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Accuracy Assessment of Land Cover Maps of Forests within an Urban and Rural Environment

Daniel R. Unger, I-Kuai Hung, and David L. Kulhavy

Land cover maps of forests within an urban and rural environment derived from high spatial resolution multispectral data (QuickBird) and medium spatial resolution multispectral data (Landsat ETM+ and SPOT 4) were compared to ascertain whether increased spatial resolution increases map accuracy of forests and whether map accuracy varies across land cover classification schemes. It is commonly assumed that increased spatial resolution would probably increase land cover map accuracy regardless of land cover classification methodology. This study assessed whether that assumption is correct within a rural and an urban environment. Map accuracy for modified National Land Cover Data (NLCD) 2001 Level II, Level I, and Unique (a modified NLCD 2001 Level II and Level I combination) shows that 30-m Landsat ETM+ data had the highest overall map accuracy for rural, urban, and combined rural/urban land cover maps. Analysis of user's and producer's accuracies shows that Landsat ETM+ data had higher levels of producer's accuracy of >90.0% for the coniferous cover type for modified NLCD 2001 Level II and Unique, excluding one instance for which SPOT 4 had a user's accuracy of 98.5% for the rural coniferous cover type. Modified NLCD 2001 Level I Landsat ETM+ data had user's and producer's accuracies for a homogeneous forest cover type of 98.4 and 90.6%, respectively. Landsat ETM+ data also outperformed SPOT 4 and QuickBird within an urban environment, creating the only map products with forest cover type user's and producer's accuracies of >90.0%.

Keywords: accuracy, forests, Landsat, SPOT, QuickBird

The ability to accurately create land cover maps of forests is crucial. Quantitative real-world information derived from these forestland cover maps, which can contain both an urban and a rural component, is used in management plans to solve problems and address issues and concerns that forest managers face on a daily basis. The question that most practicing foresters must face is how to create the most accurate land cover maps possible while maintaining cost effectiveness and efficiency.

Satellite-based remote sensing technology, starting with the launch of Landsat 1 in 1972, has been used over the last 40 years to map and monitor earth resources from a distance. Satellite-based remote sensors capture electromagnetic energy that has been reflected or emitted from objects on the surface of the earth. Because each object has its own unique characteristics of reflected and emitted electromagnetic radiation, depending on its physical makeup and environmental condition, each object's spectral signature will allow for the classification or categorization of digital imagery into like objects or classes such as forests or grasslands. The advantage of satellite-based platforms in mapping earth resources via the classification of digital imagery is that a satellite provides a large synoptic perspective of the earth surface within a single image that on a per acre basis is cheaper than traditional ground survey (Jensen 2005, Campbell 2007).

Starting with the launch of Landsat 1, the remote sensing community has observed the spatial resolution of satellite-based platforms change over the last 40 years. The spatial resolution of satellite-based multispectral digital imagery typically used to classify natural resources has ranged from 79 m for Landsat MSS (Multi-Spectral Scanner) data launched in 1972, to 30 m for Landsat TM (Thematic Mapper) data launched in 1982 and 30 m for Landsat ETM+ (Enhanced Thematic Mapper) data launched in 1999, to 20 m for SPOT 1 (Systeme Pour l'Observation de la Terre) data launched in 1986, to 10 m for SPOT 5 data launched in 2002, to 8 m for SPOT 6 data launched in 2012, to 4 m for IKONOS data launched in 1999, to 2.44 m for QuickBird data launched in 2000, and to 1.65 m for GeoEye data launched in 2008.

With the improved spatial resolution of digital imagery obtained from satellite-based platforms, will the land cover maps derived from a higher spatial resolution sensor be more accurate than those from medium spatial resolution sensors? The purpose of this research project was to compare the accuracy of land cover map products derived from three different spatial resolution sensors (ETM+ data at 30 m, SPOT 4 data at 20 m, and QuickBird data at 2.44 m) to ascertain whether increased spatial resolution increases land cover map accuracy of forest cover types with different classification schemes.

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This article uses metric units; the applicable conversion factors are: meters (m): 1 m = 3.3 ft; kilometers (km): 1 km = 0.6 mi.

Background

History of Earth Resource Satellites

In 1972, Landsat 1, also known as Landsat MSS, was launched, providing the natural resource community with a satellite dedicated to the multispectral remote sensing of earth resources. Landsat 1 at 79-m spatial resolution provided broad-scale continuous coverage of the earth's surface for the first time. Landsat data acquisition continued with the launch of Landsat 2 in 1975 and the launch of Landsat 3 in 1978 (Jensen 2005).

In 1982, Landsat 4, or Landsat TM, which carried a replacement for the MSS system flown on Landsats 1–3, was launched. Although similar to MSS data, Landsat TM had an improved multispectral spatial resolution of 30 m and included data in the far-infrared region with a spatial resolution of 120 m. With improved spatial and spectral resolution, more detailed studies of the earth surface could be conducted. Landsat 4, and later Landsat 5 launched in 1984, had an improved temporal resolution of 16 days compared with that of earlier Landsat MSS satellites at 18 days.

SPOT 1, the first in a series of SPOT satellites designed to provide medium spatial resolution multispectral data for land use studies, was launched in 1986 by the French National Center for the Study of Space in conjunction with other European agencies (Campbell 2007). The multispectral spatial resolution of SPOT 1 was 20 m, which was enhanced to 10 m with the launch of SPOT 5 in 2002 and further enhanced to 8 m with the launch of SPOT 6 in 2012.

In 1999, Landsat 7, or Landsat ETM+, was launched. Landsat ETM+ multispectral data are similar to Landsat TM data with the same spectral and temporal resolutions. The spatial resolution of far-infrared data in Landsat 7 was enhanced to 60 m and included a 15-m panchromatic band. Landsat 5 and Landsat 7 (which has a scan line failure) are no longer available, whereas Landsat 8 was recently launched in February 2013 to continue the Landsat Data Continuity Mission (LDCM).

Commercially funded satellite-based remotely sensed multispectral data programs, as opposed to previous government-funded satellite programs, came of age in 1999 with the launch of IKONOS. IKONOS multispectral data of 4-m spatial resolution are comparable to quality aerial photographs because they provide visual assessment of individual surface objects at a large scale (Brown et al. 1997). QuickBird, launched in 2000, followed IKONOS in the commercial market and increased the spatial resolution of multispectral data to 2.44 m. The spatial resolution of multispectral data from satellite-based platforms increased to 1.65 m with the launch of GeoEye in 2008.

