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Coastal Change Analysis Program Implemented in Louisiana

Elijah W. Ramsey III, Gene A. Nelson, and Sijan K. Sapkota†

U.S. Geological Survey
National Wetlands Research Center
†Johnson Controls World Services Inc.
700 Cajundome Blvd., Lafayette, LA 70506, U.S.A.

ABSTRACT

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Landsat Thematic Mapper images from 1990 to 1996 and collateral data sources were used to classify the land cover of the Mermentau River Basin (MRB) within the Chenier Plain of coastal Louisiana. Landcover classes followed the definition of the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program; however, classification methods had to be developed as part of this study for attainment of these national classification standards. Classification method developments were especially important when classes were spectrally inseparable, when classes were part of spatial and spectral continuums, when the spatial resolution of the sensor included more than one landcover type, and when human activities caused abnormal transitions in the landscape. Most classification problems were overcome by using one or a combination of techniques, such as separating the MRB into subregions of commonality, applying masks to specific land mixtures, and highlighting class transitions between years that were highly unlikely. Overall, 1990, 1993, and 1996 classification accuracy percentages (associated kappa statistics) were 80% (0.79), 78% (0.76), and 86% (0.84), respectively. Most classification errors were associated with confusion between managed (cultivated land) and unmanaged grassland classes; scrub shrub, grasslands and forest classes; water, unconsolidated shore and bare land classes; and especially in 1993, between water and floating vegetation classes. Combining cultivated land and grassland classes and water and floating vegetation classes into single classes accuracies for 1990, 1993, and 1996 increased to 82%, 83%, and 90%, respectively.

To improve the interpretation of landcover change, three indicators of landcover class stability were formulated. Location stability was defined as the percentage of a landcover class that remained as the same class in the same location at the beginning and the end of the monitoring period. Residence stability was defined as the percent change in each class within the entire MRB during the monitoring period. Turnover was defined as the addition of other landcover classes to the target landcover class during the defined monitoring period. These indicators allowed quick assessment of the dynamic nature of landcover classes, both in reference to a spatial location and to retaining their presence throughout the MRB.

Examining the landcover changes between 1990 to 1993 and 1993 to 1996, led us to five principal findings: (1) Landcover turnover is maintaining a near stable logging cycle, although the locations of grassland, scrub shrub, and forest areas involved in the cycle appeared to change. (2) Planting of seedlings is critical to maintaining cycle stability. (3) Logging activities tend to replace woody land mixed forests with woody land evergreen forests. (4) Wetland estuarine marshes are expanding slightly. (5) Wetland palustrine marshes and mature forested wetlands in the MRB are relatively stable.

ADDITIONAL INDEX WORDS: *Landsat Thematic Mapper, land cover, classification, change detection, Mermentau River Basin, location stability, residence stability, turnover, accuracy assessment.*

INTRODUCTION

Dramatic losses of wetlands within the coastal zone of Louisiana have been documented since 1956 (NATIONAL RESEARCH COUNCIL, 1987). Methods are needed to quantify these wetland changes, mitigate the losses where feasible, and manage the remaining resources in a sustainable fashion. To manage the wetland resource, a regional assessment is necessary for the present land cover, recent landcover change, and the association between wetland condition and human-induced (*e.g.,* hydrologic modification, agricultural pollution, oil exploration) and natural (*e.g.,* sea-level rise, storms, subsidence) alterations. Further, resource managers must be provided with an early warning system that is able to quickly and efficiently assess large areas in order to identify wetland stress in time to mitigate wetland loss.

The U.S. Geological Survey's (USGS) National Wetlands Research Center (NWRC) in participation with the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) developed and built a comprehensive and standardized geographic information system to detect and assess changes in land cover in and immediately surrounding the Mermentau River Basin (MRB) within the Chenier Plain of coastal Louisiana (Figure 1). Programs such as C-CAP use the Landsat Thematic Mapper (TM) sensor to provide a timely and cost effective national system of classified coastal landcover maps (KLEMAS *et al.,* 1993). Regionally, however, the development of new and the

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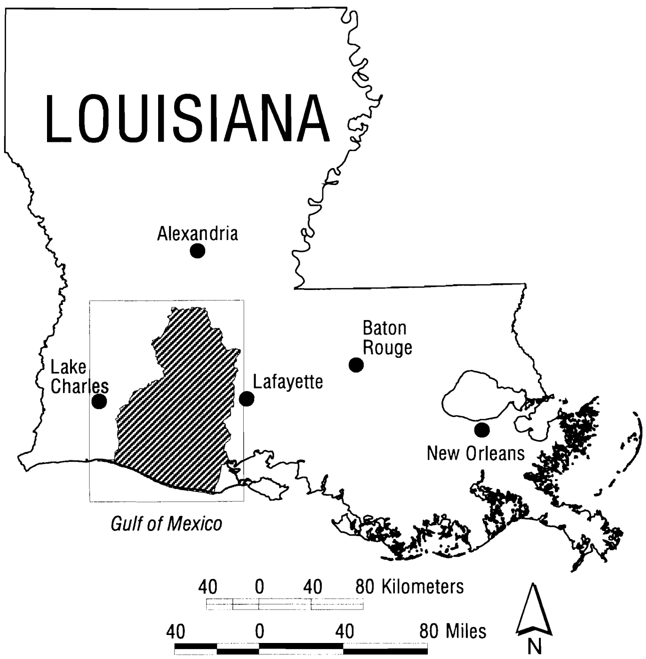

Figure 1. The Mermentau River Basin (MRB) study area includes 1,938,552 ha of coastal zone, prairie region, and forest. The hydraulic confines of the MRB encompass 964,771 ha.

modification of current methods based on national standards are desirable. The C-CAP national standard classification definitions would not change, but the methods to obtain these standard classifications may need change or revision.

The development of base line landcover information also benefits the implementation of the Nonpoint Source (NPS) Management Program for the MRB mandated by the Coastal Zone Management Act Reauthorization Amendments of 1990. The primary objective of the NPS Management Program is to implement the best management practices (BMP) that reduce the level of nonpoint source pollution in surface and ground waters and adjacent coastal waters (Louisiana Department of Environmental Quality (LDEQ) Office of Water Resources, 1990, 1992). In Louisiana, about 35% of wetlands are impacted by agricultural nonpoint source (LDEQ Office of Water Resources n.d.). Identification of these nonpoint sources not only would provide a base map for implementation of the Louisiana NPS program, but it would also provide a method to monitor results from BMP implementations.

Currently, NWRC is exploring the use of remote sensing techniques to identify and monitor wetland type and wetland health in the U.S. Gulf of Mexico coast (RAMSEY *et al.*, 1992; RAMSEY *et al.*, 1993; RAMSEY and LAINE, 1997). Results from these studies indicated that human and animal activities (*e.g.*, marsh burning, animal herbivory) and changing vegetation conditions (*e.g.*, transient aquatic vegetation, forest leaf-off and leaf-on) complicate accurate assessment of coastal resources (RAMSEY *et al.*, 1993; RAMSEY and LAINE, 1997). Added to the highly irregular and heterogeneous nature of the Louisiana coastal wetland, these problems can confound classification based on only one TM image. Collateral data (*e.g.*, photography, National Wetlands Inventory [NWI]) are helpful (WILEN and FRAYER, 1990), but indications are that higher classification accuracy is possible by using multidate TM images (RAMSEY *et al.*, 1994; RAMSEY and LAINE, 1997; LUNETTA and BALOSH, 1999).

This study drew upon results of the previous remote sensing studies conducted at NWRC. It extends our region of study from areas directly influenced by the Mississippi River to the Chenier Plain by producing a regional assessment of the land cover in the MRB and surrounding areas. Our objectives in this study were to create maps documenting the land cover and areas of change in the MRB from 1990 to 1996 and develop regional methods, as outlined in DOBSON *et al.* (1995), specifically for coastal Louisiana and for the Gulf of Mexico coastal region in general. An added component of these objectives was to design indicator variables that would allow quick assessment of the stability of a land cover at a particular location, throughout the area of study, and as influenced by changes in another land cover.

STUDY AREA

The study area included coastal wetlands and uplands in the MRB and areas surrounding the basin covered by the Landsat Thematic Mapper (TM) imagery. The entire MRB study area (TM coverage, Figure 1) encompassed 1,938,552 hectares of coastal zone, prairie region, and forest, including 964,771 hectares (LDEQ Office of Water Resources n.d.) defining the hydraulic confines of the Mermentau River Basin (Figure 1). Stretching along the Gulf shore lies a nearly continuous band of highly permeable sand and shell (cheniers) protecting extensive backbarrier marshes that extend inland 6 km to 24 km, commonly at less than 1.5 m above mean sea level with slopes of less than 0.2 m per km. Progressing farther inland, the landscape transforms to large expanses of prairie (an area of extensive rice cultivation and aquaculture), and finally, to forest. Generally, marshland is considered coastal area and forest and prairie are considered uplands (CHABRECK, 1970).

The lower MRB contains numerous management areas for fish and wildlife resources. For example, within the MRB, the Amoco Marsh (about 40,000 ha) has wintering habitat for more than 250,000 waterfowl. The MRB also contributes extensive sport and commercial fisheries (*e.g.*, fish, shrimp, crab). The U.S. Fish and Wildlife Service's Lacassine and Cameron Prairie National Wildlife Refuges (about 18,000 ha), the State of Louisiana's Rockefeller Refuge (about 34,800 ha), and several landowners are involved in the planning and implementation of marsh conservation projects.

Alteration of the water quality and hydrology has impacted the MRB coastal habitat. Fish kills have been commonly reported throughout the basin, possibly due to a combination of water pollution and hydrologic modification. Point discharges and agriculture runoff from the wide expanses of rice cultivation in the upper MRB is suspected to be responsible for the kills. The construction of control structures has led to increased inundation of the coastal marsh. Controversy exists

Table 1. *Data Sources for the Merentau River Basin.*

Landsat Imagery	Color Infrared Photography	Digital Line Graph	Habitat Data
1990			
October 10, 1990	December 8, 1985 (1:65,000)*	1988 USGS (1:24,000)	1988/90 NWI
November 11, 1990	December 8, 1990 (1:65,000)**		
1993			
November 29, 1992	November 6, 1992 (1:65,000)**		
February 1, 1993			
February 8, 1993			
1996			
November 22, 1995	January 8, 1995 (1:32,500)		
January 25, 1996	January 28, 1995 (1:32,500)		
February 17, 1996			

* Coverage for upper region of the MRB.
** Coverage for coastal region of the MRB.

over whether the higher inundation duration is aggravating marsh loss or enhancing marsh stabilization.

