An Evaluation of Landsat MSS Digital Data for Updating Habitat Maps of the Louisiana Coastal Zone

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ABSTRACT: The utility of Landsat MSS digital data and a machine classification technique was evaluated for updating a 1978 habitat map of a coastal lowland section located in southeast Louisiana. A four-band Landsat image was digitally registered to a cellularized habitat map using ground control points and image processing software. Two Landsat data files were used to derive classifications of the study area: (1) Landsat bands 2 and 4, and (2) components 1 and 2 of a four-band principal components transformation.

The habitat map was used as a mask file to develop spectral clusters for each habitat type from the Landsat data files. A gaussian maximum-likelihood classifier was used to generate a classification of each Landsat data file. The accuracies of the classifications were assessed by a direct pixel-to-pixel comparison of each classification with the cellularized habitat map.

The low mapping accuracies of the classifications derived from both Landsat data files were related to the difficulty of developing spectral signatures for the habitat types. The true spectral attributes of the habitat types were obscured by the combined effects of four factors: (1) misregistration between the cellularized habitat map and Landsat image, (2) boundary errors related to mixed pixels in the Landsat image and cellularization of the habitat map, (3) striping noise in the Landsat image, and (4) fundamental differences in the approaches used to produce the habitat map and Landsat classification.

INTRODUCTION

THE SOUND MANAGEMENT of coastal wetlands depends on the availability of reliable, timely information on the spatial distribution, identity, and condition of coastal resources. In 1981 the National Coastal Ecosystems Team (NCET) of the U.S. Fish and Wildlife Service (USFWS) implemented the Map Overlay and Statistical System (MOSS) (Lee, 1984), a subsystem of the computerized geographic information system designed to provide data and analyses on coastal zone resources. MOSS was developed by the USFWS Western Energy and Land Use Team, using software components from other systems operated by the U.S. Forest Service, Bureau of Land Management, U.S. Geological Survey (USGS), and several states.

MOSS can be used to analyze a variety of resource variables and display the information in tabular, graphical, statistical, or map form. Such variables as wetland habitat type, bottom sediment composition, salinity, bathymetry, distribution of organisms, and location of dredge spoil sites have been analyzed to support coastal zone management decisions. MOSS has also been used to address such environmental issues as (1) wetland habitat trends and change analysis, (2) potential impacts of dredge spoil deposition in coastal areas, (3) effects of oil and gas leasing on wetland and deepwater habitats, and (4) vulnerability of coastal resources to oil and toxic chemical spills (Ader and Stayner, 1982).

Habitat information maintained in the MOSS data base is produced from interpretations of aerial photographs, collateral data, and ground verification. Habitat types are modified from the hierarchical classification scheme of Cowardin *et al*. (1979), and constructed and labeled to correspond to coverage of USGS 7.5-min topographic map quadrangles. The maps are digitized, edited, verified, and entered into the MOSS data base using the Analytical Mapping System (Niedzwiadek, 1980).

The utility of any spatial information system used for coastal management, such as MOSS, is greatly enhanced by periodically updating the data base with current information on the status of coastal resources. Unfortunately, the present procedure used to update the MOSS data base (i.e., acquiring, interpreting, digitizing, editing, and verifying aerial photographs and collateral data) is labor intensive, time-consuming, and costly. The broad geographic and multidate coverage of the coastal zone offered by satellite remote sensing, therefore, coupled with computer automated processing, appeared to have the potential for low-cost information updating for the MOSS data base. Land-cover and land-use maps

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derived from machine classifications of remotely-sensed digital data have been prepared for a number of areas along the Atlantic and Gulf coasts (e.g., Brannon, 1983; Butera, 1977; Carter and Schubert, 1974; Dottavio and Dottavio, 1984; Finley *et al.*, 1981; Klemas *et al.*, 1975; Mace, 1982), but none of the prior efforts determined the feasibility of using the techniques to update habitat maps based on the Cowardin *et al.* (1979) classification system.

This study was therefore initiated by USFWS to determine whether Landsat Multispectral Scanner (MSS) digital data and computer-assisted image processing techniques could be used to update 1978 coastal habitat maps in the MOSS data base.

THE STUDY AREA

The study area is a 16,845-ha section of coastal lowland in southeast Louisiana (Figure 1). Its boundary is defined by the Barataria Pass USGS 7.5-min topographic quadrangle, which is located approximately midway between the Mississippi River and Bayou Lafourche, an abandoned distributary of the river. Tides are usually diurnal, small in amplitude, and markedly affected by wind velocity, direction, and duration. Soils in the area are the highly organic silts, clays, and mucks deposited by the river. Land cover and land use in the area are similar to those of other coastal regions in the northern Gulf of Mexico: open water, barrier islands, beaches, coastal vegetation, urban/commercial/industrial, recreation, and oil and gas exploration. Because estuarine physiography in southeast Louisiana results from complex interactions among riverine and marine processes and the subtropical climate, land cover and land use in the area are constantly altered by riverine sediment deposition, crustal subsidence, erosion, sea level changes, hurricanes, and human activities.

