A Standardized, Cost-Effective, and Repeatable Remote Sensing Methodology to Quantify Forested Resources in Texas

Dan Unger, James Kroll, I-Kuai Hung, Jeffrey Williams, Dean Coble, and Jason Grogan

ABSTRACT

A standardized remote sensing methodology was evaluated for its use in quantifying the forested resources of the state of Texas in a timely and cost-effective manner. Landsat data from 2002 were used to create a land cover base map encompassing a four-county study area in East Texas. Site-specific and non-site-specific accuracy assessments of the classified map indicate that overall the 2002 base map accuracy of 72.78% was within acceptable remote sensing standards for Landsat data and that forest cover types derived from 2002, 1987, and 1980 Landsat data were within 4.4, 0.5, and 7.4% agreement with Forest Inventory and Analysis Program data collected in 1988, 1988, and 1980 respectively. A classified image representing five age class distributions for all forest cover types, derived through a Boolean manipulation of forest cover type maps from 2002, 1997, 1992, 1987, 1984, 1980, and 1974, indicates that overall map accuracy for age class distributions based on 30-m Landsat data from 1974 through 2002 was 58.69%. Overall, results indicate that remote sensing in conjunction with ground truthing can accurately quantify forest composition and age distributions using standardized and readily available data.

Keywords: Landsat, land cover, forest, accuracy, Forest Inventory and Analysis

Accurate quantification and qualification of forest resources is crucial not only because resources can be managed wisely if timely and accurate information is provided to a land manager but also because the information derived from a forest resource assessment is important to the economic development and sustainability of any forestry-based community. Prior quantification and qualification of forest resources in East Texas have relied on measurements taken at field plots recorded by either the Texas Forest Service or the US Forest Service via the Southern Forest Inventory and Analysis program. However, for field plot measurements to be effective with respect to time and cost, plots must be physically located and data must be collected and analyzed in a timely manner. Inaccessible or remote areas, required to validate sampling procedures, may prove difficult to measure.

Satellite-based remote sensing, which has the ability to acquire information about Earth's resources from a distance, can provide a land manager accurate information concerning forested resources in a more timely manner because of its high temporal resolution and synoptic perspective (Campbell 2002). Satellite-based remotely sensed data for natural resources, available since 1972 (Lauer et al. 1997), can provide a historical perspective of resources, as well as forest composition maps (Jensen 2005), forest age class assessments (Sader et al. 2003), and biometric measurements, in a timely and repetitive manner (Lefsky et al. 1999). Products derived from satellite imagery provide a land manager not only with specific information concerning land cover, age class distributions, and site-specific biometrics but with the spatial extent and interconnectivity of these crucial resources.

Methods

This study was undertaken to assess the value of remotely sensed satellite data for rapid assessment of forest resource attributes in East Texas. Specific project objectives, adopted from a pilot study in Mississippi (Londo et al. 2001, Parker et al. 2005), were to develop a methodology for mapping the forest resources of East Texas into current forest composition by cover type and classification of forest classes by age class distribution. Constraints for the derived methodology dictated that quantification of forest cover types and age class distributions must be derived using standardized and readily available data, must be repeatable in a timely manner, and must be cost-effective.

The remote sensing methodology was tested in a four-county area of East Texas encompassing Nacogdoches, Angelina, Shelby, and San Augustine counties. The remote sensing-based methodology was divided into two distinct phases. Phase one involved the production of a forestland cover map, and phase two involved creation of an age class distribution map stratified by forest cover type for the four-county area.

Received March 20, 2007; accepted December 11, 2007.

Dan Unger (unger@sfasu.edu), Arthur Temple College of Forestry & Agriculture, Stephen F. Austin State University, East College at Raguet St., Box 6109, SFA Station, Nacogdoches, TX 75962-6109. James Kroll, I-Kuai Hung, Jeffrey Williams, Dean Coble, and Jason Grogan, Stephen F. Austin State University, Nacogdoches, TX 75962-6109. *We acknowledge help received from Dr. David Evans from Mississippi State University in formulating remote sensing methodology applied within this project. This project was funded by a grant received from the state of Texas.*

Copyright © 2008 by the Society of American Foresters.

