Multitemporal Land Use and Land Cover Classification of Urbanized Areas Within Sensitive Coastal Environments

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***Abstract*—In the presented methodology, multitemporal Landsat images were used to develop enhanced information about complex assemblages of vegetation and patterns of seasonal land cover variability, thereby facilitating improved land use and land cover (LULC) classification of urbanized areas among sensitive environments along the Mississippi Gulf Coast. For Landsat-5 and Landsat-7 images acquired for leaf-off and leaf-on conditions for 1991 and 2000, exploratory spectral analyses and field studies were conducted to detect and analyze patterns of spectral variability in land cover observed in the multitemporal image data. Patterns were identified of seasonal spectral data changes associated with seasonal vegetation changes for known land cover and land use types, thus characterizing patterns of seasonal LULC thematic change for the area. Detected seasonal variability for known land use and land cover types were used to develop formal classification rules based upon a thematic-change logic table. An image subset area based on United States Geological Survey (USGS) 1 : 24,000 quadrangles was used to develop a class-learning area within which unsupervised classification results were grouped into thematic classes. Signature files from the unsupervised classification results were applied to classify the balance of the study area. Individual images were classified for leaf-off and leaf-on conditions and thematic-change analyses were conducted. The formal class rules based on thematic-change logic were applied resulting in a classification that provided a level one accuracy exceeding 90% and a level two accuracy exceeding 85%.**

***Index Terms*—Coastal remote sensing, multitemporal, urban remote sensing, wetlands.**

I. Introduction

LULC classification of urbanized areas within lushly vegetated, sensitive coastal environments is a challenging task to accurately accomplish using synoptic Landsat imagery. Multitemporal imagery provides increased information about urbanized areas within complex assemblages of seasonally variable vegetation in temperate coastal regions. However, the complexity of vegetation cover and seasonal variability in leaf conditions blur the distinctions between land cover environments such as marshes and bottomland hardwood or grassland and barren lands. Also, densely vegetated areas obfuscate the separabililty of land use for developed or urbanized areas from forested or herbaceous land cover areas.

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TABLE I
County and Total Population for the Three Coastal Counties of Mississippi for the Past Three Decades. Overall Change in Population for the Three Coastal Counties of Mississippi for the Past Three Decades

County	Population 1970	Population 1980	Population 1990	Population 2000
Hancock	17,387	24,496	31,760	42,967
Harrison	134,582	157,665	165,365	189,601
Jackson	87,975	118,015	115,243	131,420
Total	**241,914**	**302,156**	**314,358**	**365,988**

County	% Change 1970-1980	% Change 1980-1990	% Change 1990-2000	% Change 1970-2000
Hancock	40.9%	28.7%	35.3%	147.1%
Harrison	17.2%	4.9%	14.7%	40.9%
Jackson	34.1%	-2.3%	14%	49.4%
Total	**24.9%**	**4%**	**16.4%**	**51.3%**

With an estimated 50% of the population of the United States living in coastal counties (near by oceans, gulfs, and Great Lakes) the significance of having tools specialized for coastal environment decision makers cannot be understated. The additional presence of wetlands in many of these coastal areas increases the challenges associated with land use/land cover analysis for planning. The importance of wetlands in serving as reservoirs for fresh water and in providing a vital function in earth's ecology compounds the need to develop methodologies to enable the identification of these features for urban planners. The importance of the wetlands as fresh water reservoirs cannot be under estimated. Research is presently predicting that by the year 2025 the earth's water cycle will be stressed more from population growth and development than from climate change [1]. Therefore, this paper describes a methodology in which land use/land cover analysis for coastal urban environments can be performed from Landsat imagery and in which proper concern is given to the all-important wetlands in these regions.

To facilitate logn-term planning, regional planning, local planning, or transportation planning for such complex coastal settings, improved methodologies are required that use more than a single image of the area to classify land use and land cover. To assure the long-term quality and sustainability

