salix nigra	-- --	Forest at edge of sugarcane fields
15	--	--	Pasture
17	Panicum hemitomon Zizaniopsis species	90 10	
18	Panicum hemitomon Sagittaria falcata Typha species Myrica cerifera	40 30 10 10	Not extremely homogeneous but perhaps acceptable
19	Eichhornia crassipes Alternanthera philoxeroides Cyperus species Lophotocarpus species Habeneria species Hydrocotyl species Sagittaria falcata Pontederia cordata	30 30 -- -- -- -- -- --	
21	--	--	Discard; not homogeneous
22	Sagittaria falcata Cyperus species	60 15	20-percent unidentified grass
29	Spartina patens Scirpus species Spartina alterniflora Phragmites communis Cyperus species	-- -- -- -- --	50- to 60-percent total vegetation: discard; not very homogeneous
37	--	--	100-percent water
40	--	--	100-percent water
43	Scirpus species Spartina patens and Juncus roemerianus	90 to 95 5 to 10	90- to 95-percent total vegetation; a few small barren areas

TABLE IX.- Continued

Training sample number	Species observed	Percentage	Remarks
46	Spartina patens Spartina alterniflora Juncus roemerianus Scirpus species	55 to 65 35 to 40 <5 --	85- to 90-percent total vegetation
57	Spartina patens Spartina alterniflora Juncus roemerianus	50 45 5	
58	Spartina patens Spartina alterniflora Distichlis spicata	50 40 8 to 10	60-percent total vegetation; some exposed mud
59	Spartina alterniflora	80 to 90	90- to 95-percent total vegetation
60	Spartina alterniflora Distichlis spicata	90 to 95 <5	60- to 70-percent total vegetation
63	Avicennia germinans Spartina alterniflora Pneumatophores	70 to 80 20 to 25 5 to 10	90-percent total vegetation
64	Spartina alterniflora Juncus roemerianus	60 40	85- to 90-percent total vegetation
73	Avicennia germinans Batis maritima Spartina alterniflora Pneumatophores	80 5 <5 10	95- to 100-percent total vegetation
75	Spartina alterniflora Others	80 20	50- to 70-percent total vegetation; much water
78	Avicennia germinans Spartina alterniflora	70 20 to 25	85- to 90-percent total vegetation; good mangrove sample
81	--	--	100-percent water, 0.3 to 0.6 meter (1 to 2 feet) deep
83	Avicennia germinans Spartina alterniflora	60 to 70 25 to 30	90-percent total vegetation
86	Spartina alterniflora Spartina patens Distichlis spicata Juncus roemerianus	60 35 5 --	90- to 95-percent total vegetation
87	Spartina patens Spartina alterniflora Distichlis spicata	60 20 20	70- to 80-percent total vegetation
92	Baccharis halimifolia Solidago species Phragmites communis	70 -- 8	
94	Spartina patens	--	Some water
96	Spartina patens Baccharis halimifolia	100 --	95-percent total vegetation
97	Spartina patens Pluchea species	95	Bounded by water on all sides
102	Spartina patens	95	80-percent total vegetation

TABLE IX.- Continued

Training sample number	Species observed	Percentage	Remarks
104	Carya species	35	Crown closure 80 to 85 percent; palmetto understory
	Myrica cerifera	25	
	Salix nigra	20	
	Celtis laevigata	15	
	Quercus species	10	
109	--	--	Discard; not homogeneous
121	Quercus virginiana	100	Crown closure 40 percent; Tillandsia usneoides covered much of the oak
			Understory
	Celtis laevigata	30	
	Carya species	10	
	Ulmus americana	10	
	Palmetto	30	
122	Distichlis spicata	60 to 70	
	Scirpus species	30	
	Spartina patens	5 to 10	
	Juncus roemerianus	--	In small patches
124	Liquidambar styraciflua	30	
	Quercus virginiana	30	
	Celtis laevigata	20	
	Myrica cerifera	10	
125	--	--	100-percent water
127	Spartina alterniflora	--	
	Spartina patens	--	
	Distichlis spicata	--	
128	Taxodium distichum	--	80-percent total vegetation; dead swamp
	Tillandsia usneoides	--	
	Spartina patens	--	
	Sabal species	--	
130	Spartina patens	50	
	Distichlis spicata	40	
	Spartina alterniflora	5	
	Borrichia frutescens	5	
132	--	--	Discard; large sandy patches, very unhomogeneous
133	Spartina patens	100	Good sample
135	Distichlis spicata	40	
	Spartina alterniflora	40 to 50	
	Batis maritima	5	
136	Spartina species	70	
	Batis maritima	5	
	Avicennia germinans	5	
137	Juncus roemerianus	70	
	Spartina alterniflora	20	
	Distichlis spicata	10	
139	Spartina patens	--	
	Distichlis spicata	—	In patches
141	Spartina alterniflora	40 to 45	
	Distichlis spicata	40 to 45	
	Batis maritima	5	In patches
148	--	--	No data on species or percent