Land Cover Classification Schemes

Land cover classification schemes categorize different surface features such as forest, wetlands, and urban areas into homogeneous blocks. Anderson et al. (1972, 1976), who proposed the first standardized land use/land cover classification system, argued that accuracy results of any derived land cover map are in large part determined by the capabilities or spatial resolution of the sensors used to create the land cover map.

In the United States, several classification schemes have been developed following the guidelines of Anderson et al. (1972). These approaches, which have included some land use/land cover mapping projects and the National Gap Analysis Program (GAP), have been conducted across the United States and have concentrated on agriculture and soil and water conservation issues (Whistler et al. 1995, Scott et al. 1996).

A more recent classification scheme is the National Land Cover Data (NLCD) 2001 project (Homer et al. 2007), which was updated in 2006 (Xian et al. 2009, Fry et al. 2011). The goal of the NLCD project is to provide a national land cover map so that data from the NLCD meet the needs of several federal agencies, including the US Geological Survey (USGS), Environmental Protection Agency (EPA), US Forest Service (USFS), Bureau of Land Management (BLM), National Oceanic and Atmospheric Administration (NOAA), and National Atmospheric and Space Administration (NASA).

Accuracy Assessment

Accuracy assessment of land use interpretation is complex, and errors can occur in the classification and identification of land cover categories. Hord and Brooner (1976), when dealing with classification errors, pointed out that land use classification categories are discrete variables and that each pixel is either correctly classified or incorrectly classified.

Hay (1979) proposed a five-question checklist in determining land cover map accuracy. To answer the five questions Hay proposed using an error matrix. The rows and columns reflect the number of sample units assigned to a category (from image classification) in relation to how many of those sample units actually belong to that category on the ground. Observations from the ground can then be compared with classifications from the imagery. Cells in the diagonal represent all correctly classified sample units. The matrix can then be used to determine the overall accuracy and correct predictions for each category and to determine whether a category is over- or underestimated.

Overall accuracy can be determined by summing the total correct samples and dividing that by the total number of samples. The proportion of sample sites correctly predicted for each category relative to ground truth data, which is also known as the producer's accuracy, can be determined, indicating what level of omission error there is in the final map. The user's accuracy, which is the proportion of the land cover map per category that has been classified correctly relative to land cover map categories, determines what level of commission error there is in the final map product. By measuring the producer's and user's accuracies, a determination can be made as to which categories have been overemphasized or underemphasized (Congalton et al. 1983, Congalton 1991, Stehman and Czaplewski 1998). Skirvin et al. (2004) provide a review of accuracy assessment of satellite-derived land cover data, whereas Zimmerman et al. (2013) state that the usefulness of a land cover map is dependent on sound accuracy assessment of the land cover classification.

Discrete multivariate analysis provides a measure that can be computed from each matrix. The resulting statistic, known as KHAT, accounts for confusion between the classes and can be summarized as the percentage correct beyond random chance assignment of classes (Jensen 2005). An additional test (Z test) allows a user to identify the statistical significance of an error matrix, typically above a confidence level of 95% (Congalton and Green 1999).

Salajanu and Olson (2001), working with Landsat and SPOT data, have shown that accuracy increases with improved spatial resolution. By limiting their assessment to the spectral bands that are similar in both Landsat and SPOT, they were able to compare the effects of spatial resolution on determining accuracy. The overall accuracy of SPOT was 91.6%, whereas that of Landsat was 89.2%.

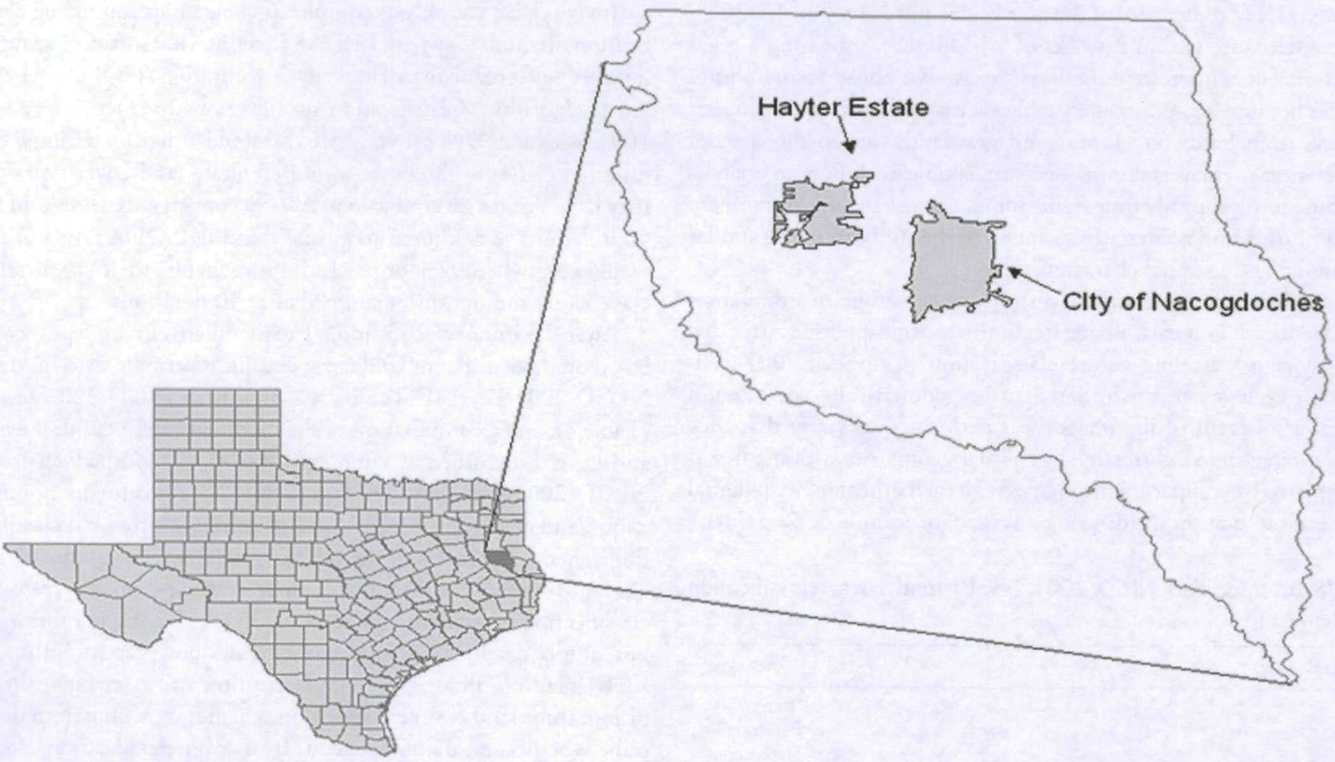

Figure 1. Location of Hayter Estate and City of Nacogdoches in East Texas.