METHODS

Cloud-free TM images were acquired of the MRB between the fall and winter months (October to February) for the years between 1990 and 1996 (for a description see Table 1). Two scenes were required to cover the MRB in 1990 and three scenes in 1993 and 1996. One of the three winter scenes used in the 1993 classification was from 1992, and similarly, a 1995 winter scene was used in the 1996 classification (Table 1). As in the use of the 1990 fall scenes, the earlier winter collections were used due to the unavailability of cloud free images. The scenes were goeregistered to a georeferenced base image and subsequently mosaiced to a UTM coordinate system by using a nearest neighbor resampling method and a spatial resolution of 25 m by 25 m. Visual inspection and the reported root-mean-square error indicated ± 0.5 pixel registration accuracy among all images. All data were entered into a common database for subsequent analysis. Collateral data sources included color infrared (CIR) photography, 1988/90 NWI habitat maps, and USGS vector data (Table 1). Because of the availability of in-house CIR photography for 1990, USGS NAPP photography was not used. The in-house photography, however, covered only the lower half of the MRB.

Classification

TM image classifications were based on methods outlined in DOBSON *et al.* (1995). The late fall 1990 TM image was considered as the base image and the winter 1993 and 1996 TM images as the later images. Final classification included sixteen classes (Table 2). Field data and collateral resources were used to refine classifications and perform accuracy assessments.

Early attempts to classify the MRB indicated additional steps had to be taken to produce satisfactory classification accuracies. The technique that was most useful in improving classification accuracies was the division of the MRB into subregions by the use of masks. The use of masks at the regional level helped to exclude spectrally inseparable classes by defining regions of commonality. As an example, flooded rice fields were impossible to tell apart from water and emergent marsh located in the wetland areas of the MRB. Separating the MRB into regions dominated by agricultural and by coastal wetlands allowed the majority of rice fields to be correctly classified. Regional implementation of the masking technique in the classification process consisted of separating the MRB classification area into regions of similar landcover types (Figure 2). The coastal (mostly wetlands) and inland (primarily agriculture) areas were each separated into three subregions and the forested image area in the northwest consisted of a single subregion. These categorizations resulted in seven subregions for each date (1990, 1993, and 1996).

An iterative clustering approach was then used to classify each subregion (*e.g.*, RAMSEY and LAINE, 1997). Each subregion was first separated into the major categories of water, upland, and wetland using an unsupervised K-means clustering algorithm (PCI Geomatics, 1998). The major categories were then masked individually per subregion and the iterative clustering process was performed on each category. After several clustering iterations of the masked data, classification labels were assigned to the spectral clusters following the C-CAP landcover classification scheme (Table 2).

Collateral data also were used to produce masks to assist in the separation of classes that tended to be inseparable, (*e.g.*, wetland estuarine and palustrine and bare land and urban areas). For the marsh areas, 1988/1990 NWI habitat data were used to create masks for wetland estuarine and palustrine classes. NWI data coverage was similar to the coverages shown for the emergent wetland regions in Figure 2. Clustering iterations were then performed under the masks in order to update and refine the NWI data. To alleviate the problem of bare land mixing with urban areas, an urban mask was produced. This was accomplished by converting a digital line graph (USGS vector data) coverage of roads located within the MRB to a raster form. With the road coverage converted to raster form, an average filter of 15 pixels by 15 pixels was applied to the raster road image. The resulting file was an image with urban areas that contained roads in close spatial proximity. The iterative clustering technique was applied under the urban mask.

In some difficult cases, human pattern recognition was

Table 2. *C-Cap Landcover Classification.*

Value	Class Name	Description
1	Developed High Intensity	Heavily built up urban centers and large constructed surfaces in suburban and rural areas. Areas tend to contain significant land area covered by concrete and asphalt.
2	Developed Low Intensity	Areas with a mixture of constructed materials and vegetation or other cover. These areas commonly included single-family housings, especially in suburban neighborhoods, but may include scattered surfaces associated with all types of landuse.
3	Cultivated Land	Areas that have been planted, tilled, or harvested.
4	Grassland	Lands covered by natural and managed herbaceous cover: included are lawns and other managed grassy areas such as parks, cemeteries, gulf courses, road right-of-ways, and other herbaceous covered, landscaped areas.
5	Woody Land Deciduous	Areas having a predominance of trees that lose their leaves or needles at the end of the frost-free season.
6	Woody Land Evergreen	Areas having a predominance of trees that do not lose their leaves or needles at the end of the frost free season.
7	Woody Land Mixed	Areas where both evergreen and deciduous trees are growing and neither predominate.
8	Woody Land Scrub Shrub	Areas that contain shrub vegetation that is <6.1 meters in height.
9	Bare Land	Areas include: dry salt flats, beaches, sandy areas other than beaches, bare exposed rock, strip mines, quarries, gravel pits, transitional areas, and mixed barren land.
10	Wetland Estuarine	Areas of deep water tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, sporadic access to the open ocean.
11	Wetland Palustrine	Areas included are all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%.
12	Woody Wetland Deciduous	Wetland forest areas having predominance of trees that lose their leaves or needles at the end of the frost-free season.
13	Woody Wetland Scrub Shrub	Areas dominated by woody vegetation <6.1 meters in height.
14	Unconsolidated Shore	Areas characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
15	Water	Habitats that are permanently flooded.
16	Floating Vegetation	Areas where plants are either attached to the substrate of float freely in the water above the bottom or on the surface.

sometimes used to define the landcover. For example, land surrounding an airport runway was presumed not pasture or under active cultivation. When these areas were misclassified as cultivated grassland, a polygon was created to encompass the airport area and the cultivated grasslands were recoded to the unmanaged grassland class.

Initial comparison of the 1990, 1993, and 1996 classification showed some misclassified areas remained mainly because of crop rotation, seasonal influences on the spectral signatures, and marsh burning. In these cases, spectrally separable class coverages on one date were used to help identify hard to separate similar class coverages on another image date. For example, a forest mask was used to help separate upland (conifer) and deciduous forest classes in the fall 1990 image classification. Applying forest masks generated from the 1993 winter image (taken when deciduous trees were without leaves) allowed better separation between woody land evergreen and deciduous forest classes in the 1990 classification.

Even with the detailed classification and the selective application of masks, higher than expected unlikely landcover transitions were uncovered in the initial determinations of land cover changes between classifications. To correct these unlikely transitions and thereby improve the classification accuracies, we adopted the premise that certain transitions between classes were so unlikely that they could be treated as forbidden. Forbidden transitions were primarily between wetland and upland classes, but also included transitions between woody land evergreen and deciduous and between wetland estuarine and palustrine. Once a forbidden transition was identified, we used a simple logic that reset the land cover in one of the two years to a more likely land cover based on the three or four classification years (1988/90 NWI data). Even though not forbidden, a similar technique was used to correct flooded rice fields that were misclassified as water primarily in 1993 and 1996 (Figure 3), and burned wetland estuarine marsh that was misclassified as water primarily in 1990 (Figure 4). In both techniques (masking and logic), better separation and more accurate classification were validated by comparison to photography and from the context of the image.

Accuracy Assessment

Accuracy assessment was carried out following guidelines outlined in DOBSON *et al.* (1995). NOAA personnel, familiar with the C-CAP landcover classification system but not involved in the imagery classification, verified and documented the accuracy assessments. Previous work by ROSENFIELD and FITZPATRICK-LINS (1986), FUNG and LEDREW (1988), CONGALTON (1991), and JENSEN *et al.* (1994) also provided guidance for the accuracy assessment and the reporting of errors.

A geometric, class stratified, random sample design to select over 30 points per landcover class (VAN GENDEREN and LOCK, 1977; CONGALTON, 1991) was used for classification accuracy assessment of all three dates. When existent, these points were then verified with CIR high-resolution photography from approximately the same time period as the TM collection (Table 1). In 1990 and 1993, photography covered