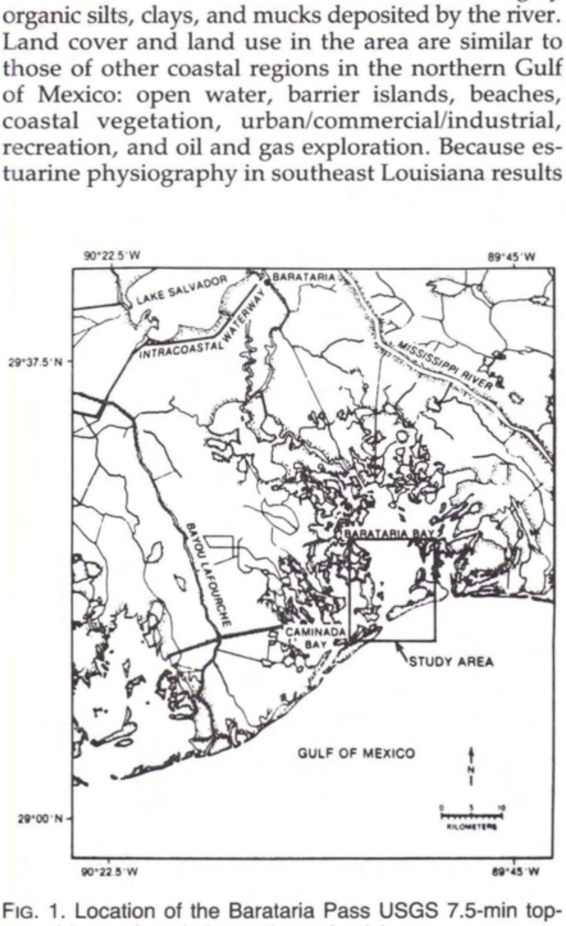

FIG. 1. Location of the Barataria Pass USGS 7.5-min topographic quadrangle in southeast Louisiana.

Information on the Barataria Pass quadrangle, stored in the MOSS data base, was produced from aerial photographs taken in October of 1956 and 1978 (Wicker, 1980). Fourteen habitat types were identified and delineated on the 1978 USFWS habitat map of the study area (Table 1). Dates and techniques used to produce this and other Louisiana coastal zone habitat maps are given in Wicker (1980). A number of changes in selected habitat types occurred between 1956 and 1978, the greatest percentage of them apparently related to activities such as canal dredging and urban expansion (Table 2).

TECHNICAL APPROACH

Digital images used in this study were processed using the Fisheries Image Processing System (FIPS) operated by the National Marine Fisheries Service. FIPS consists of a Sperry-Univac V77/600 minicomputer,* cathode-ray tube display, and associated hardware; software is modified from the Earth Resources Laboratory Applications Software (ELAS) (Graham *et al.*, 1984).

The Barataria Pass quadrangle habitat map was geographically referenced to the Universal Transverse Mercator (UTM) coordinate system, and was converted to a 50-m grid cell format. The MOSS algorithm used to convert the polygon data to grid cells assigns the dominant habitat type to each cell of the gridded map, leaving cells without a dominant type unclassified; 15 such pixels were left unclassified in the study area map. The remaining pixels (n = 67,308) were classified into the 14 habitat types described in Table 1, and the now-cellularized map was reformatted for processing in ELAS.

No cloud-free Landsat MSS image was available on the Barataria Pass quadrangle corresponding to the 15 October 1978 date (NASA flight number: 78-148; roll number: 2693; frame numbers: 909, 911, 959, and 961) of the MOSS habitat information. The Landsat MSS digital image used in this study was made approximately one year later on 27 October 1979 (scene I.D.: 8217391456XO). The four-band image was registered to the cellularized map using ELAS modules OCON and OVLA (Graham *et al.*, 1984). Ten ground-control points were used to compute the least-squares equations that transformed the Landsat image into the UTM coordinate system of the habitat map. The Landsat pixels were resampled to 50-m grid cells by bilinear interpolation; overall accuracy of the registration was about 36 m. A binary mask was then generated from the habitat map

* The use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1. HABITAT TYPES, AREAS, AND DESCRIPTIONS FOR BARATARIA PASS QUADRANGLE, LOUISIANA, OCTOBER 1978.

USFWS category	Habitat type	Habitat area (ha)	Percent of total area	Habitat description[a]
E2SS3	Black mangrove	122	0.72	Black mangrove (*Avicennia germinans*).
E2EM5N4	Salt marsh	936	5.56	Oyster grass (*Spartina alterniflora*), black rush (*Juncus roemerianus*), saltwort (*Batis maritima*), and salt grass (*Distichlis spicata*).
E1OW	Open water	15,222	90.36	Non-channelized estuarine water bodies such as embayments, ponds, lakes, and bayous.
E2BB2	Sand/shell beach	37	0.22	Wave-reworked sand and/or shell material along land-water interface.
USS1S	Spoil bank vegetation	112	0.66	Marsh elder (*Iva frutescens*), eastern baccharis (*Baccharis halimifolia*), and waxmyrtle (*Myrica cerifera*).
E1OW0	Oil/gas canals	55	0.33	Excavated or impounded estuarine water bodies, such as the brine discharge pits, rig cuts, and pipeline canals made by the oil and gas industry.
E2RF2	Oyster reef	3	0.02	Irregularly shaped deposits of living and/or dead oysters (*Crassostrea virginica*).
E2FL23	Sand/shell/mud flat	1	0.01	Unvegetated sand and/or shell and/or mud deposits.
E1OWX	Excavated open water	34	0.20	Excavated estuarine water bodies such as borrow pits and navigation canals constructed and utilized for purposes other than oil and gas activities.
UDV3	Unvegetated spoil site	78	0.46	Areas cleared of vegetation through disposal of spoil or non-liquid waste materials.
E2FL2	Sand/shell flat	6	0.04	Unvegetated sand and/or shell deposits.
UDV1	Urban/residential/ commercial/industrial	210	1.25	Residential, commercial, urban, and industrial developments on upland sites.
UDV10	Commerical/industrial	1	0.01	Industrial development associated with the oil and gas industry.
E2EM5N4D	Altered salt marsh	28	0.17	Salt marsh areas that have been partially ditched and drained but still support salt marsh vegetation.

