Habitat Change Analysis Using Landsat TM

Final Report

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Submitted by:

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On behalf of the members of the North Carolina Sandhills Conservation Partnership (NCSCP), the U.S. Fish and Wildlife Service would like to thank the Department of Defense Legacy Program for its 2002 funding to the Army Environmental Center. DoD Legacy Resource Management Program funded several important projects that generated critical data used to formulate a Conservation Reserve Design for the North Carolina Sandhills. In particular, we acknowledge the DoD Legacy Program's contribution to the completion of two Natural Community Inventories for Hoke and Scotland Counties, the construction of a region-wide GIS database housing over 300 data layers, the first comprehensive red-cockaded woodpecker regional database for the Sandhills, research to determine habitat requirements for two federal species of concern and, the development of a 2000 land cover dataset for the Sandhills. All the information generated from these projects is now available to our partners and other stakeholders in the NCSCP which include the Army Environmental Center and Fort Bragg. Without the support of the DoD Legacy Program, these projects and the invaluable information they provided would not have been possible.

Respectfully,

Peter V Campbell

Peter V. Campbell
NC Sandhills RCW Recovery Coordinator
U.S. Fish and Wildlife Service

Habitat Change Analysis Using Landsat TM

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Background

In May 2000, the U.S. Fish and Wildlife Service, the United States Army, the North Carolina Wildlife Resources Commission, the North Carolina Chapter of The Nature Conservancy, Sandhills Area Land Trust and the Sandhills Ecological Institute formed the North Carolina Sandhills Conservation Partnership (NCSCP). The mission of the NCSCP is to develop a conservation strategy for the red-cockaded woodpecker, the longleaf pine forests, and the other ecosystems and biota of the Sandhills in North Carolina. The NCSCP's ecosystem management concept is to address critical conservation issues on a landscape scale, develop realistic resource protection and management goals and strategies into a unified plan, and then collaboratively implement this strategic conservation plan. The plan emphasizes the conservation, restoration, and management of key land parcels within the mosaic of existing land uses embedded in the North Carolina Sandhills longleaf pine ecosystem. These lands will provide forested wildlife habitat corridors between and habitat buffers surrounding existing public and private conservation lands for the benefit of the endangered red-cockaded woodpecker, 14 federal species of concern and other rare federal and state recognized species .

The red cockaded woodpecker (RCW) is indigenous to the southeast of the United States. It prefers habitat with a low-density overstory of longleaf pine, with an open understory. The open understory is thought to provide the bird with forage and travel area with some protection from birds of prey. In the past century, fire suppression and development has brought about a severe decline in the acreage of this forest type in the red cockaded woodpecker's home range. The loss of habitat has led to the bird's endangered status, and the once vast population has dwindled to the point where populations of the bird are limited to a few islands of suitable habitat from North Carolina to Texas. Very often these islands are army bases, where large-scale burning operations have remained in use to clear the understory of vegetation for training purposes.

Air-borne and space-borne remote sensing systems have been widely used to characterize land cover and habitat patterns at the landscape level. Multi-temporal data have been used to monitor trends, landscape dynamics, use conflicts, and cumulative impacts. Current and historical land cover information derived from remotely sensed data have also been combined with other geographic data to provide insights about land cover associations, wildlife habitat, impacts, and changing environmental risks. The National Gap Analysis Program has supported research utilizing remote sensing data to derive land cover products used to assess the conservation status of biological diversity throughout North America. The National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean Program initiated the Coastal Change Analysis Program (C-CAP), to detect coastal upland and wetland land cover and submersed vegetation and to monitor change in the coastal region of the United States. The project utilizes remote sensing in conjunction with ancillary data to monitor changes in coastal wetland habitats and adjacent uplands.

In these and other projects, several innovative techniques have been developed to map land cover and analyze change, including image processing methodologies for spatial and temporal extrapolation of spectral data, integration of GIS data into discriminating image classification algorithms, and techniques to set up a binary change/no change masks. Hyperspectral and multispectral images have also been used to estimate leaf area index and other canopy characteristics. In this study, regional (multispectral) image data were used to map vegetation changes significant to NCSCP's wildlife management objectives. Hyperspectral image data were also investigated for use in discriminating pine forest types that provide key habitat for wildlife species of concern. Documentation of habitat losses and gains are critical to development of effective management strategies and identification of areas that are have a high potential for habitat restoration can help in the development of realistic management goals.

Objectives

The overall goal of this project was to enhance land cover information that is being used to develop a conservation reserve design for the North Carolina Sandhills by updating the existing land cover information. Specific objectives of the project included:

- Edit the 1995 South Carolina C-CAP land cover data that is being used by the U.S. Fish & Wildlife Service and its partners to manage wildlife habitat: In the 1995 C-CAP land cover database, many areas categorized as "Shrub / Scrub" and "Mixed Forest" actually had a high proportion of mature pine in the overstory or had mature pine with hardwood midstory. These areas were to be identified and re-classified, as appropriate.

- Identify areas that have changed between 1995 and 2000 and classify the current land cover type. The 1995 C-CAP land cover database was used as base time; Landsat Thematic Mapper (TM) images that were the source for the 1995 data were compared with TM images from 2000 to generate a binary change mask; areas of change were re-classified based on their 2000 land cover.

- Determine losses / gains in selected wildlife habitat types using the revised 1995 C-CAP land cover data and the 2000 land cover data (change data).

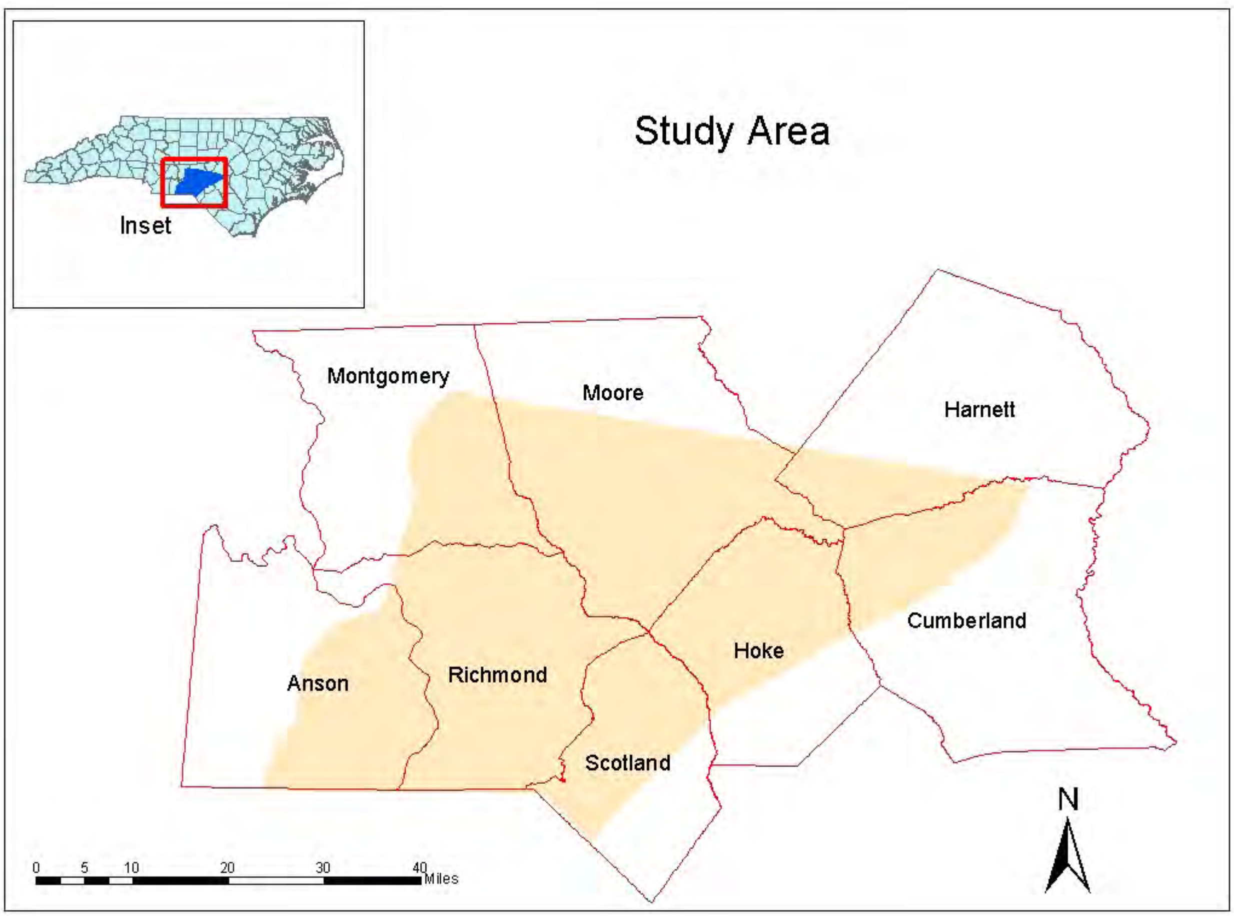
- Investigate the use of remote sensing data, in particular data derived from hyperspectral sensors, to differentiate longleaf pine from other southern yellow pine species.

- Assess the accuracy and reliability of temporal and spatial information which were generated in the change analysis and classification of selected areas and of techniques developed to categorize land cover.

Study Area

The main study area was the Sandhills region in southeastern North Carolina. This area was almost entirely covered by one Landsat TM scene (World Reference System, Path 16, Row 36), about 180 km on a side, encompassing portions of eight counties: Scotland, Richmond, Anson, Montgomery, Moore, Harnett, Hoke and Cumberland (Figure 1). The northern limit of the study area was determined by limits of the 1995 C-CAP land cover data. Representative sites within the overall study area were used to facilitate development of remote sensing techniques for extracting land cover classes and pine species composition. The hyperspectral data strips encompassed an area 2 km X 10 km in the southeastern portion of the overall study area.

