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FOREST LANDSCAPE CHANGES IN EAST TEXAS FROM 1974 TO 2002

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ABSTRACT

Timber production has been one of the most important industries in east Texas since the mid 19th century. For over 100 years, timber has represented one-third of all agricultural income in this region. In order to review forest landscape changes over time -- resulting from many years of management and investment -- historical satellite remote sensing data from 1974 to 2002 were used to determine landscape patterns and changes in four counties of east Texas: Angelina, Nacogdoches, San Augustine, and Shelby. Land cover was classified either as *forest* or *non-forest* and a land cover map was generated for seven unique time stages. Landscape patches were identified on each land cover map and landscape metrics were calculated, including patch size, aggregation of patches, and patch shape complexity. Results showed a decline of total forestland in the 1980s and a recovery in the 1990s. This observation coincided with historical information about large scale clear-cutting during this time. Mean patch size of forest showed a trend of increase, whereas that of non-forest was consistently decreasing over time. This reflected the decrease of forest patch shape complexity, while the patch shape of non-forest became more complex. The forest in east Texas plays an important role (presumably from intensive management) not only in the local economy but also in the environment. Replanting efforts have created buffers between land development such as urban sprawl and ranching. Eventually, the forest maintains the overall landscape contagion while non-forest land-use is becoming more fragmented.

KEYWORDS. landscape ecology, fragmentation, landscape metrics

INTRODUCTION

As public concerns about biodiversity, greenhouse effect, and global change increase, monitoring landscape change becomes essential for natural resource management. In the United States, forests in the South play an important role in terrestrial ecosystem. From the Atlantic to Texas, nearly every forested acre in the South has been harvested at least once in the last two centuries -- leading to multiple disturbances and land use changes over years (Wear and Greis, 2002). However, through years of replanting efforts, forestland area in the South is steadily increasing. Today, the southern forest is one of the major carbon sinks in the country (Birdsey et al., 1993).

Located in the westernmost region of southern forests, the forest in east Texas is important not only for the local economy but also for the environment. According to the Forest Inventory and Analysis Report of USDA Forest Service (Rosson, 2000), there was a total of 82,028 hectares (202,700 acres) increase of timberland between 1986 and 1992 in east Texas. Nonindustrial private lands, which took up 62% of total timberland, contributed the majority of land-use change from non-forest to timberland, whereas forest industry lands revealed a decline. For effective management, an understanding of how the changes are linked in time and space to landscape dynamics is required.

Remote sensing has become essential for landscape ecology assessment due to its capability of providing systematic, repetitive observation of the earth's land areas. Landscape ecology metrics can be derived from remote sensing data other than traditional ways. As environmental issues arise at local, regional, and global scales, remote sensing and GIS together provide possible improvements to monitor and assess any ecosystem. The objective of this study was to identify the spatial pattern of forest landscape and its changes over time in east Texas.

METHODS

Study Area and Image Acquisition

Four counties, Angelina, Nacogdoches, San Augustine, and Shelby, of east Texas comprised the study area. They represent the westernmost forests in the South (Figure 1). Encompassing a total area of 848,237 hectares (3,275 sq miles), each of the four counties is slightly different from others in socioeconomic aspects, but they are all highly associated with forest management. Without exception, every county has a partial area residing in one or both of the Angelina and Sabine National Forests (Table 1). Based on the population density in 2000, Angelina and Nacogdoches Counties were categorized as *urban*, and San Augustine and Shelby Counties as *rural*.