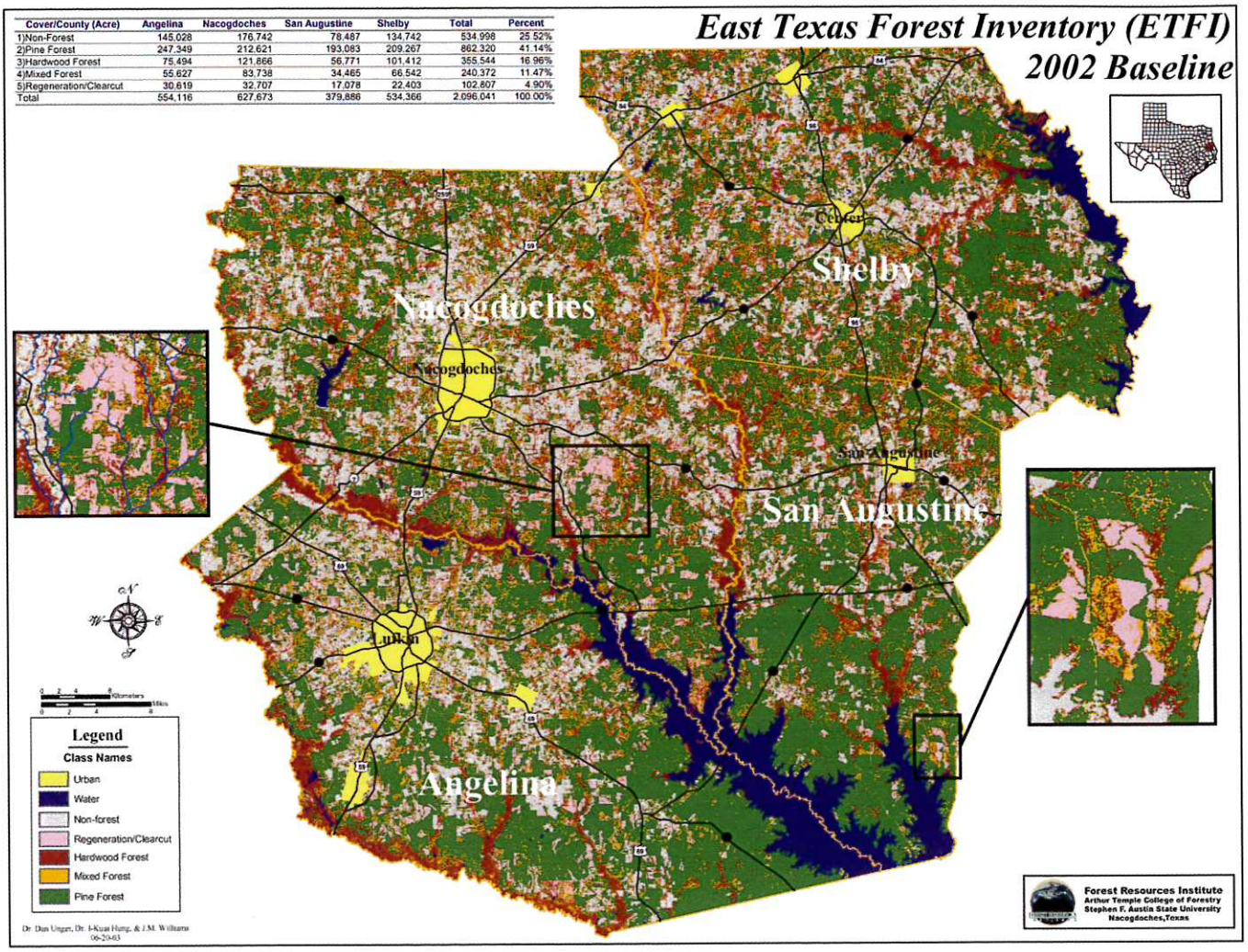


Figure 1. Land cover base map for the 2002 four-county area.

Phase One

Twenty-two geometrically corrected Landsat scenes, consisting of 2 Landsat ETM+ scenes, 11 Landsat TM scenes, and 9 Landsat MSS scenes, encompassing the four-county project area were acquired from the US Geological Survey's EROS Data Center in Sioux Falls, SD. Scenes acquired involved obtaining leaf-on (summer) and leaf-off (winter) scenes approximately every 5 years from 1974 through 2002. Dates for image acquisition included 2002, 1997, 1992, 1987, 1984, 1980 and 1974. A visual assessment of each image was performed to determine image quality and to verify general geometric accuracy. A combination of winter and summer scenes was used to produce a composite image per average 5-year cycle to aid in classification differentiation of hardwood areas.

Each image was radiometrically corrected via histogram subtraction to decrease atmospheric haze and provide the classification software with imagery representing a truer spectral signature of feature objects (Teillet 1986, Jensen 2005). In addition, any clouds present in the imagery were removed and replaced with clear imagery from a similar acquisition date and solar zenith angle.

All imagery was acquired precision terrain corrected to the Universal Transverse Mercator coordinate system using a 30-m pixel. Verification of image registration was obtained via a visual assessment by comparing each image, assumed to be the most current leaf-off scene from 2002, to a project base map composed of Texas Digital Orthographic Quarter Quadrangles from the Texas Natural Resources Information System Strategic Mapping (StratMap) program, at 30 systematically chosen points within each image. In addition, to minimize confusion in the classification process between rural and urban forest cover types, all pixels falling within an urban environment were masked using shape files obtained from the StratMap political boundary data set to increase classification accuracy.

Summer and winter scenes for 2002, representing the most currently available data for the study area, were combined to create a composite image that then was classified into 100 initial classes using unsupervised classification methodology (Jahne 2001, Campbell 2002, Jensen 2005). Constraints in the classification procedure called for 100 classification clusters, a convergence threshold of 97.5% and 50 iterations to ensure that the convergence threshold stopped the iterative self-organizing data analysis technique classification procedure and not the number of classification iterations. The 100 initial classes then were recoded to represent five distinct cover types of interest: nonforest, regeneration, pine, hardwood, and mixed pine-hardwood forest in the project area (Figure 1).