Figure 1. Location of the study area in the Sandhills Region, North Carolina.



Materials

Image Data

Landsat Thematic Mapper (TM) multispectral data, WRS Path 16, Row 36) for the 1995 base time (T_b) were provided by the US Fish and Wildlife Service. The image dates were January 5, 1995 (leaf off) and June 14, 1995 (leaf on) and were in the Universal Transverse Mercator projection, North American Datum 1927. The study took advantage of existing satellite data available at no cost to NCSU faculty, staff and students. Landsat TM data for the year 2000 (T_{b+1}) were downloaded from the NCSU Libraries geospatial collection. Leaf off and leaf on image dates were January 11, 2000 and June 3, 2000, respectively. Data were re-projected from State Plane, NAD83 to UTM NAD27 for comparison with the base data. The image from June 2000 was hazy with some cloud cover in the northwestern quadrant; otherwise, all images were excellent quality.

Digital orthophoto quarter quadrangles generated from National Aerial Photography Program (NAPP) photographs were used as references for several steps in processing the land cover data. Both 1993 black and white DOQQs and 1998 color infrared DOQQs were used. Though some changes had occurred, these photographs corresponded roughly in time with the image dates (1995 and 2000, respectively). In addition, the USFWS provided a MrSid orthophoto mosaic of the Fort Bragg area (NAPP-based).

Originally, we planned to acquire HyMap hyperspectral images from the Hyvista Corporation under their special educational discounting program. However, this program was suspended in 2001 and not re-activated. Instead, we used HyMap data acquired under a different project. The one kilometer-by-ten kilometer images fell within the Sandhills Region (Figure 2). We used two images of the same geographic area recorded May 8th, 2000 and October 22nd, 2000. The HyMap sensor has 126 bands distributed between .45 and 2.5 µm, with bandwidths of about 10 nm. The ground resolution of each pixel is approximately 4 m.

Land Cover Data

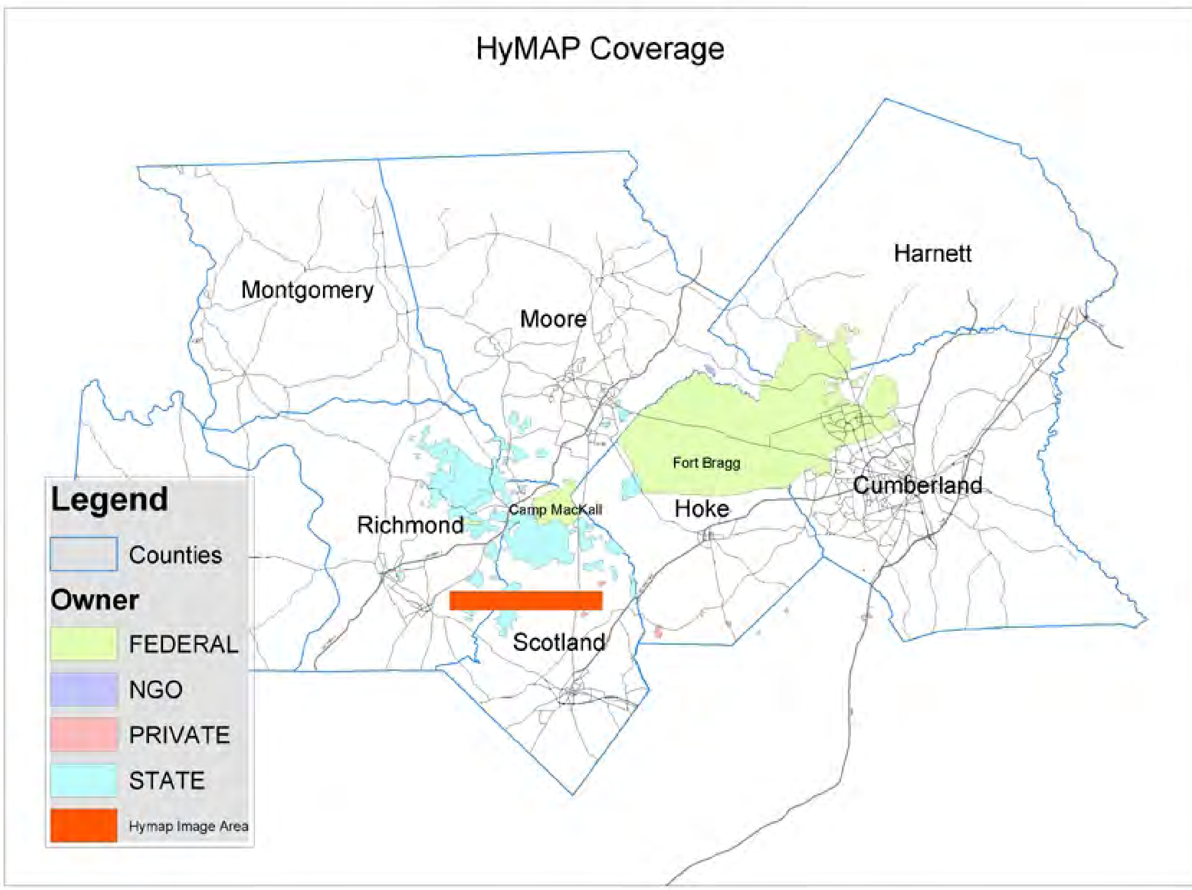
Land cover data generated for the South Carolina Coastal Change Analysis Program were provided by the US Fish and Wildlife Service. The C-CAP Coastal Land Cover Classification System is a hierarchical system that includes upland, wetland, submerged land, and water in a single, comprehensive scheme. The classification scheme is based on land cover classes that can be derived primarily through remotely sensing and that are important indicators of ecosystem change.

Land cover data generated for South Carolina encompassed most of the Sandhills Region of North Carolina, excluding the northern portion of the region. The following C-CAP categories were included in this area:

1. Developed - High Intensity
2. Developed - Low Intensity
3. Cultivated Land
4. Grassland
5. Deciduous Forest
6. Evergreen Forest
7. Mixed Forest
8. Scrub/Shrub
9. Palustrine Forest
10. Palustrine Scrub/Shrub
11. Palustrine Emergent Wetland
12. Estuarine Emergent Wetland
13. Unconsolidated Shore
14. Bare Land
15. Water

Category definitions are based on protocols given in NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation (NOAA Technical Report NMFS 123, Department of Commerce).

Figure 2. Location of HyMap image swaths.



Ancillary Data

We worked with personnel from the US Fish and Wildlife Service to collate existing reference data from selected study sites. Training data, as well as error and accuracy estimation, relied on comparison to reference images and field data from several site visits. Additional data sets used in the project included county boundaries, roads, land ownership and ecoregion.

Methods

All image manipulation, classification, and accuracy assessment were performed at the NC State University Center for Earth Observation (CEO) using IMAGINE (Leica Geosystems; formerly ERDAS, Inc.) and ArcGIS (ESRI).

Re-classification of 1995 Land Cover Data

Personnel from the USFWS felt the 1995 SC C-CAP land cover data overestimated Scrub/shrub and Mixed Forest classes, and were not as useful as they might be for locating mature pine. The 1995 land cover data were clipped to the project boundary and masked to extract the these two classes. An unsupervised classification was performed separately on the scrub/shrub and mixed forest layers. Spectral clusters were compared to existing field data from the USFWS, 1993 DOQQs and the 1995 leaf-on and leaf-off TM data to ascertain whether any of these areas should be re-assigned to the Evergreen Forest class. We based the re-classification of the Mixed Forest class primarily on the 1995 leaf-off imagery and the re-classification of the Scrub/shrub class primarily on the 1995 leaf-on imagery to take advantage of seasonal phenological conditions. We adhered to C-CAP classification criteria to determine if any of the pixels could be classified as evergreen, but were more likely to assign borderline conditions to the evergreen class rather than mixed or scrub/shrub classes. Some areas were assigned to entirely new classes (e.g. bare or grass), as appropriate. We updated the 1995 C-CAP land cover data to reflect these class assignments.

Binary Change Mask

Atmospheric conditions can alter the spectral signature of land cover features and give a false impression of change. Since the June 2000 image had haze and some clouds, for change detection we focused on the 1995 and 2000 leaf-off images, both of which were acquired in January. These near-anniversary images helped ensure that phenological conditions were very similar between dates, though moisture conditions were somewhat different. Change detection demands excellent registration between the two dates. After re-projecting the 2000 image to match the projection and datum of the 1995 image (UTM: NAD27), we verified image-to-image registration using approximately 50 control points to improve pixel-to-pixel co-registration.

The C-CAP protocols outline several methods for change detection. The general approach usually requires generating a binary mask showing areas of “change” and “no-change.” We investigated several techniques for generating the change mask, including simple band differencing, band ratios and regression techniques. We selected a combination of multi-date composite image propagation and principal components analysis as the best approach for this data set. Six reflective spectral bands from each of the 1995 and 2000 images were combined into a single file. A principal components transformation was then applied to the combined dataset. The first three bands (components) of the output dataset accounted for 89% of the variation. These bands were subsequently used in an unsupervised classification to create 'change' and 'no-change' clusters. The change, no-change layer was compared to the 1995 and 2000 images and to the 1993 / 1998 DOQQs to evaluate the accuracy of the change mask. Change areas were then used as a mask to extract areas of change from the 2000 image.

