Journal of Remote Sensing & GIS
ISSN: 2469-4134
Pan et al., J Geophys Remote Sens 2013, 2:1
DOI: 10.4172/2169-0049.1000108
Research Article Open Access

Monitoring Land-Use and Land-Cover Change in the Eastern Gulf Coastal Plain Using Multi-temporal Landsat Imagery

Shufen Pan[1,2]*, Guiying Li[2], Qichun Yang[2], Zhiyun Ouyang[1], Graeme Lockaby[2] and Hanqin Tian[2]

[1]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-9 Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[2]School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA

Abstract

Rapid population growth and intensifying human activities have driven significant changes in coastal plains. As one of the largest coastal plains in the world, the U.S. Gulf Coastal Plain supports a huge population and provides numerous goods and ecological services to the human society. Spatial information on Land-Use and Land-Cover Change (LULCC) is essential for accurate assessment of human impacts on the structure and functioning of coastal ecosystems in this region. In this study, the Florida Panhandle region was selected as a case to characterize and detect changes in Land Use/Land Cover (LULC) in the Gulf Coastal Plain from 1985 to 2005. Landsat TM images in 1985, 1996 and 2005 were collected and processed to retrieve LULC information and to reflect temporal changes of major LULC types. Results indicated that urban areas expanded quickly and increased by about 79% from 1985 to 2005. Crop/pasture decreased from 1985 to 1996 but increased quickly during 1996-2005 by replacing large area of forestland in the eastern part of the study area. Forest/woody wetland increased from 1985 to 1996 but decreased in the later time period. Population growth and tree plantation were identified as the two major driving forces for LULCC in this area. Our results imply that urban sprawl and cropland/pasture expansion as well as tree plantation could potentially affect productivity, carbon and nutrient cycling, as well as water quality in coastal ecosystems of the Gulf of Mexico. Uncertainties associated with satellite image classification and scale effect should be further addressed in future research.

Keywords: Gulf coastal plain; Panhandle; Remote sensing; Land use; land cover change

Introduction

Coastal plain ecosystems are of critical importance in supporting the human society and increasing global population [1,2]. Low topographic variations, mild climate, high productivity and convenient accesses to ports make coastal plains the best places for housing and industry [3]. It was estimated that there are approximately 1.2 billion people living within 100 km of the shoreline, and the population density in coastal plains area is two folds higher than the global average [4]. In the U.S., the coastal plains support more than 39% of the country's populations although they only account for about 10% of the total land area. Recent population projection indicated that population density in coastal areas of the South and Southeast U.S. will continue to increase in the near future [5]. In addition to the economical roles, coastal plains are also known as biodiversity hotspots [6]. Environmental gradients (elevation, water, soil salinity) from upland to coastal oceans create a series of habitats which support a variety of faunas and floras [7,8].

The U.S. Gulf Coastal Plain has undergone rapid land use and land cover changes (LULCC) in recent decades [9]. As the largest coastal plain in the U.S., the Gulf Coastal Plain provides a large amount of valuable goods and services to human society. However, due to the increasing population and thriving industrial activities, the coastal plain is experiencing intensifying anthropogenic disturbances. Urban sprawl not only reduces forest cover, but also exerts negative impacts on water quality and biodiversity. Several researchers have reported that as low as 10% increase in impervious surface area could lead to dramatic degradation of stream ecosystems [10,11]. High proportions of impervious surface lead to increasing nutrient and sediment loads to streams [11]. Urban developments were reported to increase heavy metals, bacteria loadings, temperatures and other nutrients in streams [12-14]. Forest plantation for commercial purposes could dramatically alter water cycling through enhancing evapotranspiration and deteriorate water quality through applications of chemical fertilizers and pesticides [15].

Better management of coastal land use is critical for the sustainability and integrity of coastal ecosystems. To fulfil this goal, a thorough investigation of land use history in coastal areas is needed to explore the underlying mechanisms that drive LULCC and to predict future land use patterns. Among the different methods used in land use change studies, extracting land cover information from remotely sensed images has been widely used in recent decades [16,17]. Advancements in Remote Sensing (RS) and Geographic Information System (GIS) made it possible to provide precise estimations of land use dynamics [18,19]. Reconstructing land cover information with aerial photographs and satellite data is considered the most effective and efficient way to retrieve historical land use information [20,21]. Since the 1970s, Landsat datasets (MSS, TM/ETM+) have being widely used in monitoring land cover change considering their 85 high spatial, temporal and spectral resolutions [21].

Understanding the impacts of human activities on LULC patterns is urgent in the coast plain regions of the southeastern U.S. In recent decades, this area has experienced rapid population growth and related activities which made it a good test bed to demonstrate how anthropogenic activities drive LULCC. In this study, the Panhandle region of western Florida was selected as the study area. Historical LULC information regarding the area and spatial distribution of different LULC types and their conversions over time is critical to the

***Corresponding author:** Shufen Pan, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA, E-mail: panshuf@auburn.edu

Received May 08, 2013; **Accepted** June 21, 2013; **Published** July 07, 2013

Citation: Pan S, Li G, Yang Q, Ouyang Z, Lockaby G, et al. (2013) Monitoring Land-Use and Land-Cover Change in the Eastern Gulf Coastal Plain Using Multi-temporal Landsat Imagery. J Geophys Remote Sensing 2: 108. doi:10.4172/2169-0049.1000108

potential interdisciplinary researches in this region and will provide useful implications for the whole Gulf Coastal Plain. Objectives of this study include: 1) reconstructing the LULC history in Panhandle from 1985 to 2005; 2) investigating the spatial and temporal patterns of LULCC in this region; 3) exploring drivers that contributed to LULCC.