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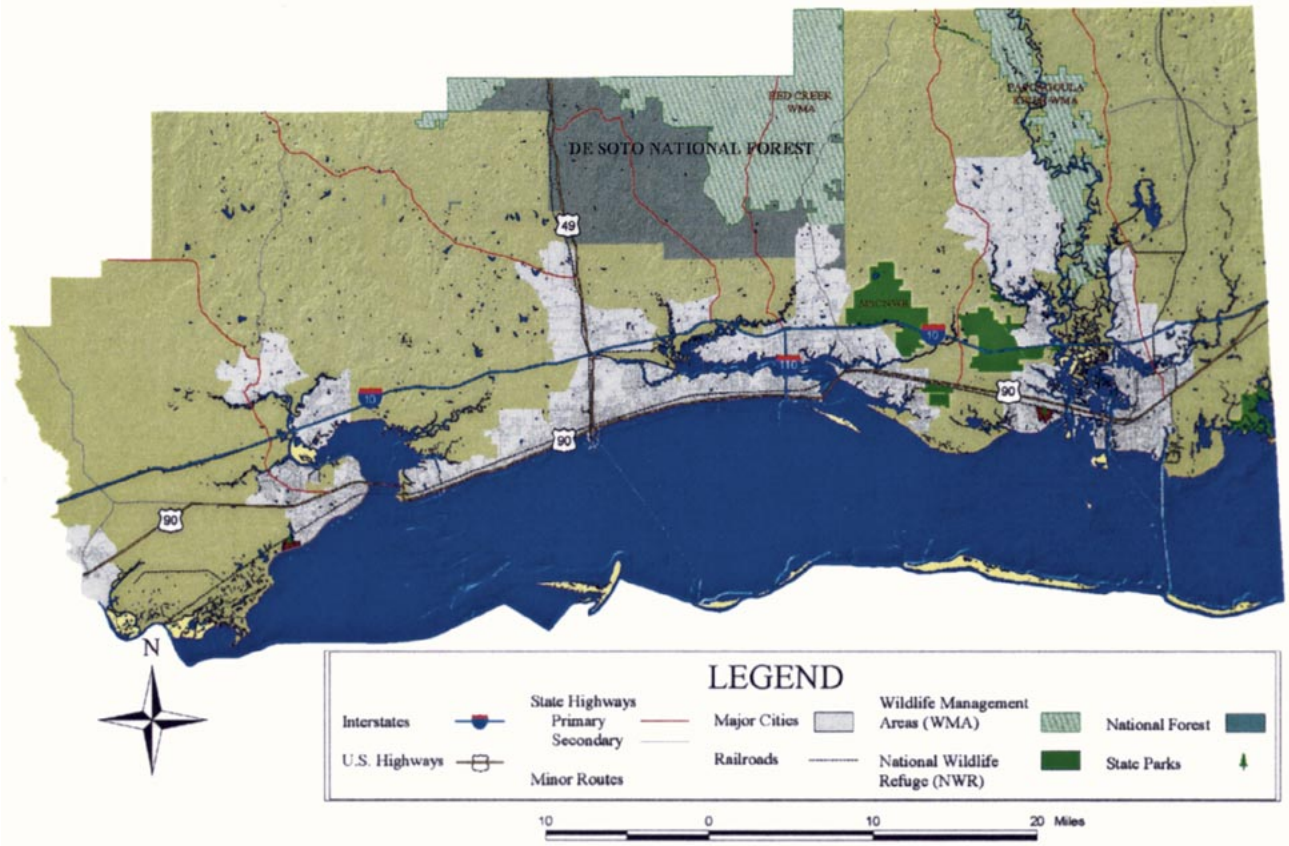

Fig. 1. Mississippi Gulf Coast counties showing major transportation features, cities, parks, forests, wildlife managements areas, and known environmentally sensitive features.

of ecosystems for the rapidly developing, environmentally sensitive Mississippi Gulf Coast, improved information are needed about LULC distribution, areas of urban growth and development, and LULC spatial trends for the study area. To assure that growth can be effectively managed and planned, accurate LULC information, as well as related spatial information features must be identified that support or constrain future urban growth and development.

Report 423A of the National Cooperative Highway Research Program [2] provides a guidebook to the "Land Use Impacts of Transportation." The guidebook documents current practices and identifies tools and practices for evaluating land use impacts of transportation. The analytical tools that are available to assess or forecast land use impacts include qualitative methods, allocation rules, decision rules, statistical models, geographic information systems (GIS), regional economic models, and formal land use models.

The analytical tools available all use similar methods to conduct analysis of land use and to determine land use impacts of a transportation project, the general steps include:

1) understand existing conditions and trends;
2) establish policy assumptions;
3) measure the transportation outcomes with and without the project;
4) estimate regional population and employment growth with and without the project (resulting from change in accessibility);
5) iInventory land with development potential;
6) estimate how the project will change the location and types of residential and business development within the study area assigning population and employment to specific locations [2].

To conduct the requisite steps for land use analysis or to determine the land use impacts of transportation, the first task requires that measurements be made of existing land use conditions and trends. GIS is the primary tool for this analysis, and data required to conduct the measurement are generally understood, but are not universally available. The availability of quality geospatial information varies to a great extent and in many cases, legacy/historical data are not available in GIS format making quantitative determination of land use trends a difficult task to conduct. Similarly, the analysis of factors that support or constrain development may be poorly represented by available GIS data.

The development of remote sensing and geospatial technologies to provide improvements in the quantitative measurement of existing land use conditions, land use development trends, land with development potential, and actual changes in land use due to transportation projects will facilitate improved abilities to forecast land use changes and, in turn, integrate these changes with travel demand models for overall improvements in transportation services and land use planning. In addition, this approach will facilitate their integration by providing a common base of quality, interoperable geospatial information.

Fig. 2. NDVI data for selected areas along the Mississippi Gulf Coast and Pascagoula River outlet to the Gulf of Mexico.

TABLE II
LANDSAT MULTISPECTRAL IMAGE DATA ACQUIRED. *LANDSAT IMAGE QUALITY INFORMATION

Image Type	Image Date	Image Quality
Landsat 5	February 14, 1991	9-Image in ideal in terms of image, spectral, and radiometric quality*
Landsat 5	September 26, 1991	9-Image in ideal in terms of image, spectral, and radiometric quality*
Landsat 7	February 15, 2000	9-Image in ideal in terms of image, spectral, and radiometric quality*
Landsat 7	July 8, 2000	9-Image in ideal in terms of image, spectral, and radiometric quality *

II. REGIONAL CONTEXT

A. Demographic Setting

Currently about 60% of the world's population lives within the coastal zone and in the United States it is estimated that at least 50% of the population is living within the small amount of land (about 20% of the contiguous United States) associated with the nation's coastal areas [3]. Population growth rates are greater in coastal states than in the remainder of the nation's states. Within coastal states the greatest amounts of population growth are associated with the coastal counties of the state, Mississippi is not an exception.[1]

Over the past three decades the state of Mississippi has had an increase in population of approximately 28% (from 2.2 million in 1970 to 2.85 million in 2000).[2] The three coastal counties of Mississippi have experienced a much more accelerated population growth over the past three decades, with the total population for Hancock, Harrison, and Jackson counties increasing from slightly less than 240 000 in 1970 to more than 360 000 in 2000, representing an overall increase of more than 50% (nearly twice that of the state). The majority of the population increase occurred between 1970 and 1980 for the three counties with less significant changes from 1980 to 1990 (Table I). Between 1990 and 2000 there was a resurgence in the population increases, which corresponds to the onset of the large casino gaming industry [4].