[a]Habitat descriptions adapted from Wicker (1980).
Source: tabulated from data provided by Floyd Stayner, NCET, USFWS.

to exclude pixels in the Landsat image that were outside the boundary of the study area.

Striping noise caused by non-linearity in the MSS detector responses was apparent in the open water areas of Landsat image bands 1, 2, and 3. A preliminary unsupervised classification based on all four bands was produced to gauge the effects of striping noise on the spectral separability of marsh, water, and marsh-water interface pixels. The striping noise had a tendency to confound the spectral signatures of some marsh, water, and marsh-water interface pixels, resulting in confusion among the three classes. The ELAS module used to destripe Landsat data did not resolve the problem, so an alternate technique was devised. As the band 4 Landsat data were apparently free of striping noise, a technique was developed to identify land pixels in the image using gray-level thresholds. Pixels with digital count values less than or equal to one were defined as water and those greater than one, as land. The land pixels in band 4 were then used as a template to replace corresponding ones in bands 1, 2, and 3, with the mean digital count value for water computed for each of the three bands. The resulting "all-water" images were filtered with two or three passes of a 7 by 7 boxcar filter to smooth the effects of the noisy pixels. The original land pixels were replaced in the filtered water image for each of the three bands, thereby removing the striping noise and retaining spatial resolution in land areas and at the interface between the land areas and open water. Finally, all bands were transformed into principal components.

TABLE 2. CHANGES IN SELECTED HABITAT TYPES, 1956–78, TABULATED FROM THE MOSS DATA BASE FOR BARATARIA PASS QUADRANGLE, LOUISIANA.

USFWS Habitat category	Habitat type	1956 area (ha)	1978 area (ha)	1956–78 change (ha)	1956–78 change (%)[a]
(b)	Salt marsh	1,903[b]	964[b]	−939	−49.3
(c)	Open water	14,710	15,232[c]	522	3.6
E2BB2	Sand/shell beach	91	37	− 54	−59.3
E10W	Oil/gas canals	5	55	50	1,000.0
E10WX	Excavated open water	2	34	32	1,600.0
UDV3	Unvegetated spoil sites	39	78	39	100.0
(d)	Urban/residential/ commercial/industrial	95	211	116	122.1

[a]1956–78 Habitat Change (%) $= \frac{(1978 \text{ habitat area} - 1956 \text{ habitat area})}{1956 \text{ habitat area}} \times 100$

[b]The 1956 area estimate includes 1,903-ha salt marsh (E2EM) compared to an estimated 936-ha salt marsh (E2EM5N4) and 28-ha altered salt marsh (E2EM5N4d) in 1978.

[c]The 1978 area estimate includes 15,222-ha open water (E10W), 3-ha oyster reefs (E2RF2), 1-ha sand/shell/mud flats (E2FL23), and 6-ha sand/shell flats (E2FL2).

[d]Includes USFWS habitat categories UDV1 and UDV10.

Source: tabulated from data provided by Floyd Stayner, NCET, USFWS.

Eigenvalues for components 1 through 4 were 3.4586, 0.4870, 0.0475, and 0.0070, respectively.

In an effort to reduce the effects of striping noise remaining in land areas, bands 1 and 3, and component 3 were excluded from further analysis. The component 4 image accounted for only 0.17 percent of the total spectral variation in the study area and was also removed from the data set. Two data files were therefore prepared for multispectral classification: (1) bands 2 and 4, and (2) components 1 and 2.

The land-water image produced from Landsat band 4 was used in two analyses of the possible effects of misregistration, water level differences, boundary pixels, and coarse resolution of the Landsat MSS on classification accuracy. The first analysis utilized the ELAS Data Base Basic (DBAS) module (Graham *et al.*, 1984) to compare the habitat map with the land-water image derived from Landsat and to identify land habitat pixels incorrectly identified as water by Landsat as well as water habitat pixels incorrectly identified as land by Landsat. In the second analysis, the DBAS module was used to implement an edge detection algorithm, based on a gray-level threshold (Gonzales and Wintz, 1977), and generate a four-class file: (1) habitat map land-water interface pixels, (2) Landsat land-water interface pixels, (3) overlapping land-water interface pixels from the habitat map and Landsat image, and (4) all other pixels.