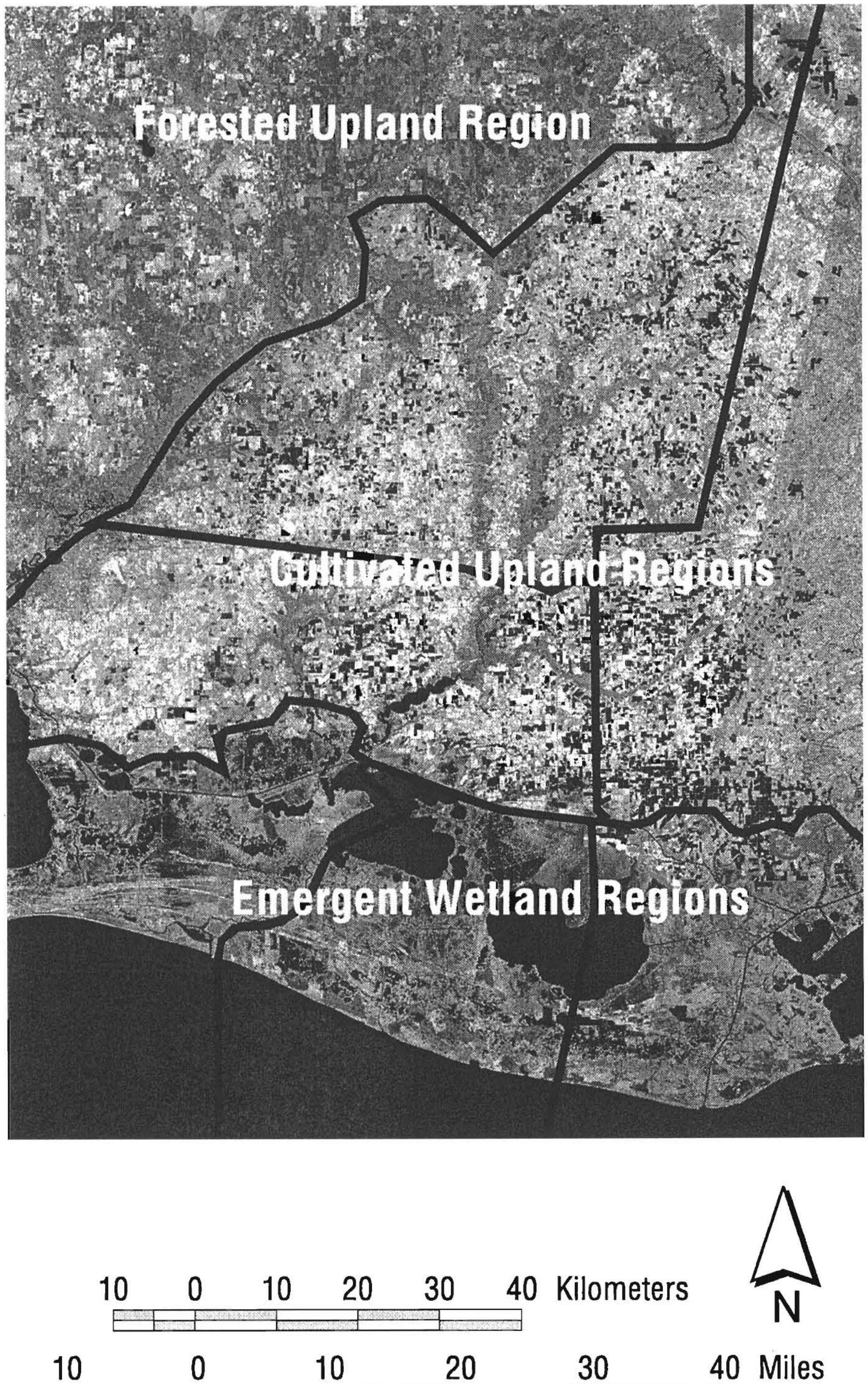

Figure 2. Landcover commonality regions in the Mermentau River Basin. The coastal and inland areas were each separated into three subregions, and the forested image area in the northwest consisted of one region.

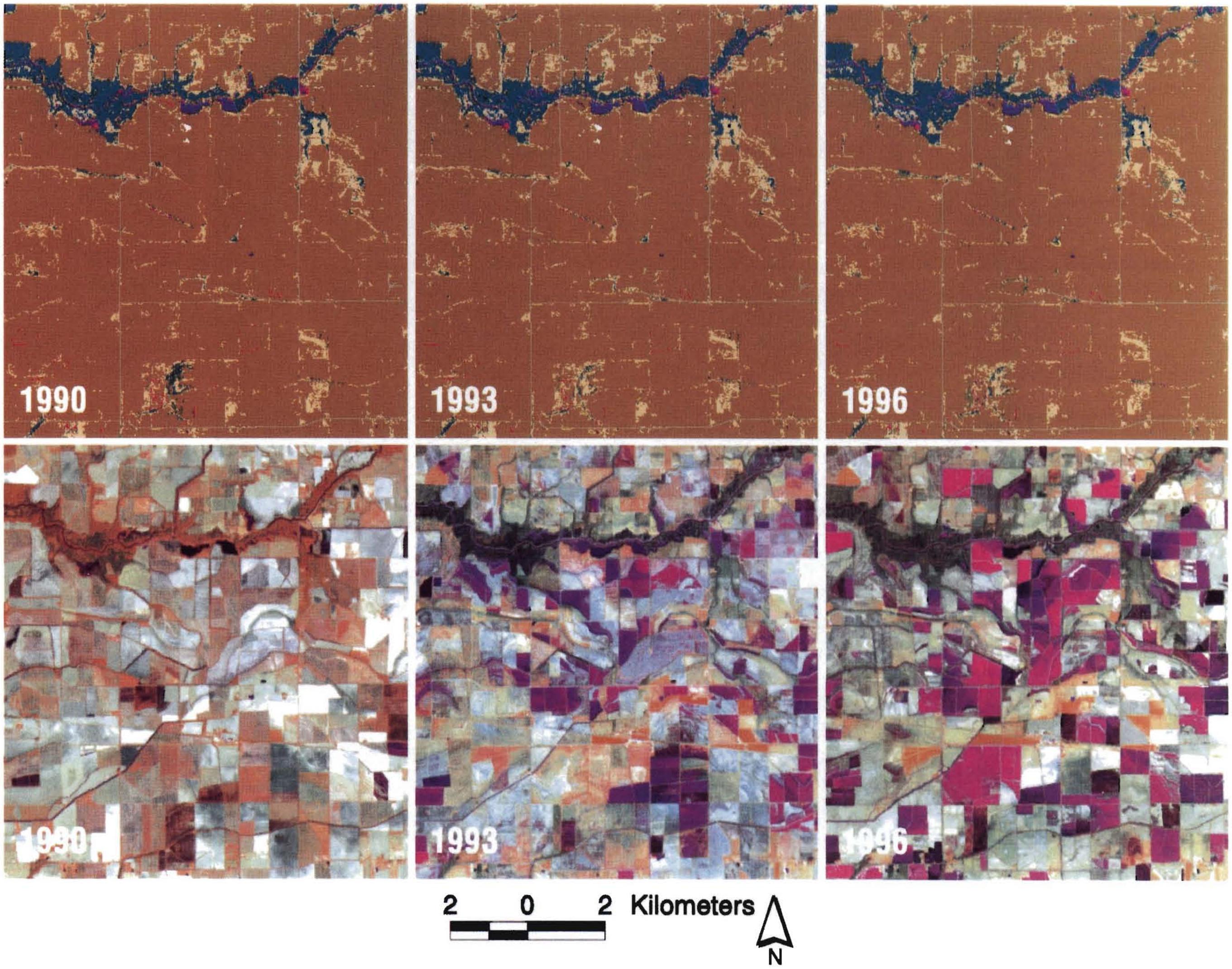

Figure 3. Seasonality and crop turnover complicated the classification of cultivated areas, especially associated with non flooded (1990) and flooded (1993 and 1996) rice fields. Note that color legends in the classified images (top) are the same as in Figure 5. In the non classified 1993 and 1996 TM images (bottom), the bright to dark magenta colors indicate flooded rice fields.

only the lower half and lower third, respectively, of the MRB. In areas outside the photographic coverage, direct inspection of available TM images and the closest photographic source (*e.g.,* 1996 CIR) was used to verify the landcover type. In 1998, additional accuracy assessment points were selected with a stratified random sample design within a 16 pixel buffer area around land transportation routes. Field verification was accomplished with a portable color laptop computer using a specialized software that displayed road networks and the current Global Positioning System over the classified image data. Field verification points were appropriate for classification and change accuracy assessments involving 1996 image data only.

Following JENSEN *et al.* (1994), we selected accuracy assessment points from homogenous areas of at least 3 by 3 pixels where appropriate. Limiting the selection criteria to homogeneous areas, however, was not appropriate where landcover classes did not tend to occupy homogeneous areas of 3 by 3 or even 2 by 2 pixels. In 1996, for example, these classes included woody land deciduous and mixed, bare land, woody wetland scrub shrub, unconsolidated shore, and floating vegetation classes. On the other hand, landcover classes where accuracy assessment point selection was limited to homogeneous areas comprising at least 3 by 3 pixels were cultivated land, woody land evergreen, wetland estuarine and palustrine, woody wetland deciduous, and water.

Change Detection

A number of change detection techniques exist in the literature for TM multiple date images (SINGH, 1989). Spectral change analysis technique, preferred by C-CAP, was not used