Table 1. Landsat 7 ETM+, SPOT 4, and QuickBird satellite resolution characteristics.

Satellite	Spatial (m)	Spectral (μm)	Wavelength (light energy)	Radiometric (bits)
Landsat 7 ETM+	30	0.45–0.52	Blue	8
		0.52–0.60	Green	
		0.63–0.69	Red	
		0.76–0.90	NIR	
		1.55–1.75	MIR	
		2.35–2.80	MIR	
SPOT 4	20	0.50–0.59	Green	8
		0.60–0.69	Red	
		0.76–0.89	NIR	
QuickBird	2.44	0.45–0.52	Blue	11
		0.52–0.60	Green	
		0.63–0.69	Red	
		0.76–0.90	NIR	

MIR, mid infrared; NIR, near infrared.

Table 2. Modified NLCD 2001 Level II land cover classification system.

Class	Cover type
1	Water
2	Forest: coniferous
3	Forest: deciduous
4	Forest: mixed
5	Herbaceous: grassland/meadow
6	Herbaceous: pasture
7	Barren
8	Urban: low intensity
9	Urban: medium intensity
10	Urban: high intensity
11	Wetlands
12	Other: clouds, shadows, etc.

Salajanu and Olson integrated the original multispectral data with high spatial resolution panchromatic SPOT images. The integrated multispectral data improved the accuracy of both SPOT and Landsat by 3%.

Methods

The purpose of this study was to compare the accuracy of land cover maps of forests within both an urban and a rural environment derived from a high spatial resolution satellite (QuickBird) with that of traditional medium spatial resolution sensors (Landsat ETM+ and SPOT 4), to compare map accuracy results to ascertain whether increased spatial resolution increases map accuracy for forests, and to evaluate map accuracy results across three land cover classification schemes.

The accuracy comparison will help forest managers determine which sensor would be optimal in classifying land cover, in particular forests, within an urban versus rural setting. Two study areas were chosen for analysis based on the availability of coincident satellite imagery for land cover classification and the availability of digital imagery for an error assessment. The first study area (urban) consisted of the City of Nacogdoches in Nacogdoches County, Texas. The second study area (rural) was centered on the Hayter Estate located approximately 8 miles (14 km) northwest of Nacogdoches, Texas (Figure 1).

Three multispectral satellite data sets, Landsat 7 ETM+, SPOT 4, and QuickBird, were used to create land cover maps with spatial resolutions of 30, 20, and 2.44 m, respectively (Table 1). All available bands of data per satellite sensor identified in Table 1 were used in the creation of each land cover map. Landsat 7 ETM+ data were obtained from the Forest Resources Institute at Stephen F. Austin State University. QuickBird and SPOT 4 data were acquired from DigitalGlobe. Both the SPOT 4 and the QuickBird imagery for Nacogdoches and the Hayter Estate were acquired on Jan. 4, 2003.

Landsat ETM+ imagery of the area was acquired on Jan. 18, 2003. These dates are within 2 weeks of one another, providing a good "leaf-off" or winter scene of East Texas. We chose to use winter scenes because leaf-off imagery makes it easier to distinguish conifer forests from hardwood forests and grasslands due to the spectral differences in the vegetation. The year 2003 was chosen for analysis because it was the only time frame for imagery available, for both the classification and accuracy assessment, of the study area with similar temporal and seasonal characteristics.

To correct for radiometric distortions, a histogram subtraction was performed on each image to eliminate atmospheric scatter due to Rayleigh scattering before classification (Campbell 2007). Although each image was ordered to be geometrically corrected, a visual assessment of the images was performed to verify that they were preregistered correctly. The visual geometric assessment was completed by comparing the images with each other and with digital orthophoto quarter quads using a systematic sample of 30 points.

Table 3. Modified NLCD 2001 Level I land cover classification system.

Class	Cover type
1	Water
2	Forest
3	Herbaceous
4	Barren
5	Urban
6	Wetlands
7	Other

Table 4. User-defined Unique land cover classification system.

Class	Cover type
1	Water
2	Forest: coniferous
3	Forest: deciduous
4	Forest: mixed
5	Herbaceous
6	Barren
7	Urban
8	Wetlands
9	Other

Image classification was completed using an unsupervised classification methodology with ERDAS Imagine 10.0 software using the iterative self-organizing data analysis technique (ISODATA) clustering algorithm. Classification specifications for each image were 100 classes at a 97% convergence threshold and 50 iterations. One hundred classes were chosen to differentiate land cover types that may have similar spectral values. A 97% convergence threshold and 50 iterations were chosen to ensure that the ISODATA algorithm would stop when 97% of pixels did not change their classification class before the algorithm stopped after 50 iterations.

After the initial classification, each land cover map was recoded based on three different land cover classification systems: a modified NLCD 2001 Level II (Table 2), a modified NLCD 2001 Level I (Table 3), and a combination of the modified NLCD 2001 Level II and Level I identified as Unique (Table 4). A modified version of NLCD 2001 was chosen in lieu of NLCD 2006 for its homogeneous land cover classification categories and to provide a classification scheme representing the land cover categories unique to East Texas. Modified classification schemes were used, not to create new classification schemes to replace NLCD Level II and I in other areas, but simply to eliminate land cover classes not present within the study area to facilitate error matrix creation and assessment. In addition, three land cover classification schemes were chosen to determine whether more homogeneous land cover classification categories increased land cover map accuracy irrespective of spatial resolution size.

After the recoding of each land cover map per land cover classification scheme, a clump and eliminate operation was conducted on each land cover map to identify and eliminate island pixels. A clump and eliminate operation smoothed each image and produced clumps of at least 9 pixels to derive a homogeneous mapping size per classification. The classification process was completed on the entire scene or footprint of each sensor.