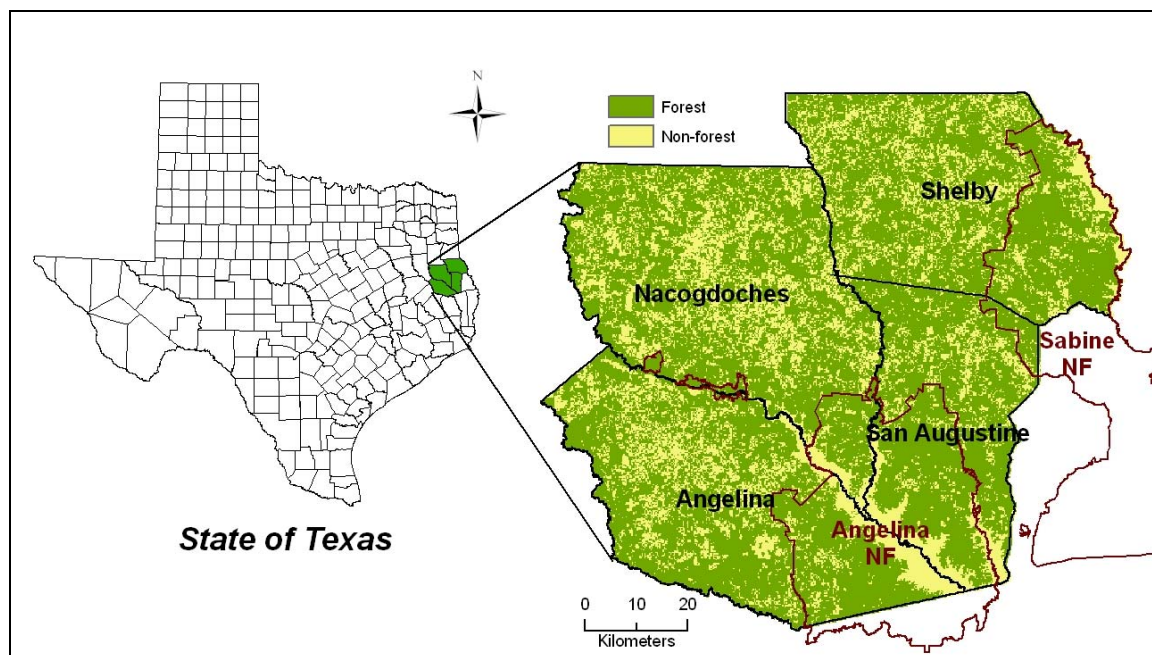


Figure 1. Land cover map of 2002 for the 4-county study area with National Forest boundary.

Historical Landsat satellite imagery was used for landscape metrics derivation. Dating from the early era of Earth Resources Technology Satellites (ERTSs), the image collection for this study included data from different sensors (MSS, TM, ETM+) in different spatial and spectral resolution. In order to depict the landscape change over time, scenes of approximately every 5 years from 1974 through 2002 were acquired. Dates for image acquisition included 1974 (MSS),

1980 (MSS), 1984 (TM), 1987 (TM), 1992 (TM), 1997 (TM), and 2002 (TM and ETM+). Each time stage included two scenes, leaf-on (summer) and leaf-off (winter) for later production of a composite image to aid in differentiating hardwood areas.

Table 1. Land area and population density of the 4-county study area.

<i>County</i>	<i>Land Area (sq km)</i>	<i>Population 2000</i>	<i>Population Density (per sq km)</i>	<i>Percent Land within National Forest Administration</i>
<i>Angelina</i>	2,242.4	80,130	35.73	25.36%
<i>Nacogdoches</i>	2,540.1	59,203	23.31	9.51%
<i>San Augustine</i>	1,537.3	8,946	5.82	43.63%
<i>Shelby</i>	2,162.5	25,224	11.66	31.89%

Unsupervised Classification

Before multitemporal data merging (leaf-on and leaf-off), each image was radiometrically corrected via histogram subtraction for haze compensation (Jensen, 1996). The composite scene of 2002 was clipped to attain pixels only within the 4-county area. The clipped 2002 image was georeferenced to UTM, WGS84 with 30-meter ground resolution and served as a base map. All other stage images were registered and resampled to the 2002 base map to assure location consistency on a pixel by pixel basis.

After resampling, each image of the seven time stages was classified into 100 initial classes using unsupervised classification based on the clustering algorithm of Iterative Self-Organizing Data Analysis Technique (ISODATA). Constraints in the classification procedure called for 100 classification clusters, a convergence threshold of 97.5% and 50 iterations. The initial classes then were recoded to represent two distinct cover types of interest: *forest* and *non-forest*.

Since historical data such as aerial photography is not available for all of the time stages, site-specific accuracy assessment was tested only for the 2002 classified image against ground truthing data. A total number of 518 sampling plots were randomly selected and ground measurement collected, which were used to generate an error matrix for accuracy assessment. In addition, non-site-specific accuracy assessment was tested for 1992 and 2002 by comparing total acreage by cover type (forest and non-forest) against USDA Forest Service Forest Inventory and Analysis (FIA) data (USDA FS, 2004). For this study, cover type classified as forest from the Landsat imagery is equivalent to the category of *timberland* of FIA data by definition.