Study Area

The Florida Panhandle underwent rapid LULC and ownership changes from the turn of the 20th century to the mid-1980s. Some private landowners in Franklin County managed over 800,000 acres of forest lands for timber products and owned about 20 miles of the nearby coastline. About 15 years ago, some private landowners decided to become land developers and started converting from timber production to real estate activities. The deforestation and urbanization changed the LULC; these actions caused 106 significantly impact upon the ecosystems, especially in the water quality and in the coastal fishery production. The water quality problems in Apalachicola Bay were so intense that it made national news (NPR News, Morning Edition, and April 30, 2007). Time-series of LULC datasets will be essential for monitoring these changes and evaluating the potential impact.

Three counties (Franklin, Gulf, and Liberty) in the Florida Panhandle region were selected for this study (Figure 1). They are located in northwestern Florida and cover an area of 6780 km^2. The total population in the three counties was 35,777 in 2010, increased by 14.9% compared from 2000. Forests and coastal wetlands are the major land cover types in the study area.

Methodology

Procedures used in this study are depicted in Figure 2. In order to explore the spatial-temporal pattern of LULCC in this study area, Landsat TM images of three time periods (February 8 and March 19, 1985; January 13 and 22, 1996; April 4 and 27, 2005 with 30m resolution) were collected (Figure 3). In addition to the Landsat TM image data, ancillary data including aerial photographs (taken in 2004 with 1×1 m spatial resolution, 108 scenes of aerial photograph were mosaicked for this study), National Land Cover Data of 1992 and 2001 (NLCD), National Wetland Inventory Data (NWI), and demographic data were collected to assist satellite image interpretation. Field surveys were also conducted to enhance data processing and to evaluate interpretation of Landsat images. To determine field observation sites, we randomly sampled one GPS point per square mile along Highway 98 near Apalachicola. A total of 68 GPS points were chosen for this study. The

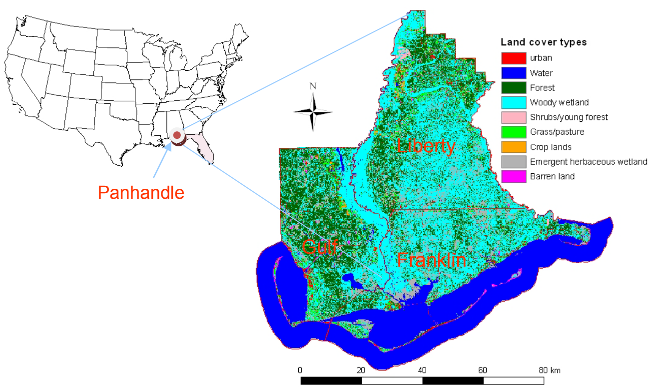

Figure 1: Location of the study area (Panhandle region) along the Gulf of Mexico.

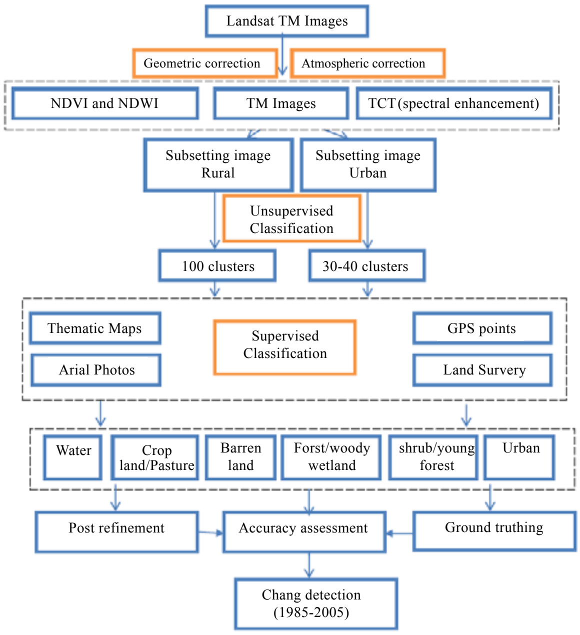

Figure 2: Flow charts of methodology used for land use/land cover classification and change Detection.

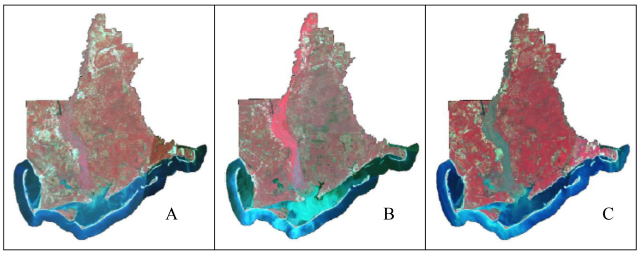

Figure 3: Landsat images of three years for the Panhandle region of Gulf Coastal Plain. Color composition with TM bands 4, 3, 2 as red, green and blue. The study area is composed of two TM scenes. A was taken on February 8 and March 19, 1985; B was taken on January 13 and 22; C was taken on April 4 and 27, 2005.