Classification of 2000 Image Data

A unsupervised classification techniques, combined with some supervised classifications for some classes, was used to classify areas that had been identified as having changed since 1995. We used the same level two classes from the C-CAP Coastal Land Cover Classification System as used in the SC land cover data to identify land cover classes for areas that had been identified as having changed. We used existing field data, site visits, and 1998 DOQQs as references to classify the areas. After classification, a stratified random sample was selected for accuracy assessment using the Accuracy Assessment Tool in Leica Imagine. The minimum count was one to ensure that every class in the study area was represented in the assessment, though we later dropped class 11, Palustrine Emergent Wetland from the assessment because of its low occurrence (~53 hectares) and accessibility issues. None of the change areas had been identified in this class. We used a 3 pixel window (3 X 3) with a majority threshold of 6 to select the sample sites in the classified 2000 image. Sites that did not have at least 6 of the same cover class present in the search window were thrown out. Using these search parameters, 255 sample points were selected and checked for the reference class. Again, we used existing field data, site visits, and 1998 DOQQs, that had not been used previously as classification training data, to determine the reference class for the accuracy assessment points.

Detailed classes within the general Scrub/Shrub Cover Class

One of the major objectives of the land cover mapping effort was to enhance the existing land cover, the 1995 CCAP classification with respect to wildlife habitat. In re-classifying the mixed forest and scrub/shrub categories, we did not find that many areas changed. The 1995 classification generally adhered to C-CAP class definitions. However, the C-CAP land cover classification scheme does not differentiate areas that are predominantly mature pine with hardwood midstory from areas that are mixed forest types (pine / hardwood co-dominant in the canopy). More importantly for wildlife habitat, areas that are dominated by woody vegetation that is 6 m (20 ft) or less in height would be classified as scrub/shrub, regardless of whether there is pine (< or > 6 m) in the overstory.

The scrub/shrub class from the original classification scheme contained variability in both structure and phenology. In order to make the classification more useful to the wildlife biologists in the Sandhills we reclassified the scrub/shrub pixels from both the 1995 and the 2000 general land cover classification into 10 detailed categories. As noted, the primary variable that distinguishes schrub/shrub from forests in the general classification is the height of the woody vegetation. Trees less than 6 meters tall are considered scrub/shrub. In the sandhills there are pine woodlands in which the majority of the trees would fall below the 6 meter limit, but scattered pines tower above. These sparse woodlands tended to be mapped as scrub/shrub. At the same time recently harvested sites would have rapid regeneration of hardwoods and/or pines, and would also be mapped in the scrub/shrub category. Many of the scrub/shrub areas were dominated by smaller hardwoods with some pine in the overstory. The suitability of these sites for wildlife may be markedly different, therefore we refined the classification within scrub/shrub in an attempt to make the map more meaningful for wildlife management.

We reclassified the scrub/shrub in both the 1995 and 2000 classifications using unsupervised classification. The summer (June) Landsat TM image was used to refine the 1995 classification. Twenty clusters were generated using Leica Imagine's ISODATA algorithm and labeled based on photo-interpretation. The 1993 black-and-white and 2000 color-infrared DOQQs were used as the reference data for the interpretation and labeling of the clusters. While labeling the 1995 imagery, the time difference between the photo and image acquisition were taken into account when interpreting the land cover for each cluster. The Landsat TM imagery available for the summer of 2000 had significant cloud cover and was therefore not used in the analysis. We were limited to the winter 2000 imagery and chose to combine the 1995 and 2000 winter images in order to develop the clusters for refining the 2000 classification. By combining the two dates we expected that the clusters would represent a group of pixels that had undergone a similar change between the 1995 and 2000 condition. A brief description of the classes derived from the scrub/shrub category are given in Table 1. Not all ten classes were present in both the 1995 and 2000 detailed land cover classifications.

Table 1. Scrub/shrub sub-classes generated from the 1995 and 2000 Land Cover databases.

Class	Description
20. scrub/shrub - hardwood dominated	This class represents hardwood dominated forested areas. Trees dominating these sites are likely to be scrub oaks. Pines are excluded from these sites either by past management or by disturbance
21 scrub/shrub - low density pine with hardwood understory	These sites have widely scattered pines with short stature hardwood trees dominating the subcanopy. Scrub oaks are often the dominant species and mature pines tend to overtop them. Pine density is less than one tree every 30 meters
22. scrub/shrub - low density pine w/ open understory	These sites contain scattered pines with either an herbaceous or exposed sand forest floor. Pine density is less than one tree every 30 meters. The open aspect may be the result of management or extremely xeric site conditions
23. scrub/shrub - moderate density pine w/hardwood understory	These sites support a higher density of pine trees with a dense sub-canopy of hardwoods. A mature pine canopy overtops the shorter stature hardwoods. Pine density is greater that 1 tree every 30 meters.
24. scrub/shrub - moderate density pine w/ open understory	These sites support a higher density of pine trees with an herbaceous or exposed sand forest floor. Pine density is greater that 1 tree every 30 meters and the open aspect may be the result of management or xeric conditions
25. scrub/shrub - pine with hardwood co-dominant	These are mixed woody areas with mature pines and hardwoods co-dominating the canopy. Their placement in the scrub/shrub class should be the result of their short stature at the time of image acquisition.
26. scrub/shrub - regenerating forest	These sites represent short stature regeneration at the time of image acquisition. Dominant species on these sites transition rapidly with succession. Loblolly pine, sweetgum and maple often occupy these sites for several years following clearing.
27. scrub/shrub - woody wetland	These represent woody wetlands dominated by shrubs. Some sites may include widely scattered mature pines over a shrubby understory. Other sites would include seepage areas including species dominated by loblolly bay, sweet bay, cyrilla and possibly cane.
28. scrub/shrub – bare	These areas are exposed sand or soils and occur as inclusions within the larger scrub/shrub class. They can occur within a larger patch of low or moderate density pines with open understory or in areas where disturbance has occurred.
29. scrub/shrub - grass	These sites represent larger patches grass or herbaceous dominated areas within the larger matrix of pine woodlands or forests.

We preformed an accuracy assessment of the 2000 Scrub/shrub sub-classes based primarily on field visits. The reference sub-classes for few sample sites were determined from photography.

Change Analysis

After classifying potential change areas in the T_{b+1} Landsat data (2000 images), the 1995 and 2000 land cover classifications were compared to determine actual amount and direction of change. The class numbers used in the 2000 classification corresponded with those in the 1995 C-CAP classification (classes 1 through 15, with no occurrences of classes 12 and 13). With 13 possible classes, there are 156 possible to-from change classes. To facilitate interpretation of the change image, we developed class numbers that would be unique for each change class. A multiple of 15 was added to each class number in the 2000 land cover classification. For example, class 4 became [4 + (4 x 15)], or class 64. Using simple subtraction of the re-coded 2000 land cover image minus the 1995 land cover image, each output pixel had a unique value based on the direction of change. Pixel values for no change were an even multiple of 15. Table 2 demonstrates the numbering system for the change image classes and can be used as a reference.

Table 2. Class definitions for the change image. Columns indicate the 2000 class; rows indicate the 1995 class. The highlighted cells are class numbers for areas that have not changed. The table is to be used as a reference for the class numbers in the change image. For example, class 42 in the change image represents areas that were Evergreen Forest (class 6) in 1995 and are Cultivated (class 3) in 2000.

		To Class (Year 2000 Class)												
		1	2	3	4	5	6	7	8	9	10	11	14	15
		High Intensity Developed	Low Intensity Developed	Culti-vated	Grass-land	Decidu-ous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Palustrine Forest	Palustrine Shrub / Scrub	Palustrine Emergent Wetland	Bare Land	Water
	Recode Value	16	32	48	64	80	96	112	128	144	160	176	194	210
From Class (Year 1995 Class)	1	15	31	47	63	79	95	111	127	143	159	175	193	209
	2	14	30	46	62	78	94	110	126	142	158	174	192	208
	3	13	29	45	61	77	93	109	125	141	157	173	191	207
	4	12	28	44	60	76	92	108	124	140	156	172	190	206
	5	11	27	43	59	75	91	107	123	139	155	171	189	205
	6	10	26	42	58	74	90	106	122	138	154	170	188	204
	7	9	25	41	57	73	89	105	121	137	153	169	187	203
	8	8	24	40	56	72	88	104	120	136	152	168	186	202
	9	7	23	39	55	71	87	103	119	135	151	167	185	201
	10	6	22	38	54	70	86	102	118	134	150	166	184	200
	11	5	21	37	53	69	85	101	117	133	149	165	183	199
	14	2	18	34	50	66	82	98	114	130	146	162	180	196
	15	1	17	33	49	65	81	97	113	129	145	161	179	195

Differentiation of Longleaf and Other Pine Species

ESRI ArcGIS software was used to create a map of the image coverage and the surrounding area. Ownership data downloaded from the NC State University Libraries geospatial database allowed us to determine what areas covered by the image were State or Federally owned, which would affect accessibility for field work. A subset of the image was created for an areas that contained a high proportion of publicly accessible lands and a large variety of cover types (Figure 3). Using this subset of the image as the area of focus allowed us to be more thorough in our field work and to speed up the computing processes, which can be formidable with hyperspectral data.