Patch Identification

Each of the 2-class images contained pixels of either forest or non-forest. In order to eliminate island pixels, a 9-by-9 moving window was applied onto each image. This neighborhood operation assigned each focal cell the value of majority based on its surrounding cells and then moved from one cell to another. Each output image became more homogenous and better describes the phenomenon at the landscape scale.

Patch identification was completed after the majority operation. On each image of the time stage, a patch was identified when a group of contiguous pixels (including diagonal neighbors), having the same value (forest or non-forest). Once patches were identified and a unique value

was assigned to all pixels of the same patch, patch areas and perimeters were calculated based on a zonal operation, where each patch was considered as a unique zone.

Landscape Metrics

In landscape ecology, the terms *contagion* and *fragmentation* are often used. Contagion is the tendency of land covers to cluster or clump into a few large patches (Wickham et al., 1996), and fragmentation is the tendency of land covers to break up into many small patches (Forman, 1995). In this study, we used two landscape metrics introduced by Frohn (1997). They are *PPU* (Patch per Unit) and *SqP* (Square Pixel). *PPU* is calculated based on the equation as follows:

$$PPU = \frac{m}{n \times \lambda} \quad (1)$$

where m is the total number of patches, n is the total number of pixels in the study area, and λ is a scaling constant equal to the area of a pixel. For this study, the metric system was used and the unit for *PPU* is the number per squared kilometer $[(\text{km}^2)^{-1}]$. *PPU* is contrasted to traditional *Contagion* or *Aggregation of Patches* for quantifying landscape clumping. *PPU* increases as the landscape becomes more fragmented.

The other metric, *SqP*, is calculated as follows:

$$SqP = 1 - \left(\frac{4 \times \sqrt{A}}{P} \right) \quad (2)$$

where A is the total area of all pixels and P is the total perimeter of all pixels in the study area. *SqP* is an alternative to traditional *Fractal Dimension* for quantifying patch shape complexity. It is unitless and constrains the values between 0 (for squares) and 1 (maximum perimeter, edge, deviation from that of a perfect square). For this study, we used the alternative form of *SqP* as follows, which gives a scaled perimeter-to-area ratio that ranges from 1 (for square) to infinity. The *SqP* value increases as a patch shape becomes more complex:

$$SqP(Sq) = \frac{1}{1 - SqP} = \frac{P}{4 \times \sqrt{A}} \quad (3)$$

All of the processes including image processing and metrics calculation were done in ERDAS Imagine™.

RESULTS AND DISCUSSION

Accuracy of the 2002 land cover map was assessed through a traditional site specific error matrix by comparing *in-situ* land cover assessment visited by a ground measurement team with corresponding land classifications at each of the 518 sample plots. Results indicated that the 2002 land cover map had an overall accuracy of 98.46% and a kappa statistic of 95.66% suggesting that the accuracy of the map was 95.66% better than one would expect by chance (Table 2).

Table 2. Error matrix resulting from field measurement against 2002 land cover map.

<i>Count</i>	<i>Reference</i>			
<i>Class</i>	<i>Non-forest</i>	<i>Forest</i>	<i>Total</i>	<i>User's</i>
<i>Non-forest</i>	116	3	119	97.48%
<i>Forest</i>	5	394	399	98.75%
<i>Total</i>	121	397	518	Overall Kappa
<i>Producer's</i>	95.87%	99.24%		98.46% 95.66%

In order to verify the classification methodology and to assess the relative accuracy of the overall acreage, a non-site-specific assessment described by Campbell (2002) was performed. By comparing the classified forested acreage totals to forest acreage assessment data obtained from the USDA Forest Service FIA program (Table 3), the classified data tended to have higher overall forest cover percentage than the FIA. The difference was systematic and remained at about 4% for the 4-county area. This gave us more confidence in detecting landscape change over time since our image classification for each of the time stages was performed based on the same procedure.

Table 3. Non-site specific assessment between classified image and FIA data in 1992 and 2002.