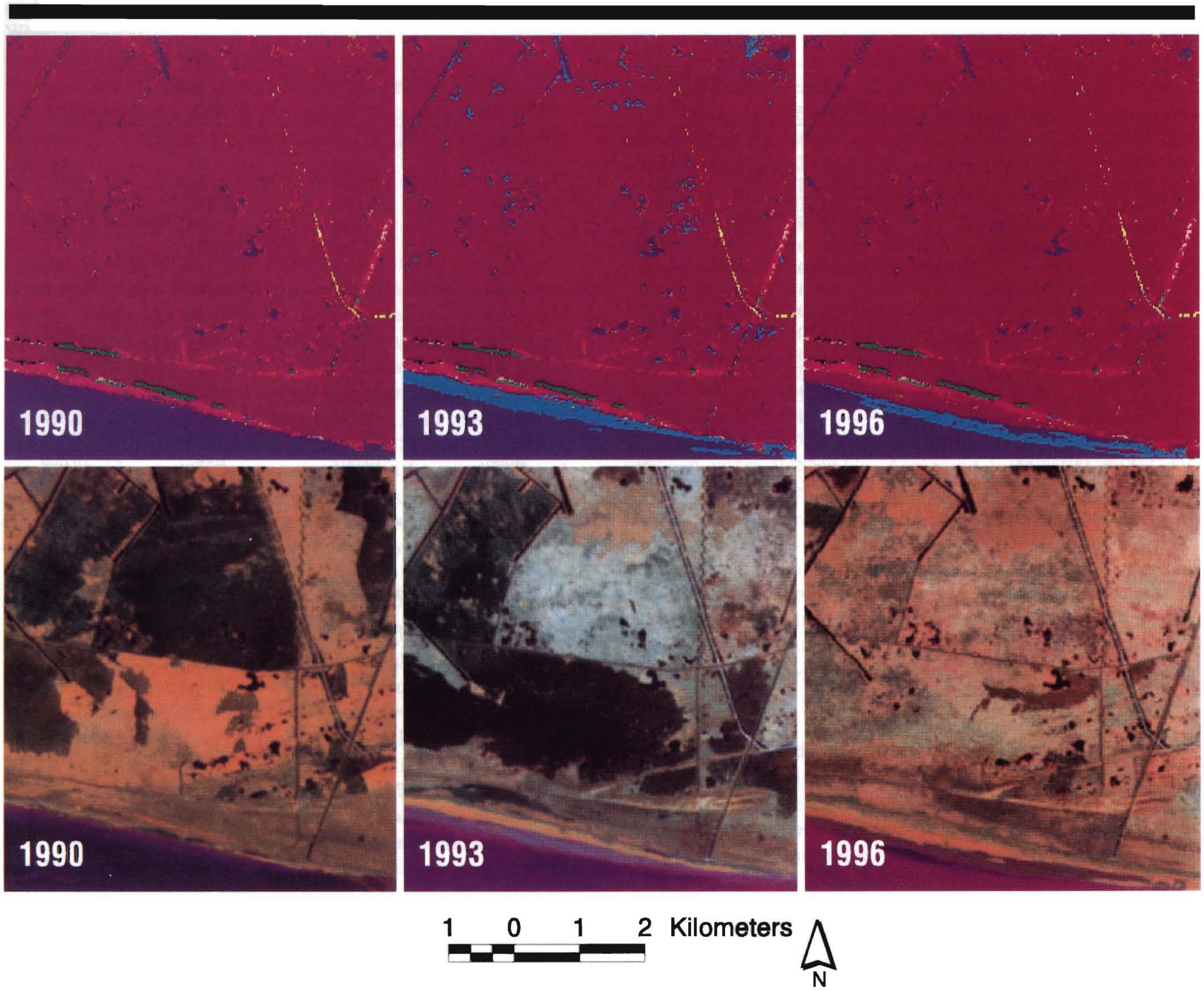

Figure 4. Marsh burns were highly confused with other land covers, especially water. By combining information from the 1988/90 NWI map and all three classifications, these misclassifications were mostly eliminated. Note that the color legends in the classified images (top) are the same as in Figure 5. Also notice the accretion of shoreline from 1990 to 1996. The darkest areas within the marsh indicate burned marsh in the 1990 and 1993 non classified TM images (bottom).

because of the seasonal differences between images within and between the yearly composites and because of the inability to generate atmospherically corrected or atmospherically normalized images of the MRB (*e.g.,* HALL *et al.,* 1991). Instead, post classification analyses were performed between 1990, 1993, and 1996 classified maps by using all 16 classes. This resultant change detection matrix contained "from landcover class to landcover class" change information. The off-diagonal elements in the change matrices contain the number of hectares each class either contributes to or benefits from another class.

To improve interpretation of landcover change, we derived two indicators of class stability: *location* and *residence.* Location stability refers to the percentage of a landcover class that remained as the same class in the same location at the beginning and end of the monitoring period. For instance, a 93% location stability associated with grassland suggests that of the grassland in 1990, 93% stayed as grassland at the same location in 1993 and 7% of it changed.

$$\text{Location stability (per class)} = [(\text{base year coverage} - \text{loss of base year coverage}) \div \text{base year coverage}] \times 100 \quad (1)$$

Loss of base year coverage refers to loss at the same spatial location from the base to the final year. Residence stability refers to the percent change in each class within the entire MRB during the monitoring period. A zero residence stability associated with a landcover class indicates no net change in its total area of coverage within the MRB within the moni-

Table 3. *Total land cover and change per class during 1990, 1993, and 1996.*

	Year			Change from		
	1990 Hectare	1993 Hectare	1996 Hectare	1990 to 1993 Hectare	1993 to 1996 Hectare	1990 to 1996 Hectare
1. Developed High	9,074	9,074	9,073	0	−1	−1
2. Developed Low	19,677	19,740	19,777	63	37	100
3. Cultivated Land	664,561	663,313	661,811	−1,248	−1,502	−2,751
4. Grassland	186,910	193,479	175,358	6,569	−18,121	−11,552
5. Woody Land Deciduous	1,491	1,416	1,430	−75	15	−61
6. Woody Land Evergreen	155,193	163,559	155,185	8,366	−8,374	−8
7. Woody Land Mixed	30,990	19,974	19,390	−11,016	−584	−11,600
8. Woody Land Scrub Shrub	52,432	49,285	77,650	−3,147	28,365	25,218
9. Bare Land	1,700	1,633	1,768	−67	135	69
10. Wetland Estuarine	120,104	119,232	121,098	−871	1,866	995
11. Wetland Palustrine	144,554	143,920	143,886	−634	−34	−669
12. Woody Wetland Deciduous	202,125	202,861	202,781	736	−80	656
13. Woody Wetland Scrub Shrub	8,522	7,269	7,156	−1,253	−114	−1,366
14. Unconsolidated Shore	940	3,181	2,333	2,241	−848	1,394
15. Water	354,371	340,538	337,317	16,167	−3,221	12,946
16. Floating Vegetation	15,908	76	2,538	−15,831	2,462	−13,369
Total:	1,938,552	1,938,552	1,938,552			

Note: A negative number in the change column indicates a loss (likewise a positive is a gain) in hectares within a specific class.

toring period. Likewise, a positive residence stability indicates an increased presence or coverage compared to the base year. A negative residence indicates a decreased presence or coverage in the MRB compared to the base year.

$$\text{Residence stability (per class)} = [(\text{final year coverage} - \text{base year coverage}) \div \text{base year coverage}] \times 100 \quad (2)$$

The location and residence stabilities need not compliment each other. For example, the dynamic nature of the scrub shrub class portends a low location stability, but if compensated by grassland transition to scrub shrub, residence stability for scrub shrub would be near zero. In essence, these indicators of stability allow a more direct understanding of whether a class is in flux, and if so, the nature of the flux.

Change point accuracy was conducted using only field verification points gathered in January of 1998. One hundred and eleven observations were collected in cultivated land, grassland, woody land evergreen, mixed, and scrub shrub classes. Only four verification points were obtained for the woody land mixed class. The NOAA and USGS change verification team attempted to validate the change points by observing the condition and type of vegetation that existed on the ground in January 1998 and relating it back to the winter of 1990.

RESULTS

The summations show that the largest spatial coverages for 1996 were associated with cultivated land (34%), grassland (9%), woody land forests (deciduous, evergreen, mixed, scrub shrub, 13%), woody wetland forests (deciduous, scrub shrub, 11%), wetland palustrine (7%) and wetland estuarine (6%) marshes, and water (17%) (Table 3; Figure 5 showing 1996). The remaining 3% were spread mostly between developed high and low classes of the MRB.

Accuracy Assessment

Except for woody land scrub shrub, bare land, and unconsolidated shore classes in 1990 and 1993, and woody land deciduous and mixed in 1993, over 30 points per class were assessed for accuracy in 1990, 1993. In 1996, over 30 points were used in all class assessments. The 1990, 1993 and 1996 classification accuracy percentages (associated kappa statistics) were 80% (0.79), 78% (0.76), and 86% (0.84), respectively (Tables 4a–c). Most classification errors were associated with confusion between grassland, cultivated, and woody land scrub shrub; between woody land evergreen and mixed; between woody wetland deciduous and woody land deciduous and mixed; between woody wetland deciduous and scrub shrub; between bare land and unconsolidated shore; between water and unconsolidated shore; and especially in 1993, between water and floating vegetation. This classification confusion led to the highest omission errors associated with grassland, woody land deciduous, mixed, and scrub shrub, bare land, woody wetland scrub shrub, and unconsolidated shore (Tables 4a–c). In all three years, cultivated land and woody wetland deciduous were related to high commission errors. In 1990 and 1993, relatively high commission errors also were centered around developed high, woody land mixed and scrub shrub, bare land, and especially unconsolidated shore in 1990 and woody wetland deciduous and water in 1993. When the cultivated and grassland and the water and floating vegetation were combined into single classes, the accuracies for 1990, 1993, 1996 increased to 82%, 83%, and 90% with associated kappa statistics of 0.81, 0.82, and 0.89, respectively.

Accuracy assessment for the change points from 1990 to 1996 resulted in an overall accuracy of 80% and a kappa statistic of 0.74 (Table 5). A majority of disagreement in the "from-to" pixels was in the class of grassland to scrub shrub. Due to the difficulty of estimating scrub shrub height in 1990 solely based on the observations gathered in 1998, grassland

and scrub shrub classes were combined into a single class. When combined, the change detection accuracy for the limited 1990 to 1996 data set improved to 90% with a kappa statistic of 0.87. Even though the field data set did not represent the wetland classes, the change accuracy assessment included land classes encompassing a majority of the MRB land area.

Change Analyses

From 1990 to 1993, location stability (≥99%) showed that about half of the landcover classes experienced little or no change (Table 6a). Of these landcover classes, only wetland estuarine and water were linked to a change in the absolute residence stability of 1% or greater. Location stabilities of grassland and woody land evergreen were about 93% indicating up to a 7% loss in the original 1990 land covers at the same spatial locations in both 1990 and 1993. Taking into account residence stability percentages of 4% (grassland) and 5% (evergreen), however, indicated about an 11% turnover of other land classes to these landcovers. For example, in the case of grassland, the 100% of original coverage minus approximately 93% location stability plus the 4% residence gain results in an 11% turnover of other land classes to grassland from 1990 to 1993. Turnover percentage is defined as

$$\text{Turnover (per class)} = (100\% \text{ base year coverage} - \text{location stability} + \text{residence stability}). \quad (3)$$

The same calculations show about half of woody land deciduous and bare land losses were offset by the turnover of other land classes. It also revealed that there was little or no turnover to offset the decrease in location stability associated with woody land mixed and woody wetland scrub shrub. Location stability of about 71% associated with woody land scrub shrub was nearly compensated by a high turnover of other landcovers. A low location stability was related to a high net increase in unconsolidated shore and a zero location stability was related to an almost total loss of floating vegetation (−100% residence and 0% turnover) from 1990 to 1993.

Landcover classes with nearly 100% location stabilities in 1990 to 1993 again had high location stabilities in the 1993 to 1996 change analysis (Table 6b). Similarly, within this group of high location stability, only wetland estuarine and water were linked to any notable changes in residence stability. Converse to changes from 1990 to 1993, however, wetland estuarine was associated with an increase in residence stability and water with a decrease. From 1993 to 1996, both location and residence stability of woody wetland scrub shrub improved dramatically, compared to 1990 to 1993. Location stabilities of woody land deciduous and bare land were improved and were associated with a reversal in residence stability (decreases in 1990 to 1993 to increases in 1993 to 1996). A prominent reason for the residence reversal was an increase in turnover of other land covers to these classes. Woody land mixed showed a dramatic increase in location stability in the 1993 to 1996 time period, and even though a small decrease persisted, residence stability also dramatically increased. Compared to 1990 to 1993, grassland and woody land evergreen both showed decreases in location stability. A co-occurring decrease in the turnover of other land covers also added to the reversal in their residence stabilities. In 1993 to 1996, location stability identified with floating vegetation increased nearly 25% as compared 1990 to 1993. Residence stabilities were reversed compared to the 1990 to 1993 time period, however; unconsolidated shore lost and floating vegetation gained in coverage.