B. Environmental Setting

The Mississippi Gulf Coast (Fig. 1) is located in the humid subtropical climate region, which dominates all of the states adjacent to the Gulf of Mexico. This typically provides for warm summers and relatively mild winters with occasional cold waves [5]. The winter storms, summer thunderstorms, and tropical systems help to yield an annual precipitation accumulation of approximately 165 cm. This annual rainfall total makes this region second in annual rainfall in the continental United States, with the Pacific Northwest being the only region with more annual rainfall.

The Mississippi Gulf Coast is located predominately in Coastal Plain Physiographic Division, which may also be described as the Coastal Terrace. Geologically this area is composed of clay, loam, and sand features that were deposited as coastal sediments during the Pleistocene. The Coastal Plain landscape is typical of extensive marshes and swamps adjacent to the coast, which extend inland along streams and rivers that drain the coastal region. The remainder of coastal Mississippi is situated in the Pine Hills Physiographic Division, which is underlain by gravel and sands of the Citronelle geologic formation intermixed with Miocene sands. The Pine Hills area is typical of an upland plain that has been dissected by streams forming a region of slopes [6]. These physiographic and geomorphologic features create an environment that is very complex and sensitive. Ecologically the Mississippi Gulf Coast is in the Mississippi Delta Province of the Louisianian Biogeographic Region, an area rich with biodiversity [7]. Fig. 2 highlights the dense vegetation in the region by showing high values of normalized difference vegetation idex (NDVI) in darker green. NDVI values are further illuminated by a "green shading" method that uses a hillshade of the NDVI as a brightness theme for the NDVI layer.

Environmental stresses due to growth and development (from human activities) of such sensitive areas are of an increasing concern. The rapid population growth and land development trends along the Mississippi Gulf Coast compete with sensitive environmental conditions in areas such as National Forests, state parks, wildlife management and refuge areas, conservation areas, or wildlife sanctuaries. Rapid changes to the landscape can drastically affect these types of fragile coastal environments. Most often the these changes are responsible for loss of habit, interception of water and sediment, invasions of exotic species, increased rates of sea level rise, and increased pollution

[1]National Oceanic and Atmospheric Administration Coastal Population and Development. See http://spo.nos.noaa.gov/projects/population/population.html.

[2]University of Mississippi, State Data Center of Mississippi, Public Law Data (PL 94-171) Percent Population Change for Mississippi Counties 1970–2000. See http://www.olemiss.edu/depts/sdc/countygro.pdf.