County	1992			2002		
	Classified (A)	FIA (B)	(A) - (B)	Classified (A)	FIA (B)	(A) - (B)
<i>Forest Area (ha)</i>						
Angelina	171,907	149,750	22,157	162,187	137,488	24,698
Nacogdoches	181,345	153,655	27,691	177,339	162,191	15,148
San Augustine	122,430	112,672	9,759	119,604	113,996	5,608
Shelby	161,784	144,748	17,036	160,531	137,596	22,934
<i>4-county Area</i>	<i>637,467</i>	<i>560,825</i>	<i>76,642</i>	<i>619,660</i>	<i>551,271</i>	<i>68,389</i>
<i>Forest Coverage (%)</i>						
Angelina	76.66%	71.68%	4.98%	72.33%	66.23%	6.10%
Nacogdoches	71.39%	63.16%	8.23%	69.82%	66.14%	3.67%
San Augustine	79.64%	83.04%	-3.40%	77.80%	83.38%	-5.58%
Shelby	74.81%	70.69%	4.13%	74.23%	66.90%	7.33%
<i>4-county Area</i>	<i>75.15%</i>	<i>70.75%</i>	<i>4.40%</i>	<i>73.05%</i>	<i>69.33%</i>	<i>3.73%</i>

From 1974 to 2002, forests occupied more than 60% land of the 4-county area (Figure 2). The results showed an overall trend of forest coverage increase over time and are in agreement with the reports of Rosson (2000) and Wear and Greis (2002). The forestland recovery from the 1970s to the 1990s in the 4-county area was part of the regrowth process of the southern forests following wholesale land abandonment after extensive logging. Forestland declined in 1984 and in 1997, which reflected large scale timber harvest at those stages, but was soon replaced with new plantations thereafter.

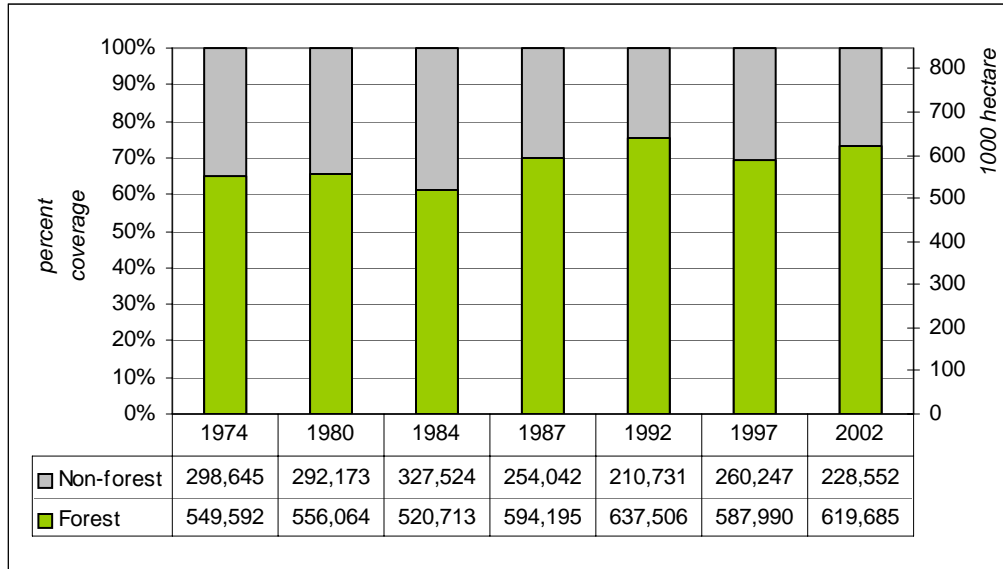


Figure 2. Forest area change over time in the 4-county study area.

During the forest regrowth over time, forestlands aggregated from smaller pieces of land coverage to form larger land coverages. Results in Figure 3 indicate that the mean patch size of forest increased over time except whenever there was a decrease of total forestland, which was a result of large scale harvesting during that period of time. Conversely, the mean patch size of non-forest showed a trend of decline. This was due to cropland reduction and urban development. When forests were reestablished on cropland and urban development occurred and nested in forested area, the mean patch size of non-forest land decreased.