A classification technique combining supervised and unsupervised approaches was used to develop spectral signatures for each habitat type. The ELAS Within Class Cluster (WCCL) module examines a user-specified group of pixels in a one-channel mask file and develops spectral signatures from corresponding pixels in a multichannel data file using point-clustering and user-controlled parameters to develop spectral clusters for the mask file category of interest. In this study, the habitat map was specified as the mask file and, with the data files, was used to develop spectral clusters for each of the 14 habitat types. Spectral clusters with singular variance-covariance matrices were either deleted with the ELAS Statistics Utility (STUT) module or were regenerated by altering parameters in the WCCL module. Similar spectral clusters within each habitat type were identified using pairwise divergence measures and merged using the STUT module. The ELAS module MAXL, a gaussian maximum-likelihood classifier, was used without a threshold or *a priori* probabilities to classify the data files. Landsat classification accuracy was assessed by tabulating omission and commission errors from contingency tables derived from a direct pixel-to-pixel comparison of each classification with the cellularized habitat map.

RESULTS

The large number of omission and commission errors resulted in low mapping accuracy for nearly all habitat types (Tables 3 and 4). Mapping accuracies for salt marsh habitats, in particular, were substantially lower than the figures previously reported for other wetland areas along the Gulf and Atlantic coasts (Butera, 1977; Klemas *et al.*, 1975). Overall mapping accuracy of the Landsat bands 2 and 4 classification was markedly higher than that of the principal components, but this is somewhat misleading because about 90 percent of the land cover in the Barataria Pass quadrangle is open water, which was mapped at a high level of accuracy (Table 4). Transformation of the four-band Landsat image seemed to exacerbate the problems of intraclass variability and spectral overlap of some habitat categories (Figures 2 and 3). This resulted in a high

TABLE 3. ACCURACY ASSESSMENT COMPARING RESULTS OF THE TWO CLASSIFICATIONS FOR THE 14 HABITAT TYPES, BARATARIA PASS QUADRANGLE, LOUISIANA.

		Landsat data file					
		Bands 2 and 4			Principal components 1 and 2		
Habitat type	Total no. of pixels	Omission error (%)	Commission error (%)	Mapping accuracy (%)	Omission error (%)	Commission error (%)	Mapping accuracy (%)
Black mangrove	485	69.5	172.2	11.2	58.4	225.6	12.8
Salt marsh	3,754	97.9	1.9	2.0	97.1	828.4	0.3
Open water	60,829	4.1	0.4	95.5	76.7	0.3	23.2
Sand/shell beach	152	49.3	128.9	22.1	57.9	8,820.4	0.5
Spoil bank vegetation	417	86.8	134.1	5.6	62.6	446.5	6.8
Oil/gas canals	230	57.4	746.1	5.0	84.3	650.4	2.1
Oyster reef	16	75.0	675.0	3.2	50.0	693.8	6.3
Sand/shell/mud flat	4	50.0	6,125.0	0.8	100.0	0.0	0.0
Excavated open water	139	71.2	1,318.0	2.0	73.4	1,243.9	2.0
Unvegetated spoil site	308	85.1	112.7	7.0	79.2	65.3	12.6
Sand/shell flat	24	66.7	358.3	7.3	58.3	187.5	14.5
Urban/residential	839	16.4	145.5	34.0	45.6	23.5	44.0
Commercial/industrial	5	100.0	1,520.0	0.0	100.0	3,920.0	0.0
Altered salt marsh	106	55.7	131.1	19.2	39.6	312.3	14.6
Unclassified	15	(a)	(a)	(a)	(a)	(a)	(a)
Overall mapping accuracy (%)[b]				88.6			22.8

[a]Not determined.
[b]Unclassified pixels from habitat map excluded from tabulations.

TABLE 4. ACCURACY ASSESSMENT COMPARING RESULTS OF THE TWO CLASSIFICATIONS FOR 14 HABITAT TYPES AGGREGATED INTO LAND AND WATER CATEGORIES FOR BARATARIA PASS QUADRANGLE, LOUISIANA.

				Landsat data file					
				Bands 2 and 4			Principal components 1 and 2		
Category	Total number of habitat types	Total no. of pixels	Percent of total area	Omission error (%)	Commission error (%)	Mapping accuracy (%)	Omission error (%)	Commission error (%)	Mapping accuracy (%)
Land	11	6,110	9.08	80.9	63.5	11.7	81.4	794.5	18.6
Water	3	61,198	90.90	4.4	6.2	90.0	76.7	5.5	23.3
Unclassified	(a)	15	0.02	(a)	(a)	(a)	(a)	(a)	(a)

[a]Not determined.

number of omission errors in the open water category, based on principal components 1 and 2 (Table 3).