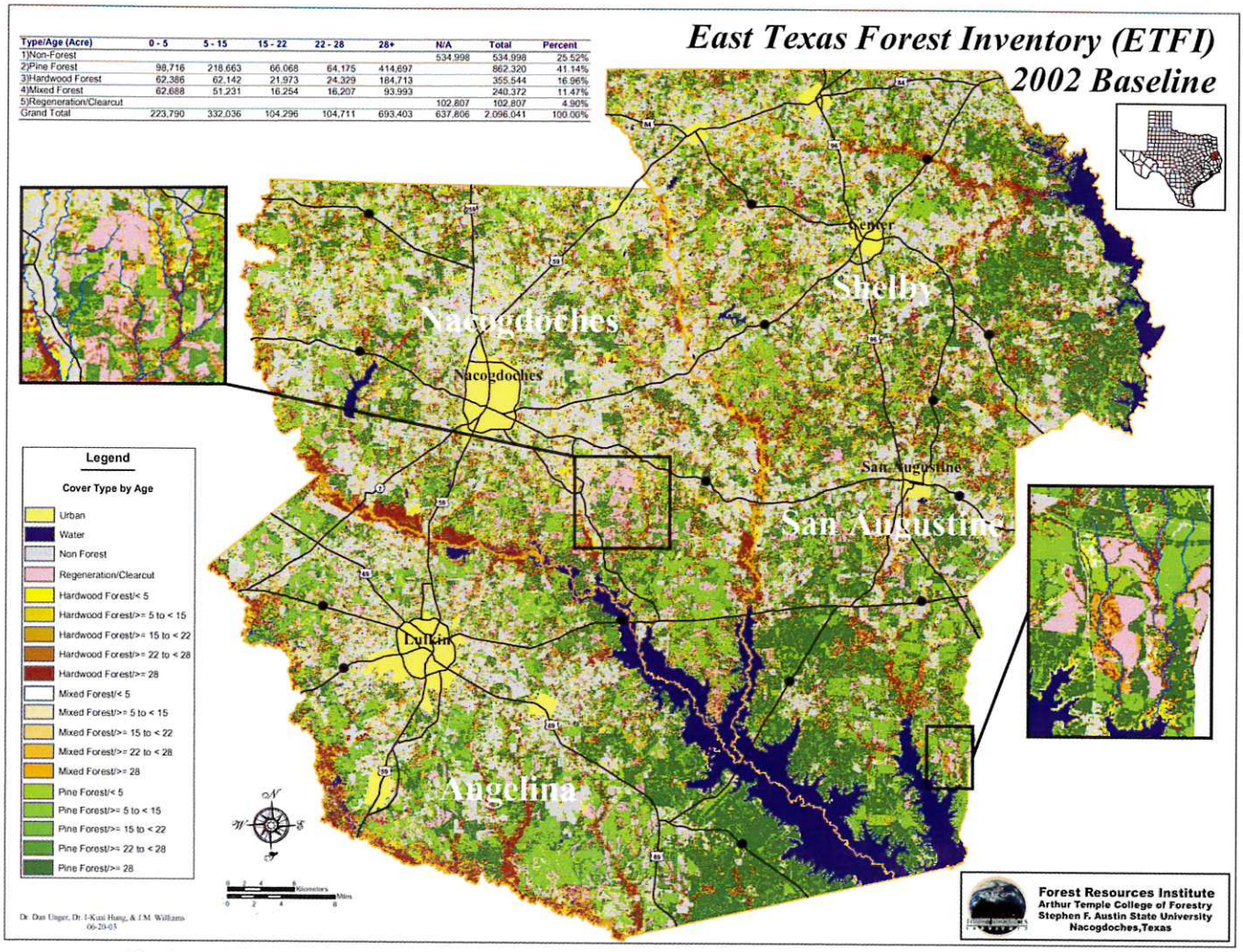


Figure 2. Map of land cover stratified by age class distributions for the four-county area.

Table 1. Summary of acres per cover type for the 2002 four-county land cover base map.

County and Cover	Acreage	Percentage	Overall percentage
Angelina			
Nonforest	145,028	26.17	6.92
Pine forest	247,349	44.64	11.80
Hardwood forest	75,494	13.62	3.60
Mixed forest	55,627	10.04	2.65
Regeneration	30,619	5.53	1.46
Total	554,116	100.00	26.44
Nacogdoches			
Nonforest	176,742	28.16	8.43
Pine forest	212,621	33.87	10.14
Hardwood forest	121,866	19.42	5.81
Mixed forest	83,738	13.34	4.00
Regeneration	32,707	5.21	1.56
Total	627,673	100.00	29.95
San Augustine			
Nonforest	78,487	20.66	3.74
Pine forest	193,083	50.83	9.21
Hardwood forest	56,771	14.94	2.71
Mixed forest	34,465	9.07	1.64
Regeneration	17,078	4.50	0.81
Total	379,886	100.00	18.12
Shelby			
Nonforest	134,742	25.22	6.43
Pine forest	209,267	39.16	9.98
Hardwood forest	101,412	18.98	4.84
Mixed forest	66,542	12.45	3.17
Regeneration	22,403	4.19	1.07
Total	534,366	100.00	25.49
Four-county			
Nonforest	534,998		25.52
Pine forest	862,320		41.14
Hardwood forest	355,544		16.96
Mixed forest	240,372		11.47
Regeneration	102,807		4.90
Grand total	2,096,041		100.00

Table 2. Site-specific accuracy assessment report for the 2002 four-county base map.

Class	Reference					Total	User's	κ
	Nonforest	Pine	Hardwood	Mixed	Regeneration			
Angelina								
Nonforest	18	1	2	1	8	20	90.00%	87.96%
Pine	1	46	2			65	70.77%	51.28%
Hardwood			20			20	100.00%	100.00%
Mixed	1	5	6			15	20.00	22.67%
Regeneration	2				8	10	80.00	78.69%
Total	22	52	28		8	130	Overall	Overall
Producer's	81.82%	88.46%	71.43%	15.00%	100.00%		73.08%	62.52%
Nacogdoches								
Nonforest	19			1		20	95.00%	94.14%
Pine		35	1	15		51	68.63%	53.12%
Hardwood		1	27	1		29	93.10%	90.36%
Mixed		7	9	4		20	20.00%	23.17%
Regeneration					10	10	100.00%	100.00%
Total	19	43	37	21	10	130	Overall	Overall
Producer's	100.00%	81.40%	72.97%	19.05%	100.00%		73.08%	64.27%
San Augustine								
Nonforest	19	1				20	95.00%	93.96%
Pine		55	1	12		68	80.88%	61.76%
Hardwood			17	2		19	89.47%	87.41%
Mixed		8	3	1		12	8.33%	8.55%
Regeneration	3				6	9	66.67%	65.03%
Total	22	64	21	15	6	128	Overall	Overall
Producer's	86.36%	85.94%	80.95%	6.67%	100.00%		76.56%	64.96%
Shelby								
Nonforest	20					20	100.00%	100.00%
Pine		39	1	15		55	70.91%	54.98%
Hardwood		4	22	1		27	81.48%	74.39%
Mixed	1	3	12	2		18	11.11%	12.15%
Regeneration	3		1		6	10	60.00%	58.06%
Total	24	46	36	18	6	130	Overall	Overall
Producer's	83.33%	84.78%	61.11%	11.11%	100.00%		68.46%	56.20%
Four-county								
Nonforest	76	2		2		80	95.00%	93.99%
Pine	1	175	5	58		239	73.22%	55.68%
Hardwood		5	86	4		95	90.53%	87.61%
Mixed	2	23	30	10		65	15.38%%	17.75%
Regeneration	8		1		30	39	76.92%	75.50%
Total	87	205	122	74	30	518	Overall	Overall
Producer's	87.36%	85.37%	70.49%	13.51%	100.00%		72.78	62.51%

Table 3. Non-site-specific accuracy assessment report for the 2000 four-county base map.

