

Forest Cover Change Assessment for North Central Florida Using Landsat Thematic Mapper Data

Levent Genc and Scot Smith

ABSTRACT: Land cover change and its temporal trends were assessed between 1985 and 2000 in an area in northeastern Florida primarily covered by pine plantations. Landsat imagery was the principle sensor employed and the image processing techniques included the normalized difference vegetation index and a combination of supervised and unsupervised classification techniques. Results showed that during the 15-year period, mature pine plantation cover and young pine plantation cover declined by 9 percent and 2 percent, respectively, while open field increased by 10 percent. It was also determined that wetland forests declined by 5 percent. Because trees serve as highly efficient carbon storage devices, the decline in forest cover (pine plantation and wetland trees) leads to increased pollution of the atmosphere with carbon dioxide.

KEYWORDS: Image classification, forest, remote sensing, deforestation.

Introduction

Deforestation and degradation of forests is significantly increasing atmospheric carbon dioxide in the world. The magnitude of this problem was assessed by Brown (1993), Fearnside (1996), and Houghton *et al.* (2000). According to Brown 1993 and Kummer and Turner (1994), the most effective way to reduce uncertainty in carbon flux is to improve the mapping of area changes in forest age cover using remote sensing technology.

Work by Fearnside (1982) using Landsat Multi-Spectral Scanner (MSS) data suggested that spectral differentiability between mature and young tropical forests was lost after two years. Using SPOT HRV (High Resolution Visible) data and ground measurements, Skole *et al.* (1994) found that mature forests and newly regenerated young forest growth could be discriminated accurately. Steininger (1996) indicated that in Landsat Thematic Mapper (TM) imagery, spectral signatures of mature and young forests are the same for trees at around 14 years of age. Steininger (1996) found that the age determination of these forests,

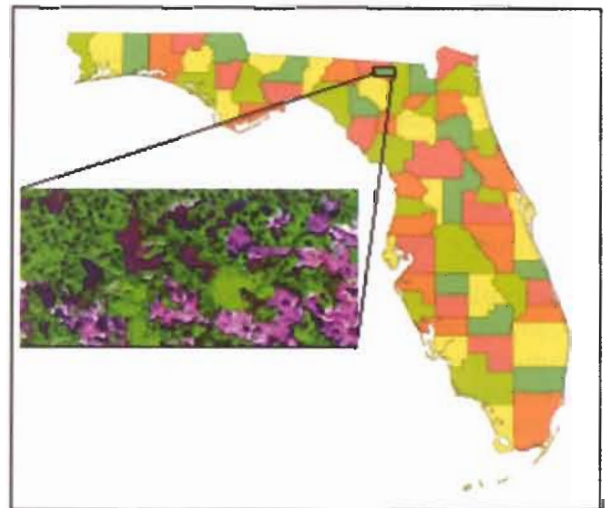


Figure 1. The study area.

which ranged from 2 to 19 years, resulted from public surveying.

Landsat images have been found to be particularly well suited for mapping the age of trees because they are relatively low cost and cover large areas (Steininger 1996; Boyd *et al.* 1996). A variety of image processing techniques including the Normalized Difference Vegetation Index (NDVI) (Genc *et al.* 2002; Lillesand and Kiefer 2000; Jensen 1996) and various unsupervised and supervised classification approaches have been used for forest mapping applications (Jensen 1996; Kimes *et al.* 1998).

In mapping forested lands for carbon estimates, it is important to differentiate between the different age classes of the trees. Questions exist concerning

Levent Genc is post doctoral associate, Geomatics/Civil and Coastal Engineering, 345 Weil Hall, P. O Box 116580, University of Florida, Gainesville, FL 32611-6580, Tel: (352) 392-9492 and Kahramanmaraş Sutcu Imam University, Agriculture Engineering Dept., Kahramanmaraş TURKEY 46060. **Scot Smith** is Associate Professor, Geomatics/Civil and Coastal Engineering, 345 Weil Hall, P. O Box 116580, University of Florida, Gainesville, FL 32611-6580, Tel: (352) 392-9492

	1985	1990	1995	2000
Date	Jan 02, 1985	Jan 12, 1990	Jan 14, 1995	Jan 16, 2000
Bands	1,2,3,4,5,7	1,2,3,4,5,7	1,2,3,4,5,7	1,2,3,4,5,7
Image size	7.5 kmx15 km	7.5 kmx15 km	7.5 kmx15 km	7.5 kmx15 km
RSEM	0.5 pix	0.5pix	0.09pix	0.5pix

Table 1. Description of TM imagery.

the ability of satellite sensor data to differentiate age classes within a forest. The objectives of this study were to: (1) determine the appropriate classification method for mapping land cover types from Landsat images and develop a time series of land cover for the years 1985, 1990, 1995, and 2000 in the study area; and (2) identify trends in the coverage of pine plantation status.