The generally low mapping accuracies shown in Table 3 are directly related to the high intraclass variability and spectral overlap of the habitat types (Figures 2 and 3). Spheriods in Figures 2 and 3 depict the magnitude of the spectral overlap, the area

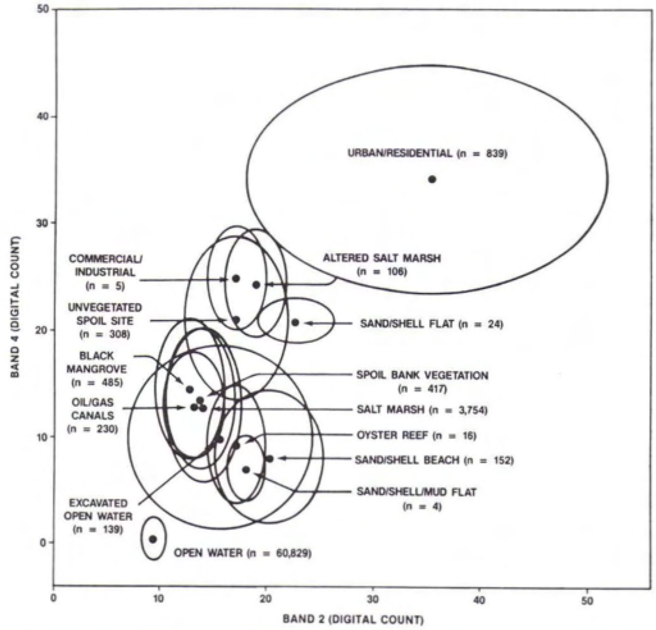

FIG. 2. Mean digital count value, standard deviation, and total number of pixels (n) for each of the 14 habitat types derived from Landsat bands 2 and 4 for Barataria Pass quadrangle, Louisiana.

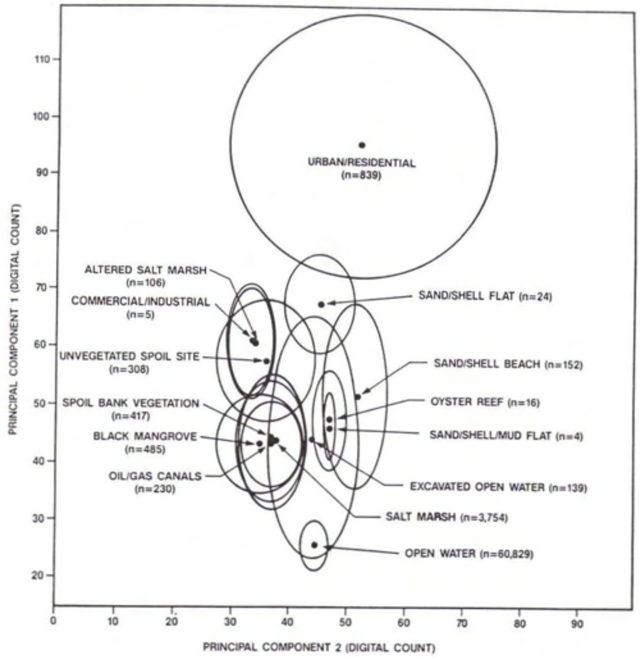

FIG. 3. Mean digital count value, standard deviation, and total number of pixels (n) for each of the 14 habitat types derived from principal components 1 and 2 for Barataria Pass quadrangle, Louisiana.

of each spheriod encompassing 68 percent of the spectral values in each habitat type. If these spheriods were redrawn to include the remaining 32 percent of the observations (i.e., using three standard deviations from the mean instead of one), virtually all of the types would overlap.

A particularly large number of omission errors occurred for open water, where 4.1 percent of the pixels identified as open water in the habitat map were incorrectly classified by Landsat into the 11 land habitat types (Table 3). MAXL classifications of Landsat bands 2 and 4 in coastal areas usually resulted in a high level of separation between land and water, and the large open water error contradicted the expectation of maximum discrimination between land and water. The mean, standard deviation, and range of the four-band Landsat data for each habitat type were then plotted (Figure 4); results for band 4 are of particular interest because of spectral signature irregularities for most of the habitat types. Band 4 digital count values for water were previously defined as less than or equal to one, while those for land had values greater than one. However, minimum digital count values for six of the 11 land habitat types were zero, indicating that some pixels had signatures that were characteristic of water (Figure 4). All three water classes (open water, oil/gas canals, and excavated open water) had values indicative of land, that is, values greater than one (Figure 4).

Signature anomalies were investigated by determining the number and identity of both land habitat pixels incorrectly identified as water by Landsat and water habitat pixels incorrectly identified as land by Landsat (Table 5). Results suggest that land areas in the Barataria Pass quadrangle were overestimated in the Landsat image by about 32 percent.

At the same time, hourly water levels before, during, and after the overflights were plotted and show a difference in levels between the habitat map and Landsat image (Figure 5). The water level was about 17 cm lower at the time of the Landsat overpass than were water level conditions recorded at the time of the habitat map overflight.