Landsat TM images were first registered to the UTM coordinate system with root mean square errors less than 0.5 pixels. The 1992 National Land Cover Classification System was adopted as classification scheme here. Initially, eleven LULC types included urban, water; evergreen forest, deciduous forest, mixed forest, shrub, emergent herbaceous wetland, woody wetland, cropland, grass/pasture, and barren land were identified. The definitions of these classes can be found at USGS website (http://landcover.usgs.gov/classes.php). We used different methods to improve classification performance. Initially, we used an unsupervised classification ISODATA algorithm to generate a number of spectral clusters following by labeling each cluster.

We found that unsupervised classification based on spectral characteristics alone is not capable of differentiating some land cover types due to the similarity of their spectral properties, such as between fallow field, impervious surface, and bare land; also between wetland and forest. In order to overcome these problems, we incorporated the Normalized Difference Vegetation Index (NDVI, Equation 1) and the Normalized Difference Moisture Index (NDMI, Equation 2) into

1985 1996	Water	Forest/Woody wetland	Shrub/young forest	Urban	Grass/pasture/crop/herbaceous wetland	Barren land	Total
Water	172399	1647	56	83	1636	808	176629
Forest/Woody wetland	785	350129	30379	3220	34256	11577	430346
Shrub/young forest	11	19359	5913	576	3133	2436	31428
Urban	80	2483	494	2443	1091	1048	7640
Grass/pasture/crop/herbaceous wetland	766	15986	2507	691	6671	2064	28686
Barren land	420	1541	231	398	554	2592	5736
Total	174460	391145	39581	7412	47341	20526	680466
1996 2005	**Water**	**Forest/Woody wetland**	**Shrub/young forest**	**Urban**	**Grass/pasture/crop/herbaceous wetland**	**Barren land**	**Total**
Water	173848	780	80	147	1435	1437	177727
Forest/Woody wetland	1006	369701	19685	2088	15151	770	408402
Shrub/young forest	4	4982	2074	164	740	187	8150
Urban	113	5961	1957	2758	1556	953	13297
Grass/pasture/crop/herbaceous wetland	1379	47443	7328	1677	9376	623	67826
Barren land	246	1519	316	807	425	1763	5076
Total	176596	430386	31440	7641	28684	5733	680478
1985 2005	**Water**	**Forest/Woody wetland**	**Shrub/young forest**	**Urban**	**Grass/pasture/crop/herbaceous wetland**	**Barren land**	**Total**
Water	172429	1474	83	74	1862	1698	177621
Forest/Woody wetland	545	337446	27662	3024	28969	10786	408432
Shrub/young forest	1	4267	2200	177	579	925	8150
Urban	117	6412	1545	2234	1516	1474	13298
Grass/pasture/crop/herbaceous wetland	1090	40123	7706	1485	13844	3566	67814
Barren land	273	1383	371	412	564	2073	5076
Total	174454	391105	39568	7407	47334	20523	680391

Table 1: Land cover change matrix during 1985-2005 (unit: hectare)

Year	1985			1996			2005		
LULC types	**Producers Accuracy**	**Users Accuracy**	**Conditional Kappa**	**Producers Accuracy**	**Users Accuracy**	**Conditional Kappa**	**Producers Accuracy**	**Users Accuracy**	**Conditional Kappa**
Water	94.50%	100.00%	1.00	90.91%	100.00%	1.00	100.00%	100.00%	1.00
Forest/Woody wetland	80.27%	87.37%	0.86	80.38%	86.00%	0.84	74.55%	86.00%	0.84
Shrub/young forest	72.92%	72.67%	0.70	70.07%	68.00%	0.65	72.83%	67.00%	0.64
Urban	97.78%	93.33%	0.93	99.17%	94.17%	0.94	94.18%	90.00%	0.89
Grass/pasture/crop/herbaceous wetland	87.66%	76.95%	0.76	80.56%	74.17%	0.73	92.50%	80.84%	0.80
Barren land	91.06%	88.89%	0.88	83.33%	83.33%	0.82	93.55%	96.67%	0.96
Overall Accuracy	86.95%			85.88%			85.65%		
Overall Kappa	0.8540			0.8445			0.8418		

Table 2: Accuracy assessment of LULC classification.

original Landsat bands. Because of the impact of atmosphere on short wavelengths and the high correlation between the visible bands, TM band 1 (blue band) was not used in the image classification.