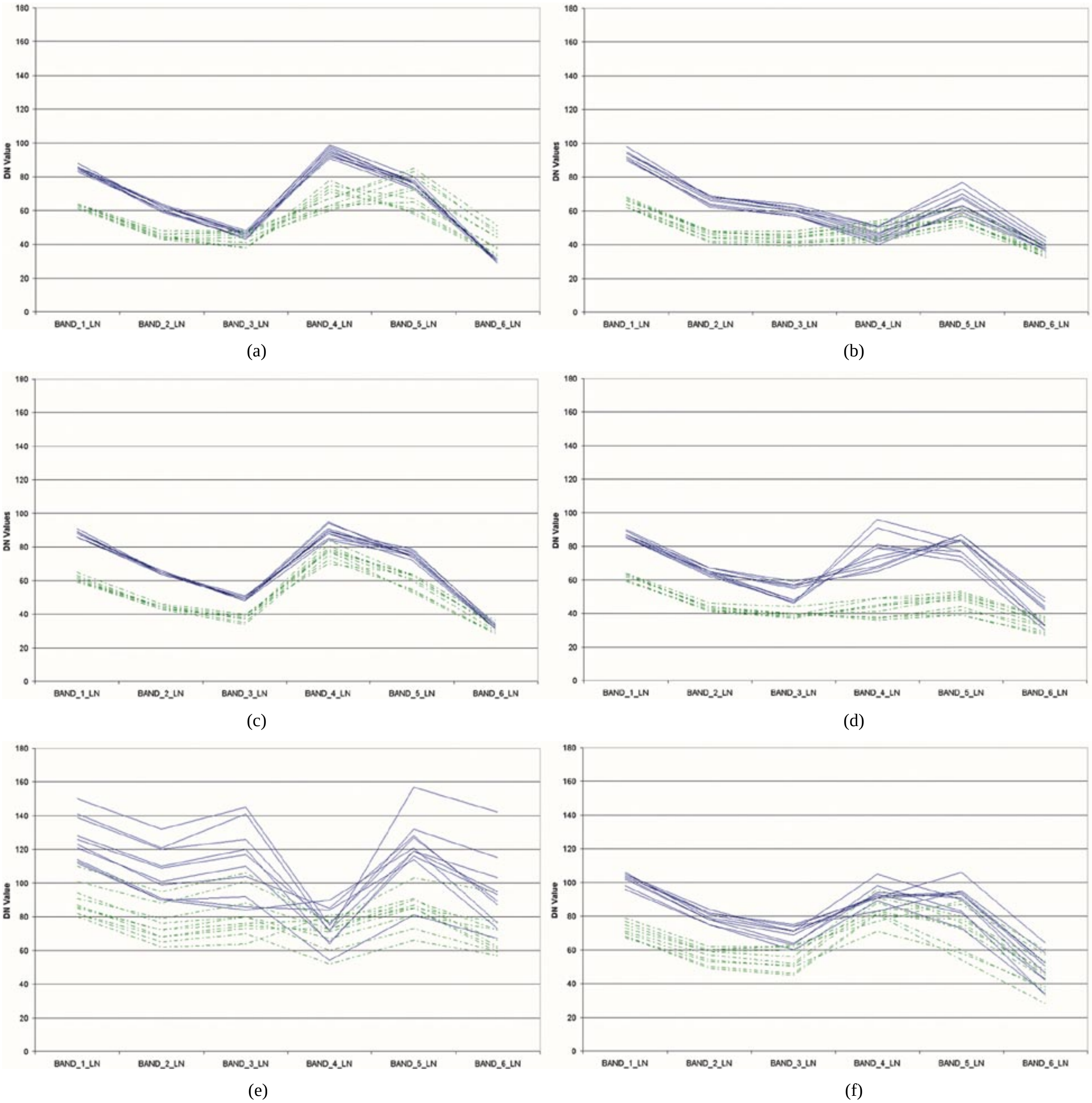

Fig. 3. Leaf-off (green) and leaf-on (blue) spectral profiles for (a) Bottomland Hardwood, (b) Coastal Marsh, (c) Deciduous, (d) Freshwater Marsh, (e) High Density Urban, and (f) Low Density Urban areas.

and nutrients of the near shore environments [3]. The sensitive environmental conditions and a high rate of population growth and land development combine to provide a challenge to develop the region in a manner that is sustainable and preserves the natural environment.

III. Methodology

A. Introduction

Thematic classification of single remote sensing image scenes is highly susceptible to temporal changes in geospatial image data characteristics. Whether foreseen or unforeseen, these temporal changes can significantly impact the qualitative human value and quantitative accuracy of the classification results. Furthermore, lack of systematic analysis of temporal changes assures that any underlying structure in the changes will be overlooked [8]. Traditional "synoptic" approaches to land use and land cover classification cannot help but to misclassify a significant portion of the scene because time-varying information content does not meet the classification model requirements.

The new methodology presents a classification approach that uses conventional image analysis and classification tools in a procedure that quantifies and exploits, within a multitemporal image classification, the underlying structure of temporal change in geospatial image data characteristics. In this approach, multitemporal spectral characteristics are compiled for distributed training sites within the study area for locations of known land use and land cover types of interest for the classification. The spectral characteristics for leaf-on and leaf-off conditions are used to conduct an initial unsupervised classification for image subsets based on USGS quadrangles that contain the locations of known land use and land cover. Restricting the area of the initial unsupervised areas limits the computational requirements of the initial classification and facilitates an adaptive learning of classes for those areas by using human knowledge and interaction to "apply" the classification. The results for the geographically distributed, but size-restricted areas, are applied to the entire scene in a supervised classification that extends the learned classes to the landscape. The operation is conducted for scenes collected for leaf-off and leaf-on conditions and the resultant thematic classifications are compared, the results of which are used to decide upon the final classification based on logical structure within the observed thematic change. In this classification, temporal changes in image data characteristics are 1) quantified for specific land use and land cover types, 2) employed to conduct multitemporal classifications, 3) thematically compared between two classifications, and 4) the comparison results are used to reclassify the area based on decision rules of thematic-change logic derived from the observed underlying structure for spectral change in the classes.

B. Early Research

In previous studies [9], LULC classifications using data exploration methods were performed to provide improved understanding of the general distribution of environments, the nature and variability of LULC types, the distribution of transportation features, and the growth of urban areas on the Mississippi Gulf Coast. This initial "Data Exploration"classification method produced an overall accuracy of 73% based on a modified Anderson level one classification [9].

Early research led to the detailed examination of various LULC classification methods to ascertain relative strengths and weaknesses of the approaches, as well as to determine specific environments and LULC types which existing methods do not accurately classify. Problematic environment types and regions within the study area were noted, and class descriptions were developed for each class to be included in the classification. Descriptions for level one classes follow:

1) *Water*—Streams, canals, lakes, reservoirs, bays, and estuaries
2) *Wetland*—Bottomland and riverine forests, meander belts, saltwater marshes, bogs, and riverine estuaries
3) *Urban/Built-up*—Residential, commercial, and industrial development
4) *Forested Vegetation*—All forest vegetation types including evergreen, deciduous, and pine savannahs
5) *Nonforested Vegetation*—All vegetation features that are not indicative to forests, including grasslands, pastures, recreational grasses, scrub or shrub like vegetation and agricultural lands
6) *Barren*—Little to no vegetative growth including beaches and cleared areas.

Fig. 4. USGS 1 : 24 000 quadrangles selected for the class-learning area were geographically distributed within the study area, but contained representative LULC classes.

C. Selection of Images

To accurately classify LULC for the Mississippi Gulf Coast, high-quality Landsat-5 and Landsat-7 images (as described in Table II) were acquired for the study area (Path/Row, 021/039). For 1991, two Landsat-5 scenes were selected, and for 2000, two Landsat-7 scenes were selected all providing good image quality and excellent spectral and radiometric quality. Images were selected to provide high-quality images with maximum spectral difference between images due to seasonal leaf condition change. Pairs of images were selected for the same year to capture leaf-off and leaf-on conditions with as short a time between images as possible to minimize changes in actual land use due to land development activities that occur during the time which passed between images.