Methods

The study area was a 7.5 km x 15 km area located in Hamilton County, Florida. Thematic Mapper images taken in 1985, 1990, 1995, and 2000 were used (Figure 1). Table 1 shows the exact dates when the images were obtained, the bands used, and the root mean square error of the rectification of the images.

The Image Processing Approach

Many applications of remote sensing require that two or more scenes of the same geographical region are acquired at different dates but registered spatially together. In this study, all of the TM images were registered to the year 2000 image with a UTM projection (WGS84 datum) using an "image-to-image" registration technique (Jensen 1996). Image-to-image registration is the processes of finding a location function that images one image space into the other, such that each pixel at the same position in the two images corresponds to the same point in the imaged scene. The base image was a U.S. Geological Survey (USGS)

digital orthophoto quadrangle (DOQ). Digital Orthophoto Quadrangles are digitized aerial photographs in which image displacement caused by terrain relief and camera tilt has been removed. They combine the image characteristics of a photograph with the geometric qualities of a map. The image-to-image registration accuracy errors (expressed as root mean square error (RMSE) for each TM image; Table 1) were less than one pixel in each case. Resampling was performed using the nearest-neighbor transformation algorithm.

The Normalized Difference Vegetation Index (NDVI) has been used extensively to measure vegetation cover characteristics on a broad scale worldwide and has been incorporated into many large-scale forest and crop assessment studies (Campbell 1996; Jensen 1996; Richard and Jia 1999; Lillesand and Kiefe 2000). The NDVI was calculated for each year. The NDVI value can be calculated by using the difference between the visible (red; band3) and the near-infrared (NIR; band 4) bands divided by their sum (Equation 1).

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (1)$$

After producing NDVIs, we combined each year's NDVI with the original 6-band images for that year. The resulting composite images for every year were used to produce an unsupervised classification with 20 clusters of which we chose six (Table 2). Because we had 63 Landsat images taken between 1975 and 2000 for the study area, tree ages were determined by tracking the years before and after the areas were cleared entirely of trees through the process known in forestry as "clear cutting".

Class	1985		1990		1995		2000	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Clear-cut	552	5	2205	20	471	4	1107	10
Young Forest	3173	27	1493	13	1780	15	3020	26
Mature Forest	4701	41	4914	43	5772	50	4640	40
Natural Forest	325	3	676	4	200	2	366	3
Wetland Forest	2183	19	1845	17	1764	15	1555	14
Open Field Road	566	5	326	3	703	6	812	7
% Total	11500	100	11500	100	11500	100	11500	100

Table 2. Unsupervised classification results for the 7.5 km x 15 km study area, based on imagery from 1985, 1990, 1995, and 2000.

Class	1985		1990		1995		2000	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Clear-cut	180	2	1839	15	569	5	1037	9
Young Forest	2700	23	639	6	2089	18	2462	21
Mature Forest	5926	51	6293	54	4625	40	4825	42
Natural Forest	459	3	396	3	359	3	300	3
Wetland Forest	1831	18	2046	17	1959	17	1397	12
Open Field	405	3	286	3	1899	15	1479	13
% Total	11500	100	11500	100	11500	100	11500	100

Table 3. Supervised classification results for the 7.5 km x 15 km study area, based on imagery from 1985, 1990, 1995, and 2000.

Year	CC	YPP	MPP	NF	WF	OFR	Overall Accuracy (%)
1985	89	90	89	77	89	72	82
1990	90	90	90	89	83	84	89
1995	85	87	78	96	93	80	87
2000	100	97	98	83	81	88	91

Table 4. Comparison of user accuracy.

Land cover classes determined for this study were: young pine plantation (YPP), mature pine plantation (MPP), and clear-cut (CC). In addition, DOQ data and fieldwork helped to determine the following categories: wetland forest (WF), natural forest (NF), and open field/road (OFR) classes for classification. After deciding the land cover types, the test site signature files were created according to Jensen (1996). Following classification, the area for each land cover class was calculated for the years 1985, 1990, 1995, and 2000 (Table 3).