DISCUSSION

Masking and progressive clustering were used to classify the 1990, 1993, and 1996 TM images of the MRB. Spectral change analysis was not applied because along with the problem of identifying constant reflectance targets, the seasonal differences between available TM images made the already complicated task of matching the phenology of land covers between years impossible. According to the NOAA C-CAP classification scheme, masking combined with progressive clustering was used when landcover classes were not spectrally separable. Geographic separation of coastal wetlands, agriculture, and forest diminished classification confusion, as did application of urban and residential masks for separating grasslands and cultivated land. Additionally, masks applied to specific land covers helped to decrease classification confusion, for example, the use of a forest mask generated during deciduous leaf-off conditions helped to separate deciduous and conifer classes during leaf-on conditions.

A post classification correction highlighted class transitions between years that were highly unlikely, such as between upland and wetland forests. As part of this correction technique, forbidden transitions between landcovers were identified and misclassified landcovers were corrected in the change analyses. The highest corrections for the three dates were associated with correcting confusion among wetland marshes, cultivated lands and grasslands (about 4,200 ha); between upland and wetland forests (about 6,000 ha); and among cultivated lands, grasslands and wetland forests (about 21,000 ha). Another important correction was related to wetland estuarine burns that were misclassified as water causing the appearance of high turnovers between these classes (Figure 4). By combining the 1988/90 NWI classification with the 1990, 1993, 1996 classifications, over 10,000 ha (nearly 8%) of misclassified estuarine marsh were corrected. All corrections improved the classification accuracy, but excluding wetland estuarine, the small percentage of the combined land covers these corrections represented (*e.g.,* [21,000 ha of corrections]/[1,000,000 ha of cultivated land, grassland, and wetland forests] or about 2.0%) resulted in minor improvement per combined class. Even though post classification corrections mostly represented minor changes in the original landcover classifications, improvements of the change detection results were dramatic.

Landcover Classification Accuracy

Accuracy assessment revealed that in all three dates the remaining classification errors were primarily linked to classification of spatial and spectral continuums, spectral simi-

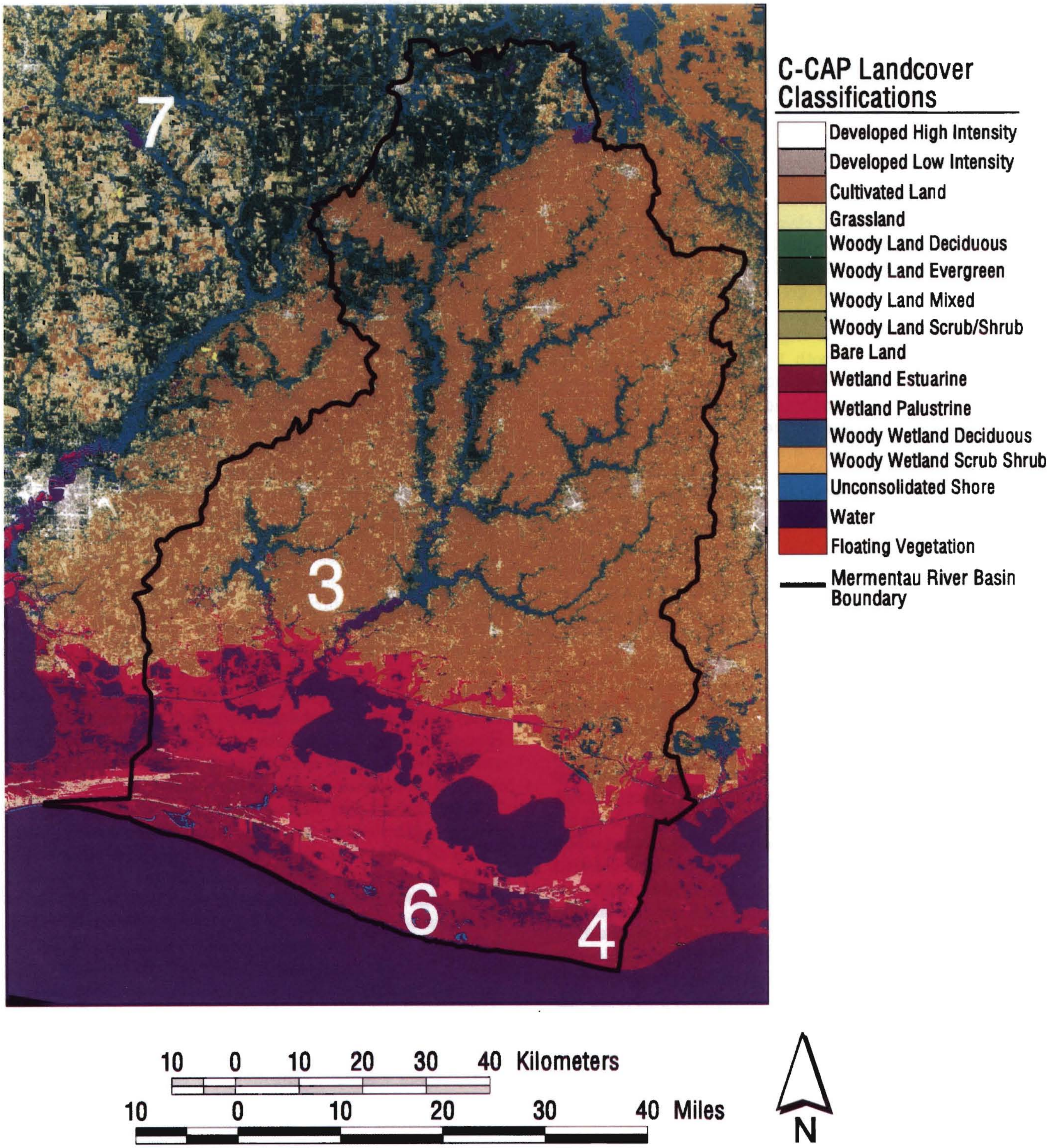

Figure 5. The 1996 C-CAP classification of the Mermentau River Basin study area. The spatial coverage included 34% cultivated, 9% grassland, 13% woody land forests, 11% woody wetland forests, 7% wetland palustrine, 6% wetland estuarine, 17% water, and about 2% developed. The number inserts in the figure refer to the area illustrated in Figures 3, 4, 6, and 7, respectively.

larities, and boundaries. Misclassifications caused by overlaying discrete boundaries on a spectrally and spatially continuous surface were, in particular, related to the logging and regrowth cycle in forests. The continuum of regrowth from grassland to scrub shrub to forest is associated with changes in the remotely sensed signal, however, these subtle reflectance changes obstruct the application of discrete classification boundaries. Consequences related to applying a discrete classification to a continuum gradient were apparent in the confusion between grassland and woody land scrub shrub and similarly among wetland estuarine, wetland palustrine, and woody wetland scrub shrub. Likewise, confusion between woody wetland deciduous and scrub shrub also elevated classification errors. The spectral continuum between pure evergreen stands with variable canopy closure and a mixed evergreen and deciduous stands also resulted in classification errors. Classification confusion was further compounded by the nearly year around presence of leaves on some deciduous trees (*e.g.,* live oak) and the forced use of an October 1990 image taken during leaf-on conditions. Use of leaf-off images enhanced the ability to separate stands of woody land deciduous and evergreen, but classification confusion still persisted between woody land evergreen and mixed.

Another type of confusion that played a part in misclassification of woody wetland scrub shrub and the upland woody land classes was related to the similarity of spectral signatures. In the MRB, for example, correct classification of the woody land and woody wetland deciduous and scrub shrub classes probably relied more on the background presence of standing water to distinguish the upland and wetland hardwood stands than on leaf optical or canopy structural differences. In the case of managed (cultivated) and unmanaged grasslands, spectral distinction was slight to none, as for example, in the case of a fallow field (unmanaged grassland) compared to a grassland used for grazing livestock (cultivated).

Additional errors were revealed in the form of pixels transitioning the boundary between land covers; cultivated land to forest or developed low classes and water to unconsolidated shore or floating vegetation. Furthermore, the classification accuracy was limited when the pixel size was larger than the ground area occupied by the target class. For example, this classification confusion occurred where narrow ($\leq$25 m) levies separated rice fields, narrow wooded cheniers bifurcated the coastal marsh, and canopy gaps approaching the pixel spatial scale occurred in an otherwise continuous forest cover. In both spatial transitional cases, increased error resulted from a somewhat arbitrary assignment of class boundary pixels to one class that included more than one class within the sensor spatial resolution.

Finally, the timing of the image data collection with human activities or seasonal changes could aggravate classification error. In some cases, ongoing logging activities resulted in decreased forest density possibly at times creating the false impression of a conversion to scrub shrub, rather than to bare or grassland classes. In other cases, agriculture fields active in one year but fallow and used for grazing in the next created the false impression of conversion from cultivated land to unmanaged grassland. Problems in classification related to seasonal changes were most apparent in the floating vegetation and forest classes. Ubiquitous during most of the year, the ephemeral floating vegetation could partially or completely disappear, especially in the winter, revealing open water. In this case, the near simultaneous collection of imagery and ground points could be crucial to the correct assessment of classification accuracy. The lateness and variability of the deciduous leaf loss also aggravated classification problems, however, the use of late winter scenes and masking alleviated most confusion.

Landcover Changes

Low location and highly variable residence stabilities were associated with the highly transitional floating vegetation and unconsolidated shore classes. Even though accuracy assessment showed some classification confusion existed among these classes and water, the magnitude of losses to water and the physical association between these classes and water suggest a very dynamic turnover among these landcover classes. The high turnovers in the 1993 to 1996 change analysis associated with floating vegetation resulted from its almost total disappearance between 1990 and 1993 and its partial recovery between 1993 and 1996. Hurricane Andrew's landfall about 80 km east of the MRB in August 1992 may have been responsible for the dramatic disappearance in floating vegetation, although, this was not verified. More importantly, turnovers in unconsolidated shore and water were directly related to marsh stability.