Four factors were thus identified that might account for aberrations in the band 4 digital count ranges:

- Misregistration between the cellularized habitat map and Landsat image,
- Boundary errors related to mixed pixels in the Landsat image and cellularization of the habitat map,

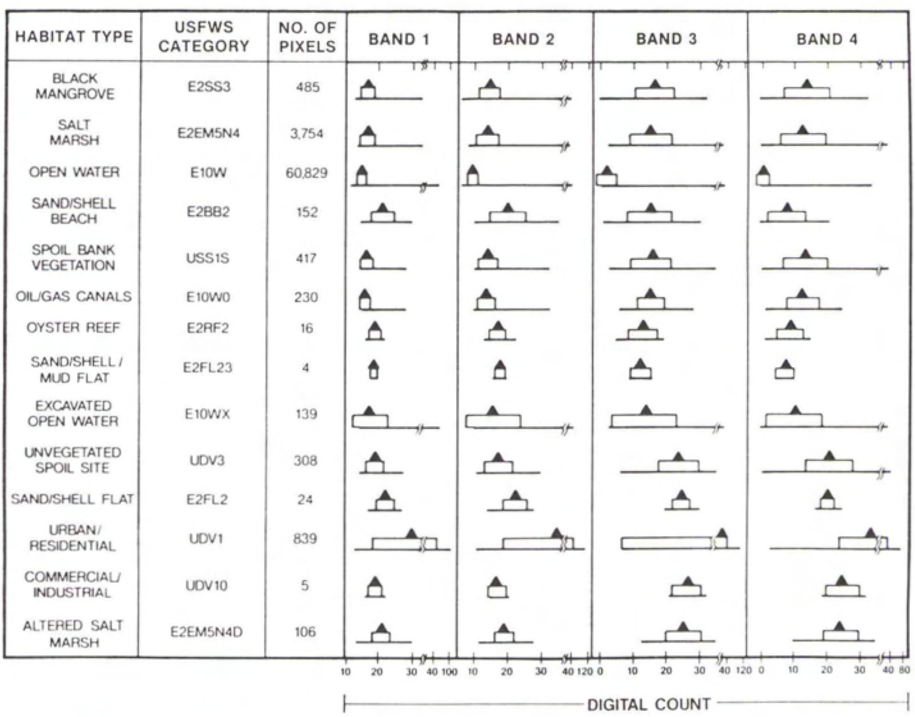

FIG. 4. Digital count values developed from the four-band Landsat MSS image for each of the 14 habitat types, Barataria Pass quadrangle, Louisiana. The black triangle is the mean, the white bar is one unit of standard deviation on each side of the mean, and the black horizontal line is the range.

TABLE 5. NUMBER AND IDENTITY OF HABITAT PIXELS INCORRECTLY IDENTIFIED AS LAND OR WATER BY LANDSAT FOR BARATARIA PASS QUADRANGLE, LOUISIANA.

Habitat data			Landsat data		
Category	Habitat type	Total no. of pixels	Land	Water	Incorrectly identified pixels (%)
Land	Black mangrove	485	474	11	2.27
Land	Salt marsh	3,754	3,672	82	2.18
Water	Open water	60,829	2,709	58,120	4.45
Land	Sand/shell beach	152	132	20	13.16
Land	Spoil bank vegetation	417	405	12	2.88
Water	Oil/gas canals	230	228	2	99.13
Land	Oyster reef	16	15	1	6.25
Land	Sand/shell/mud flat	4	4	0	0.00
Water	Excavated open water	139	118	21	84.89
Land	Unvegetated spoil site	308	307	1	0.32
Land	Sand/shell flat	24	24	0	0.00
Land	Urban/residential	839	839	0	0.00
Land	Commercial/industrial	5	5	0	0.00
Land	Altered salt marsh	106	106	0	0.00
(a)	Unclassified	15	(a)	(a)	(a)
	Total number of incorrect pixels[b]		3,055	127	
	Total area (ha)[b]		763.76	31.75	
	Percent of total area[b]		32.40	2.08	

[a]Not determined
[b]Unclassified pixels from habitat map excluded from tabulations.

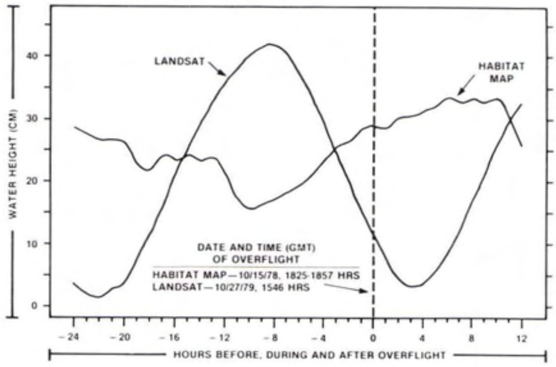

FIG. 5. Hourly water level readings, converted to Greenwich Mean Time (GMT), collected from the National Ocean Survey guage at Grand Isle, Louisiana, before, during, and after each overpass.

- Water level differences between the habitat map and Landsat image, and
- Inadequate spatial resolution of the Landsat MSS.

The combined effects of these four factors are shown in Plate 1. Shoreline displacement is related to misregistration, water level differences, and mixed pixels in the Landsat image, while water bodies in the interior areas of some islands are poorly discriminated by Landsat. The effects of sensor resolution are particularly evident in linear features, such as oil and gas canals and excavated open water. Mapping errors related to cellularization of the habitat map were also apparent in linear features.

DISCUSSION

The land-cover and land-use changes that occurred in the study area during the one-year period between habitat mapping and Landsat imaging were probably negligible, but could possibly have affected the classification accuracy of some habitat types. Newly deposited dredge spoil, for example, would probably be colonized by such vegetation as marsh elder, eastern baccharis, and waxmyrtle within a one-year period. The unavailability of suitable Landsat data also prevented such important objectives as determination of the optimum season for updating habitat information or enhancing classification accuracy with multidate image files.