To check for error in the supervised classification, we calculated an error matrix for accuracy assessment. Producer and user accuracy for each class cover were calculated for each year (Congalton 1991; Campbell 1996). In order to identify the major conversion of land cover classes, cross-tabulations were generated for the 1985-1990, 1990-1995, and 1995-2000 (i.e., every 5 years), and 1985 and 2000 (first and last year) area statistics, based on the supervised classifications.

Results

Mature pine plantations (i.e., those older than eight years) were not separated from natural pine plantation in the unsupervised classification for all years (Figures 2, 3, 4, and 5). Nevertheless, the land cover changes between open field/road, wetland forest, and young pine plantation (less than 8 years old) was easily detected using a composition images of both the unsupervised and supervised classification (Figure 2). Wetland forest for all years was detected and mapped using supervised classi-

fication only. Unsupervised classification was particularly very good for natural forest and mature pine plantations (Table 2).

After the forests were clear-cut, they were either regenerated immediately or about two to four years after clearing and burning dead organic matter. Even if the clear-cut area was regenerated with young pine plantations, the area still contained reflected spectral information due to canopy cover and the fact that the study site had many wetland and depression areas. Due to the spectral similarity of (1) clear-cut and young pine plantations, (2) open field/road and wetland forest, and (3) natural forest and young pine plantations, misclassification occurred in the years 1985, 1995, and 2000.

We separated land cover classes by using six signature files to facilitate the comparison among years for the supervised classification. Despite the fact that the forest age classification was based on the time of clearcut on all of the images (Table 4), all the classification accuracies were high (85 percent). For all supervised classified images, we could thus easily separate young pine plantations from mature pine plantations (Figure 2a, Figure 3a, Figure 4a, and Figure 5a).

Forest Alteration Trends

In the 1995 and 2000 supervised classification with 6 signature files (Table 3), young pine plantation was five percent higher than young pine plantation found in the unsupervised classification (26 percent) (Table 2).

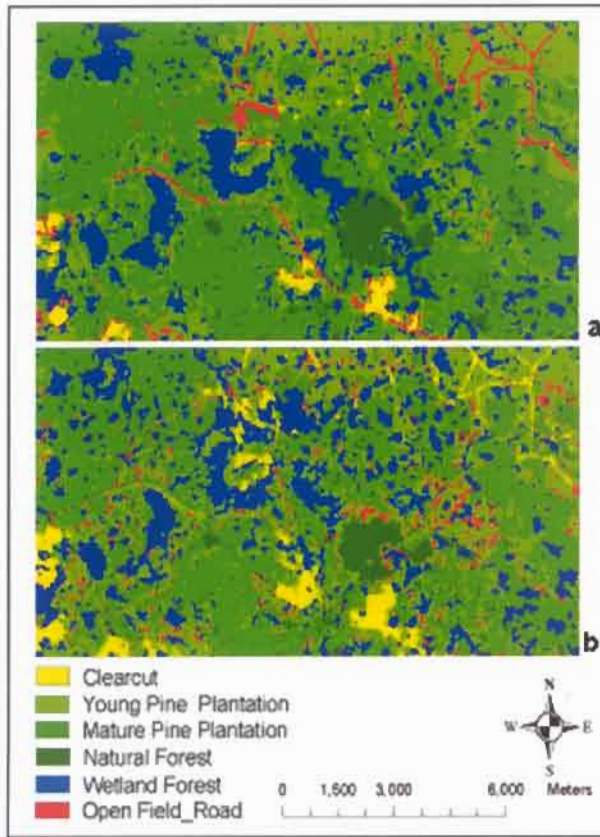


Figure 2. 1985 (a) Supervised classification (b) Unsupervised classification.

Annual land cover conversions are shown Tables 5-8. Conversion from clear-cut to young pine plantation during 1985 - 1990 was 17 percent (30.6 ha) and clear-cut to mature pine plantation was 11 percent (19.8 ha). Contrary to expectations there was no conversion from clear-cut to natural forest. In some cases, wetland forest in the study area was cut to produce timber, and, the two percent (3.6 ha) of clear-cut observed in 1985 was converted to wetland forest in 1990 (Table 5). Both these factors may have been the reason for misclassifications. In 1990, 3 percent (5.4) of clear-cut became open field/road land cover. Because of similarities, we could not separate the conversion from clear-cut to open field/road accurately. However, the con-

	1985 CC (%)	1985 YPP (%)	1985 MPP (%)	1985 NF (%)	1985 WF (%)	1985 OFR (%)
1990 CC	67	12	20	2	7	21
1990 YPP	17	6	6	0	1	11
1990 MPP	11	59	66	29	26	39
1990 NF	0	0	1	65	1	0
1990 WF	2	18	6	3	64	8
1990 OFR	3	4	1	0	1	21
Total %	100	100	100	100	100	100

Table 5. Percentage of land cover transformation between 1985 and 1990.