Wetland palustrine changes in both time periods were predominately associated with water, although losses between 1990 and 1993 were over four times higher, during this change period palustrine gains (almost non existent between 1993 and 1996) made-up for half of these losses. Between 1990 and 1993, palustrine losses were mainly associated with managed flooding of a large fresh water impounded area (about 1,200 ha) in the south central MRB. Other losses and gains were mostly along streams and small ponds throughout the marsh. In this case, fluctuating water levels would have aggravated the problem in classifying boundary pixels resulting in small but misleading appearance of gains and losses in the palustrine marsh. Wetland estuarine net losses to water were low and similar during both change periods, but losses to unconsolidated shore from 1990 to 1993 were relatively high and possibly connected to the impact from Hurricane Andrew. Transitions to unconsolidated shore occurred along the banks of streams and open water ponds. From 1993 to 1996, these losses were overcompensated by gains from unconsolidated shore. These gains confirmed the accreting nature of the eastern shoreline of the MRB (Figure 4). Additionally, in some areas while the shoreline was still transgressing, filling in of small coastal embayments continued to add marsh area (Figure 6). The accretion mechanisms have been observed in field verifications and are predicted from studying westerly sediment plumes originating at the Atchafalaya River mouth (Dr. Oscar Huh, Louisiana State University, *personal communication*). This accretion is in contrast to losses occurring east of the Atchafalaya River and demonstrates the consequences of the lack of sediment and

Table 4a. *Accuracy assessment of the 1990 classified image.*

Classified 1990 TM	Landcover Observed 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	Total	% Correct	% Commission
1. Developed High	21	5	0	3	0	0	0	0	2	0	0	0	0	0	0	0	31	68	32
2. Developed Low	1	30	0	1	0	0	0	1	0	0	0	0	0	0	0	0	33	91	9
3. Cultivated Land	0	0	40	13	1	1	1	0	1	0	0	0	1	0	0	0	58	69	31
4. Grassland	1	0	0	29	0	0	1	2	0	0	0	0	0	0	0	0	33	88	12
5. Woody Land Deciduous	0	0	0	0	31	0	0	2	1	0	0	0	3	0	0	0	37	84	16
6. Woody Land Evergreen	0	0	0	0	0	34	5	3	0	0	0	0	0	0	0	0	42	81	19
7. Woody Land Mixed	0	0	0	2	1	0	23	3	0	0	0	0	3	0	0	0	32	72	28
8. Woody Land Scrub Shrub	0	0	0	4	0	0	0	14	0	0	0	0	3	0	0	0	21	67	33
9. Bare Land	0	0	0	1	0	0	0	0	14	0	0	0	0	7	0	1	23	61	39
10. Wetland Estuarine	0	0	0	1	0	0	0	0	1	62	0	0	3	0	0	1	68	91	9
11. Wetland Palustrine	0	0	0	0	0	0	0	0	0	0	38	0	2	0	0	0	40	95	5
12. Woody Wetland Deciduous	0	0	0	0	6	0	4	2	0	0	0	36	15	0	0	0	63	57	43
13. Woody Wetland Scrub Shrub	0	0	0	1	0	0	0	2	0	0	0	0	37	0	0	0	40	93	8
14. Unconsolidated Shore	0	0	0	0	0	0	0	0	2	0	0	0	2	5	0	0	9	56	44
15. Water	0	0	0	0	0	0	0	0	0	0	0	0	0	5	41	1	47	87	13
16. Floating Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	49	51	96	4
Total	23	35	40	55	39	35	34	29	21	62	38	36	71	17	41	52	628	Overall Accuracy: 80.25% Kappa Statistics:	
% Omission	9	14	0	47	21	3	32	52	33	0	0	0	48	71	0	6		0.79	

sediment enrichment to coastal wetlands along the Gulf of Mexico coast.

After unconsolidated shore and floating vegetation, the next lowest location stabilities were related to landcover classes linked to the lumber industry. These classes included all the woody land upland classes. From 1990 to 1993, heavily logged woody land mixed and evergreen classes transformed these land covers to grasslands (Figure 7). Turnover of mainly woody land scrub shrub, however, more than offset evergreen losses, while turnovers to woody land mixed did not nearly compensate the over 35% loss in original land coverage. Between 1993 and 1996, logging activities nearly doubled the conversions of woody land evergreen to grasslands, but hardly affected mixed forests (Figure 7). In each change

Table 4b. *Accuracy assessment of the 1993 classified image.*

Classified 1993 TM	Landcover Observed 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	Total	% Correct	% Commission
1. Developed High	21	5	0	2	0	0	0	0	3	0	0	0	0	0	0	0	31	68	32
2. Developed Low	2	30	0	2	0	0	0	1	0	0	0	0	0	0	0	0	35	86	14
3. Cultivated Land	0	0	40	13	1	1	1	0	1	0	0	0	1	0	0	0	58	69	31
4. Grassland	0	0	0	33	0	0	0	4	1	0	0	0	0	0	0	0	38	87	13
5. Woody Land Deciduous	0	0	0	2	20	1	0	0	0	0	0	0	3	0	0	0	26	77	23
6. Woody Land Evergreen	0	0	0	0	0	33	4	2	0	0	0	0	0	0	0	0	39	85	15
7. Woody Land Mixed	0	0	0	0	1	0	21	1	0	0	0	0	3	0	0	0	26	81	19
8. Woody Land Scrub Shrub	0	0	0	2	0	0	2	12	0	0	0	0	3	0	0	0	19	63	37
9. Bare Land	0	0	0	0	0	0	0	0	9	0	0	0	0	6	0	0	15	60	40
10. Wetland Estuarine	0	0	0	1	0	0	0	0	1	62	0	0	3	0	0	0	67	93	7
11. Wetland Palustrine	0	0	0	0	0	0	0	0	1	0	38	0	2	0	0	0	41	93	7
12. Woody Wetland Deciduous	0	0	0	0	6	0	4	2	0	0	0	36	10	0	0	0	58	62	38
13. Woody Wetland Scrub Shrub	0	0	0	1	0	0	0	1	0	0	0	0	20	0	0	0	22	91	9
14. Unconsolidated Shore	0	0	0	0	0	0	0	0	1	0	0	0	0	11	0	0	12	92	8
15. Water	0	0	0	1	0	0	0	0	0	0	0	0	0	2	41	16	60	68	32
16. Floating Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	23	35	40	57	28	35	32	23	17	62	38	36	45	19	41	16	547	Overall Accuracy: 78.06% Kappa Statistics:	
% Omission	9	14	0	42	29	6	34	48	47	0	0	0	56	42	0	100		0.76	

Table 4c. *Accuracy assessment of the 1996 classified image with CIR photography and field verification.*

Classified 1996 TM	Landcover Observed from CIR Photography and Field Verification 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	Total	% Correct	% Commission
1. Developed High	40	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	44	91	9
2. Developed Low	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	100	0
3. Cultivated Land	0	3	247	46	2	0	0	2	4	0	0	0	2	0	0	0	306	81	19
4. Grassland	0	2	0	39	1	0	1	8	2	0	1	0	1	0	0	0	55	71	29
5. Woody Land Deciduous	0	0	0	0	35	0	0	0	0	0	0	0	3	0	0	0	38	92	8
6. Woody Land Evergreen	0	0	0	1	1	84	4	0	0	0	0	0	0	0	0	0	90	93	7
7. Woody Land Mixed	0	0	0	0	0	0	45	0	0	0	0	0	3	0	0	0	48	94	6
8. Woody Land Scrub Shrub	0	0	0	0	1	0	2	39	0	0	0	0	3	0	0	0	45	87	13
9. Bare Land	0	0	0	0	0	0	0	0	36	0	0	0	0	5	0	0	41	88	12
10. Wetland Estuarine	0	0	0	0	0	0	0	0	1	68	0	0	3	0	0	0	72	94	6
11. Wetland Palustrine	0	0	0	0	0	0	0	0	1	0	46	0	5	0	0	0	52	88	12
12. Woody Wetland Deciduous	0	0	0	0	8	0	5	1	0	0	0	66	14	0	0	0	94	70	30
13. Woody Wetland Scrub Shrub	0	0	0	0	0	0	0	0	0	0	1	0	47	0	0	0	48	98	2
14. Unconsolidated Shore	0	0	0	0	0	0	0	0	1	0	0	0	2	27	0	1	31	87	13
15. Water	0	0	0	1	0	0	0	0	0	0	0	0	0	4	43	0	48	90	10
16. Floating Vegetation	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	32	34	94	6
																		Overall Accuracy: 86.06% Kappa	
Total	40	51	247	87	48	84	57	50	47	68	49	66	84	36	43	33	1090	Statistics:	
% Omission	0	14	0	55	27	0	21	22	23	0	6	0	44	25	0	3		0.84	

period, about 25% of the woody land scrub shrub grew into forests, offsetting about 85% of the woody land forest lost to logging between 1990 and 1993 and about 75% between 1993 and 1996. Between 1990 and 1993, only about 40% of woody land scrub shrub losses were replaced by grassland turnover, while between 1993 and 1996 losses were replaced two to one by grassland and somewhat by cultivated land turnovers. The former gain in woody land scrub shrub was caused by the increased planting of seedlings in the northwestern portion of the MRB.

Contrary to grassland gains from logging between 1990 and 1993, substantial losses due to increased seedling planting between 1993 and 1996 were not entirely compensated by logging turnover. Related to these losses, cultivated land, even though demonstrating high location and nearly unchanging residence stabilities, lost acreage during both change periods. Although losses were minor relative to the total cultivated land, losses were higher than gains. Notwithstanding the low percentage decrease and known errors, there was a tendency to suspect a small decrease in cultivated land throughout the period. On the other hand, grassland gains and losses are related mostly to the logging cycle of clearing, recovery, and regrowth. The continuation of this cycle should see a reversal in grassland loss.