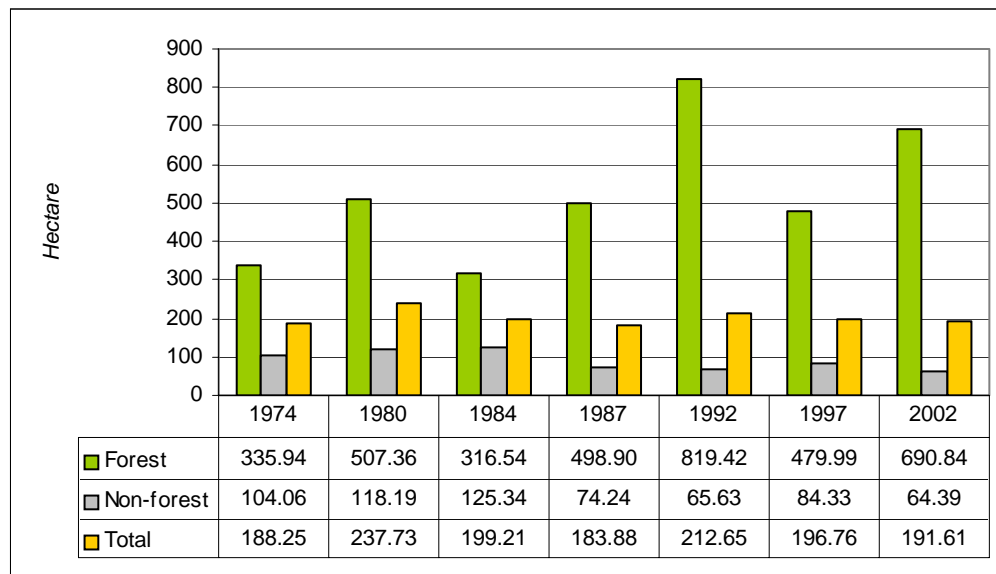


Figure 3. Mean patch size change over time in the 4-county study area.

Results of patch contagion in Figure 4 showed a similar trend to that of mean patch size. As *PPU* of non-forest increased over time, non-forest lands became more fragmented, whereas forest became more aggregated due to forest regrowth. Notice should be taken that patch contagion of total land cover, including both forest and non-forest as a whole, remained stable. It indicated that replanting efforts created a buffer between non-forest land use and maintained the overall landscape contagion.

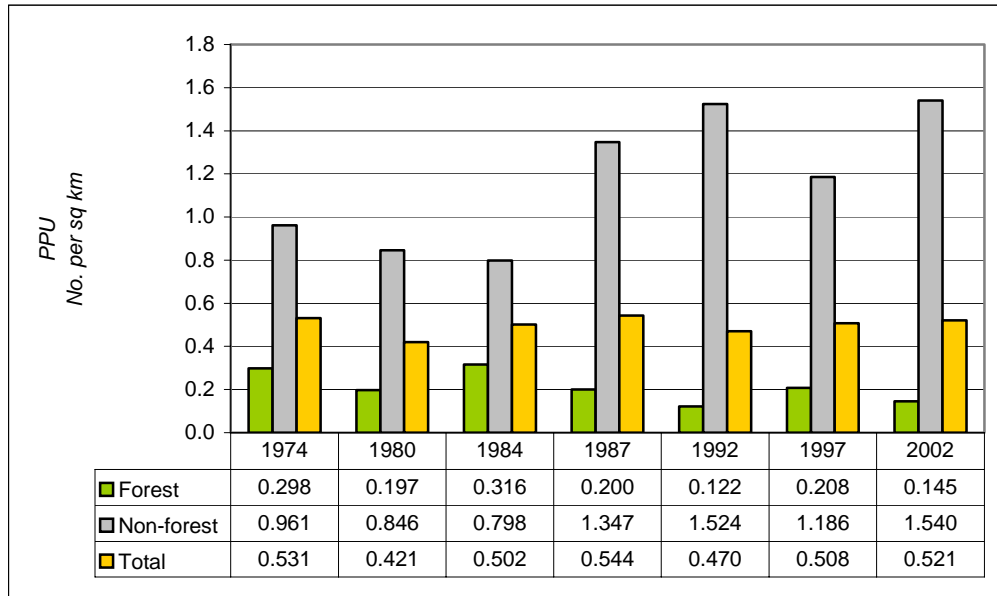


Figure 4. Patch contagion change over time in the 4-county study area.

Since non-forest lands were becoming more fragmented, one could expect the patch shape of non-forest to become more complex. Results in Figure 5 confirmed the increased trend of patch shape complexity for non-forest. On the other hand, patch shape of forest became less complex due to, again, forest regrowth. Furthermore, replanting efforts suppressed total patch shape complexity on the landscape scale.