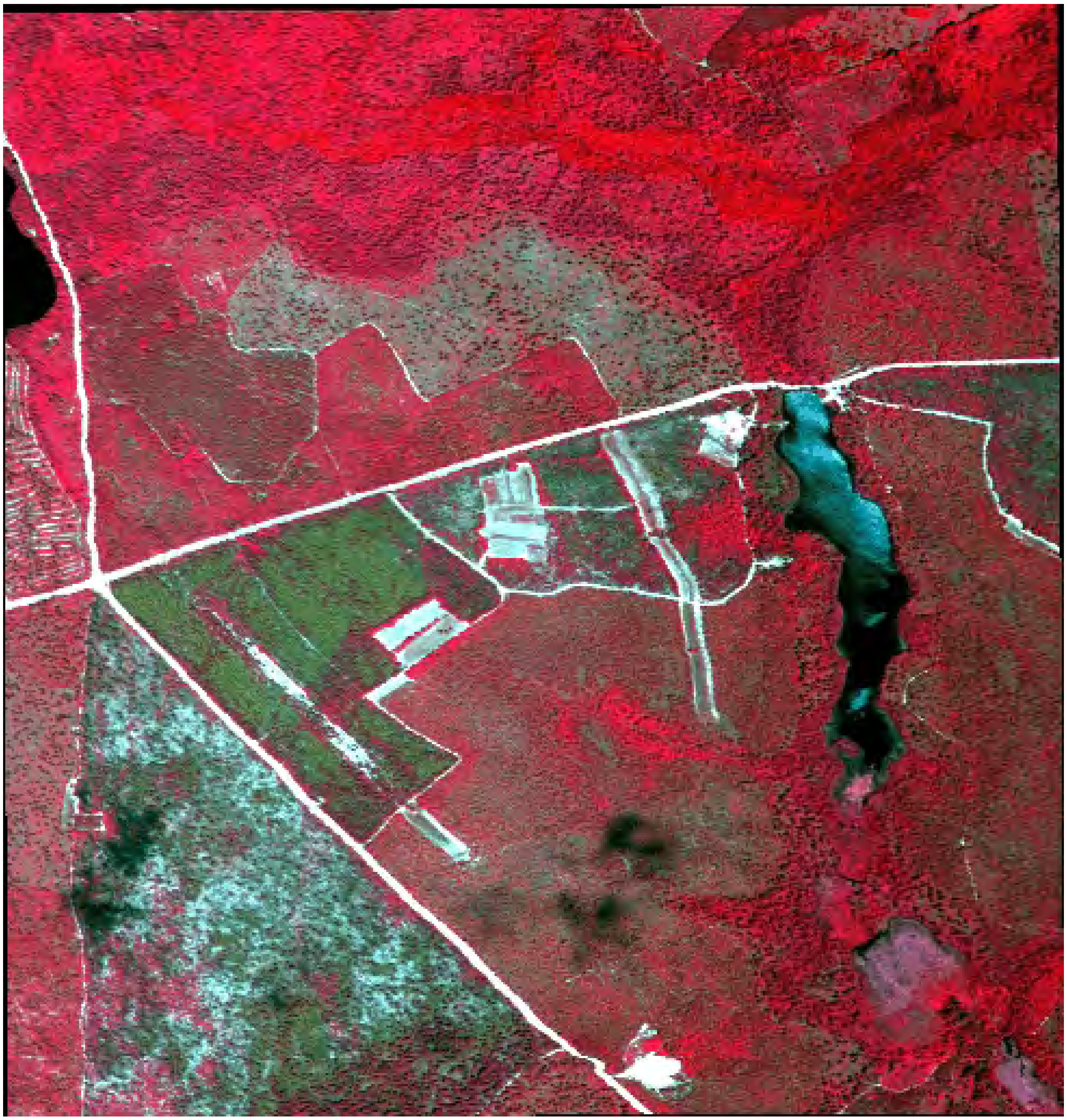
ESRI ArcGIS software was used to delineate stand boundaries within the study area. This initial classification of stand types was done to help us stratify the image for different forest types and conditions and was used to guide the field data collection.Using the ESRI ArcPad software package loaded on a Trimble GeoXM GPS rover, graduate students traveled to the study area and determined the cover type of the polygons *in situ*. During the site visits, we recorded information on forest type and condition, including overstory speies, understory species, percent canopy closure in both the understory and overstory and approximate age (young or mature). During data collection, field crews walked a transect through each polygon sampled to determine the uniformity of the area and to identify any unusual conditions.

We decided to use the ENVI image processing software package for analysis of the image because of ENVI's capabilities with large hyperspectral data sets. The first step was to derive spectral response signatures for different pine forest types. Using the field-verified cover map overlaid on the image of the study area, we were able to extract spectral response curves for longleaf pine and other yellow pines under different conditions for areas selected by the analyst. We set our average window to three-by-three pixels, which takes the average value for each band in the 3 x 3 window and generates a (near) continuous band response curve. This allows the user to compare spectral response curves from different areas within the image. Using this technique, we were able to identify specific bands within the imagery where significant differences occurred between longleaf pine, loblolly pine and other cover types. These significant bands were selected to run classification algorithms that would be most likely to separate different forest types in the study area.

A K-means unsupervised classification technique was used to classify the cover types within the study area. We ran several different classifications using various band combinations and classification thresholds and compared output results with field data. Because of the limited size of the study area and cost constraints, we did not perform a formal accuracy assessment, but used field data previously used in the spectral analyses to assess classification results.

We classified Landsat TM data (2000) from the same study area using several techniques including selecting for the relevant bands and using band ratios and NDVI.

Figure 3. Hyperspectral image subset. The focus area for species differentiation is about 1 km square and encompasses the entire swath width (north-south). Note the green shades that correspond to the presence of longleaf pine.



Results

Re-classification of 1995 Land Cover Data

Approximately 66,913 ha were re-classified from either Mixed Forest or Scrub/shrub to the Evergreen Forest class (Table 3). This is nearly a 50% increase in the area identified as Evergreen Forest. Most of the areas that were modified occurred around the perimeters of areas previously determined to be Mixed Forest or Scrub/shrub. Using fuzzy classification decision rules, these types of areas could be considered “acceptable” (i.e. correct) in either of two (or more) categories. The modified land cover image weights the decision towards the Evergreen Forest class.

Some of the Scrub/shrub areas were determined to be in other classes. When this occurred, we found that in almost all instances, the area appeared to have changed between January 1995 and June 1995, usually due to clearing. In a few instances, we felt pixels bordering water bodies were dominated by water.

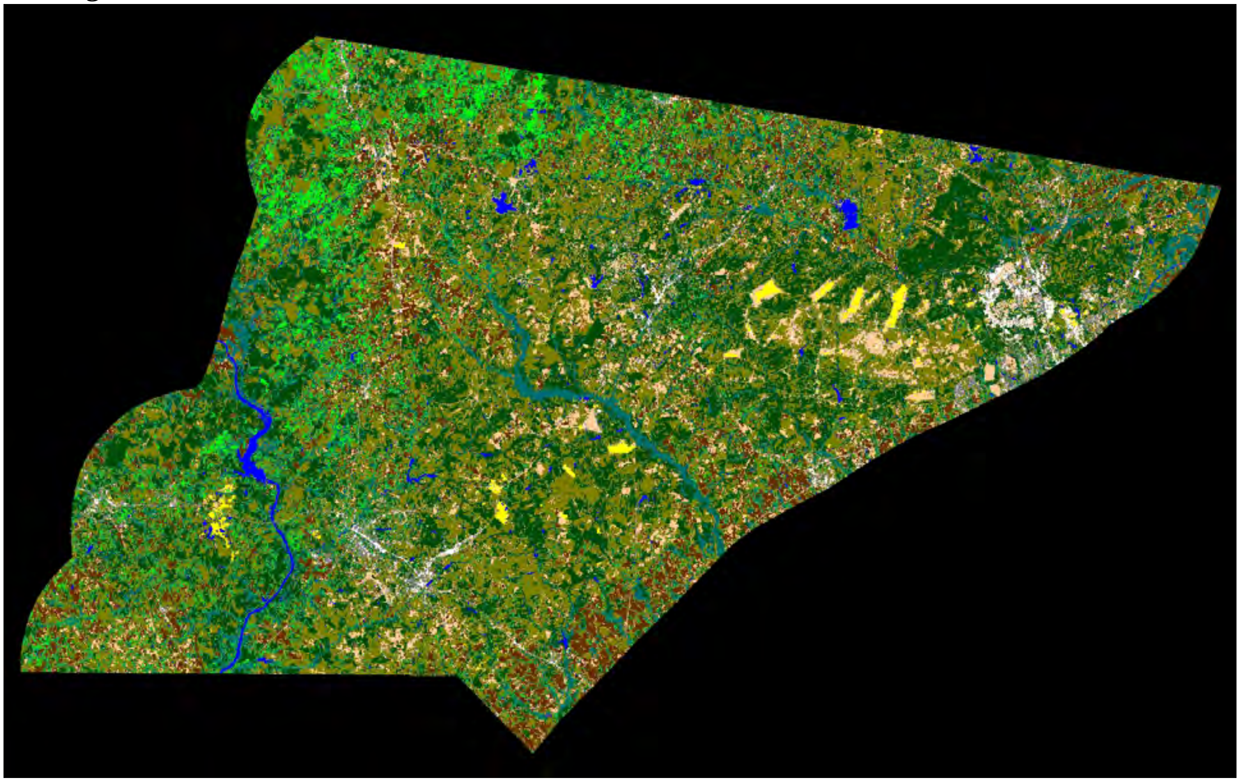
Table 3. Summary of from-to modifications in the 1995 land cover classification. Units are hectares.

	To Class			
From Class	Evergreen Forest	Grass	Bare	Water
Mixed Forest	18,859.6	-	-	-
Scrub/shrub	48,053.0	11,774.1	1,795.1	397.7

The C-CAP data had previously been assessed for classification accuracy. No accuracy assessment was performed on the 1995 modifications due to the difficulty in assessing prior conditions. The 1995 original and modified classifications are shown in Figure 4 and included on the data CD. Color codes for the classification are in Table 4.

Figure 4. The original (A) and modified (B) 1995 land cover data.