After Landsat 7 ETM+, SPOT 4, and QuickBird scenes were classified, an accuracy assessment per classified map was performed by comparing pixels in each image with corresponding high spatial resolution of 1 m multispectral imagery from the EMERGE sensor on Jan. 1, 2003. The total number of maps compared for accuracy was 27: 9 maps for modified NLCD 2001 Level II (3 combined, 3

Table 5. Error matrix example for Landsat 7 ETM+ accuracy assessment for control points selected within the Hayter Estate (rural) using modified NLCD 2001 Level II classification.

		Reference												
	Cover type	Water	Forest: coniferous	Forest: deciduous	Forest: mixed	Herbaceous: grassland	Herbaceous: pasture	Barren	Urban: low	Urban: medium	Urban: high	Wetlands	Total	User's accuracy (%)
	Water	12		4	1								17	70.6
C	Forest: coniferous		81		9				1				91	89.0
L	Forest: deciduous		2	14	2								18	77.8
A	Forest: mixed		1	3	14				1				19	73.7
S	Herbaceous: grassland					0	12						12	0.0
S	Herbaceous: pasture			8			12						20	60.0
I	Barren						2	0	1				3	0.0
F	Urban: low								0				0	NA
I	Urban: medium								1	0			1	0.0
E	Urban: high										0		0	NA
D	Wetlands											1	1	100.0
	Total	12	84	29	26	0	26	0	4	0	0	1	134	
	Producer's accuracy (%)	100.0	96.4	48.3	53.8	NA	46.2	NA	0.0	NA	NA	100.0	Overall	73.6
	κ													63.2
	Z statistic													7.17

NA, no sample points. Null hypothesis: $\kappa = 0$; if $Z >= 1.96$, then reject null hypothesis.

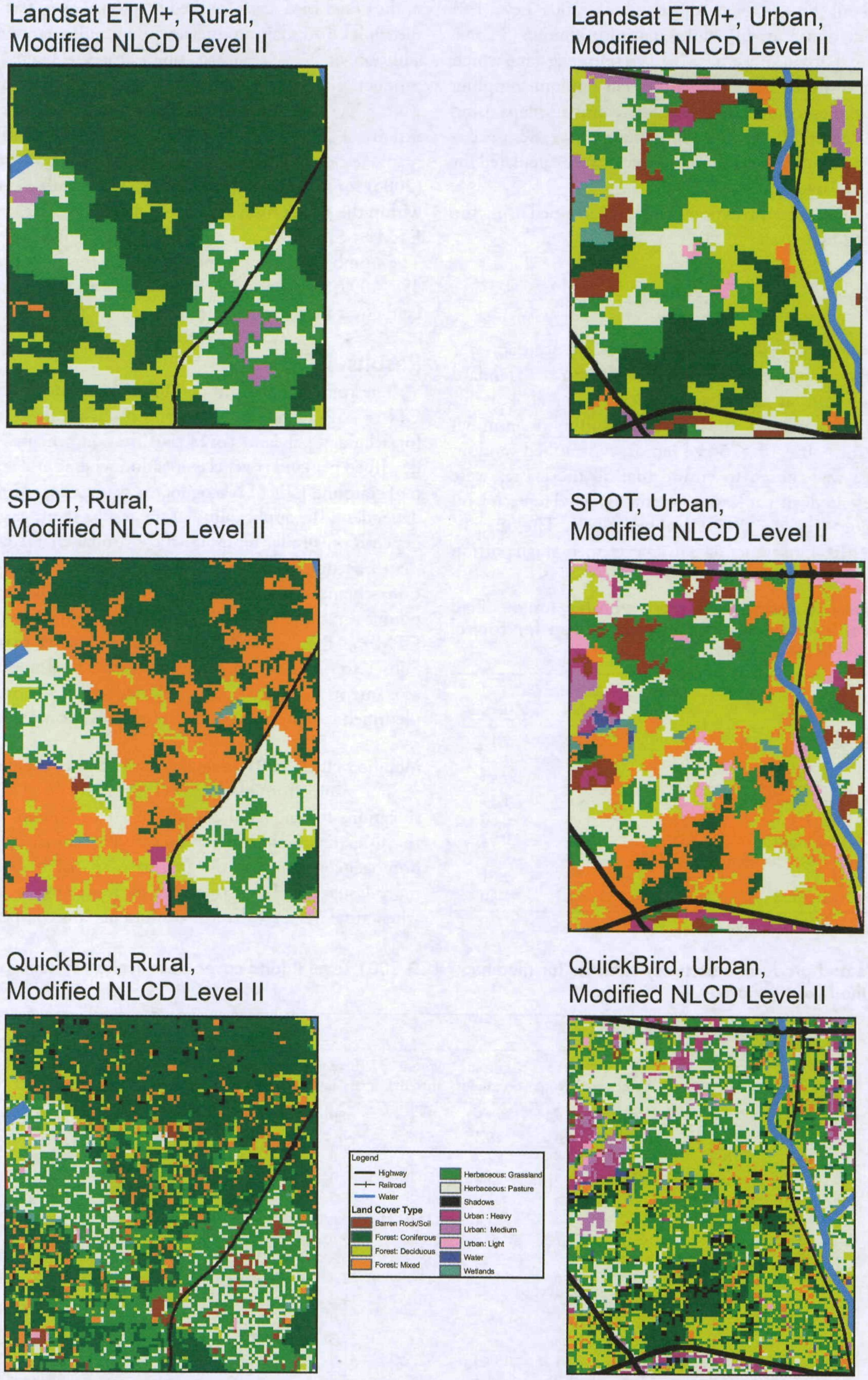

Figure 2. Land cover map subsets within Hayter Estate (rural) and City of Nacogdoches (urban) for modified NLCD 2001 Level II classification.

rural, and 3 urban); 9 maps for modified NLCD 2001 Level I (3 combined, 3 rural, and 3 urban); and 9 maps for Unique (3 combined, 3 rural, and 3 urban). In situ EMERGE reference data, which were located for control points using stratified random sampling (Hay 1979), were then compared against the classified maps using an error matrix (Jensen 2005). Overall map accuracy, user's accuracy, producer's accuracy, κ statistic, and Z score were calculated for each error matrix (Table 5).