In shallow coastal areas of nearly uniform relief, such as the marshes in southeast Louisiana, small changes in tidal height can have a profound effect on the extent of land exposed or inundated. The effects of the small water level difference between the two overflight periods, however, were probably masked by the 80 by 80-m ground resolution of the Landsat MSS.

With the availability of high resolution imaging systems, such as the Landsat Thematic Mapper (TM) and French SPOT satellite, water level changes will have important implications in the use of time-sequential, machine classifications of remotely sensed data for monitoring coastal resources in Louisiana. The mapping of temporal changes in the areal extent of land and water may be an artifact of a water level difference between the two thematic maps used

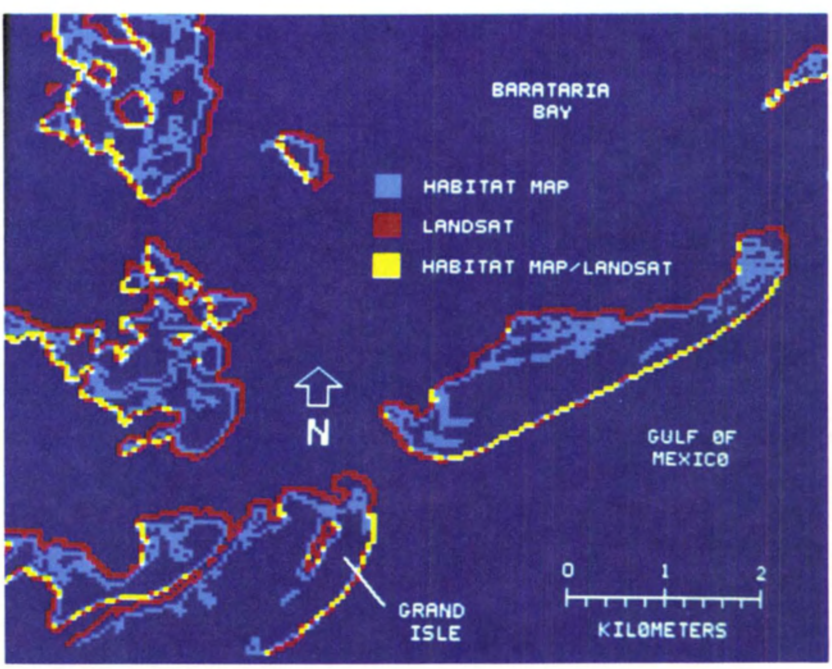

PLATE 1. Image file with superimposed land-water interfaces, developed from the habitat map and Landsat image for a portion of the Barataria Pass quadrangle, Louisiana.

in the comparison, rather than an actual change in land cover. Such effects may be more pronounced in coastal areas where the land-water interface is highly convoluted. These areas are characterized by intricate networks of water bodies, such as tidal channels, bayous, ponds, lakes, and canals, and may be far more affected by a water level difference than the Barataria Pass quadrangle, where the spatial complexity of the land-water interface is relatively low.

Predicted tidal levels in southeast Louisiana are usually unreliable because of the overriding influence of winds, especially in autumn during the passage of cold-air fronts. The strong northerly winds that accompany the passage of a front have a tendency to lower water levels by pushing water out of the coastal marshes and into the Gulf of Mexico, while prolonged southerly winds have the opposite effect, raising water levels in the marsh. Thus, the determination of water height for a remotely-sensed image of the Louisana coastal zone requires data recorded on a gauge located in the area of interest at the time of the overflight.

A fundamental problem encountered in this study was the inability to adequately register the Landsat image to the cellulurized habitat map. The selection of ground control points (GCPs) was particularly troublesome because of the relatively coarse Landsat MSS resolution. All of the fixed landmarks in the study area that were suitable for GCPs (oil and gas structures, bridges, and highway intersections) were below the instantaneous field-of-view (IFOV) of the Landsat MSS and were thus not visible in the image. Additionally, such landmarks as power lines, highways, oil and gas structures, and bridges are not routinely mapped on habitat maps stored in the MOSS data base. The only landmarks common to both images were located at the land-water interfaces. The ten selected ground control points consisted primarily of shoreline protrusions on the perimeter of islands in the study area. This approach undoubtedly introduced errors during the process of transforming the Landsat image into the habitat map coordinate system.

Kirby and Steiner (1978) noted that the geometric integrity of an image registered using transformation equations based on least-squares can be adversely affected by at least two factors: (1) measurement errors between the pairs of coordinates for each GCP and (2) failure to select GCPs that are well dispersed throughout the image. These requirements were difficult to satisfy for two reasons. First, the position of the land-water interface in the Landsat image relative to the habitat map shoreline was displaced because of boundary pixels. Because most of the GCPs common to both images occurred at the land-water interface, there were probably substantial measurement errors between pairs of coordinates for each GCP. Second, selecting GCPs that were well scattered throughout the study area was very difficult because of the configuration of the landscape in the Barataria Pass quadrangle. This area is predominately open water, with the islands oriented in the shape of a "V" toward the southeast. It was thus impossible to obtain an even distribution of GCPs across the study area.