A. Original Land Cover



B. Modified Land Cover

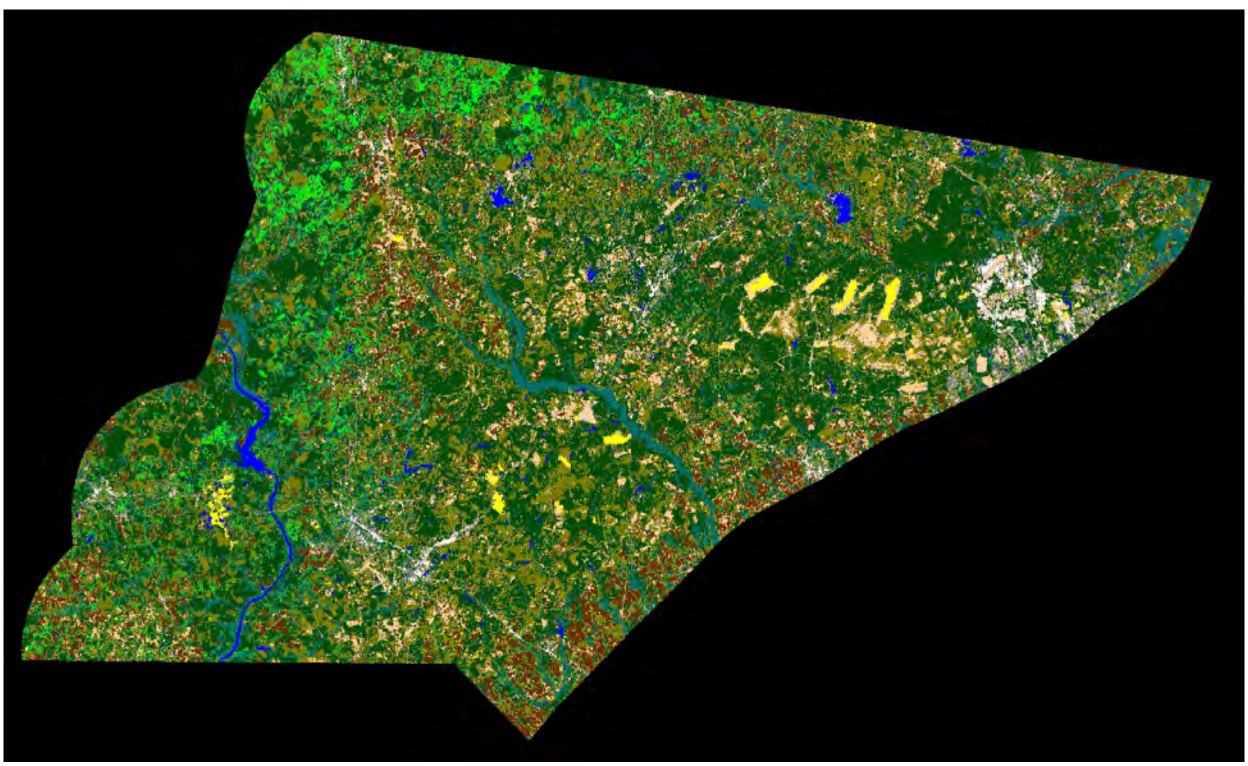


Table 4. Color coding for 1995 and 2000 land cover classifications. The detailed Scrub/shrub sub-classes are not included in this list.

Class	**Color**
Background	
Developed - High Intensity	
Developed - Low Intensity	
Cultivated Land	
Grassland	
Deciduous Forest	
Evergreen Forest	
Mixed Forest	
Scrub/Shrub	
Palustrine Forest	
Palustrine Scrub/Shrub	
Palustrine Emergent Wetland	
Bare Land	
Water	

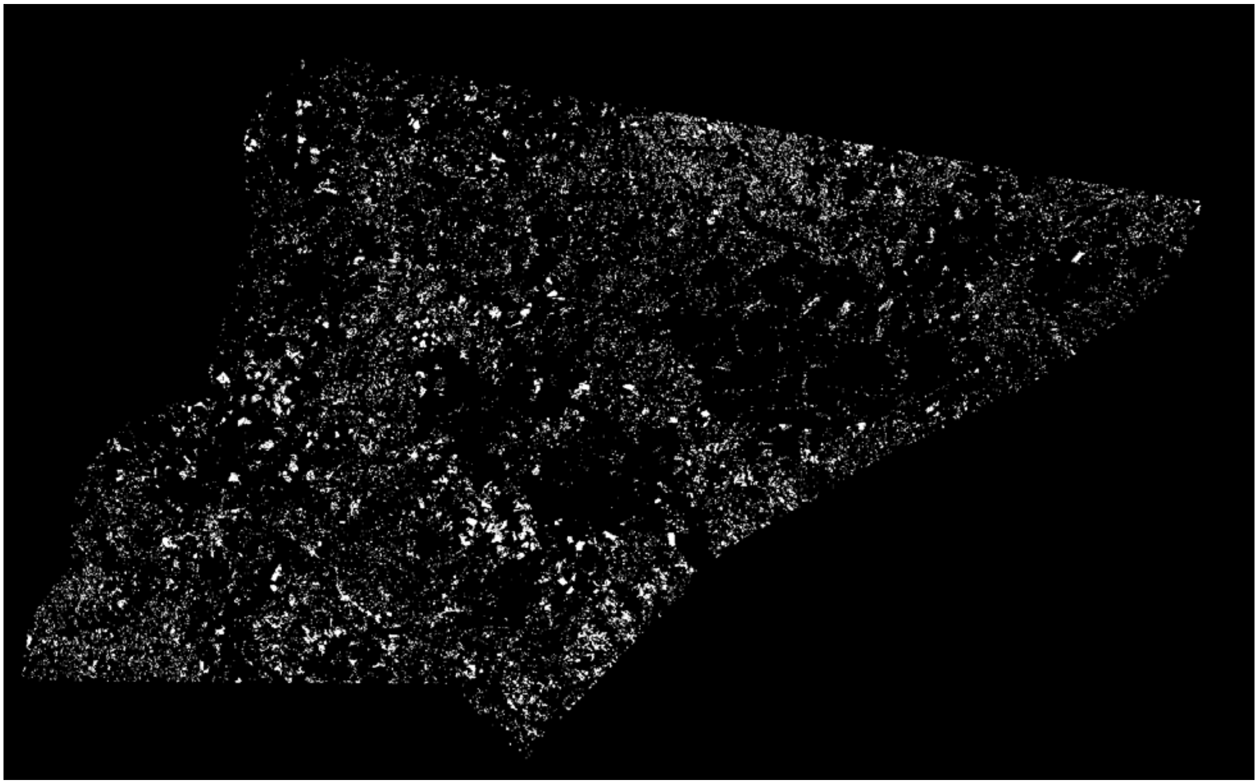
Binary Change Mask

When generating the binary change mask, we made an effort to minimize omission errors in the ‘change’ class. In other words, we tried to minimize the likelihood of missing an area that had actually changed by calling it ‘no change.’ This resulted in an overestimation of the area identified as changed, but most of these areas would maintain the correct classes for ‘no change’ in the subsequent classification of in the 2000 image (Figure 5). The overall accuracy of the change mask was 84% (Table 5). The relatively low overall accuracy reflects the high omission error in the no change class. Producer’s accuracy for the change class was around 95% meaning few areas that were actually changed were missed in the binary mask.

Table 5. Accuracy assessment for binary change mask.

Image Data	Reference Data: Change	No Change	Total	Commission Error	User's Accuracy
Change	36	14	50	28.0%	72.0%
No change	2	48	50	4.0%	96.0%
Total	38	62	100		
Omission Error	5.3%	22.6%			
Producer's Accuracy	94.7%	77.4%			

Figure 5. Binary change mask generated for the study area. Area of change was overestimated to minimize the probability missing areas that had actually changed.



Classification of 2000 Image Data

Change areas in the 2000 data were classified into the same C-CAP categories found in the 1995 data (Figure 6; Table 4). The overall accuracy of the classification was 93.4% based on over 200 sample sites (Table 6).

Figure 6. Land cover classification for 2000. Color coding is the same as the 1995 classification (Figure 4; Table 4).

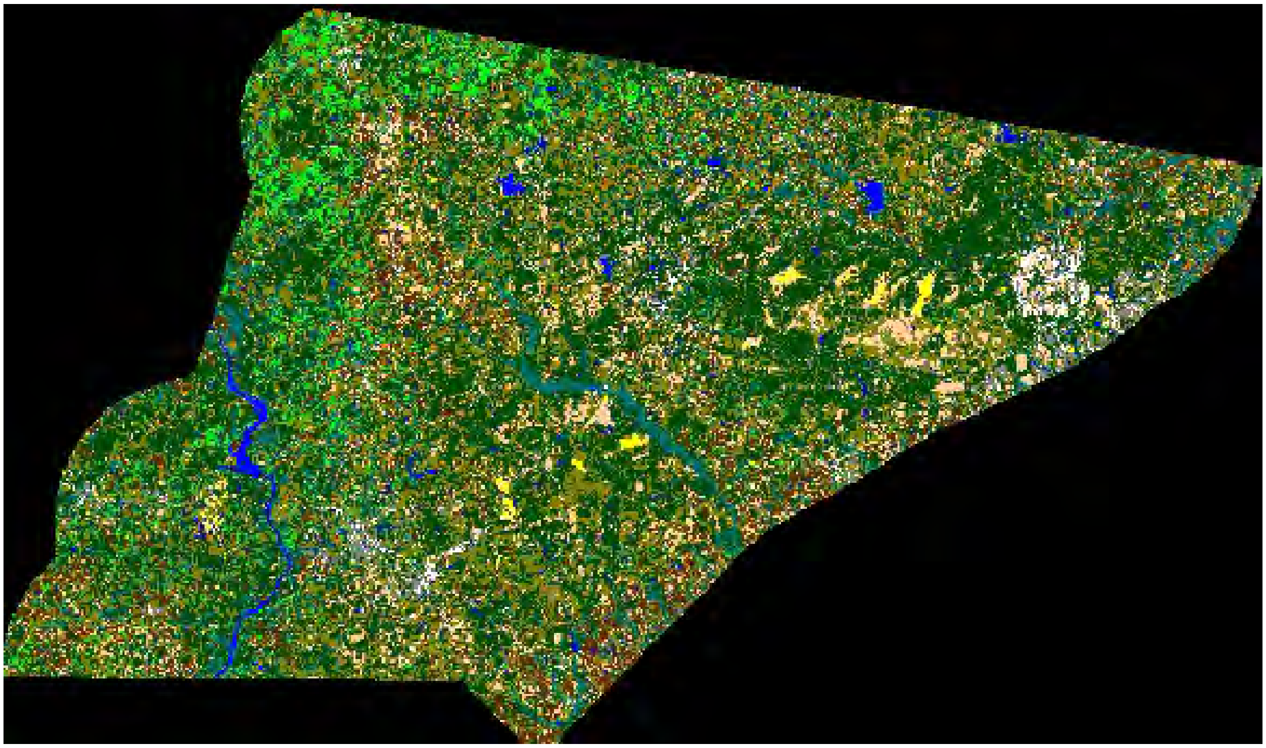


Table 6. Accuracy assessment matrix for the 2000 land cover classification.