The initial numbers of control points were determined using the equation described by Jensen (2005)

$$N = \frac{Z^2(p)(q)}{E^2}$$

where N is the sample size, p is the expected percent accuracy, q is $100 - p$, E is the allowable error, and $Z = 2$ from the standard normal deviate of 1.96 at the 95% confidence interval. For this study, p was set at 90, q at 10, and E at 2.5, resulting in an initial number of control points of 576 per sensor. A stratified random sampling scheme was chosen to ensure that all the classes were adequately represented with at least 30 points assigned to each land cover class category (Jensen 2005, Campbell 2007). The unavailability of the EMERGE reference data in an extremely small portion of the QuickBird scene resulted in fewer than 576 control points for the QuickBird map products, while simultaneously resulting in an addition of 3 extra control points for the Landsat ETM+ map products. The total numbers of control points created for analysis were 579, 576, and 565 for the combined rural and urban map extent for Landsat ETM+, SPOT 4, and QuickBird land cover maps, respectively, and met the requirements described by Jensen (2005) for selecting control points. The numbers of control points within the subset rural area were 182, 167, and 239 for the Landsat ETM+, SPOT 4, and QuickBird land cover maps, respectively. The numbers of control points within the subset urban area were 397, 409, and 326 for the Landsat ETM+, SPOT 4, and QuickBird land cover maps, respectively.

Table 6. Accuracy assessment summary statistics for modified NLCD 2001 Level II land cover classification system for control points selected within the two study areas.

Area	N	Sensor	Overall accuracy (%)	κ statistic (%)	Z statistic
Rural	182	Landsat ETM+	73.6	63.2	7.17
	167	SPOT 4	59.9	45.0	3.80
	239	QuickBird	50.2	36.4	2.53
Urban	397	Landsat ETM+	49.6	44.6	1.34
	409	SPOT 4	39.4	35.6	0.80
	326	QuickBird	35.6	28.0	0.62
Combined	579	Landsat ETM+	57.2	51.8	4.77
	576	SPOT 4	45.3	39.1	1.61
	565	QuickBird	41.0	33.6	1.40

Null hypothesis: $\kappa = 0$; if $Z >= 1.96$, then reject null hypothesis.

Results

The rural, urban, and combined land cover maps per Landsat ETM+, SPOT 4, and QuickBird multispectral data were assessed for accuracy per land cover classification scheme. The results are described per land cover classification scheme and apply to the Hayter Estate and City of Nacogdoches study areas. Although not scene dependent, the applicability of the results to other geographic areas depends on similar temporal and seasonal characteristics. An error matrix accuracy assessment was performed per land cover classification scheme using 579, 576, and 565 stratified random control points for the combined (rural and urban map extent) Landsat ETM+, SPOT 4, and QuickBird land cover maps, respectively. Subset stratified random points for the rural and urban accuracy assessments for control points selected within the two study areas are identified in Tables 6, 8, and 10 per classification scheme.

Modified NLCD 2001 Level II Classification Scheme

The results from modified NLCD 2001 Level II land cover classifications for the rural and urban environments indicate visually that as spatial resolution increases land cover map classes become less homogeneous because the increased spatial resolution allows for more visual detail and therefore more heterogeneity. In addition, when rural versus urban environments are compared, land cover

Table 7. User's and producer's accuracy statistics for modified NLCD 2001 Level II land cover classification system for control points selected within the two study areas.

				Cover type										
Area	N	Sensor	Accuracy	Water	Forest: coniferous	Forest: deciduous	Forest: mixed	Herbaceous: grassland	Herbaceous: pasture	Barren	Urban: low	Urban: medium	Urban: high	Wetlands
Rural	182	Landsat ETM+	User's	70.6	89.0	77.8	73.7	0.0	60.0	0.0	NA	0.0	NA	100.0
			Producer's	100.0	96.4	48.3	53.8	NA	46.2	NA	0.0	NA	NA	100.0
	167	SPOT 4	User's	9.7	82.5	22.7	7.8	0.0	14.0	0.0	0.0	0.0	0.0	3.0
			Producer's	75.0	73.3	65.2	50.0	0.0	41.2	0.0	0.0	NA	NA	33.3
	239	QuickBird	User's	66.7	87.6	61.9	25.9	6.5	50.0	25.0	23.1	0.0	NA	14.3
			Producer's	66.7	71.6	35.1	25.0	28.6	17.1	53.3	100.0	0.0	NA	100.0
Urban	397	Landsat ETM+	User's	100.0	61.1	30.3	90.5	43.8	51.7	41.7	71.9	31.3	56.8	56.0
			Producer's	54.5	95.7	77.1	38.8	36.8	31.9	75.0	27.7	48.4	67.7	77.8
	409	SPOT 4	User's	23.1	80.0	43.2	45.1	38.8	27.3	18.2	62.2	31.4	38.6	34.6
			Producer's	46.2	25.0	45.7	56.1	44.2	25.7	28.6	34.1	26.2	50.0	60.0
	326	QuickBird	User's	33.3	87.5	65.5	72.7	27.9	24.5	100.0	35.3	7.7	30.4	12.5
			Producer's	66.7	53.8	69.1	27.6	25.5	50.0	4.3	12.8	11.5	37.2	75.0
Combined	579	Landsat ETM+	User's	82.8	81.1	38.3	82.5	31.8	51.9	40.5	48.9	31.9	91.3	57.7
			Producer's	70.6	96.3	64.1	44.0	36.8	37.0	75.0	26.4	48.4	67.7	78.9
	576	SPOT 4	User's	30.0	92.5	47.0	39.2	37.3	32.0	16.7	62.2	29.7	37.8	30.3
			Producer's	52.9	60.7	53.4	54.8	34.5	30.8	27.3	33.7	26.8	50.0	55.6
	565	QuickBird	User's	36.4	86.7	63.8	40.5	16.7	29.5	27.3	30.0	7.7	34.8	11.4
			Producer's	66.7	69.7	55.4	26.3	25.9	25.7	23.7	18.0	11.1	37.2	80.0

NA, no sample points.