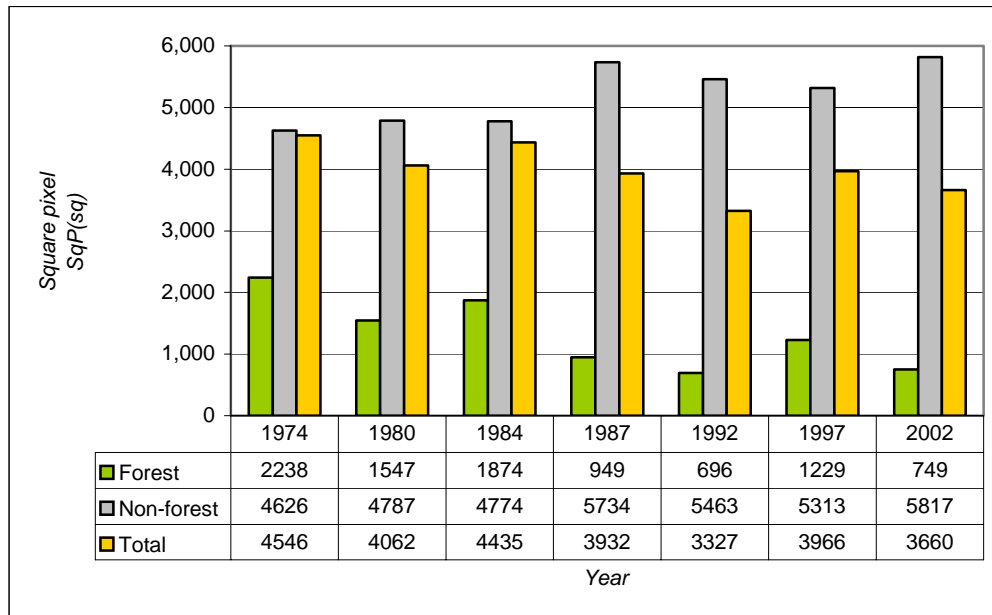


Figure 5. Patch shape complexity change over time in the 4-county study area.

Even though the overall contagion and complexity were constrained, the non-forest land use became more fragmented and complex in shape and should not be ignored. Since more developments (commercial or residential) were nested in forested areas, they created the *wildland-urban interface* (WUI). WUI is an area where increased human influence and land use conversion are changing natural resource goods, services, and management (Macie and Hermansen, 2002). In recent years, severe wildfires throughout the country demonstrated the challenge imposed on the WUI. Efforts have been ongoing to help people understand and to influence change in the WUI through integration of research, information, and technology transfer.

As mentioned earlier, each of the four counties has some influence from the National Forests. The mean patch size by county data (Figure 6) indicated that the mean patch size by county was proportional to the percentage land area within national forest administration in each county. With 43.63% of the total land within National Forest administration (Table 1), San Augustine County had the greatest mean patch size of forest at all times. On the other hand, Nacogdoches County always had the lowest mean patch size while it had only 9.51% of land area falling within the national forest.