Woody wetland deciduous remained locally stable and showed little to no change in residence stability during both change periods. The only notable gain in woody wetland deciduous was from turnover of woody wetland land scrub shrub between 1990 and 1993. Although this addition reduced woody wetland scrub shrub coverage by 15%, it ac-

Table 5. *Accuracy assessment (field verification) on change points.*

Classified 1990 TM	Field Observation (January 1998) 2.	3.	4.	6.	7.	8.	9.	11.	13.	Total	% Correct	% Commission
2. Developed Low	1	0	0	1	0	0	0	0	0	2	50	50
3. Cultivated Land	0	18	1	0	0	1	0	0	1	21	86	14
4. Grassland	0	0	11	0	0	12	0	0	0	23	48	52
6. Woody Land Evergreen	0	0	0	26	0	0	0	0	0	26	100	0
7. Woody Land Mixed	0	0	0	5	4	0	0	0	0	9	44	56
8. Woody Land Scrub Shrub	0	0	0	1	0	31	0	0	0	32	97	3
9. Bare Land	0	0	0	0	0	0	1	0	0	1	100	0
11. Wetland Palustrine	0	0	0	0	0	0	0	0	1	1	0	100
13. Woody Wetland Scrub Shrub	0	0	0	0	0	0	0	0	0	0	0	0
											Overall Accuracy: 80.00%	
Total	1	18	12	33	4	44	1	0	2	115	Kappa Statistics:	
% Omission	0	0	8	21	0	30	0	0	100		0.74	

Table 6a. *Change analysis in land cover of the MRB from 1990 to 1993.*

1993	1990: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	Total (hectare)
1. Developed High	9,073	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	9,074
2. Developed Low	0	19,672	2	28	4	4	0	7	18	0	0	0	0	0	5	0	19,740
3. Cultivated Land	0	0	662,212	514	4	44	270	114	22	0	5	10	1	0	99	16	663,313
4. Grassland	0	0	1,345	173,778	53	7,400	10,018	812	34	0	1	20	6	0	12	1	193,479
5. Woody Land Deciduous	0	0	0	10	1,313	0	0	92	0	0	0	0	0	0	0	0	1,416
6. Woody Land Evergreen	0	0	53	2,420	5	147,257	17	13,788	0	0	1	0	0	0	19	0	163,559
7. Woody Land Mixed	0	0	2	146	0	8	19,702	114	0	0	0	2	0	0	0	0	19,974
8. Woody Land Scrub Shrub	0	0	598	9,814	111	397	961	37,395	0	0	0	7	1	0	1	0	49,285
9. Bare Land	0	0	18	4	0	1	3	88	1,489	0	0	17	9	0	4	0	1,633
10. Wetland Estuarine	0	0	0	0	0	0	0	0	0	118,579	1	0	0	19	623	10	119,232
11. Wetland Palustrine	0	0	4	3	0	1	0	0	0	3	143,118	3	0	37	702	47	143,920
12. Woody Wetland Deciduous	0	0	11	19	1	17	11	18	0	0	2	201,469	1,253	0	57	4	202,861
13. Woody Wetland Scrub Shrub	0	0	6	1	0	1	0	0	0	0	0	7	7,245	0	3	5	7,269
14. Unconsolidated Shore	0	0	0	1	0	0	0	0	0	1,080	67	0	0	247	1,747	39	3,181
15. Water	1	4	309	172	0	65	8	4	137	439	1,358	591	6	635	321,086	15,722	340,538
16. Floating Vegetation	0	0	0	0	0	0	0	0	0	1	0	0	0	1	11	62	76
Total (hectare)	9,074	19,677	664,562	186,910	1,491	155,193	30,990	52,432	1,700	120,104	144,554	202,125	8,522	940	324,370	15,908	1,938,552
Location Stability (%)	100	100	100	93	88	95	64	71	88	99	99	100	85	26	99	0	
Residence Stability (%)	0	0	0	4	−5	5	−36	−6	−4	−1	0	0	−15	239	5	−100	
Turnover (%)	0	0	0	11	7	11	1	23	8	1	1	1	0	312	6	0	

Note: For clarity purpose, all landcover areas and stability percentages are rounded to integral values. A value less than 0.5 ha is shown as 0 ha. The main diagonal elements represent the land cover that remained the same in the same location during the monitoring period 1990–1993. Marginal row and column totals are the total land covers (in hectares) per class in 1990 and 1993, respectively.

Table 6b. *Change analysis in land cover of the MRB from 1993 to 1996.*

1996	1993																Total
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	(hectare)
1. Developed High	9,073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,073
2. Developed Low	0	19,734	4	22	1	9	0	1	5	0	0	0	0	0	0	0	19,777
3. Cultivated Land	0	0	660,043	1,103	9	152	153	282	7	0	2	4	1	0	54	0	661,811
4. Grassland	0	0	901	157,765	69	16,223	139	0	75	0	2	24	3	0	156	0	175,358
5. Woody Land Deciduous	0	0	0	58	1,295	0	0	77	0	0	0	0	0	0	0	0	1,430
6. Woody Land Evergreen	0	0	3	1,210	2	142,398	14	11,521	0	0	0	15	0	0	19	0	155,185
7. Woody Land Mixed	0	0	5	198	0	13	18,898	275	0	0	0	1	0	0	1	0	19,390
8. Woody Land Scrub Shrub	0	0	2,173	33,013	37	4,612	741	37,028	18	0	1	20	4	0	3	0	77,650
9. Bare Land	0	0	35	61	2	59	22	86	1,476	0	0	7	9	0	11	0	1,768
10. Wetland Estuarine	0	0	1	1	0	0	0	0	0	119,054	7	0	0	1,998	35	2	121,098
11. Wetland Palustrine	0	0	5	1	0	1	0	0	0	2	143,577	2	0	274	23	0	143,886
12. Woody Wetland Deciduous	0	0	9	20	1	12	1	7	0	0	1	202,589	96	0	46	0	202,781
13. Woody Wetland Scrub Shrub	0	0	1	6	0	0	0	0	0	0	0	1	7,146	0	0	0	7,156
14. Unconsolidated Shore	0	0	0	0	0	0	0	0	0	1	1	0	0	846	1,439	44	2,333
15. Water	1	5	130	21	1	80	5	7	51	176	328	196	9	62	336,237	11	337,317
16. Floating Vegetation	0	0	3	0	0	0	0	0	0	0	1	2	1	0	2,513	19	2,538
Total (hectare)	9,074	19,740	663,313	193,479	1,416	163,559	19,974	49,285	1,633	119,232	143,920	202,861	7,269	3,181	340,538	76	1,938,552
Location Stability (%)	100	100	100	82	91	87	95	75	90	100	100	100	98	27	99	24	
Residence Stability (%)	0	0	0	−9	1	−5	−3	58	8	2	0	0	−2	−27	−1	3,225	
Turnover (%)	0	0	0	9	10	8	2	82	18	2	0	0	0	47	0	3,300	

Note: For clarity purpose, all landcover areas and stability percentages are rounded to integral values. A value less than 0.5 ha is shown as 0 ha. The main diagonal elements represent the land cover that remained the same in the same location during the monitoring period 1993–1996. Marginal row and column totals are the total land covers (in hectares) per class in 1993 and 1996, respectively.

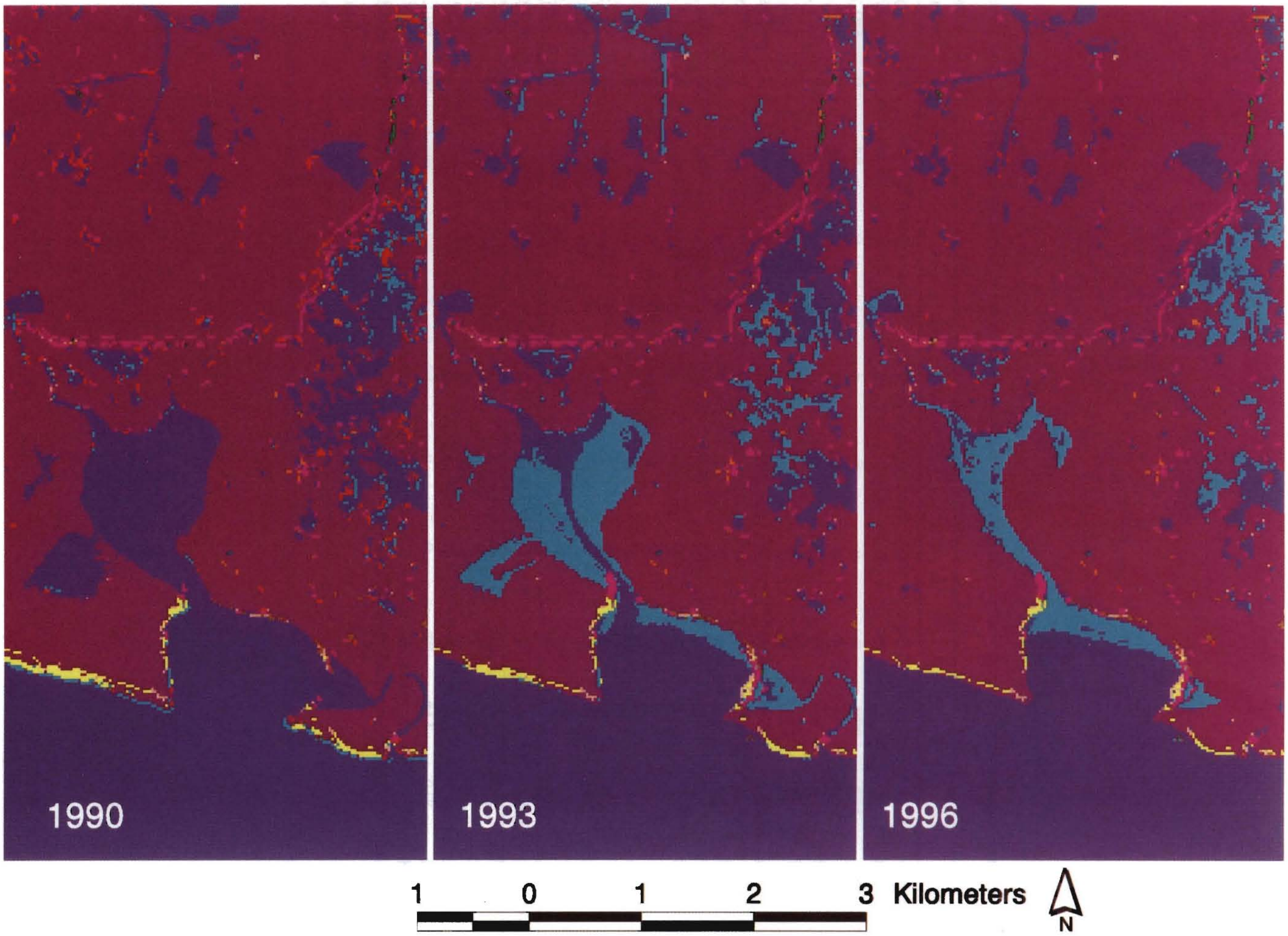

Figure 6. In this area, the progressive infilling of inland embayments and subsequent conversion to estuarine marsh was co-occurring with marsh loss from shoreline retreat. Note that the color legends are the same as in Figure 5.

counted for less than a 0.5% change in the wetland deciduous land cover. Other small losses and smaller additions were mainly associated with water and were most likely due to confusion between open water and flooded open canopies. Other than the 1990 to 1993 losses, there were no other changes of consequence associated with woody wetland scrub shrub.