			Reference Class													
			1	2	3	4	5	6	7	8	9	10	11	14	15	Total Image	Users Accuracy
Image Class	1	High Intensity Developed	4													4	100%
	2	Low Intensity Developed		6												6	100%
	3	Cultivated			14											14	100%
	4	Grassland	1			20										21	95.2%
	5	Deciduous Forest					6									6	100%
	6	Evergreen Forest					1	83			1					85	97.6%
	7	Mixed Forest							5							5	100%
	8	Shrub / Scrub				1	1	1		32				1		36	88.9%
	9	Palustrine Forest						2		2	12					16	75.0%
	10	Palustrine Shrub / Scrub						2				3				5	60.0%
	11	Palustrine Emergent Wetland														0	NA
	14	Bare				1								9		10	90.0%
	15	Water													4	4	100%
		Total Reference	5	6	14	22	8	88	5	34	13	3	0	10	4	212	
		Producer's Accuracy	80.0%	100%	100%	90.9%	75.0%	94.3%	100%	94.1%	92.3%	100%	NA	90.0%	100%		overall 93.4%

Detailed classes within the general Scrub/Shrub Cover Class

Sub-division of the 2000 Scrub/shrub category was limited by cloud cover and haze in the 2000 leaf-on image. Summer images would give a better indication of hardwood presence in these areas. Not all ten classes were present in both the 1995 and 2000 detailed land cover classifications. Accuracy assessment indicated the first four sub-categories (hardwood dominated and low to moderate pine density sub-classes) are most reliable. Scrub/shrub with a very low density of vegetation (bare) and dominated by herbaceous vegetation (grass) were also easily distinguishable (Table 7).

Table 7. Accuracy assessment for the scrub/shrub sub-classes.

		Reference Class										
		20	21	22	23	24	25	26	27	28	29	User's Accuracy
Image Class	20	31	5	1	1							81.6%
	21	1	28					2				90.3%
	22			46				1				97.9%
	23		1		58			2				95.1%
	24											NA
	25											NA
	26											NA
	27								1			100%
	28									11		100%
	29	1	4	2	2	1					19	65.5%
	Producer's Accuracy	93.9%	73.7%	93.9%	95.1%	0.0%	NA	0.0%	100%	100%	100%	

20	hardwood dominated
21	low density pine w/ hardwood understory
22	low density pine w/ open understory
23	moderate density pine w/ hardwood understory
24	moderate density pine w/ open understory
25	pine with hardwood co-dominate
26	regenerateing forest
27	woody wetland
28	bare
29	grass

Change Analysis

We generated 156 change categories and 13 no-change categories. The key to change - no change classes is given in Table 2 which defines the direction of change by class number. We found the greatest changes occurred in the amount of bare land (Table 8), primarily due to clearing that appeared concentrated in the southwestern portion of the study area. Scrub/shrub and Cultivated Land also had considerable change. Scrub/shrub areas converted primarily to Evergreen Forest (successional) or Bare Land (clearing). Most of the reduction in Cultivated Land is reflected in additions to Grassland, indicating change in use or rotation. Table 9 shows the area of change (hectares) by class and change direction.

Table 8. Change in hectares, by class, 1995 to 2000.

		1995	2000	Change
1	High Intensity Developed	6,417.5	6,959.3	541.8
2	Low Intensity Developed	13,978.0	13,978.0	0.0
3	Cultivated	43,021.4	36,265.1	-6,756.4
4	Grassland	44,697.0	52,154.2	7,457.2
5	Deciduous Forest	16,255.4	14,775.2	-1,480.2
6	Evergreen Forest	207,884.7	204,536.9	-3,347.8
7	Mixed Forest	16,486.5	14,853.1	-1,633.4
8	Shrub / Scrub	105,845.8	95,711.4	-10,134.4
9	Palustrine Forest	46,756.7	42,734.8	-4,021.9
10	Palustrine Shrub / Scrub	13,512.2	11,994.9	-1,517.3
11	Palustrine Emergent Wetland	59.1	53.0	-6.1
14	Bare Land	6,212.7	27,482.3	21,269.6
15	Water	7,774.6	7,403.6	-371.0
	Total Hectares	528,901.6	528,901.7	

Table 9. Area of each change class, by direction of change. Rows represent the 1995 classes; columns are the 2000 classes. Units are hectares Off-diagonal cells show area changed from [row class] to [column class]. Highlighted cells represent no change.

From Class (Year 1995)	To Class (Year 2000 Class)												
	1	2	3	4	5	6	7	8	9	10	11	14	15
	High Intensity Developed	Low Intensity Developed	Culti-vated	Grass-land	Decidu-ous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Palustrine Forest	Palustrine Shrub / Scrub	Palustrine Emergent Wetland	Bare Land	Water
Recode Value	16	32	48	64	80	96	112	128	144	160	176	194	210
1	6,417.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	13,978.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	15.2	0.0	35,547.8	5,133.1	0.0	1,007.6	0.0	480.2	0.0	0.0	0.0	837.5	0.0
4	25.3	0.0	596.0	41,088.2	0.0	2,181.5	0.0	965.4	0.0	0.0	0.0	840.6	0.0
5	9.0	0.0	3.5	201.9	14,775.2	441.2	0.0	136.0	0.0	0.0	0.0	688.7	0.0
6	329.7	0.0	6.4	3,734.5	0.0	187,800.5	0.0	1,907.8	0.0	0.0	0.0	14,105.9	0.0
7	9.3	0.0	3.3	177.9	0.0	900.4	14,853.1	108.4	0.0	0.0	0.0	434.2	0.0
8	64.3	0.0	51.7	1,731.3	0.0	10,382.3	0.0	91,426.9	0.0	0.0	0.0	2,189.3	0.0
9	44.5	0.0	1.2	458.7	0.0	954.1	0.0	409.6	42,734.8	0.0	0.0	2,153.9	0.0
10	18.7	0.0	2.3	195.2	0.0	627.6	0.0	147.0	0.0	11,994.9	0.0	526.4	0.0
11	< 0.5	0.0	0.0	1.7	0.0	< 1.0	0.0	< 0.5	0.0	0.0	53.0	2.7	0.0
14	9.3	0.0	52.6	359.0	0.0	181.7	0.0	93.2	0.0	0.0	0.0	5,516.9	0.0
15	16.1	0.0	0.0	72.7	0.0	59.2	0.0	36.5	0.0	0.0	0.0	186.2	7,403.6

We also determined the change in Scrub/shrub category for those sub-classes that occurred in both time periods (Table 10). We found that most of the areas called Regenerating Forest (26) were indistinguishable from Scrub/shrub with low to moderate density pine so this class was not separated in the 2000 sub-classification. Lack of a clear leaf-on image in 2000 also made it difficult to distinguish areas with pine/hardwood co-dominant (25) and we did not identify any areas from category 24 in 2000.

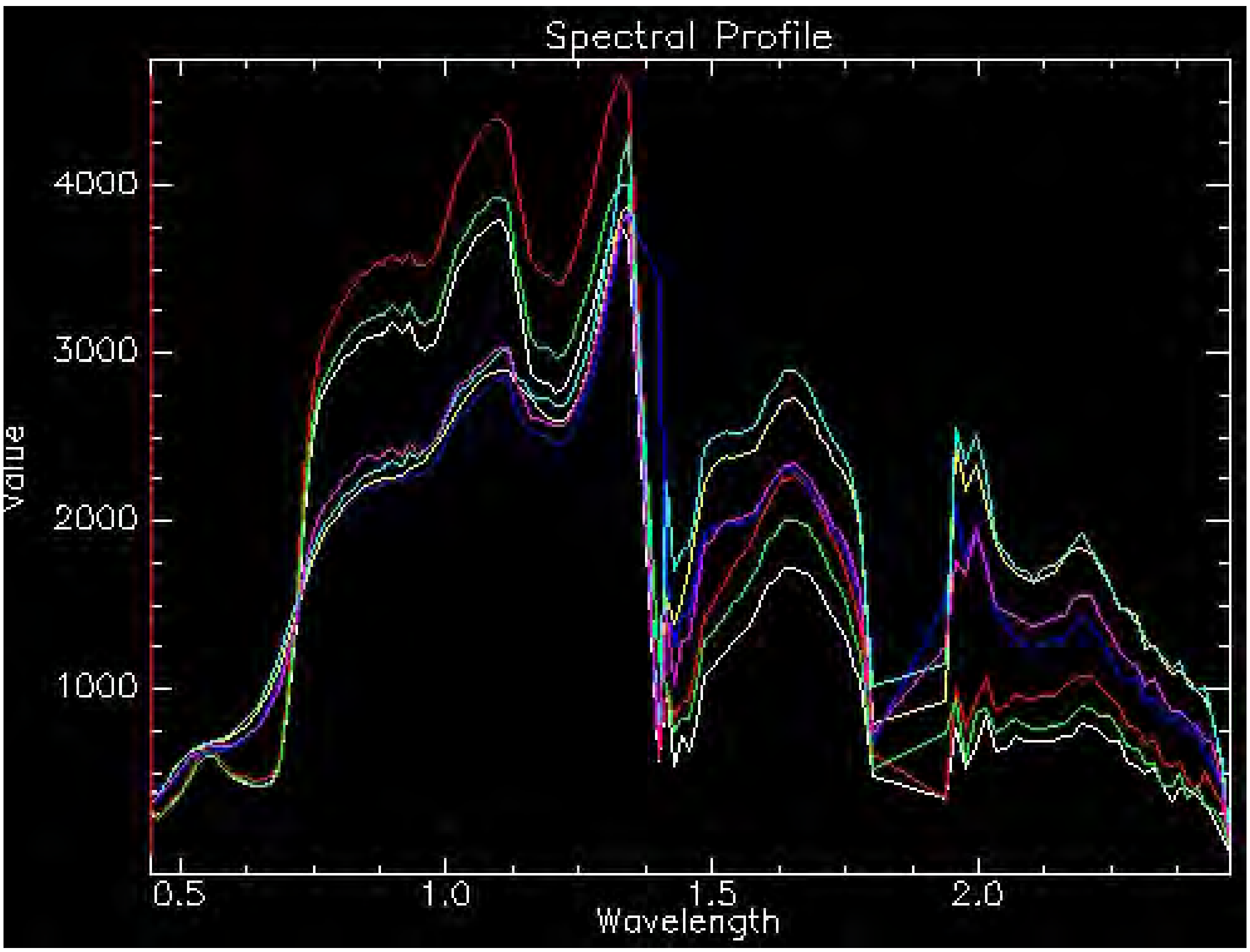
Table 10. Shrub/Scrub habitat, by year. Units are hectares.