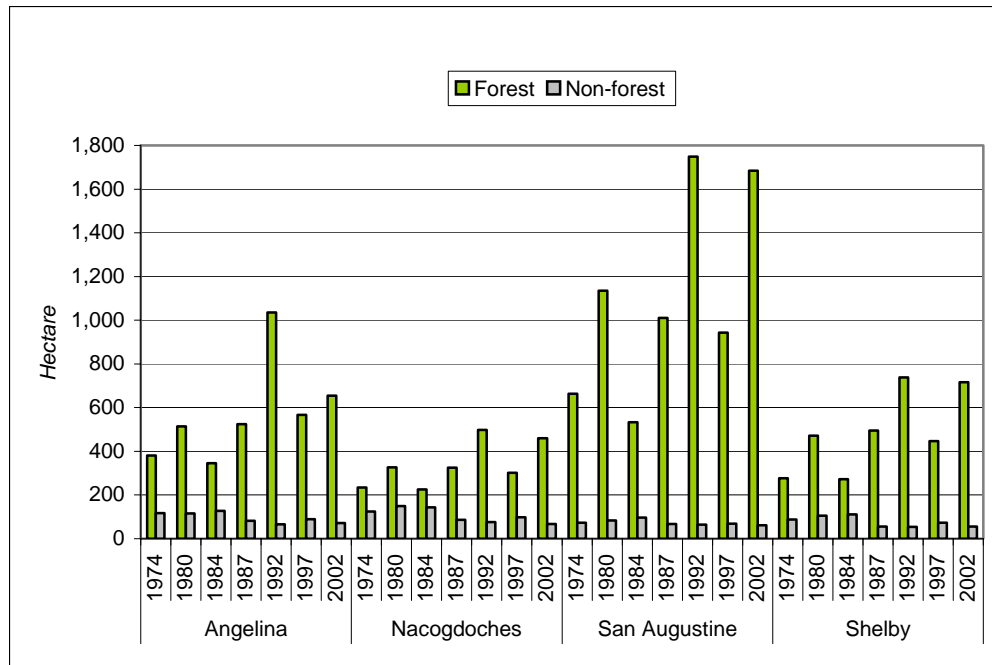


Figure 6. Mean patch size change over time in the study area by county.

From the contagion aspect, *PPUs* of forest for San Augustine County were lower than others at all times (Figure 7). This was due to its relatively low population density (15.11 per sq mile) and high percentage of National Forest land (43.63%), which led to forest patches larger in area and less in number. Phenomenally, *PPUs* of non-forest for Shelby County increased abruptly at 1987 stage and remained high throughout the years thereafter. Combined with the patch shape complexity, patches of non-forest in Shelby County became smaller in size and more complex in shape between 1984 and 1987 (Figure 7 and 8).

Li (2002) used historical Landsat imagery for research in monitoring landscape patterns of the Angelina National Forest, Texas, from 1974 to 1997. He reported that the landscape changed from large clumped patches to smaller, more-fragmented patches. This is consistent with our results of non-forest patches. There is a difference in the forest patches - Li classified land cover of forest into three more detailed categories: pine-forest, pine-regeneration, and hardwood instead of a single lumped forest class. Compared with our findings, Li's land cover maps showed more numerous patches with a smaller mean patch size. This issue is similar to what is known as *modifiable areal unit problem* (MAUP) (O'Sullivan and Unwin, 2003). MAUP is a problem where we might observe very different patterns and relationships if the spatial units in a particular study were specified differently. Caution should be used when comparing landscape pattern change between two studies if they used different systems for land cover classification.

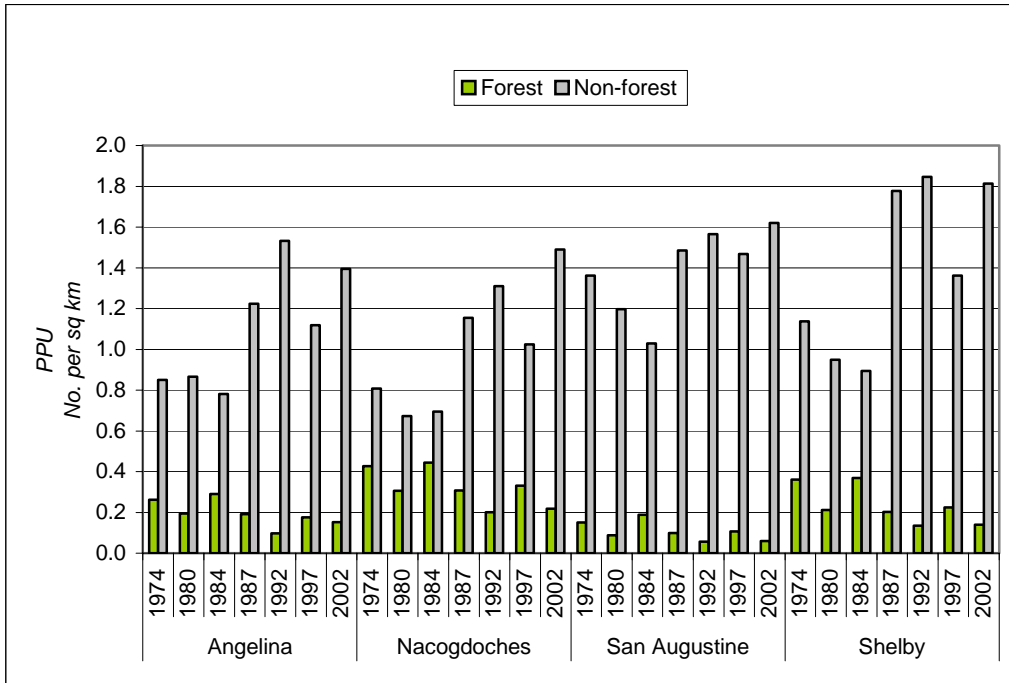


Figure 7. Patch contagion change over time in the study area by county.