$$NDVI = \frac{\rho(band4) - \rho(band3)}{\rho(band4) + \rho(band3)} \quad (1)$$

$$NDMI = \frac{\rho(band4) - \rho(band5)}{\rho(band4) + \rho(band5)} \quad (2)$$

Considering the good performance of NDVI in identifying water bodies, the NDVI map was first used to distinguish surface water from other land use types. Since natural vegetation has low red-light reflectance and high near-infrared reflectance, land surfaces covered by plants have brighter color than developed regions. As a result, developed and undeveloped areas in Panhandle can be identified through the NDVI map. Considering the difference in vegetation structure, land use diversity and human impacts, it is necessary to conduct classification over developed and undeveloped separately. The images were then roughly stratified as urban area and rural area. An unsupervised classification was implemented for each stratum respectively. Different numbers of clusters were produced for each stratum considering the complexity of landscapes of the two stratums. For example, 100 spectral clusters were generated for the rural portion and 30-40 clusters for the urban portion. Each spectral cluster was visually checked against the Landsat imagery as well as the ancillary data such as aerial photographs, existing LULC data, National Wetland Inventory, etc., and was labelled with the land cover type it represents. These methods are helpful to separate wetland from forest, and developed features from fallow field and bare land. Also we have conducted another spectral enhancement to TM images, specifically, Tasseled Cap Transformation (TCT). TCT transforms Landsat TM reflectance bands (band1 through band 5 and band 7) into three orthogonal indices called soil brightness, vegetation greenness and soil/vegetation wetness, removes redundant or unnecessary information and saves computer storage and processing time. Previous studies using TCT to detect forest changes and disturbances as well as vegetation type differentiation provide promising practices for our research, in which forests and wetland mostly cover the study region. It is helpful for separating some types of forest and wetland, bare soil and developed features. In addition, any cluster that could not be assigned with a specific land cover type due to spectral similarities between land cover types was masked out for further analyses. All unlabeled pixels were then subjected to additional unsupervised classification, and each cluster was assigned with specific land cover type. For developed area, including high residential, medium residential, low residential and commercial/transportation/industrial were largely delineated manually or using supervised classification for each year by comparing the original TM images with corresponding year's aerial photographs and LULC data. We also conducted intensive field work to assist land cover classification. The whole land cover map for each time period was merged by adding individual portions together. Post refinement was conducted to correct misclassification in the previous step. Finally, eleven land cover classes were aggregated into six LULC types, namely urban, water, forest/woody wetland, crop/pasture/emergent wetland, shrub, and barren land; areas and percentages of each land cover type were calculated.

The quality of land cover maps is essential prerequisite for post-classification comparison based change detection. Thus, the accuracy assessment of resulting LULC maps of three time periods was conducted with a randomly sampling method. Samples of 15-75 points were taken for each LULC type depending on each class' area. A total of 425 samples were obtained for 1985 and 1996, and 450 samples were obtained for 2005 by using the stratified random sampling method. The reference data was collected from high spatial resolution aerial

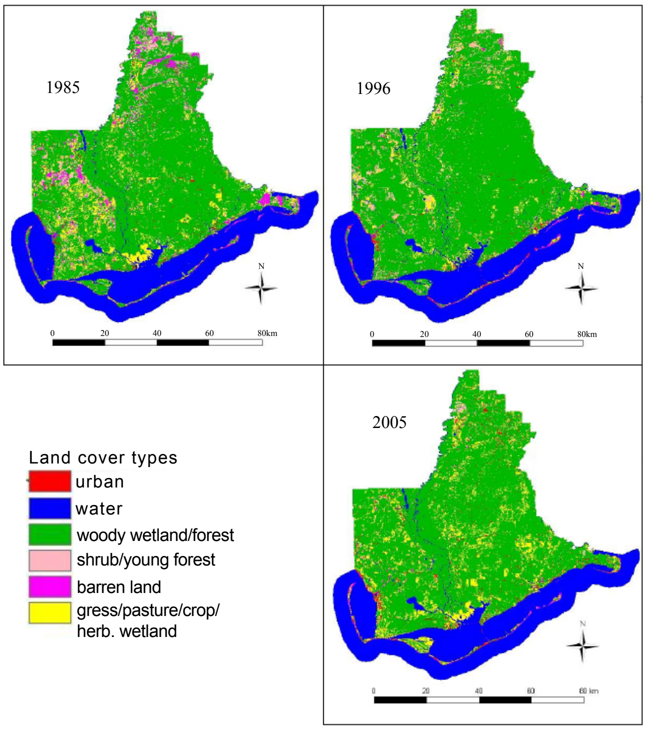

Figure 4: Land cover pattern in the Panhandle region of Gulf Coastal Plain classified from Landsat TM data.

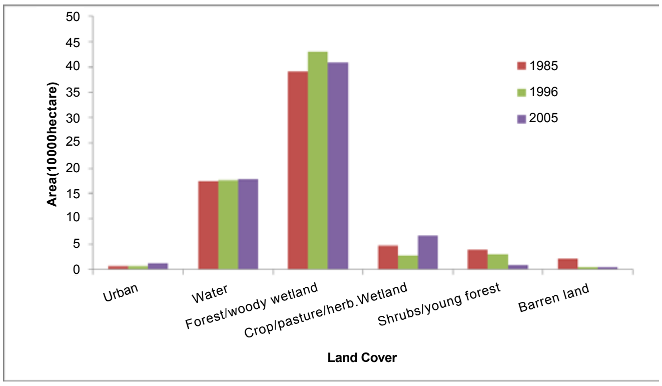

Figure 5: Major land use types in Panhandle region of Gulf Coastal Plain for the years: 1985, 1996 and 2005.

photographs and from ground truths. The overall accuracy, producer's accuracy, user's accuracy, and the Kappa coefficient statistic were calculated based on the error matrices. In general, the classification of different LULC types matched the reference data well. The overall accuracies for 1985, 1996, and 2005 are 86.95%, 85.88%, and 85.65%, respectively. The overall Kappa coefficients for 1985, 1996, and 2005 are 0.8540, 0.8445 and 0.8418, respectively. The accuracies for water body and urban are greater than 90%. The shrub/young forest has the lowest accuracy of classification (Table 2).