		1995	**2000**	**Change**
20	Scrub/shrub - hardwood dominated	33,078.0	16,684.7	-16,393.3
21	Scrub/shrub - low density pine w/hardwood understory	8,970.1	11,923.1	2,953.0
22	Scrub/shrub - low density pine w/open understory	23,450.7	19,238.5	-4,212.2
23	Scrub/shrub - moderate density pine w/hardwood understory	8,164.8	27,370.4	19,205.6
24	Scrub/shrub - moderate density pine w/open understory	5,083.0	0.0	-5,083.0
25	Scrub/shrub - pine with hardwood co-dominate	14,144.9	0.0	-14,144.9
26	Scrub/shrub - regenerating forest	12,954.2	0.0	-12,954.2
27	Scrub/shrub - woody wetland	0.0	2,051.5	2,051.5
28	Scrub/shrub - bare	0.0	6,371.4	6,371.4
29	Scrub/shrub - grass	0.0	12,071.8	12,071.8
	Total	105,845.8	95,711.4	

Differentiation of Longleaf and Other Pine Species

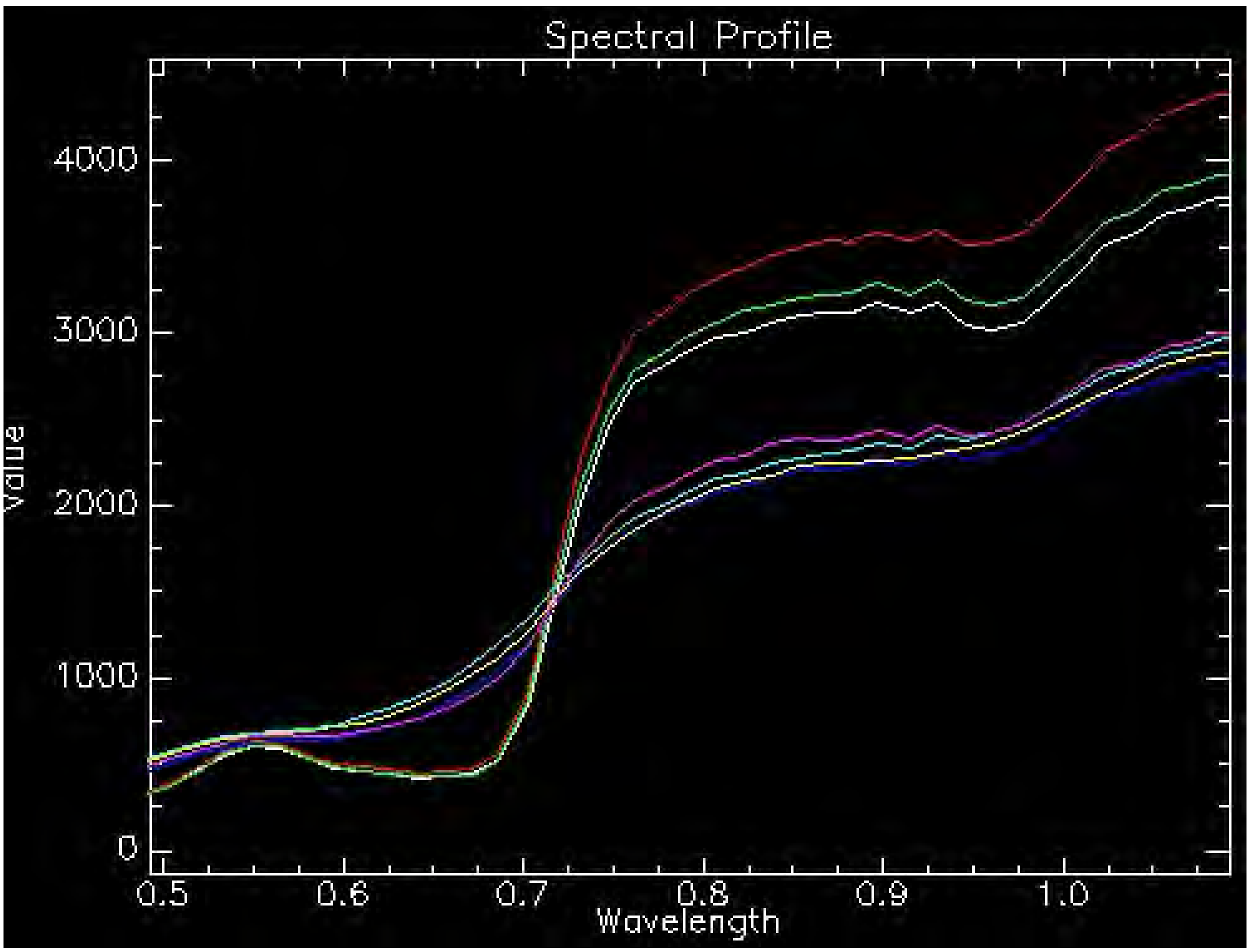
We studied spectral profiles of various forest types, concentrating on differences between longleaf and loblolly pines. Differences between these species are clearly visible in false color composites generated from green, red, and reflected infrared hyperspectral bands. Figure 7 shows two clusters of spectral response curves, one for loblolly (red, green, and gray lines) and one for longleaf (magenta, cyan, yellow and blue lines). There are large differences in reflectance around .6 micrometers (visible green) and in the near infrared range around .8 micrometers. There are also significant differences in the reflected infrared around 2.25 micrometers.

Table 7. Spectral response curves for loblolly pine (red, green, and gray) and longleaf pine (magenta, cyan, yellow and blue). Spikes and abrupt changes in the curves are the product of atmospheric interference and data gaps inherent in the sensor.



Many hyperspectral sensors collect spectra in fewer and broader wavelength intervals than the HyMap sensor, so we focused on regions of the spectrum more common to the majority of multi- or hyperspectral sensors. Figure 8 shows a close up view of the .5 to 1.0 micrometer range of the spectrum. Note the differences in the cluster of lines that dip around .675 micrometers, then gap around .8 to .9 micrometers. We exploited these gaps in our classification in order to differentiate between loblolly and long leaf pine.

Figure 8. Spectral response profiles for loblolly pine (red, green, and gray) and longleaf pine (magenta, cyan, yellow and blue) focusing on visible and near infrared wavelengths.



Based on analysis of spectral profiles, we classified the hyperspectral data using an eight bands subset from the original 126 bands. HyMap wavelengths (and bands) that were clearly associated with species discrimination included: .6563 µm (15); .8078 µm (25); .8689 µm (29); .8839 µm (30); .8966 µm (32); 1.1012 µm (45); 2.1243 µm (105); 2.1597 µm (107).

The image was then filtered using a 33 majority filter (Figure 9). We noted that in many areas, only scattered, individual longleaf trees are present, while loblolly tended to occur in greater density. Since we were focusing on identifying longleaf pine under different conditions, we excluded longleaf from the filtering process. The final classified image includes six classes: long leaf pine, other yellow pine (primarily loblolly in this area), hardwood, herbaceous dominated ground cover, bare earth and water/wet ground. We did not have enough field data for a statistically significant accuracy assessment, but most of the area had been ground checked. We evaluated the classification using visual inspection and cross-validating with the same field data used to develop spectral profiles. We found the forest types, ground cover and bare earth classes are very representative of the area. Because the resolution of the original image is 4 by 4 meters, individual tree crowns are visible. In many places, it is possible to see individual longleaf pines scattered throughout the study area. There is some mis-classification, primarily in the water/wet ground category. There are several places in the study area where shadows from trees and clouds, are classified as water. The lack of reflectance from these spots makes their spectral response curves very similar – a long flat line – and very hard to distinguish from one another.

The coarse scale of the TM image compared to the hyperspectral image is apparent (Figure 10). Although there is some separation of pine species, image resolution has a significant impact on the success of differentiating longleaf from other pines. With longleaf often occurring in open stands with a low crown density, the inability to resolve individual tree crowns in the TM data reduces classification success (Figure 11).

Summary and Conclusions

- The 1995 land cover data being used by the U.S. Fish & Wildlife Service and its partners tends to overestimate Scrub / Shrub and Mixed Forest. We extracted these areas from the 1995 land cover data, and modified them using leaf-off TM imagery (January 1995). Stands which were clearly mature pine dominated (with hardwood mid- or under-story) were identified and re-classified as Pine, as appropriate.