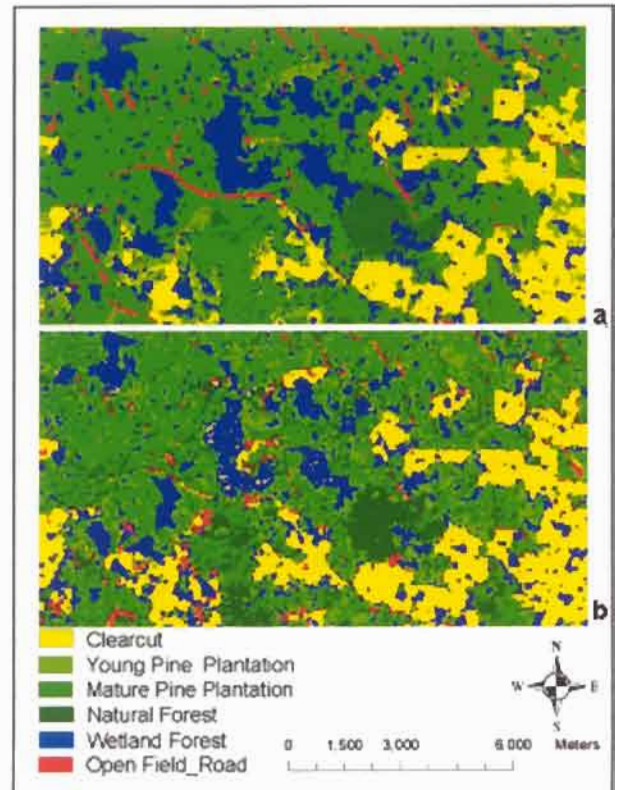


Figure 3. 1990. (a) Supervised classification (b) Unsupervised classification.

version, in 1990, of 59 percent (1872 ha) of young pine plantation remotely sensed in 1985 to mature pine plantation was very clear.

Land conversion from 1990 to 1995 is more distinguishable for all classes. As much as 55 percent of clear-cut were converted to young pine plantation in 1995 and just 6 percent converted to mature pine plantation. Only 34 percent of young pine plantations in 1990 were converted to mature pine plantations in 1995 (Table 6). From 1995 to 2000, 37 percent of young pine plantations were converted to mature pine plantations and 45 percent of clear-cut were converted to young pine plantations (Table 7).

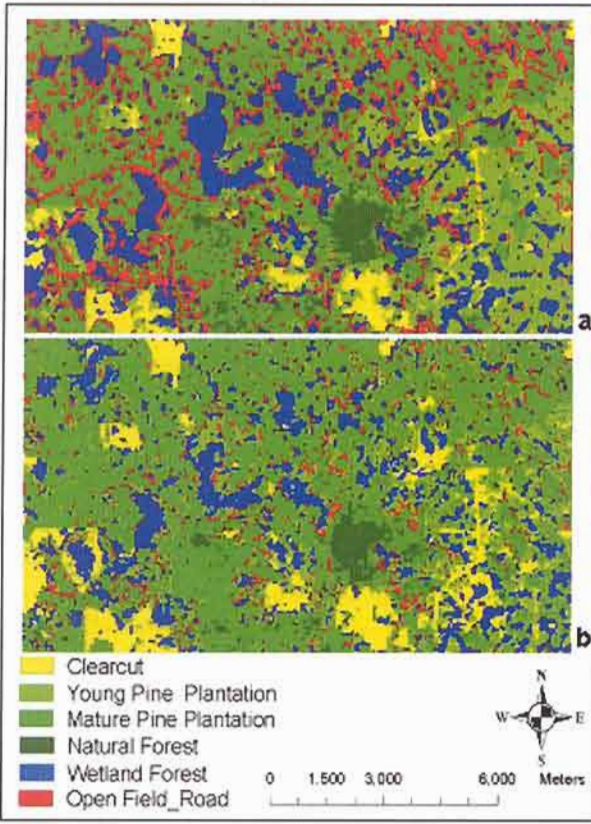


Figure 4. 1995. (a) Supervised classification (b) Unsupervised classification.