County and Cover	Acreage in 1,000s		Cover	Acreage in 1,000s			
	Landsat 2002	FIA 1988		Landsat 1987	FIA 1988	Landsat 1980	FIA 1980
Nacogdoches							
Nonforest	193	221	Nonforest	233	221	257	188
Pine	227	158					
Hardwood	121	148	Forest	394	380	371	413
Mixed	58	74					
Total	599	601	Total	627	601	628	601
Angelina							
Nonforest	156	135	Nonforest	189	135	208	129
Pine	260	225					
Hardwood	71	46	Forest	364	374	346	387
Mixed	41	103					
Total	528	509	Total	553	509	554	516
Shelby							
Nonforest	149	148	Nonforest	165	148	193	157
Pine	223	109					
Hardwood	100	173	Forest	369	358	341	350
Mixed	45	76					
Total	517	506	Total	534	506	534	507
San Augustine							
Nonforest	84	52	Nonforest	105	52	107	47
Pine	205	178					
Hardwood	56	85	Forest	275	284	273	288
Mixed	20	21					
Total	365	336	Total	380	336	380	335
Four-county							
Nonforest	582	556	Nonforest	692	556	765	521
Pine	915	670					
Hardwood	348	452	Forest	1,402	1,396	1,331	1,438
Mixed	164	274					
Total	2,009	1,952	Total	2,094	1,952	2,096	1,959

Table 4. Summary of acres per cover type stratified by age class. NA, not applicable.

County and Cover	Age (years) 0–5	5–15	15–22	22–28	28+	NA	Total	Percentage	Overall percentage
Angelina				(ac)					
Nonforest						145,028	145,028	26.17	6.92
Pine forest	27,804	66,180	20,249	17,616	115,499		247,349	44.64	11.80
Hardwood forest	11,274	12,850	4,359	4,320	42,691		75,494	13.62	3.60
Mixed forest	13,742	11,817	3,932	4,019	22,116		55,627	10.04	2.65
Regeneration						30,619	30,619	5.53	1.46
Total	52,821	90,847	28,540	25,955	180,306	175,646	554,116	100.00	26.44
Nacogdoches									
Nonforest						176,742	176,742	28.16	8.43
Pine forest	29,193	60,153	18,569	17,516	87,190		212,621	33.87	10.14
Hardwood forest	24,365	22,133	8,820	9,280	57,269		121,866	19.42	5.81
Mixed forest	23,017	19,045	6,419	5,793	29,464		83,738	13.34	4.00
Regeneration						32,707	32,707	5.21	1.56
Total	76,575	101,331	33,808	32,589	173,923	209,448	627,673	100.00	29.95
San Augustine									
Nonforest						78,487	78,487	20.66	3.74
Pine forest	18,751	44,701	10,990	11,949	106,693		193,083	50.83	9.21
Hardwood forest	8,435	8,957	1,899	3,934	33,546		56,771	14.94	2.71
Mixed forest	8,293	6,453	1,355	2,180	16,185		34,465	9.07	1.64
Regeneration						17,078	17,078	4.50	0.81
Total	35,478	60,111	14,244	18,063	156,424	95,566	379,886	100.00	18.12
Shelby									
Nonforest						134,742	134,742	25.22	6.43
Pine forest	22,968	47,629	16,261	17,094	105,315		209,267	39.16	9.98
Hardwood forest	18,312	18,203	6,895	6,794	51,208		101,412	18.98	4.84
Mixed forest	17,636	13,915	4,548	4,216	26,227		66,542	12.45	3.17
Regeneration						22,403	22,403	4.19	1.07
Total	58,916	79,747	27,704	28,104	182,750	157,145	534,366	100.00	25.49
Four-county									
Nonforest						534,998	534,998		25.52
Pine forest	98,716	414,697	218,	663	64,175		862,320		41.14
Hardwood forest	62,386	184,713	62,142	21,973	24,329		355,544		16.96
Mixed forest	62,688	93,993	51,231	16,254	16,207		240,372		11.47
Regeneration						102,807	102,807		4.90
Grand total	223,790	693,403	332,036	104,296	104,711	637,806	2,096,041		100.00
	10.68%	33.08%	15.84%	4.98%	5.00%	30.43%	100.00%		

Accuracy of the 2002 baseline cover type map was assessed through a traditional site-specific error matrix by comparing in situ land cover assessment with corresponding land classifications at 518 stratified points in the four-county area (Congalton et al. 1983, Congalton 1991). To verify classification methodology and to assess relative accuracy of overall acreage (hectares), a non-site-specific assessment described by Campbell (2002) was performed by comparing classified forested acreage totals to forest acreage assessment data obtained from US Forest Service Forest Inventory and Analysis (FIA) program for the four-county area.

Phase Two

In addition to creating a base map consisting of present land cover, the age distribution of each land cover category is also of paramount importance to any land manager. The physical creation of an age class distribution map for each forestland cover type derived in the 2002 land cover base map (i.e., pine, hardwood, and mixed pine-hardwood) involved first combining the winter and summer scenes for each approximately 5-year interval, represented by image acquisition dates (i.e., 1997, 1992, 1987, 1984, 1980, and 1974). Once combined per approximately 5-year interval, each combined image then was classified into 100 initial classes using traditional unsupervised classification methodology (Jahne 2001, Campbell 2002, Jensen 2005). Constraints in the classification procedure called for 100 classification clusters with a percentage breakdown of 97.5% and 50 iterations to ensure that the number of iterations stopped the iterative ISODATA classification procedure.