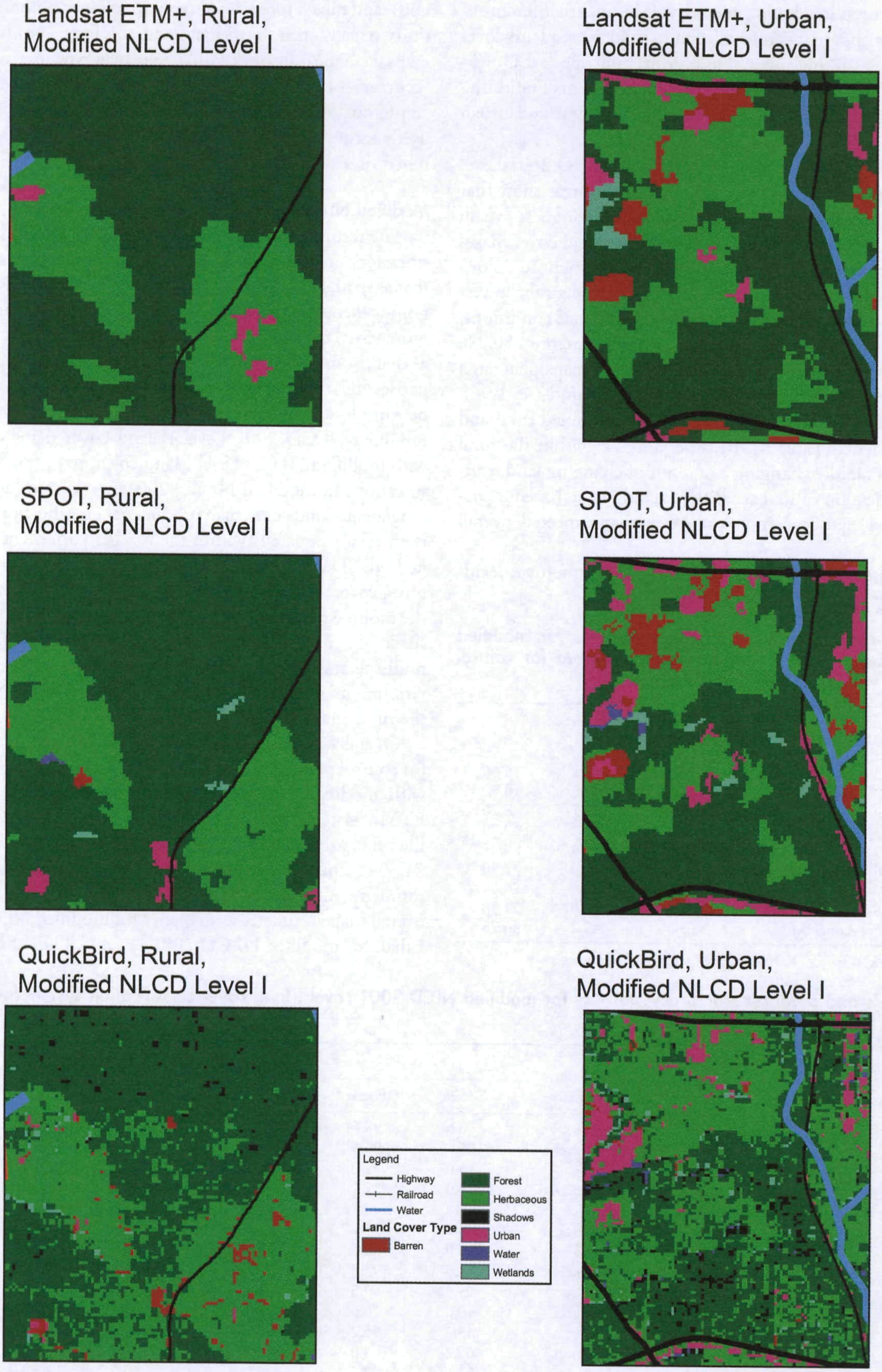

Figure 3. Land cover map subsets within Hayter Estate (rural) and City of Nacogdoches (urban) for modified NLCD 2001 Level I classification.

map classes become less homogeneous within an urban environment. Especially apparent is the addition of shadow as a land cover class with the 2.44-m high spatial resolution multispectral QuickBird data within both the rural and urban environments, indicating fragmentation and misclassification of both the rural and urban forests (Figure 2).

Overall map accuracy statistics for modified NLCD 2001 Level II for control points selected within the two study areas show that the 30-m Landsat ETM+ data consistently had the highest overall map accuracy for the rural, urban, and combined land cover maps, which ranged from 49.6% within an urban environment to 73.6% within a rural environment. QuickBird 2.44-m data had the lowest overall map accuracies within all three environmental conditions, which ranged from 35.6% within the urban environment to 50.2% within a rural environment. Only the land cover maps generated within a rural environment were statistically significant ($Z \geq 1.96$), excluding 30-m Landsat ETM+ data for the combined rural and urban environments (Table 6). Because land use within the rural Hayter Estate is rapidly changing as a result of changing land strategies, misclassification of herbaceous grasslands as herbaceous pasture contributed significantly to the lower-than-expected overall map accuracies.

Analysis of user's and producer's accuracies for coniferous, deciduous, and mixed forest cover types for control points selected within the two study areas shows that Landsat ETM+-produced land cover maps were the only ones with forest cover type user's and producer's accuracies of >90.0% with a high of 96.4% producer's accuracy for coniferous forest within a rural environment, excluding a 92.5% user's accuracy for coniferous forest for SPOT 4 data within a combined rural and urban environment (Table 7).

Table 8. Accuracy assessment summary statistics for modified NLCD 2001 Level I land cover classification system for control points selected within the two study areas.

Area	N	Sensor	Overall accuracy (%)	κ statistic (%)	Z statistic
Rural	182	Landsat ETM+	90.1	77.1	16.60
	167	SPOT 4	81.4	53.0	10.50
	239	QuickBird	63.6	32.7	8.20
Urban	397	Landsat ETM+	74.6	66.2	39.80
	409	SPOT 4	62.8	50.4	9.27
	326	QuickBird	63.2	51.0	7.90
Combined	579	Landsat ETM+	79.4	70.8	24.64
	576	SPOT 4	68.2	55.6	21.50
	565	QuickBird	62.2	49.2	46.78

Null hypothesis: $\kappa = 0$; if $Z >= 1.96$, then reject null hypothesis.