D. Preprocessing

A base image was closely registered to a transportation network vector database and all other images were coregistered to the base image. Resultant RMS values for images ranged from 0.14 to 0.3 pixels. The images were coregistered to maximize spatial agreement between images.

E. Data Exploration Analyses

The "leaf-on"and "leaf-off"images were used to determine variability in vegetation and to characterize seasonal changes that might occur within the coastal environment over a year. The study area was analyzed for different class types that would be included in the classification, and what areas best demonstrated these classes.

F. Multitemporal Spectral Characteristics of Desired Classes

Using a priori knowledge of locations within the study area with known land cover, spectral information from each Landsat band were compiled for the leaf-off and leaf-on conditions. Spectral profiles were assembled and used to assess spectral values characteristic of desired LULC types for the study area (Fig. 3). These profiles illustrate seasonal variability of vegetation condition which strongly influences the aerial spectral appearance and results in the thematic change between the scenes.

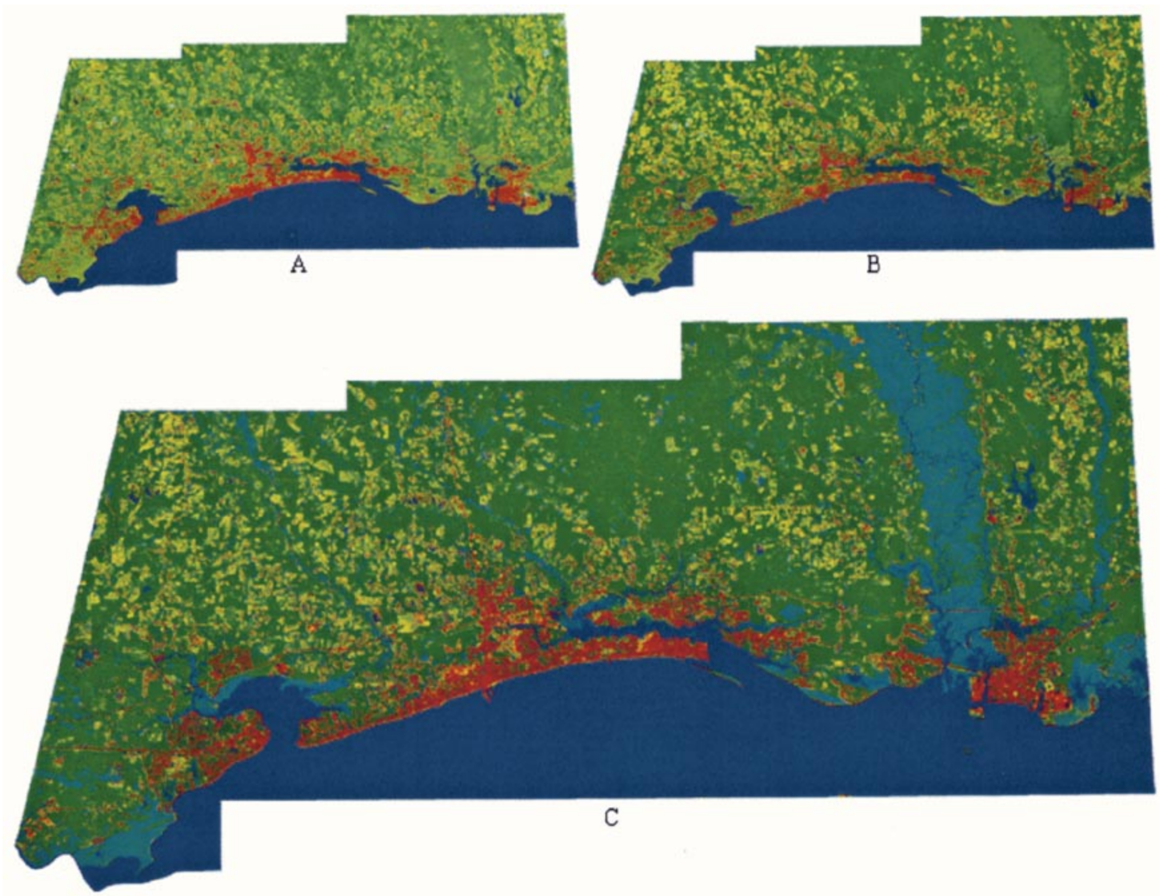

Fig. 5. Classified 2000 leaf-off (A) and leaf-on (B) results were used to perform thematic change, the results of which were classified (C) using formal classification rules and thematic-change logic.

TABLE III
SELECTED CLASSIFICATION RULES AND CORRESPONDING THEMATIC CHANGE LOGIC

	Thematic Change Logic	
Classification Rule	**Was – leaf off**	**Is – leaf on**
Bottomland Hardwood	Wetland	Forested
Low Density Urban	Urban/built-up	Forested
Grassland/Pastureland	Barren	Non-Forested
Deciduous	Non-Forested	Forested
Water	Water	Any Class
Low Density Forest	Barren or Non-Forested	Forested

TABLE IV
CONFUSION MATRIX FOR LEVEL ONE 2000 LULC. OVERALL ACCURACY IS 90.1

	C1	C2	C3	C4	C5	C6	Row Total
C1. Water	3	0	0	0	0	0	3
C2. Wetland	0	12	0	2	1	0	15
C3. Urban	0	0	20	0	0	0	20
C4. Forested	0	0	0	20	1	0	21
C5. Non-Forested	0	0	0	1	16	0	17
C6. Barren	0	0	0	0	3	2	5
Column Total	3	12	20	23	21	2	81

G. Selection of Class-Learning Area

An image subset was created for each scene using USGS 1 : 24 000 quadrangles (quads) boundaries. Seven quads were selected known to contain areas representative of all desired LULC classes (Fig. 4).