Once classified, all 100 initial classification categories then were recoded into two unique classes, creating binary maps representing forest (value = 1) or nonforest (value = 0) pixels. The binary maps of forest/nonforest pixels for each approximately 5-year interval, as well as the 2002 baseline forest cover type map recoded to a forest/nonforest bitmap condition, were then imported into a spatial model created to identify the age of each individual pixel (ERDAS 1997). The spatial model identified the age of each pixel through Boolean manipulation, whereby if the value of any given pixel location remained a constant value of forest over time (value = 1), pixel age then must be equal to or greater than the date of the oldest available satellite imagery for the project. Conversely, if a mid-aged pixel was identified as a nonforest pixel, the spatial model via Boolean manipulation would identify the age of that pixel location as the age associated with the next available date for a forest pixel for that given location (ERDAS 1997).

The spatial model, via its Boolean manipulations, created seven age class distributions within the project area corresponding to the approximately 5-year intervals. All seven age classes then were recoded to create five age class distributions representing age classes that best represent the growing stages of forest resources in East Texas. Final age class distributions represented forest conditions less than 5 years old, 5 to less than 15 years old, 15 to less than 22 years old, 22 to less than 28 years old, and greater than or equal to 28 years of

Table 5. Site-specific accuracy assessment report for land cover age class distributions.

Class	Reference							Total	User's	κ
	Nonforest	Regeneration	0–5/0–7 years	5–15/8–14 years	15–22/15–20 years	22–28/21–28 years	28+ years			
Angelina										
Nonforest	19		1					20	95.00%	93.81%
Regeneration	2	8						10	80.00%	78.69%
0–5/0–7	1		2	6		1		10	20.00%	16.80%
5–15/8–14	1			3	10 1		3	18	16.67%	5.80%
15–22/15–20	1				8	2	3	14	57.14%	48.41%
22–28/21–28						2	1	3	66.67%	64.48%
28+	1		2	6	4	2	40	55	72.73%	57.28%
Total	25	8	5	15	22	8	47	130	Overall	Overall
Producer's	76.00%	100.00%	40.00%	20.00%	36.36%	25.00%	85.11%		63.08%	52.30%
Nacogdoches										
Nonforest	20							20	100.00%	100.00%
Regeneration		10						10	100.00%	100.00%
0–5/0–7			1	8				9	11.11%	3.70%
5–15/8–14				4	7		5	16	25.00%	14.47%
15–22/15–20				2	2	6	4	14	14.29%	6.36%
22–28/21–28			1		1		3	5	0.00%	-6.56%
28+			8	2	1	2	43	56	76.79%	59.76%
Total	20	10	10	16	11	8	55	130	Overall	Overall
Producer's	100.00%	100.00%	10.00%	25.00%	18.18%	0.00%	78.18%		61.54%	49.14%
San Augustine										
Nonforest	19		1					20	95.00%	93.96%
Regeneration	3	6						9	66.67%	65.03%
0–5/0–7			1	6	2		1	10	10.00%	4.79%
5–15/8–14				2	10	1	1	14	14.29%	2.91%
15–22/15–20				2	2	3	4	11	18.18%	4.79%
22–28/21–28						3	4	7	42.86%	37.48%
28+			5	5	4	4	39	57	68.42%	48.83%
Total	22	6	7	15	18	11	49	128	Overall	Overall
Producer's	86.36%	100.00%	14.29%	13.33%	11.11%	27.27%	79.59%		56.25%	42.85%
Shelby										
Nonforest	20							20	100.00%	100.00%
Regeneration	3	6					1	10	60.00%	58.06%
0–5/0–7	1			2				3	0.00%	−11.11%
5–15/8–14			1	2	6	1		10	20.00%	11.86%
15–22/15–20					5	5	8	18	27.78%	17.64%
22–28/21–28				1		1	4	6	16.67%	9.72%
28+			12	7	5	3	36	63	57.14%	31.22%
Total	24	6	13	12	16	10	49	130	Overall	Overall
Producer's	83.33%	100.00%	0.00%	16.67%	31.25%	10.00%	73.47%		53.85%	38.90%
Four-county										
Nonforest	78		2					80	97.50%	96.97%
Regeneration	8	30					1	39	76.92%	75.50%
0–5/0–7	2		4	22	2	1	1	32	12.50%	6.16%
5–15/8–14	1		1	11	33 3		9	58	18.97%	8.75%
15–22/15–20	1			4	17	16	19	57	29.82%	19.40%
22–28/21–28			1	1	1	6	12	21	28.57%	23.08%
28+	1		27	20	14	11	158	231	68.40%	48.52%
Total	91	30	35	58	67	37	200	518	Overall	Overall
Producer's	85.71%	100.00%	11.43%	18.97%	25.37%	16.22%	79.00%		58.69%	45.82%

age. In addition to creating five distinct forestland cover age classes, the spatial model also was written so that the most recent forest binary map from 1997 was combined with the nonforest land cover portion from the 2002 land cover base map to derive a forest regeneration category. These were defined as areas considered forest in 1997 but classified as nonforest in 2002.

The 2002 baseline land cover map was combined with the map of five distinct age classes of forestland cover to derive a final age distribution per cover type that encompassed 19 classes: urban, water, nonforest, regeneration, and five unique age classes per pine, hardwood, and mixed pine-hardwood forest cover type (Figure 2). The accuracy of the age class distribution map was assessed through a traditional site-specific error matrix by comparing in situ age assessments with corresponding Boolean-derived age at 518 stratified points in the four-county area (Congalton et al. 1983, Congalton 1991).