Modified NLCD 2001 Level I Classification Scheme

The results from modified NLCD 2001 Level I land cover classifications for the rural and urban environments indicate visually that as spatial resolution increases land cover map classes become less homogeneous because the increased spatial resolution allows for more visual detail and therefore more heterogeneity, the same result as that for modified NLCD 2001 Level II. In addition, in the comparison of rural versus urban environment land cover, map classes become less homogeneous within an urban environment. When modified NLCD 2001 Level II land cover maps were compared with modified NLCD Level I land cover maps, the land cover classifications in modified NLCD 2001 Level I produced a more homogeneous land cover map product per classification category. This is especially apparent within the rural environment because modified NLCD 2001 Level I merged coniferous, deciduous, and mixed forest cover type classes into one forest class. As was apparent within the modified NLCD 2001 Level II land cover maps, the addition of shadow as a land cover class with the 2.44-m spatial resolution multispectral QuickBird data within both the rural and urban environments indicated fragmentation and misclassification of both the rural and urban forest (Figure 3).

Overall map accuracy statistics for modified NLCD 2001 Level I for control points selected within the two study areas, as was the case with modified NLCD 2001 Level II, show that 30-m Landsat ETM+ data consistently had the highest overall map accuracy for the rural, urban, and combined land cover maps, which ranged from 74.6% within an urban environment to 90.1% within a rural environment. All three Landsat ETM+ (rural, urban, and combined) overall map accuracies were higher for modified NLCD 2001 Level I than for modified NLCD 2001 Level II. QuickBird 2.44-m data

Table 9. User's and producer's accuracy statistics for modified NLCD 2001 Level I land cover classification system for control points selected within the two study areas.

				Cover type					
Area	N	Sensor	Accuracy	Water	Forest	Herbaceous	Barren	Urban	Wetlands
Rural	182	Landsat ETM+	User's	70.6	98.4	75.0	0.0	100.0	100.0
			Producer's	100.0	90.6	92.3	NA	25.0	100.0
	167	SPOT 4	User's	75.0	92.0	70.8	0.0	0.0	14.3
			Producer's	75.0	89.1	58.6	0.0	0.0	33.3
	239	QuickBird	User's	66.7	92.7	23.3	25.0	23.5	14.3
			Producer's	66.7	73.0	23.8	53.3	100.0	100.0
Urban	397	Landsat ETM+	User's	100.0	68.5	83.6	40.5	89.7	56.0
			Producer's	54.5	93.5	60.0	75.0	71.7	77.8
	409	SPOT 4	User's	23.1	80.5	59.8	18.2	74.2	34.6
			Producer's	46.2	76.6	62.8	28.6	58.2	60.0
	326	QuickBird	User's	33.3	85.7	58.7	100.0	70.6	12.5
			Producer's	66.7	68.0	76.1	4.3	62.1	75.0
Combined	579	Landsat ETM+	User's	82.8	82.5	78.1	40.5	89.0	57.7
			Producer's	70.6	91.9	67.6	75.0	70.0	78.9
	576	SPOT 4	User's	30.0	86.4	62.3	16.7	72.4	30.3
			Producer's	52.9	83.0	61.7	27.3	58.2	55.6
	565	QuickBird	User's	36.4	90.2	47.4	27.3	66.1	11.4
			Producer's	66.7	71.2	56.6	23.7	63.3	80.0

NA, no sample points.

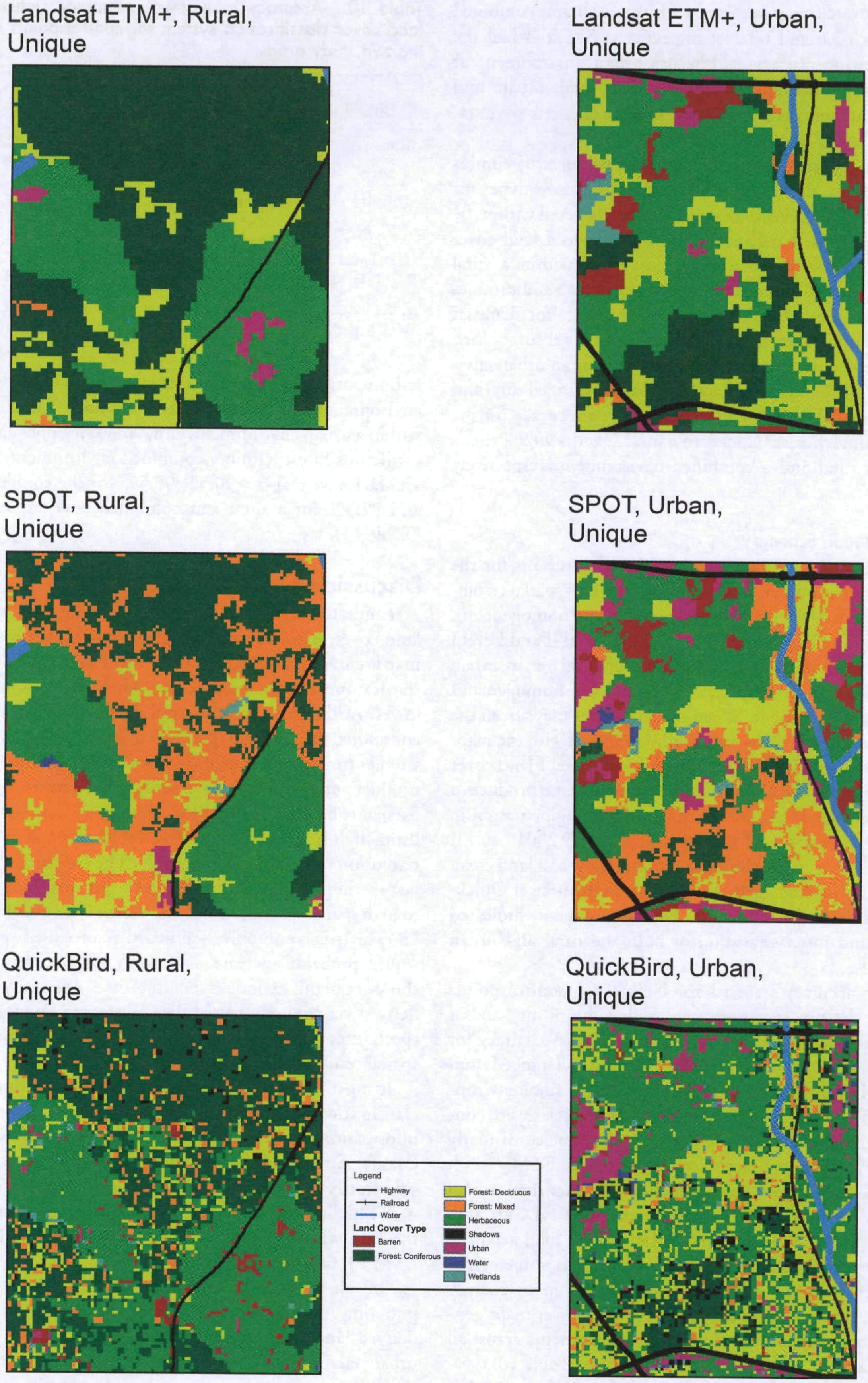

Figure 4. Land cover map subsets within Hayter Estate (rural) and City of Nacogdoches (urban) for Unique classification.

had the lowest overall map accuracy with the rural and combined environments at 63.6 and 62.2%, respectively. SPOT 4 had the lowest overall map accuracy within the urban environment at 62.8%. All land cover maps generated within rural, urban, and combined environments across all three satellite data sets were statistically significant ($Z \geq 1.96$) (Table 8).