H. Unsupervised Classification of the Class-Learning Area

The subset images were processed using an unsupervised classification method containing 210 classes for the seven sample quads. The unsupervised classification method utilized the iterative self-organizing data analysis technique (ISODATA) to establish clusters based on inherent similarities within the data. The ISODATA technique is a modified version of K-means clustering and aids in the categorization of pixels based on the spectral differences in each band, this allows for the development of unique class signatures and diminishes the spectral distance between classes [10]. Each pixel was classified on a diagonal mean with a scaling range of one standard deviation. The classification was allowed to run for ten iterations with a minimum convergence threshold of 95%.

The hypothesis that class variability increases with increasing area and spatial distance between areas in similar classes, led to

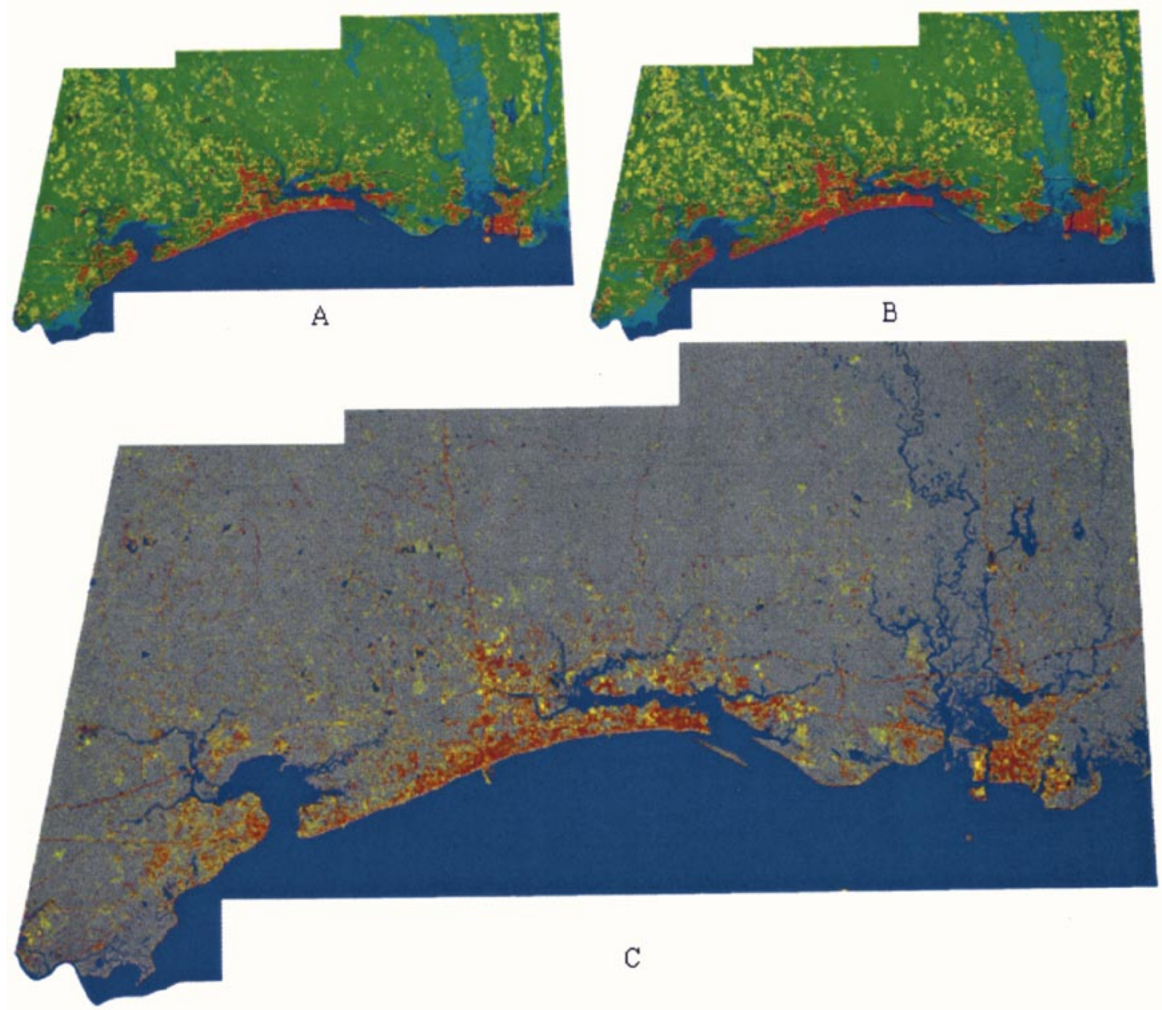

Fig. 6. LULC classifications for 1991 (A) and for 2000 (B) were used to conduct thematic-change assessment, results of which are shown (C). Brownish areas are areas that were classified in 1991 as urban, and areas shown in yellow have been developed in the period between 1991 and 2000.

experimenting with the numbers of unsupervised classes to determine an ideal number of classes to provide statistical separability of the desired classes across the study area. As a general rule, it was found that when trying to create 10 to 15 classes using seven 1 : 24 000 quads to subset the class-learning area, the number of classes selected for unsupervised classification to provide good separability should be at least 30 classes per quad, resulting in 210 overall classes to be generated by the unsupervised classification procedures. For other studies, similar experimentation would be required to develop general rules for the number of unsupervised classes required to provide ideal separability.