Results and Discussion

Results from the phase 1 land cover classification indicated that the four-county project area encompasses 2,096,041 ac (848,600 ha), with pine being the dominant forest cover type in each of the four counties, encompassing 862,320 ac (349,117 ha) or 41.41% of the land cover within the four-county study area (Table 1). The site-specific accuracy assessment indicated that the 2002 land cover map had an overall accuracy of 72.78%; variable user and producer accuracies per individual cover type ranging from 13.51 to 100%, and a κ statistic of 62.51%, suggesting that the accuracy of the baseline map was 62.51%, better than one would expect by chance (Table 2). Results from the non-site-specific accuracy assessment by comparing the 2002 classified map data with FIA inventory assessments indicated that the 2002 baseline forest acreage was within 4.4% agreement with 1988 FIA acreage

Table 6. Acreage comparison between inside and outside national forest boundaries.

Administration and Cover	Age (years) 0–5	5–15	15–22	22–28	28+	N/A	Total	Percentage
				(ac)				
Angelina Forest								
Nonforest						88,264	88,264	25.16
Pine forest	13,951	36,726	8,870	12,557	118,860		190,964	54.43
Hardwood forest	4,278	5,461	874	2,401	25,543		38,558	10.99
Mixed forest	4,747	3,238	750	1,282	10,563		20,580	5.87
Regeneration						12,507	12,507	3.56
Total	22,977	45,425	10,494	16,241	154,965	100,771	350,873	100.00
Sabine Forest								
Nonforest						39,239	39,239	21.10
Pine forest	6,204	14,088	5,142	7,562	58,883		91,878	49.40
Hardwood forest	3,695	4,543	1,406	2,413	18,965		31,021	16.68
Mixed forest	3,263	2,748	871	1,149	8,686		16,718	8.99
Regeneration						7,128	7,128	3.83
Total	13,162	21,379	7,419	11,124	86,533	46,367	185,984	100.00
Two forests combined								
Nonforest						127,503	127,503	23.75
Pine forest	20,155	50,813	14,012	20,119	177,743		282,843	52.68
Hardwood forest	7,973	10,005	2,280	4,814	44,507		69,579	12.96
Mixed forest	8,011	5,986	1,621	2,431	19,248		37,298	6.95
Regeneration						19,635	19,635	3.66
Total	36,139	66,805	17,913	27,365	241,499	147,137	536,857	100.00
	6.73%	12.44%	3.34%	5.10%	44.98%	27.41%	100.00%	
Non-national forest								
Nonforest						407,495	407,495	26.14
Pine forest	78,561	167,850	52,057	44,056	236,953		579,477	37.17
Hardwood forest	54,413	52,137	19,693	19,515	140,206		285,964	18.34
Mixed forest	54,677	45,244	14,633	13,776	74,745		203,074	13.02
Regeneration						83,173	83,173	5.33
Total	187,651	265,231	86,383	77,347	451,904	490,668	1,559,184	100.00
	12.04%	17.01%	5.54%	4.96%	28.98%	31.47%	100.00%	
Four-county overall								
Nonforest						534,998	534,998	25.52
Pine Forest	98,716	218,663	66,068	64,175	414,697		862,320	41.14
Hardwood Forest	62,386	62,142	21,973	24,329	184,713		355,544	16.96
Mixed Forest	62,688	51,231	16,254	16,207	93,993		240,372	11.47
Regeneration						102,807	102,807	4.90
Grand Total	223,790	332,036	104,296	104,711	693,403	637,806	2,096,041	100.00
	10.68%	15.84%	4.98%	5.00%	33.08%	30.43%	100.00%	

National forest areas include only the portions located within the four-county study area. They comprise 25% of the four-county land.

data, 1987 classified forest acreage was within 0.5% agreement with 1988 FIA acreage data, and 1980 classified forest acreage was within 7.4% agreement with 1980 FIA acreage data (Table 3).

Results from the phase 2 age class assessment indicated that pine was the dominant cover type within each county and that the overriding age of the majority of any given forest cover type was greater than or equal to 28 years (Table 4). Results from the site-specific age class accuracy assessment indicated that the age class distribution map had an overall accuracy of 58.69%, variable user and producer accuracies per individual age class ranging from 11.43 to 100%, and a κ statistic of 45.82%. This indicated that the accuracy of the age class distribution per cover type classification category was 45.82%, better than one would expect by chance but not sufficient for land managers to have confidence in the results at the local level and in particular with stands less than 28 years old (Table 5).

In addition to land cover classification and age class assessment, value-added analysis to provide a land manager with information relative to site-specific decisions involved stratifying the acreage within each cover type by age between inside and outside national forest boundaries to ascertain location differences in forest cover types and age by administration boundaries (Table 6). Results indicated that 389,720 ac (157,781 ha), or 26.7% of the 1,458,236 ac (590,378 ha) of forestland in the four-county study area, lies within the boundaries of the Angelina and Sabine National Forests. Within the two national forests, 241,499 ac (97,773 ha), or 61.9%, of national forestland was classified as forest at least 28 years old. This is consistent with historic forest management for these areas.

An analysis of acreage between federal land and nonfederal land (Table 7) indicated that pine forest occupied 78.05% of federal land, with hardwood forest occupying the second most dominant acreage at 13.55%. With respect to nonfederal land, pine still was the dominant cover type at 37.35%, but hardwood forest and mixed hardwood-pine forest occupied a more dominant percentage of forestland compared with federal land, with 17.31% and 12.25% of the nonfederal land mass respectively. An analysis of diversity and evenness (Magurran 1988, Zar 1998) between federal and nonfederal land within the four-county area indicated that the nonfederal land was more diverse and had a more evenly distributed acreage of cover types across all five age class distributions than the federal land within the Angelina and Sabine National Forests in East Texas (Figure 3; Table 8). Again, this is supported by historical information on National Forest management in Texas.