TABLE IX.- Continued

Training sample number	Species observed	Percentage	Remarks
149	Spartina patens	80	
	Distichlis spicata	10	
	Scirpus species	5	
151	Spartina patens	100	
165	Scirpus species	80	95- to 100-percent total vegetation
	Eichhornia crassipes	<5	
	Typha species	5	
	Sagittaria falcata	5 to 10	
	Spartina patens	5	
	Others	5	
167	Salix nigra	50 to 60	95- to 100-percent total vegetation; willow crown closure is 50 to 60 percent
	Eichhornia crassipes	40 to 50	
175	Spartina patens	95 to 100	70-percent total vegetation, 5-percent dead vegetation; some bare ground and standing water visible
	Dead vegetation	5	
177	--	--	100-percent water
178	Spartina patens	95	Good sample
	Scirpus species	3	
	Cyperus species	2	
179	Spartina patens	99	90-percent total vegetation
	Spartina alterniflora	1	
	Juncus roemerianus	--	One or two small patches
180	--	--	100-percent water
181	Spartina patens	80	Water level appears high; may discard
	Spartina alterniflora	20	
182	Spartina patens	80	80-percent total vegetation; very evenly mixed
	Polygonum species	10	
	Sagittaria falcata	5	
	Pluchea species	3	
	Scirpus species	2	Patchy
186	--	--	Discard; excessive water
196	Phragmites communis	90	
198	--	--	100-percent water
199	--	--	100-percent water
200	--	--	100-percent water
201	--	--	100-percent water
202	--	--	100-percent water
203	--	--	100-percent water
204	--	--	100-percent water
205	--	--	100-percent water
206	--	--	100-percent water
207	--	--	100-percent water
208	--	--	100-percent water
209	--	--	100-percent water

TABLE IX.- Concluded

Training sample number	Species observed	Percentage	Remarks
210	Spartina alterniflora	80	
	Spartina patens	15	
	Distichlis spicata	5	
212	Juncus roemerianus	60 to 70	Patchy sample
	Spartina alterniflora	15 to 20	
	Salicornia species	--	
	Distichlis spicata	--	
	Spartina patens	--	
213	Distichlis spicata	30	
	Spartina alterniflora	30	
	Spartina patens	30	
	Juncus roemerianus	<5	
214	Juncus roemerianus	80 to 90	Good sample
	Spartina alterniflora	5	
	Borrichia frutescens	--	
	Batis maritima	--	
	Distichlis spicata	--	
215	Spartina alterniflora	60	
	Spartina patens	25 to 30	
	Distichlis spicata	10 to 15	
216	Spartina alterniflora	90	
	Spartina patens	10	