Results

Historical land use pattern

In the study area, the predominant land cover type was forest/woody wetland (Figures 4 and 5). Percentages of forest/woody wetland area were 57.5%, 63.2%, and 60% in 1985, 1996, and 2005 respectively. Forest/woody wetland distributed evenly over the whole study area for the three time periods. Since the satellite images covered a considerable amount of ocean area, water was identified as the second largest land cover type. Although there were some small streams and lakes in the study area, their areas were relatively negligible compared to other land cover types. Cropland/Pasture/Herbaceous wetland was another major land cover type in this region. Herbaceous wetlands were mainly located in the estuary regions of the Apalachicola River. In 1985, most cropland/pastures occurred in the western part of the study area. After that, cropland increased significantly by replacing large areas of forest and expanded eastward. Shrub land/young forest mainly occurred in northern and western part of this region. Large areas of barren land were identified in 1985, but not in the other two time periods. Urban area covered about 1% to 1.95% of the total area in the region. Most developed areas were located in the southern coastal areas of the region.

Land use conversions

Figure 6 shows the net changes of each major land cover type for the study area. The area change of major land cover types was calculated by subtracting the area of each land cover type in 1996 and 2005 with the area of the same type in 1985. From 1985 to 2005, there were two land cover types that showed opposite conversions in different time periods. One was the forest/woody wetland, which increased by approximately 40,000 hectares from 1985 to 1996, but decreased by more than 18,000 hectares from 1996 to 2005, resulting in a net increase of forest/woody wetland area by 22,000 hectares. The other type was the crop/pasture/herbaceous wetland, which decreased by about 18,000 hectares from 1985 to 1996 but increased by more than 38,000 hectares during

Citation: Pan S, Li G, Yang Q, Ouyang Z, Lockaby G, et al. (2013) Monitoring Land-Use and Land-Cover Change in the Eastern Gulf Coastal Plain Using Multi-temporal Landsat Imagery. J Geophys Remote Sensing 2: 108. doi:10.4172/2169-0049.1000108

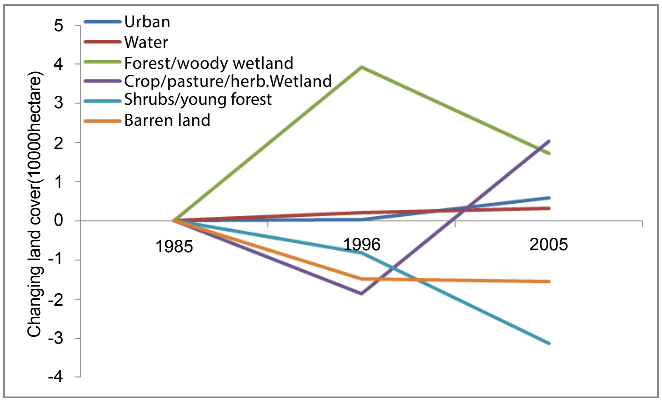

Figure 6: Temporal changes of 6 major land use types in the Panhandle region of Gulf Coastal Plain.

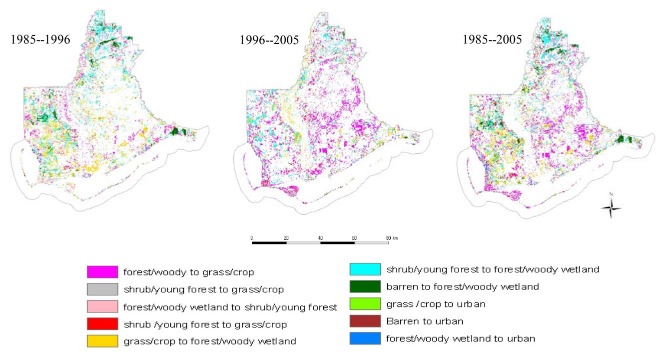

Figure 7: Landsat-derived land use and land cover changes in the Panhandle region of Gulf Coastal Plain from 1985 to 2005.

the later time period, leading to a net increase of more than 22,000 hectares. For the other land cover types, their temporal trends were consistent in the two-study period. Although the total area of urban land was much smaller than that of other land cover types, urban area almost doubled during the study period. The rate of urban expansion increased quickly in the second time period. From 1985 to 1996, urban area only increased by about 0.1% of the study area, but it increased by 0.8% in the later 9 years. Reduction of shrub land/young forest was the most notable land use conversion with a net decrease of more than 30,000 hectares from 1985 to 2005. Barren land decreased too during the study period.