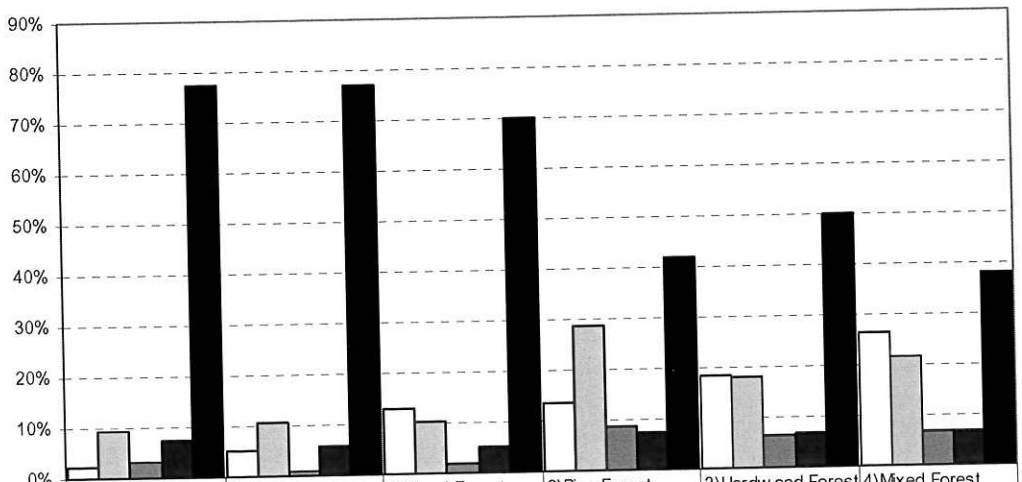
Table 7. Acreage comparison between federal and nonfederal land. NA, not applicable.

Ownership and Cover	Age (years) 0–5	5–15	15–22	22–28	28+	NA	Total	Percentage
				(ac)				
Federal–Angelina						5,505	5,505	4.27
Nonforest							99,248	77.00
Pine forest	2,198	8,463	2,778	7,217	78,592		18,722	14.52
Hardwood forest	1,105	2,110	122	1,134	14,251		4,097	3.18
Mixed forest	641	403	48	192	2,813		1,324	1.03
Regeneration						1,324	128,896	100.00
Total	3,945	10,975	2,948	8,543	95,656	6,830		
Federal–Sabine						1,191	1,191	1.80
Nonforest							52,953	80.11
Pine forest	1,403	5,789	2,144	4,287	39,331		7,701	11.65
Hardwood forest	298	741	133	426	6,104		3,440	5.20
Mixed forest	321	386	88	185	2,460		812	1.23
Regeneration						812	66,096	100.00
Total	2,021	6,916	2,365	4,898	47,895	2,002		
All federal						6,696	6,696	3.43
Nonforest							152,200	78.05
Pine forest	3,601	14,251	4,921	11,503	117,923		26,423	13.55
Hardwood forest	1,402	2,850	255	1,560	20,355		7,537	3.87
Mixed forest	962	789	136	378	5,273		2,136	1.10
Regeneration						2,136	194,992	100.00
Total	5,966	17,891	5,312	13,441	143,551	8,832		
	3.06%	9.18%	2.72%	6.89%	73.62%	4.53%	100.00%	
Nonfederal, private						528,302	528,302	27.79
Nonforest							710,119	37.35
Pine forest	95,115	204,412	61,147	52,672	296,774		329,121	17.31
Hardwood forest	60,984	59,291	21,718	22,769	164,358		232,835	12.25
Mixed forest	61,726	50,442	16,118	15,829	88,720		100,671	5.30
Regeneration						100,671	1,901,048	100.00
Total	217,824	314,145	98,983	91,270	549,852	628,974		
	11.46%	16.52%	5.21%	4.80%	28.92%	33.09%	100.00%	
Federal percentage						1.25%	1.25%	
Nonforest							17.65%	
Pine forest	3.65%	6.52%	7.45%	17.92%	28.44%		7.43%	
Hardwood forest	2.25%	4.59%	1.16%	6.41%	11.02%		3.14%	
Mixed forest	1.53%	1.54%	0.84%	2.33%	5.61%		2.08%	
Regeneration						2.08%	9.30%	
Total	2.67%	5.39%	5.09%	12.84%	20.70%	1.38%		

Federal land includes the national forest lands owned by the federal government within the four-county study area. It comprises 9.3% of the four-county land area

Conclusions

A standardized remote sensing methodology in conjunction with ground truthing, developed to quantify the forested resources of the state of Texas, was shown to be effective in a timely and cost-effective manner using standardized and readily available data. Landsat 30-m data were used to create a land cover



	Federal			Non-federal		
□ < 5	2.37%	5.31%	12.76%	13.39%	18.53%	26.51%
□ >= 5 to < 15	9.36%	10.79%	10.47%	28.79%	18.02%	21.66%
▩ >= 15 to < 22	3.23%	0.97%	1.80%	8.61%	6.60%	6.92%
■ >= 22 to < 28	7.56%	5.90%	5.01%	7.42%	6.92%	6.80%
■ >= 28	77.48%	77.04%	69.95%	41.79%	49.94%	38.10%

Figure 3. Cover type stratified by age between federal and nonfederal land.

Table 8. Proportional differences in land cover between federal and nonfederal land.