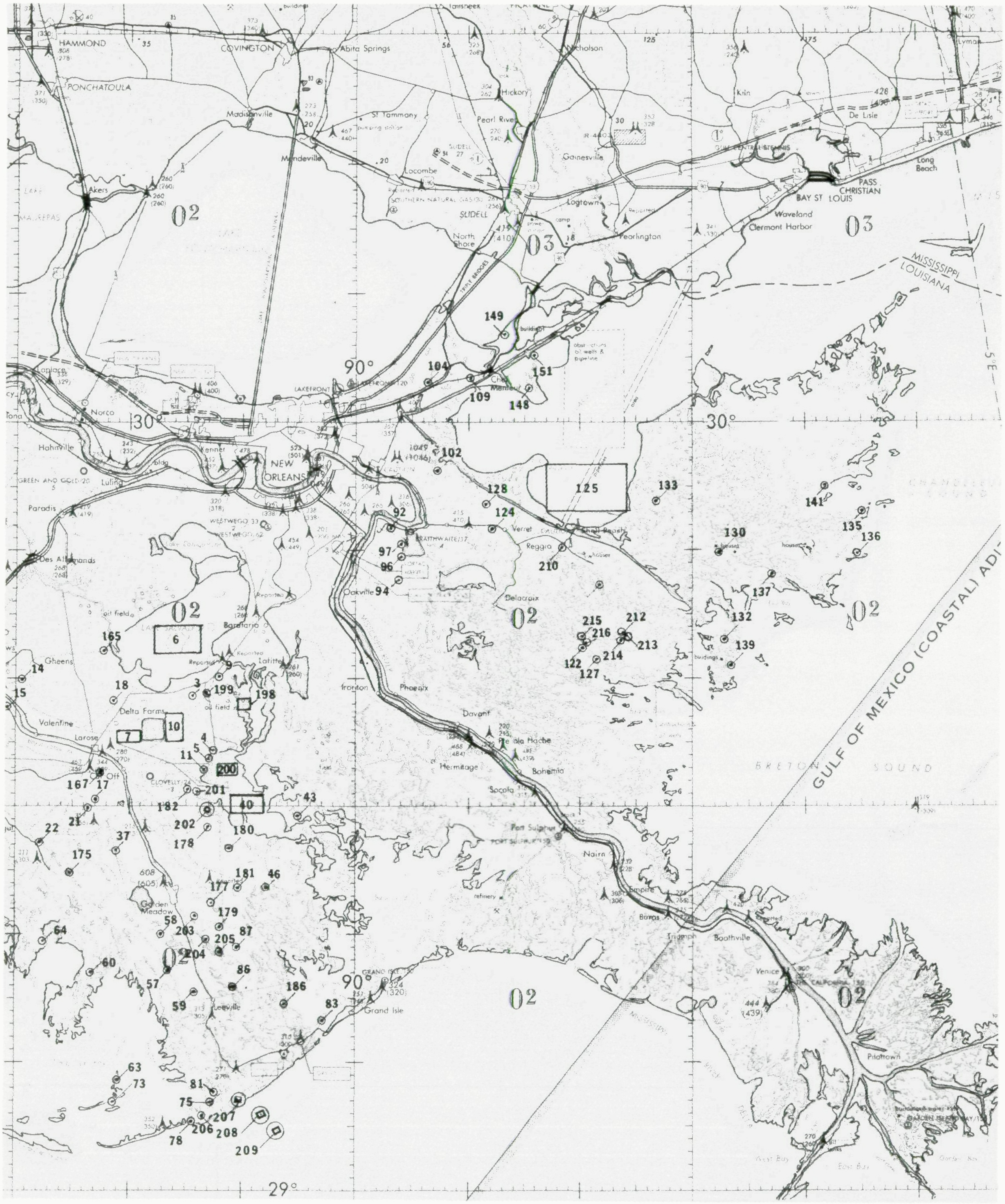


Figure 11.- Map of Lake Borgne and Terrebonne Bay study areas indicating approximate locations of training fields by number.

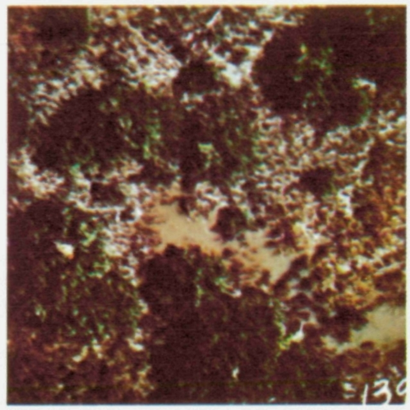
(a) Sagittaria falcata (in foreground), a fresh marsh species. The plants are approximately 1 meter in height.

(b) Aerial view of Panicum hemitomon, a fresh marsh species. The photograph was taken from approximately 15 meters above the vegetation.

(c) Spartina patens (in foreground), a brackish marsh species. The plants are approximately 1 to 1.5 meters in height.

Figure 12.- Ground and aerial photographs of vegetation indicators for the Louisiana marsh salinity zones.

(d) Spartina alterniflora, a saline marsh species, growing along the edge of a bayou. The plants are approximately 1 meter in height.



(e) Areial photograph of Avicennia germinans (dark green), a saline marsh species. The photograph was taken from approximately 15 meters above the vegetation.

(f) Juncus roemerianus (in foreground, a saline marsh species. The grayish vegetation is growth from the previous year. The plants are approximately 1 to 1.5 meters in height.

Figure 12.- Concluded.

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