Spatial patterns of land use conversions

Land conversions between forest/woody wetland and other land cover types determine the spatial patterns of land use conversions. As the major land cover type in Panhandle, forest/woody wetland was involved in deforestation, afforestation, cropland expansion and urbanization. From 1985 to 1996, forest/woody wetland increased (Figure 7). Afforestation during this time period mainly occurred in northern Liberty County and southern Franklin County. From 1996 to 2005, afforestation continued in northern Liberty county and northern Gulf county and along the Apalachicola River valley. Forest converted from cropland mainly responsible for the increase of forestland during the first time period. From 1985 to 1996, cropland/pasture in the central and southern Gulf County and southwestern Franklin County was replaced by forest. In the later time period, there were also some regions where cropland was abandoned and converted to forest. For example, cropland replaced by forest in the county boundary regions between the Gulf County and the Liberty County from 1996 to 2005. Forest/woody wetland decreased during 1996-2005 as large areas of forest were converted to cropland/pasture and resulted in significant increase in cropland areas. Conversion from barren land to mature forest also contributes to the increase of forest cover during the study period. From 1985 to 1996, large area of shrub/young forest in the northern Liberty County and the western Gulf County became mature forest. Afforestation on barren land also contributed to the increase of forestland. Most barren land in the northern Gulf County, the northern Liberty County and the eastern Franklin County were forested between 1985 and 1996. Figure 8A gives an example of changes from clear out barren land to forest.

Figure 9 demonstrates urban expansion during the study period. Urban sprawl mainly occurred around small cities such as Carrabelle, East Point, Apalachicola, Wewahitchka, Bristal and Hosford. In addition, urban areas in southern coastal regions of the Franklin County and along the Little St. George Island have increased dramatically since 1985.

Discussion

Drivers of land use changes

LULCC is driven by both land natural properties and human activities. According to Veldkamp & Fresco (1996), all the factors that drive land use change can be categorized as either biological factors or human factors. Specifically, biological factors refer to physical and chemical conditions of soil, climate factors, as well as pest and disease impacts [22]. For this study, since the total area is relatively small, we assume that all these biological factors are relatively homogeneous over the whole region. As a result, human factors, such as population increase and economic activities should have played the major role in driving LULCC in the study area.

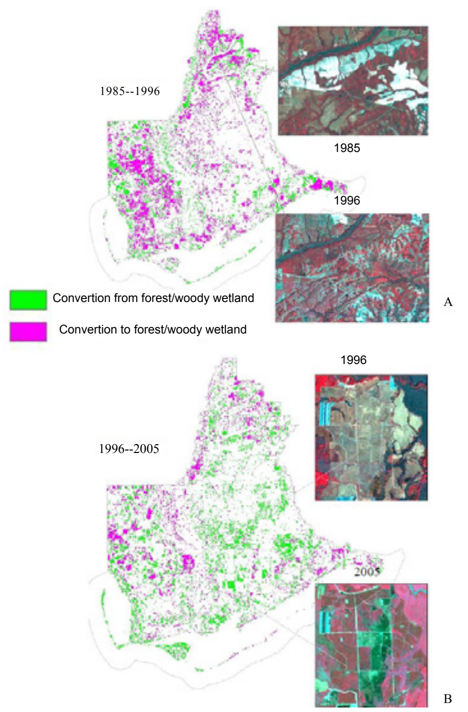

Figure 8: Landsat-derived Forest/woody wetland changes in the Panhandle region of Gulf Coastal Plain.

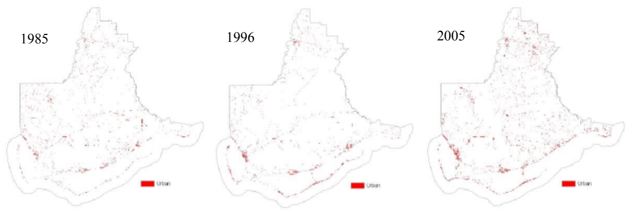

Figure 9: Landsat-derived urban expansion in the Panhandle region of Gulf Coastal Plain during 1985-2005.

Population growth is one major reason for urban expansion in the study area. The US Census data shows that population increased by 18%, 39% and 58% from 1985 to 2005 for the Franklin County, Gulf County, and Liberty County, respectively (http://www.census.gov). As presented in previous sections, increasing urban areas were found in northern Liberty County around the Bristol city and coastal areas. Growing populations need additional food and settlement as well as commercial facilities. As a result, large areas of forest or other land use types were cleared and paved for settlement. Increasing populations also required more agricultural products, which led to increasing cropland from 1996 to 2005. The change matrix table (Table 1) shows that during the period of 1996-2005, about 6000 ha of forest/woody wetland were converted to urban. To support the increasing population, highways were built to improve the transportation system. Figure 7 shows that developed areas were increasing along major highways. In addition, tourism was another factor for the increase in developed areas [23]. Lots of settlements were built along the coastal lines for people to spend their vacations, and this trend will be enhanced as the population growth continues.

Another factor that accounted for the land use changes in this study is timber production. In the southeast U.S., the timber industry is an important business in this region. For example, forestry related industries accounted for more than 64% of the total output from the Agriculture and natural resource related industries in the Liberty County in 2008 [24]. Forestry industries are also important employers in the other two counties. Timber industry could impact land use changes to a great extent, as it is directly involved in tree plantation and deforestation [25]. From the turn of the 20th century to the mid-1980s, St. Joe's Lumber Company, Florida's largest private landowner managed over 800,000 acres of forest lands for forest products, also owned 20 miles of coastline in Franklin County. About 15 years ago, the company decided to switch from a timber company to a land developer, and use its land for people, instead of trees. Now St. Joe Company is one of Florida's largest real estate development companies and Northwest Florida's largest private landowner with approximately 567,000 acres of land, concentrated primarily between Tallahassee and Destin. St. Joe's vast land holdings include over 300,000 acres within 40 miles of the new Northwest Florida Beaches International Airport. In addition, the company manages timber operations on thousands of acres and offers certain rural acreage for sale. St. Joe Company plans to develop hundreds of thousands of acres land in Panhandle region.