Boundary effects in the Landsat images and habitat map probably had an adverse effect on classification accuracy. A primary difference between the Landsat-derived classification and habitat map was the presence of mixed pixels in Landsat images, occurring as narrow transition areas between adjacent land-cover types. Spectral characteristics of those mixed pixels are unlike the land-cover types on either side and, depending upon the classification technique, may be incorrectly grouped into separate classes. Relatively large numbers of mixed pixels, occurring at the land-water interface, would be expected in Landsat MSS images of the Louisiana coastal zone considering the numerous, intricately-shaped, and small water bodies in the area and 80-m ground resolution of the sensor (Markham and Townshend, 1981). In contrast to the Landsat images, there are no mixed pixels in the habitat map because manual interpretation of photography allows a sharp demarcation between adjacent habitat types. There were, however, mapping errors resulting from converting the habitat map to grid cells from a polygon format. These errors were particularly evident in the cellularized habitat map as (1) unclassified cells and (2) visual distortions in natural shorelines, oil and gas canals, and excavated open water. The magnitude of such errors is inversely related to the sizes of the grid cells (Wehde, 1982). Thus, boundary errors related to mixed pixels in the Landsat image and cellularization of the habitat map probably contributed to some of the classification errors associated with the direct updating approach used in this study.

Residual striping noise over land areas probably also contributed to errors in the classification derived from Landsat bands 2 and 4. Striping over the land areas was apparently removed by transforming the four-band Landsat image into principal components and discarding component 3. The classification based on components 1 and 2 produced generally lower mapping accuracies than the classification derived from the untransformed Landsat data file. Components 1 and 2 of the principal components transformation, however, visually appeared to enhance cultural features and vegetation in the study area to a greater extent than the untransformed data set.

Image enhancement techniques based on principal component transformations of multispectral digital data are largely unexplored as tools for coastal habitat mapping. The potential of the technique for broad-scale habitat mapping may be limited, however, because the results obtained are entirely dependent on the spectral attributes of a given landscape, characteristics of the imaging system, and the analyst's decision to use computer-assisted or manual techniques in the classification process. Because estuarine land cover and land use varies markedly in identity, areal extent, and distribution from one region of the country to another, the utility of the technique for mapping coastal habitats will probably have to be determined on a case-by-case basis.

The combined effects of misregistration, boundary errors, and striping noise had a highly uncertain outcome on the development of spectral signatures for each habitat type. The true spectral attributes of each habitat type were obscured by these three factors during signature development with the hybrid classifier. Given that the true spectral signature of each habitat type could be developed from Landsat MSS data, the resulting machine classification would probably not meet the mapping accuracy required for this study, reflecting fundamental differences in the approaches used to produce the habitat map and Landsat classification.

The hierarchical classification system of Cowardin *et al*. (1979) requires manual interpretation of high-quality aerial photographs and collateral data for application to estuarine habitats. Aerial photographs, salinity measurements, vegetation maps, published reports, and ground verification were essential to map coastal habitats in Louisiana (Wicker, 1980), and this approach contrasts sharply with the use of relatively low-resolution satellite digital data and a machine classifier to update coastal habitat maps based on the Cowardin *et al*. (1979) system. Simple decision rule classifiers, such as the gaussian maximum-likelihood algorithm used in this study, are not designed to utilize the *a priori* information or non-image data to map coastal habitats by the Cowardin *et al*. (1979) system. Although the increased spectral and spatial resolution of Landsat TM imagery is likely to enhance efforts to map land cover in the coastal zone (Dottavio and Dottavio, 1984), its use with the Cowardin *et al*. (1979) system has not been determined.

CONCLUSIONS AND RECOMMENDATIONS

- The 16-day lag for repetitive Landsat coverage, coupled with problems of cloud cover and water levels, will seriously limit the potential for monitoring coastal resources in southeast Louisiana with remotely-sensed satellite data. Such a program, therefore, will have to supplement Landsat imagery with aircraft remote sensing to insure adequate coverage of the coastal zone at regular intervals.
- The use of machine classifications derived from high-resolution, remotely-sensed images for inventorying and monitoring coastal resources in Louisiana may require data on water level conditions at the time of each overflight. In the case of Landsat TM data, the preliminary screening of images for cloud cover and image quality should include water level comparisons, preferably based on continuously recorded data from a gauge located in the area of interest. Unfortunately, *in situ* water level data may not be available for some coastal zone areas.
- The careful selection of fixed ground control points is essential to reduce misregistration errors. The higher spatial resolution of Landsat TM data will facilitate the selection of suitable ground control points for the habitat maps. Two approaches are suggested for including ground control points in habitat maps: (1) digitally embedding ground control points in the habitat map or (2) creating a separate mask file from the habitat maps and then digitally embedding the ground control points.
- The complexity of the coastal zone landscape and requirements for updating habitat maps will require a more sophisticated classification approach. A machine classifier would have to utilize large amounts of collateral data and *a priori* information to accurately assign habitat pixels. The design and implementation of such a classifier would be formidable and expensive. An alternate approach, not evaluated in this study, is manual interpretation of habitat boundaries from color composites generated by such image enhancement techniques as principal components transformation or band ratioing. Habitat polygons mapped on the color composites could then be processed for storage in the MOSS data base.

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