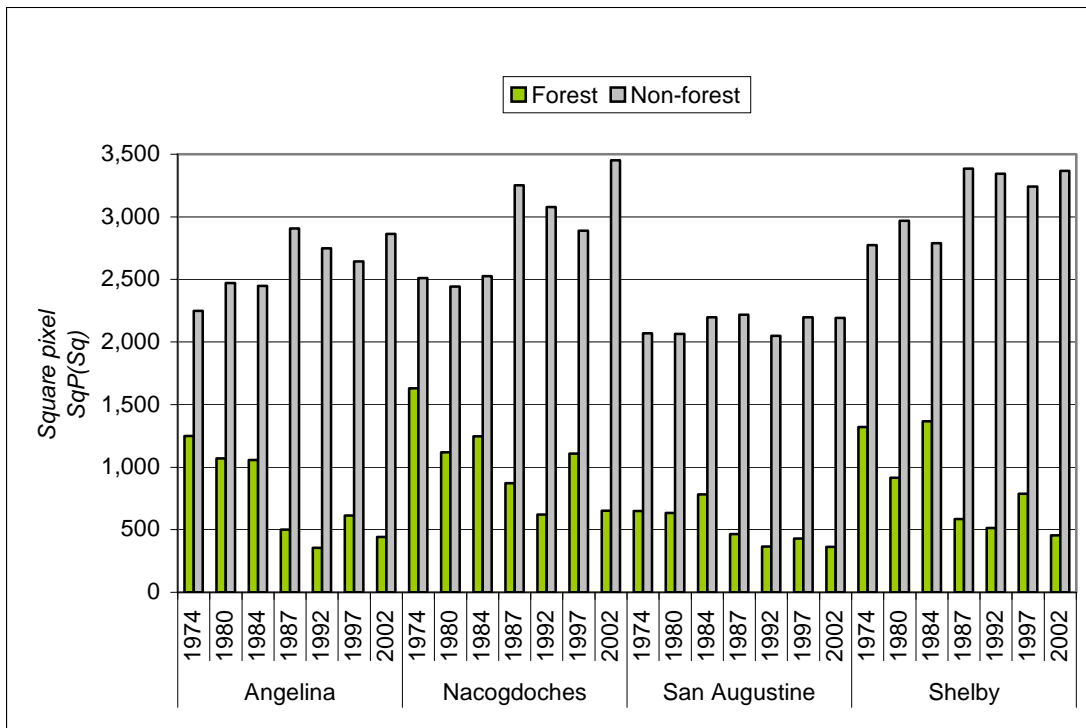


Figure 8. Patch shape complexity change over time in the study area by county.

Another issue is the effect caused by the difference in spatial resolution of satellite imagery. Although the metrics *PPU* and *SqP* that we used are believed to alleviate the problem (Frohn, 1997), Li (2002) reported in his study that the abrupt change between 1992 (Landsat MSS, 60 m) and 1997 (Landsat TM, 30 m) might include the effect of spatial resolution; therefore, the comparison should be conservative. In our study, there was not a significant outcome due to the difference between MSS and TM since we resampled the MSS from 60 m (pixel size of the data received from the US Geological Survey) to 30 m. Ideally, one should use satellite imagery from the same sensor for landscape change detection.

CONCLUSIONS

From 1974 to 2002 in the four counties of east Texas, the total area of forestland showed a general trend of increase. This is important not only for economy such as timber production but also for the environment such as carbon sequestration. Over time, patches of forest became larger in size and less complex in shape due to forest regrowth, whereas patches of non-forest became smaller and more fragmented. The forest in the study area maintained the overall landscape contagion and created buffers between land development such as urban sprawl and ranching. Noteworthy is that forests within National Forests played a more important role in stabilizing landscape dynamics even though most of the forests in the study area were privately owned. Forest management mixed with urban development on the same landscape introduced wildland-urban interface (UWI), where efforts should be focused to maintain ecosystem health and sustainability.

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