The resultant 210 classes were manually recoded into 14 modified Anderson level two classes using areas of known LULC, visual inspection, and spectral profiles that were compiled for the region. In some cases, digital ortho-imagery data which had been compiled area-wide were used to assist in classification.

The class-learning term is used to describe the process wherein smaller, well-characterized areas within a larger study unit are used to develop LULC classifications from which signature files are generated and applied in a supervised classification to the entire study area—A process in which the classification of the larger area is learned from the results of classification for the smaller area.

I. *Supervised Classification*

For the balance of the study area, a supervised classification of the image was performed using the signature files from the previous unsupervised classification. For the supervised classification, no nonparametric rules were used, and a maximum likelihood rule was used for a parametric rule. All zeros were left as unclassified so that the resultant classes were not skewed by misclassed zeros.

The entire process was completed for leaf-on and leaf-off images for 1991 and 2000 resulting in two classified image products (leaf-off classification and leaf-on classification) for each year. Level two classifications were grouped to provide modified Anderson level one classification [11].

J. *Thematic Change and Formal Rule-Based Classification*

Thematic-change detection analyses were performed on the leaf-on and leaf-off images to account for seasonal variations in the vegetation. These thematic-change analyses used the leaf-off

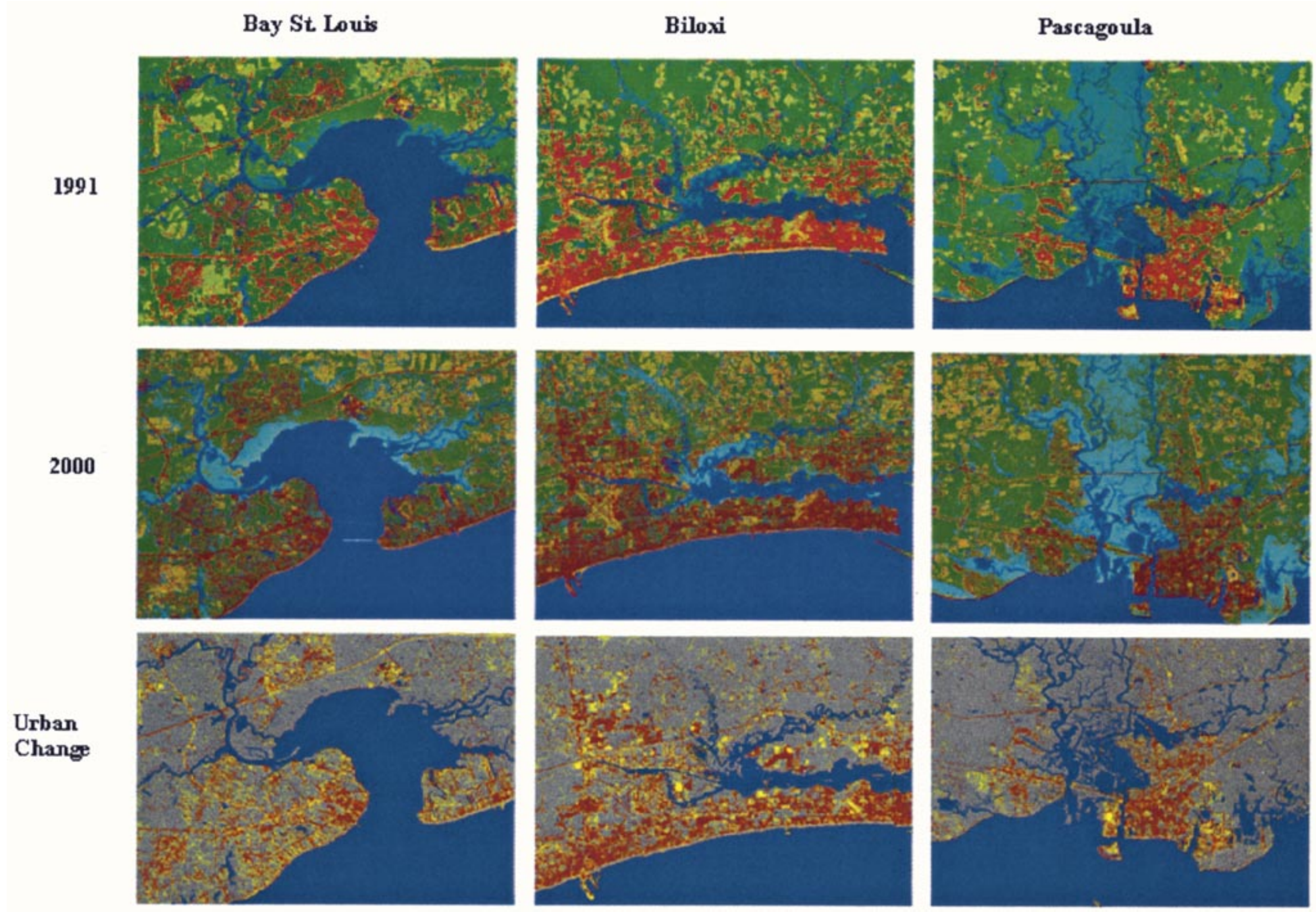

Fig. 7. Change in LULC and growth in urban areas near the cities of Bay St. Louis, Biloxi, and Pascagoula can be seen by comparing red urban areas in the 1991 images against the reddish-brown areas in the 2000 image. The change images summarize urban growth by showing areas that were urban in brown and areas of growth in yellow.

classified image as the "before" image and the leaf-on classified image as the "after" image, allowing for a comparison and separation of the previously defined classes based on phenologic trends of the vegetation. Formal classification rules based on a thematic-change logic table (based on or guided by the thematic-change layer) are applied to the resultant composite classification to produce a final classification for a given year (Fig. 5). The thematic-change layer is derived from observed and quantified phenologic variability and trends as shown in Fig. 3. The thematic-change logic table compiles rules for urbanization (i.e., if urban in leaf-off, then it must be urban in leaf-on) as well as for seasonal variability in vegetative coverage that are indicative of specific environments (Table III).