- The C-CAP land cover database was used as “base” (1995) time. Landsat TM source images for the 1995 data were compared with Landsat TM images from 2000 (acquired through the NCSU Libraries GIS Services) to generate a binary change mask identifying areas that had potentially changed land cover during that time period. The accuracy of the change mask was evaluated using aerial photography and field visits.

- Leaf-on and leaf-off Landsat TM data from 2000 were used to classify areas that had changed between 1995 and 2000.

- A change matrix was generated showing losses and gains in all land cover types, by direction of change, using the modified 1995 land cover and the 2000 land cover data.

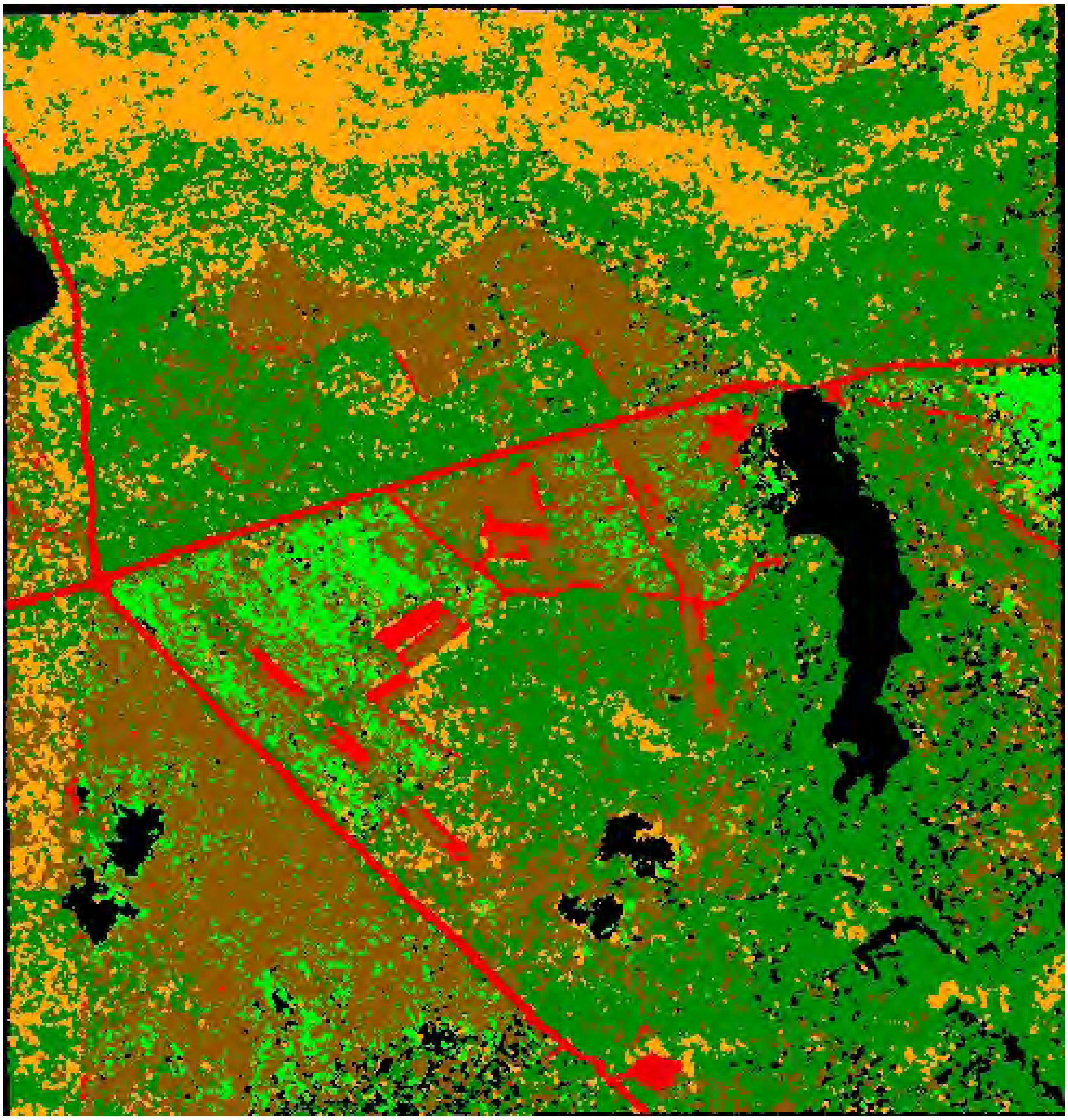
- For both the 1995 land cover and the 2000 land cover, Scrub / Shrub areas were further broken down into sub-classes on the basis of pine presence. The presence of pine on these sites could indicate potential for red-cockaded woodpecker habitat restoration.

- We used hyperspectral images acquired over an area near Laurinburg, NC to differentiate longleaf pine from other southern yellow pine species, especially loblolly pine. Field plots were established to identify a variety of conditions in which these species are found (mature; young; closed canopy; open canopy). Spectral characteristics of these areas were analyzed to determine which bands are significant for differentiating these species. A classification approach generates excellent results using the hyperspectral data but is not directly reproducible using TM data.

In addition to these activities, we supported data collection in a related project investigating the use of hyperspectral data combined with Lidar for characterizing stand conditions. The detailed 2000 land cover classification (with scrub/shrub sub-classes) was used to help guide selection of an appropriate study area. Field data were collected in cooperation with the Army Corps of Engineers Research Lab in return for hyperspectral data acquired over an area southwest of Ft. Bragg. Our studies indicate that, using hyperspectral data, longleaf is easily distinguishable from other pine species and other forest types . If Lidar can be linked to meaningful measures of structure, it will greatly enhance habitat evaluation and restoration. The spectral characteristics of the hyperspectral data in the CERL project differ from the data over the SE part of the Sandhills. Data are being evaluated to determine if procedures and spectral profiling developed in this project are transportable to another area and sensor.

The methodology of using remote sensing data to map land cover and habitat types can lead to production of valuable tools for land managers and researchers concerned with wildlife habitat conservation and restoration.

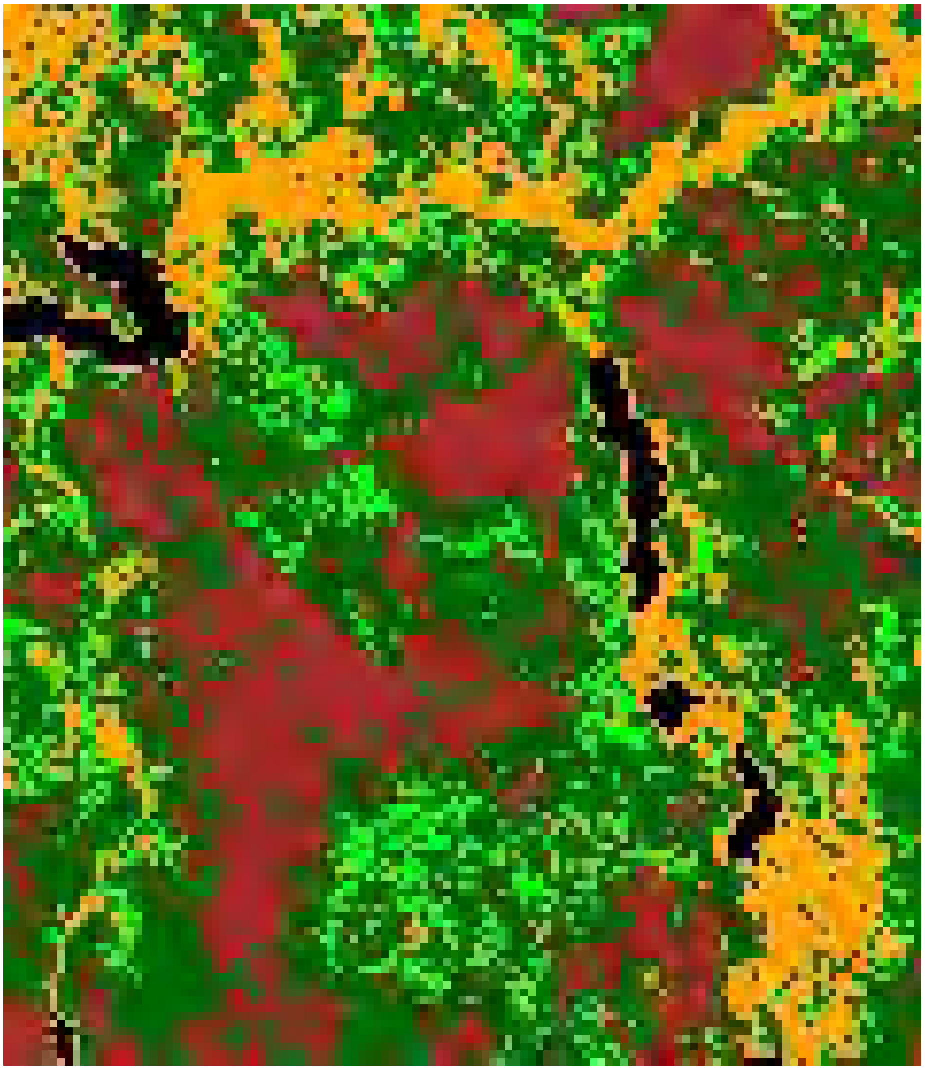
Figure 9. Classification of Longleaf and other pines using hyperspectral data.



Hymap Classification	
Longleaf	
Loblolly	
Hardwood	
Ground Cover	
Bare Earth	
Water	

Figure 10. Landsat TM image window covering the same area as the hyperspectral image. Window size is approximately 3.5 km on a side (12 sq km).

Figure 11. Classification of Landsat TM data for the same area as the hyperspectral image. There is confusion between pine species and individual crowns in open stands of longleaf pine are not mapped.



TM Classification	
Longleaf	
Loblolly	
Hardwood	
Ground Cover	
Bare Earth	
Water	