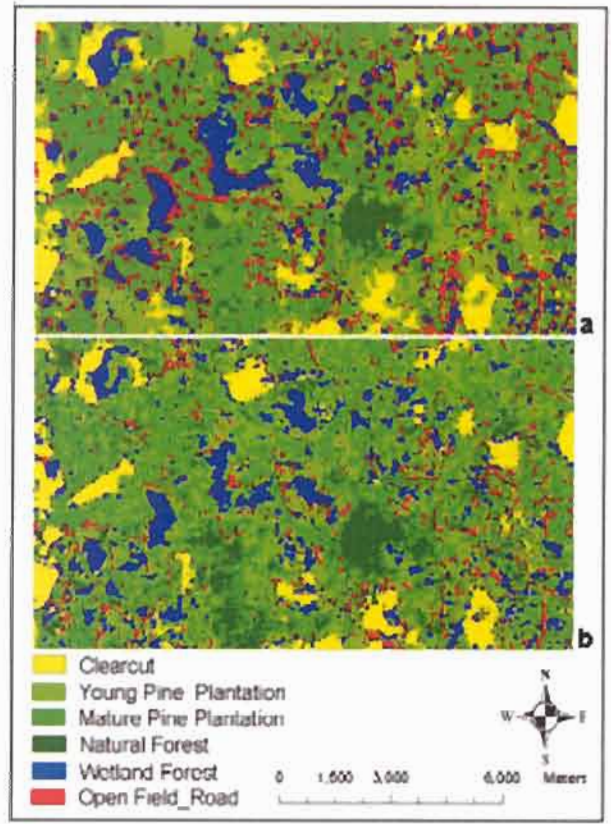


Figure 5. 2000. (a) Supervised classification (b) Unsupervised classification.

From 1985 to 2000, a total of 16 percent (32.2 ha) were convert from clear-cut to young pine plantations and 19 percent (34.2 ha) to mature pine plantation (Table 8). Forty-five percent of young pine plantation (1215 ha) became mature pine plantation during the same period (Table 8).

To sum up, the acreage of mature and young pine plantation forests in the study area decreased to 54 ha (2 percent) and 533 ha (9 percent), respectively, while open field road and clear-cut (pastureland, agriculture and fire scars) increased to 17 percent from 1985 to 2000 (Table 3).

Conclusions

The use of Landsat images using the year of a clear-cut as a base significantly improved the ability of separating land cover types and was shown to be a good tool for comparisons among years. Determining the clear-cut year gave the basis for the age of the forest stand and the trend of land cover from one type to another. From supervised classified results, it could be concluded that mature pine plantations and young pine plantations have been decreasing in the study area between 1985 and 2000. Unsupervised classification was found

	1990 CC (%)	1990 YPP (%)	1990 MPP (%)	1990 NF (%)	1990 WF (%)	1990 OFR (%)
1995 CC	15	3	4	0	1	6
1995 YPP	55	39	10	3	7	16
1995 MPP	6	34	63	28	6	23
1995 NF	0	1	1	67	0	0
1995 WF	13	5	5	1	66	8
1995 OFR	11	18	17	1	19	47
Total %	100	100	100	100	100	100

Table 6. Percentage of land cover transformation between 1990 and 1995.

	1995 CC (%)	1995 YPP (%)	1995 MPP (%)	1995 NF (%)	1995 WF (%)	1995 OFR (%)
2000 CC	36	6	9	3	8	6
2000 YPP	45	41	12	5	21	20
2000 MPP	5	37	72	25	2	30
2000NF	0	0	1	67	0	0
2000 WF	1	2	1	0	59	8
1995 OFR	13	13	5	0	11	35
Total %	100	100	100	100	100	100

Table 7. Percentage of land cover transformation between 1995 and 2000.

	1985 CC (%)	1985 YPP (%)	1985 MPP (%)	1985 NF (%)	1985 WF (%)	1985 OFR (%)
2000 CC	60	7	9	8	8	14
2000 YPP	16	21	22	16	21	23
2000 MPP	19	45	52	26	12	34
2000NF	0	0	1	48	0	0
2000 WF	1	11	4	0	46	5
1995 OFR	4	16	12	2	13	24
Total %	100	100	100	100	100	100

Table 8. Percentage of land cover transformation between 1985 and 2000.

to be the best method for defining such land cover as natural forest.

Because mature and young pine plantations are declining in the region, biomass is also decreasing. The study area is becoming a source of carbon in the atmosphere because open field and road and clear-cut, which have lower biomass, are substituting for natural forest vegetation. If the same trend persists, one might expect a continuous decline in forested area in the region, and as a result of this, CO₂ concentrations at the ground level will increase. More research is required to evaluate CO₂ production from this landscape.

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