K. Accuracy of LULC Results

To assess the accuracy of the LULC results, a random selection of accuracy points were visited and actual land use and land cover was tabulated for each point location. The tabulated LULC data were used to determine the accuracy of both the level one and level two classifications. Confusion matrices were developed and the accuracy for the level one classification was determined to exceed 90% and the accuracy for the level two classification was determined to exceed 85% (Table IV).

TABLE V
SUMMARY OF AREAS FOR LAND COVER CLASSES FOR THE 2000 CLASSIFICATION

Classes - 2000	Pixel Count	Acres	Percent
Water	1619828	324979.2	23.9%
Wetland	1345456	269933.1	19.8%
Urban/Built-up	482531	96808.1	7.1%
Forested Vegetation	2414379	484386.6	35.6%
Non-Forested Vegetation	685614	137551.8	10.1%
Barren	233688	46883.8	3.4%
Total	6781496	1360542.7	

IV. DISCUSSION

LULC classification results for 1991 and 2000 were used to perform thematic-change detection to spatially quantify urban development along the Gulf Coast (Fig. 6). Spatial quantification of change provides more information than simple tabular calculation and facilitates the determination of spatial trends of development for the region. Additionally, estimations of sprawl can be made using the demographic information as well as the increases in developed areas (Tables V and VI).

The thematic change determined for the period from 1991 to 2000 is highlighted by a greater than 36% increase in

TABLE VI
CHANGES IN LEVEL 1 LULC BETWEEN 1991 AND 2000

LULC Change from 1991 to 2000		
Class	Acreage Change	Percent Change
Water	-14179.0	-4.2%
Wetland	-63.4	0.0%
Urban/Built-up	25827.2	36.4%
Forested Vegetation	-25094.7	-4.9%
Non-Forested Vegetation	-24270.9	-15.0%
Barren Land	37780.8	415.0%

urban/built-up areas for the period with almost 26 000 acres developed. The corresponding increase in population of over 50 000 people or 16.4% shows that the population increase resulted in a disproportionate increase in the amount of developed land, a good indication of sprawl due to people making increased use of an improved transportation network, choosing to live farther from work, and living in larger homes and lots in suburban developments. Fig. 7 illustrates some of this change for three urban areas in the study area.

The significant increase in barren land of over 37 000 acres can largely be attributed to the drought conditions experienced during the 2000 leaf-on period. Barren areas may be over represented for the time period. The increase by over 400% may overstate the amount of areas that have been either cleared or are now barren, but also provide a strong indication that areas are being rapidly cleared for development activities.

V. CONCLUSION

Research on the application of remote sensing and geospatial technologies to transportation planning and environmental assessment has led to the development of a methodology to provide accurate, dependable LULC classifications in urban areas located in coastal zones. The LULC classification methodology provides significant accuracy improvements over synoptic approaches via data and information processing methods that employ knowledge management, phenologic change, and formal rule-based classification employing a thematic-change logic table. The new method proves to be quick and accurate and produces highly useful and manageable products for analysis, planning, and mapping.

For the urbanized Mississippi Gulf Coast study area, the results of classification were analyzed and used to determine land cover and land use distribution, to facilitate the spatial analysis of areas of urban growth and development, and to enable the determination of land use and land cover spatial trends for the study area. Through analysis of resultant land use and land cover information as well as related spatial information, features were identified that support or constrain future urban growth and development.

Although the results of the LULC project provide significant accuracy improvements over previous synoptic classification efforts for the area, some limitations of the results were noted. The region experienced climate variability during the period of study, including drought conditions during the time of the 2000 leaf-on imagery acquisition. The drought conditions caused some instances of grassland and pastures to be classified as barren, but the increases in barren areas may also be an indication of areas cleared for development activities that are ongoing. Additionally, a significant period of time passed between image acquisition (2000) and accuracy assessment of the final classification (summer 2002). Therefore, some areas field assessed as developing subdivisions (low-density urban) were classed from the image data as low-density vegetation.

Over and above the improved accuracy of the classification, the multitemporal approach yielded some broad benefits including: enhanced ability to classify deciduous vegetation, improved ability to identify wetlands, improved ability to identify low-density urban areas, and improved detection of deforested areas as well as areas of forest regrowth in previously cut areas.

Future LULC studies are planned that will compare the results of this study to those that can be obtained using object-based approaches to the classification of multitemporal Landsat image data. Additionally, research will be conducted on the use of high-resolution image and/or elevation data to add spatial accuracy, resolution, and further precision to the classification. Finally, additional case studies are being planned to test the methodology in similar urbanized coastal environments.

The proposed new methodology for LULC in sensitive coastal environments will assist urban planners who have the challenge of satisfying the quality of life demands of a burgeoning coastal population while providing for environmental stewardship.

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