Implications for land use policy makers

As a typical coastal plain that experienced anthropogenic-driven land use changes, land use change history in the study area could provide useful information for land use management over the whole Gulf Coastal Plain. As a result of population growth, urban areas have been increasing in the study area, and the urban expansion rate from 1996 to 2005 was much higher than that in the previous decades, indicating more intensive land conversions from forest, cropland and other land use types to urban areas. Much concern on negative impacts of urban expansion has been raised, special attention should be paid to quantifying urbanization-induced changes in water quality, hydrology and biodiversity in rivers and coastal areas [10,11,13].

Increasing cropland/pasture is another concern. Farming activities such as tillage could enhance soil erosion and lead to elevated sediment export through streams. In order to increase food production, chemical fertilizers have been extensively used. Non-point nutrient pollution from cropland has become a serious problem for water quality degradation [26]. Impacts of expanding cropland on water quality should be further evaluated in future land use management. Since timber production is important to the economic growth of this region, tree plantation and harvesting occurred frequently in the Gulf Coastal Plain. Our study indicated that timber production could significantly result in changes in forest cover and other related land use types. Although the increase of forest cover has increased timber production, water consumption by trees will probably become a concern in this region, especially because some studies suggested that Southeast U.S. will experience more severe droughts in the future [27,28]. As a result, it is necessary for land use policy makers to consider the impacts of forest cover change on water cycling, particularly when future climate scenarios are involved in land use policy making.

Uncertainties analysis

It is important to note the methodological limitations of the analyses associated with this study. Uncertainties of this study lie in the data sources, methods employed in data processing, as well as the insufficient consideration of spatial heterogeneity over the entire Gulf Coastal Plain.

One major source of uncertainty for the results and conclusion is the satellite data. In this study, TM images for the three years were used to retrieve land use information. Since two scenes of TM data were used to cover the whole region, we tried to collect images taken at similar phonological season to avoid effects of plant phenology on the identification of different plant covers. However, limited data made it difficult to eliminate the influence of plant phenology. In addition, for the 20-year land use history reconstruction, we used only three time periods of Landsat images, which could miss information on land use conversions between these years.

Another source of uncertainty is the data processing method. Land use classification and change detection in the subtropical landscape are especially difficult due to overlap of spectral signature between land cover types and impacts of complex environmental conditions on land surface reflectance. There is usually lots of misperception on spectral signature between woody wetland and forest, among different forest types (especially leaf-on images), between pasture, grass and crop, and even between urban and barren land. That is the reason that 11 land cover types were aggregated to 6 categories based on their spectral responses. Environmental conditions also influence the spectral response of land surface features. For example, fluctuating water content changes the spectral reflectance of vegetation and other land cover types and makes it difficult to separate vegetation types and urban. High soil water contents under the vegetated areas often reduce the vegetation reflectance, especially in the near and shortwave infrared wavelength bands which are critical for accurate separation of vegetation classes. Land cover classification based on pure spectral signatures in the wetland environment often results in poor classification performance. For better separation of wetland from other upland vegetation, images acquired when the wetlands are at their highest water levels could improve identification of this land use types [29]. As a result, more ancillary information such as hydrological data, soil, elevation and census data are needed to improve the classification performance. The low spatial resolution is also an important factor, resulting in misclassification because of the mixed pixels is inherent in the remote sensing data. Higher spatial resolution data will be helpful for identification of urban landscape. More ground truth data should be collected for assisting the land cover classification and for the evaluation of classification results. Finally, this study is an initial investigation of land use/land cover changes in coastal plains of the U.S. To draw more accurate conclusions of land use/land cover change and to make precise projections of future land use pattern in the Gulf Coastal Plain, more thorough investigations over the entire Gulf Coastal Plain and additional land use types are needed.

Summary

Information on Land Use and Land Cover Change (LULCC) in the Gulf Coastal Plains is essential to accurately assess human impacts on coastal ecosystems. In this study, we selected the Florida Panhandle region as a case study for reconstructing historical LULCC and the underlying driving forces in the Eastern Gulf Coastal Plains. Landsat TM images were used to retrieve land use information in 1985, 1996 and 2005. Our results suggested that forests/woody wetland were the predominant land use type in this region. Although urban areas only covered a small area, they expanded at a much higher rate from 1996 to 2005 than in the previous decade. Population growth and timber production industry were considered as the two major driving forces for land conversions from 1985 to 2005. Results drawn from this study provided some useful information for land use policy makers in the coastal plain regions. There is an important need to investigate impacts of urbanization on water quality, hydrology and biodiversity due to rapid population growth and urban sprawling in the Gulf Coastal Plains. Influence of forest plantation on water cycling should also be noticed as the Southeast U.S. may experience more droughts in the future.

Acknowledgement

This study has been supported by USDA Coop agreement #SRS 05-CA-11330150-219, NASA Interdisciplinary Science Program (NNX10AU06G) and Auburn University Center for Forest Sustainability. We thank Dr. Wayne C. Zipperer for supporting this research and Larry Prince for data processing.