CONCLUSION

A number of classification problems were overcome by using one or a combination of techniques: separating the MRB into subregions, iterative clustering, collateral data, and masking in the refinement stage of the classification. Separating the MRB into subregions permitted a more detailed analysis within regions that were defined by different groupings of land covers, especially during the initial stage of the classification. For example, many rice fields were saturated with water and were indistinguishable from water and emergent marsh located in the wetland areas of the MRB. Separating the MRB into regions dominated by agricultural and by coastal wetlands reduced misclassifications and allowed the majority of rice fields to be correctly classified as cultivated land. The same technique improved classification distinction between grasslands and cultivated lands in developed areas and between bare lands and urban development. Another technique based on the use of the multiple classifications identified and corrected misclassifications that were associated with highly unlikely landcover transitions. This technique was highly successful in uncovering misclassified burned marsh and misclassified upland and wetland forests. The ultimate advantage of the masking and post classification correction techniques was to reduce human intervention during the classification process that is often necessary to recode incorrectly classified land covers.

Accuracy assessments showed classification errors were mainly centered around four types of confusion. First, classification errors resulted from the inherent limitation of classifying composition and spatial continuums. These types of

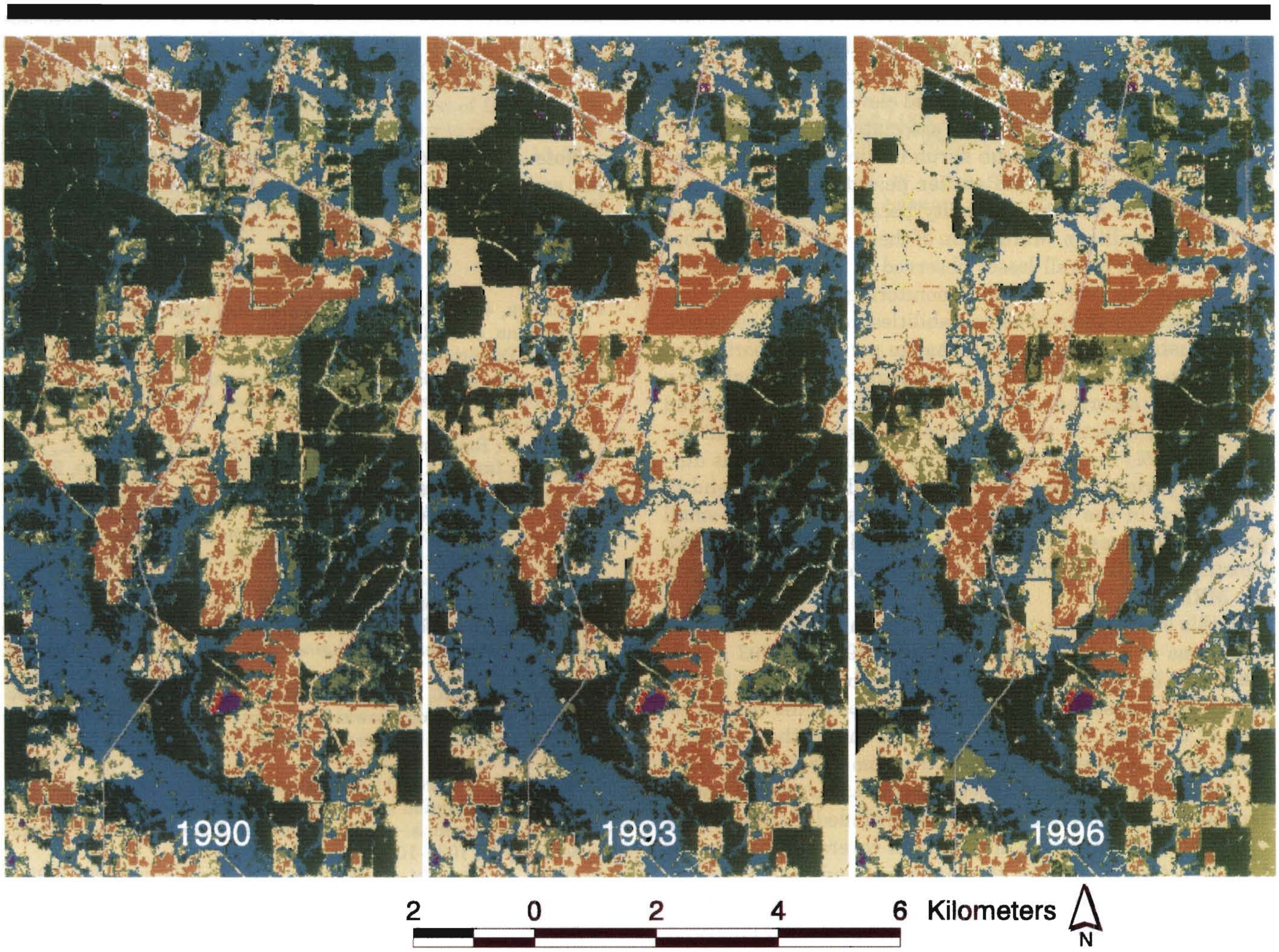

Figure 7. This area was chosen because it contains a mixture of forest types and landcover changes associated with the logging cycle. The small and scattered stands representing the distribution of woody land deciduous could not be well depicted. One of the few continuous stands of woody land mixed, however is shown (upper left). This stand and a large portion of the woody land evergreen stands were logged from 1990 to 1996. Areas of grassland conversion to scrub shrub to forest are also depicted as well as the stability of the woody wetland deciduous forests. Note that the color legends are the same as in Figure 5.

errors were most apparent in forest regrowth and mixed classes where discrete boundaries were overlaid on subtle changes in the remotely sensed signal. Second, confusion existed between classes that were spectrally inseparable. Masking alleviated some of these problems, but problems in discriminating managed (cultivated) and unmanaged grasslands and deciduous upland and wetland forests remained. Third, errors were associated with boundary areas where the spatial resolution of the sensor included more than one land cover type. For instance, the closely coupled and transient nature of water, floating vegetation, and unconsolidated shore resulted in apparent classification errors. Finally, human activities increased classification confusion. This was most apparent in activities involving lumber industry and agricultural activities such as farming and grazing. In these cases, accuracy assessment errors could have resulted primarily from the lack of simultaneous collection of ground-based observations and image data and secondly the highly transient nature of the land covers resulting from such activities.

Our analyses of changes in the monitoring period between 1990 and 1996, combined with improved methods of depicting this information, allowed greater detailed assessment of change and provided more opportunity to examine interaction between classes as related to changes in the MRB. Location and residence stability indicators defined within this manuscript allowed quick assessment of the stability or the dynamic nature of different landcover classes, both in reference to a spatial location and to retaining their overall presence throughout the MRB. Finally, the turnover described the resultant gain and loss of landcovers in terms of addition from other land covers.

Separating the change detection into two periods from 1990 to 1993 and 1993 to 1996 increased insight into why and how land covers were transformed and the validity of the transformation. We observed that logging activities tend to replace woody land mixed forests with woody land evergreen forests, decreasing the mixed forest location and residence stabilities. Between 1993 and 1996, we observed elevated forest clearing, but the increase was primarily associated with woody land evergreen. Woody land scrub shrub retained about the same location stability as in the earlier period, but there was a reversal in the residence stability because of the increased planting of seedlings. Maturation of these seedlings will more than offset the overall losses observed in woody upland forests during the 1990 and 1996 monitoring period.

High location and residence stabilities in wetland estuarine and palustrine classes in both change periods supported the contention of marsh stability in this region even though some conversions occurred. Conversions to and from grassland were linked directly to the lumber industry, and small decreases (0.5%) in residence stability in cultivated lands during both periods hinted there may be a decreasing trend in agriculture in the MRB. High location stability and small positive increases in residence stability during both periods substantiated the stableness of mature forested wetlands in the MRB.

In this study we created maps documenting the land cover and areas of change in the MRB from 1990 to 1993 and to 1996 and developed regional methods for applying C-CAP protocols to coastal Louisiana and perhaps to the coastal region of the Gulf of Mexico. As part of the method development, we generated solutions to overcome problems unique to this area which are at times common to large area and or multiple date classifications. These included distinguishing spectrally and physically similar land covers, accounting for human activities altering the landscape and changing vegetation conditions, classifying spatial and spectral continuums, and identifying and correcting highly unlikely landcover transitions. We completed accuracy assessments that documented lingering classification problems. We defined two indicators of landcover stability and used these with the three classification dates to uncover and clearly substantiate trends in the MRB landscape. By defining percent turnover, we detailed the interrelationships between specific landcover classes showing how the change of one land cover influenced the stability of another land cover. Using three points (1990, 1993, and 1996) for landcover change analysis instead of two, we produced a detailed change analysis that more clearly exposed how each land cover either contributed to or benefited from another landcover's stability, and how human interactions or natural forces may have influenced these transitions.

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