Ownership and Cover	Age (years) 0–5	5–15	15–22	22–28	28+	N/A	Total	Statistics diversity	Evenness
				.(%)					
Federal									
Nonforest	0.00	0.00	0.00	0.00	0.00	3.43	3.43		
Pine forest	1.85	7.31	2.52	5.90	60.48	0.00	78.05		
Hardwood forest	0.72	1.46	0.13	0.80	10.44	0.00	13.55		
Mixed forest	0.49	0.40	0.07	0.19	2.70	0.00	3.87		
Regeneration	0.00	0.00	0.00	0.00	0.00	1.10	1.10		
Total	3.06	9.18	2.72	6.89	73.62	4.53	100.00	H_s=1.5379	J' or $E_{H'}$0.5428
Nonfederal									
Nonforest	0.00	0.00	0.00	0.00	0.00	27.79	27.79		
Pine forest	5.00	10.75	3.22	2.77	15.61	0.00	37.35		
Hardwood forest	3.21	3.12	1.14	1.20	8.65	0.00	17.31		
Mixed forest	3.25	2.65	0.85	0.83	4.67	0.00	12.25		
Regeneration	0.00	0.00	0.00	0.00	0.00	5.30	5.30		
Total	11.46	16.52	5.21	4.80	28.92	33.09	100.00	H_s=2.3661	J' or $E_{H'}$0.8351
Federal									
Pine forest	1.93	7.66	2.64	6.18	63.34	81.76			
Hardwood forest	0.75	1.53	0.14	0.84	10.93	14.19			
Mixed forest	0.52	0.42	0.07	0.20	2.83	4.05			
Total	3.20	9.61	2.85	7.22	77.11	100.00		H_s=1.3914	J' or $E_{H'}$0.5138
Nonfederal									
Pine forest	7.48	16.07	4.81	4.14	23.33	55.82			
Hardwood forest	4.79	4.66	1.71	1.79	12.92	25.87			
Mixed forest	4.85	3.97	1.27	1.24	6.97	18.30			
Total	17.12	24.70	7.78	7.17	43.22	100.00		H_s=2.3699	J' or $E_{H'}$0.8751

base map for 2002 including forest and nonforest Boolean maps for the years 2002, 1997, 1992, 1987, 1984, 1980, and 1974. Once created, the land cover maps were shown to be effective in quantifying land cover for any given year as well as effective in stratifying land cover by age class distribution for the years analyzed.

It must be noted that there can be confusion when classifying mixed forests, resulting in a lower overall map accuracy, due to low user and producer accuracy for the mixed forest class. A field plot visited by two different survey crews with the same training could end up with different classification results if the plot is neither pure pine nor pure hardwood. The mixed forest class, with its typically low accuracy, is the gray area for forestland cover differentiation. This low accuracy is common due to the natural environment or management practices in the East Texas region. The same difficulty applies to young forests during ground truthing in determining age class since natural regeneration creates a continuum in age that may lead to confusion.

From a remote sensing perspective, there is also difficulty in assessing the age class of young forest stands due to the similar spectral signatures inherent in identifying young forests. In addition, the temporal availability of usable remotely sensed data may add to age class confusion by not providing a small enough window between image acquisition dates to accurately identify the change from preharvest to green-up of a young stand. Land managers should recognize this weakness in remotely sensed assessments compared with ground-based assessments and should recognize that any age class assessment, although usable over a large geographic area, may not be applicable for small areas. Although there are limitations in any remotely sensed derived product, the land cover map accuracies achieved following the project methodology are within acceptable standards of overall map accuracy and can be used to assess land holdings at the local and county level.

Literature Cited

CAMPBELL, J.B. 2002. *Introduction to remote sensing.* The Guilford Press, New York. 621 p.

CONGALTON, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens. Env.* 37(1):35–46.

CONGALTON, R.G., R.G. ODERWALD, AND R.A. MEAD. 1983. Assessing land classification accuracy using discrete multivariate analysis statistical techniques. *Photo. Eng. Remote. Sens.* 49(12):1671–1678.

EARTH RESOURCES DATA ANALYSIS SYSTEM (ERDAS). 1997. *ERDAS field guide.* ERDAS, Inc., Atlanta, GA. 656 p.

JAHNE, B. 2001. *Digital image processing.* Springer, New York. 555 p.

JENSEN, J.R. 2005. *Introductory digital image processing.* Prentice-Hall, Upper Saddle River, NJ. 526 p.

LAUER, D.T., S.A. MORAIN, AND V.V. SALOMONSON. 1997. The Landsat program: Its origins, evolution, and impacts. *Photo. Eng. Remote Sens.* 63:831–838.

LEFSKY, M.A., W.B. COHEN, A.T. HUDAK, S.A. ACKER, AND J.L. OHMANN. 1999. Integration of LIDAR, Landsat ETM+ and forest inventory data for regional forest mapping. *Int. Arch. Photo. Remote Sens.* 32:119–126.

LONDO, H.A., P. GLASS, D.L. EVANS, K.L. BELLI, T.G. MATNEY, R.C. PARKER, AND E. SCHULTZ. 2001. *Pilot program for a statewide forest monitoring and information system.* Spatial Information Technologies Laboratory, Department of Forestry, Mississippi State Univ., Mississippi State, MS. 29 p.

MAGURRAN, A.E. 1988. *Ecological diversity and its measurement.* Princeton Univ. Press, Princeton, NJ. 192 p.

PARKER, R.C., P.A. GLASS, H.A. LONDO, D.L. EVANS, K.L. BELLI, T.G. MATNEY, AND E.B. SCHULTZ. 2005. *Mississippi's forest inventory pilot program: Use of computer and spatial technologies in large area inventories.* Forest and Wildlife Research Center Bulletin FO-274. Mississippi State Univ., Mississippi State, MS. 43 p.

SADER, S.A., M. BERTRAND, AND E.H. WILSON. 2003. Satellite change detection of forest harvest patterns on an industrial forest landscape. *For. Sci.* 49(3):341–353.

TEILLET, P.M. 1986. Image correction for radiometric effects in remote sensing. *Int. J. Remote Sens.* 7(12):1637–1651.

ZAR, J.H. 1998. *Biostatistical analysis.* Prentice-Hall, Inc., Upper Saddle River, NJ. 929 p.