References

1. Tian HQ, Chen G, Zhang C, Liu M, Sun G, et al. (2012) Century-scale response of ecosystem carbon storage to multifactorial global change in the Southern United States. Ecosystems 15: 674-694.
2. Kambly S, Moreland TR (2009) Land cover trends in the Southern Florida Coastal Plain. U.S. Geological Survey Scientific Investigations Report 2009-5054, pp. 16.
3. Hugo G (2011) Future demographic change and its interactions with migration and climate change. Global Environmental Change 21: S21-S33.
4. Small C, Nicholls RJ (2003) A global analysis of human settlement in coastal zones. Journal of Coastal Research 19: 584-599.
5. NOAA (2012) Spatial Trends in Coastal Socioeconomics Demographic Trends Database: 1970-2010.
6. Midgley GF, Hannah L, Millar D, Rutherford MC, Powrie LW (2002) Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology and Biogeography 11: 445-451.
7. Cui B, Yang Q, Yang Z, Zhang K (2009) Evaluating the ecological performance of wetland restoration in the Yellow River Delta, China. Ecological Engineering 35: 1090-1103.
8. Cui B, Yang Q, Zhang K, Zhao X, You Z (2010) Responses of saltcedar (Tamarix chinensis) to water table depth and soil salinity in the Yellow River Delta, China. Plant Ecology 209: 279-290.
9. Bosch D, Sullivan D, Sheridan J (2006) Hydrologic Impacts of Land-Use Changes in Coastal Plain Watersheds. Transactions of the ASABE 49: 423-432.
10. Schueler TR (1994) The Importance of Imperviousness. Watershed Protection Techniques 1: 100-111.
11. Booth DB, Jackson CR (1997) Urbanization of Aquatic Systems: Degradation thresholds, Stormwater Detection, and the Limits of Mitigation. Journal of the American Water Resources Association 33: 1077-1090.
12. Schoonover J, Lockaby BG, Pan S (2005) Changes in chemical and physical properties of stream water across an urban-rural gradient in western Georgia. Urban Ecosystems 8: 107-124.
13. Callender E, Rice KC (2000) The Urban Environmental Gradient: Anthropogenic Influences on the Spatial and Temporal Distributions of Lead and Zinc in Sediments. Environmental Science & Technology 34: 232-238.
14. Krause CW, Lockard B, Newcomb TJ, Kibler D, Lohani V, et al. (2004) Predicting Influences of Urban Development on Thermal Habitat in a Warm Water System. Journal of American Water Resources Association 40: 1645-1658.
15. Nelson GC, Robertson RD (2008) Green gold or green wash: Environmental consequences of biofuels in the developing world. Review of Agricultural Economics 30: 517-529.
16. Liu J, Liu M, Tian H, Zhuang D, Zhang Z, et al. (2005) Spatial and temporal patterns of China's cropland during 1990-2000: An analysis based on Landsat TM data. Remote Sensing of Environment 98: 442-456.
17. Huang C, Goward SN, Schleeweis K, Thomas N, Masek JG, et al. (2009) Dynamics of national forests assessed using the Landsat record: Case studies in eastern United States. Remote Sensing of Environment 113: 1430-1442.
18. Chen H, Tian HQ, Liu M, Melillo JM, Pan S, et al. (2006) Effect of land-cover change on terrestrial carbon dynamics in the southern USA. Journal of Environmental Quality 35: 1533-1547.
19. Brown D, Pijanowski B, Duh J (2000) Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA. Journal of Environmental Management 59: 247-263.
20. Mildrexler DJ, Zhao M, Running SW (2009) Testing a MODIS Global Disturbance Index across North America. Remote Sensing of Environment 113: 2103-2117.
21. Carlson TN, Arthur ST (2000) The Impact of land use - Land cover changes due to urbanization on surface microclimate and hydrology: a Satellite perspective. Global and Planetary Change 25: 49-65.
22. Veldkamp A, Fresco LO (1996) CLUE: a conceptual model to study the Conversion of Land Use and its Effects. Ecological Modelling 85: 253-270.
23. Rounsevell MDA, Reginster I, Araújo MB, Carter TR, Dendoncker N, et al. (2006) A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems & Environment 114: 57-68.
24. Rahmani M, Hodges AW, Clouser RL (2010) Economic Contributions of Agriculture, Natural Resources, and Related Industries in Florida Counties, 2008.
25. Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, et al. (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11: 261-269.
26. Powers SE (2007) Nutrient Loads to surface water from row crop production. The International Journal of Life Cycle Assessment 12: 399-407.
27. Seager R, Tzanova A, Nakamura J (2009) Drought in the Southeastern United States: Causes, Variability over the Last Millennium, and the Potential for Future Hydroclimate Change. Journal of Climate 22: 5021-5045.
28. Chen G, Tian H, Zhang C, Liu M, Ren W, et al. (2012) Drought in the Southern United States over the 20th century: Variability and its impacts on terrestrial ecosystem productivity and carbon storage. Climatic Change 114: 379-397.
29. Schriever JR, Congalton RG (1995) Evaluating seasonal variability as an aid to cover-type mapping from Landsat thematic mapper data in the northeast. Photogrammetric Engineering & Remote Sensing 61: 321-327.