Analysis of user's and producer's accuracies for forest (a combination of coniferous, deciduous, and mixed forest cover types for modified NLCD 2001 Level I) for control points selected within the two study areas shows that Landsat ETM+-produced land cover maps had the highest user's accuracy for forest within a rural environment at 98.4%. In addition, of six other user's and producer's accuracies of >90.0%, three of them were for Landsat ETM+-derived land cover maps: a 90.6% producer's accuracy for a rural environment, a 93.5% producer's accuracy for an urban environment, and a 91.9% producer's accuracy for a combined rural and urban environment. SPOT 4 had a 92.0% user's accuracy for the rural environment, whereas QuickBird had 92.7 and a 90.2% user's accuracies for a rural and a combined environment, respectively (Table 9).

Unique Classification Scheme

The results from the Unique land cover classifications for the rural and urban environment indicate visually that as spatial resolution increases land cover map classes become less homogeneous, which was also found in modified NLCD 2001 Level II and Level I classifications. In addition, in a comparison of rural versus urban environments, land cover map classes become less homogeneous within an urban environment. When the land cover maps from the Unique classification scheme were visually compared with the maps produced by modified NLCD 2001 Level II and Level I land cover classification schemes, the Unique classification scheme produces a more homogeneous map product with less visual fragmentation in the landscape. As was observed with modified NLCD 2001 Level II and Level I land cover maps, the addition of shadow as a land cover class with the 2.44-m high-spatial resolution multispectral QuickBird data within both the rural and urban environments indicated fragmentation and misclassification of both the rural and urban forests (Figure 4).

Overall map accuracy statistics for Unique for control points selected within the two study areas show that the 30-m Landsat ETM+ data consistently had the highest overall map accuracy for the rural, urban, and combined land cover maps, which ranged from 66.5% in an urban environment to 80.8% within a rural environment. Although Landsat ETM+ overall map accuracies were consistently the highest land cover map product, they were consistently lower than the overall map accuracies for Landsat ETM+ with modified NLCD 2001 Level I and consistently higher than overall map accuracies for Landsat ETM+ with modified NLCD 2001 Level II. QuickBird 2.44-m had the lowest overall map accuracy within a rural environment at 51.5% and within a combined environment at 54.9%. SPOT 4 had the lowest overall map accuracy within the urban environment at 53.3%. All land cover maps generated within rural, urban, and combined environments across all three satellite data sets were statistically significant (Table 10).

Analysis of user's and producer's accuracies for coniferous, deciduous, and mixed forest cover types for control points selected within the two study areas shows that there were four user's and producer's accuracies at >90.0% that were derived from Landsat ETM+: 96.4% producer's accuracy for coniferous forest within a rural environment, 90.5% user's accuracy for mixed forest within an urban environment, 95.7% producer's accuracy for coniferous forest within a urban environment, and, 96.3% for producer's accuracy of coniferous forest within a combined environment. SPOT 4 user's accuracies were also >90.5%:98.5% for the coniferous cover type and 92.5% for a rural and combined environment, respectively (Table 11).

Table 10. Accuracy assessment summary statistics for Unique land cover classification system for control points selected within the two study areas.

Area	N	Sensor	Overall accuracy (%)	κ statistic (%)	Z statistic
Rural	182	Landsat ETM+	80.8	72.8	11.50
	167	SPOT 4	65.9	52.4	6.03
	239	QuickBird	51.5	36.3	5.89
Urban	397	Landsat ETM+	66.5	59.1	9.51
	409	SPOT 4	53.3	41.8	5.13
	326	QuickBird	59.2	48.2	6.70
Combined	579	Landsat ETM+	71.0	65.6	17.03
	576	SPOT 4	57.1	48.7	4.55
	565	QuickBird	54.9	47.9	4.32

Null hypothesis: $\kappa = 0$; if $Z >= 1.96$, then reject null hypothesis.

Discussion and Conclusions

Landsat 7 ETM+ multispectral data produced the most accurate land cover maps, consistently producing higher overall land cover map accuracy than SPOT 4 and QuickBird data. SPOT 4 produced the next most accurate land cover maps, whereas QuickBird was the lowest of the three multispectral data sets analyzed. These results contradict the initial hypothesis that improved spatial resolution would provide a forest manager with a more accurate land cover map product and contradict the findings of Kayitakire et al. (2002) and Salajanu and Olson (2001) for creation of a land cover map product using high spatial resolution IKONOS data and comparing spatial resolution capabilities, respectively. The conclusion that Landsat in fact is still producing accurate land cover map products as opposed to high spatial resolution sensors such as QuickBird may not be well known. It is commonly assumed that increased spatial resolution would probably increase land cover map accuracy; our research shows that this is indeed not the case. Accuracy of any product derived via remotely sensed data appears to be more a function of spectral resolution and homogeneity of the pixel than of increased spatial resolution.

It must be kept in mind that this study used an unsupervised classification scheme. This method does not take into account any information other than spectral signatures and is an attempt to classify natural groupings of spectral classes with respect to the classification system used. Thus, although more detail was obtained with a higher spatial resolution sensor, the most accurate sensor was the one with the more coarse spatial resolution data (Landsat ETM+). Our results concur with the findings of Vogelmann et al. (1998) on the accuracy of 30-m Landsat TM data. Further compounding the problem is the addition of shadows in QuickBird-derived land cover maps. Shadows in QuickBird data within the urban environment within the City of Nacogdoches decreased QuickBird overall accuracies and their respective κ statistics.

A problem that affected all of the satellite data analyzed is the fact that Nacogdoches, Texas, like other cities in East Texas, is a highly forested city. From an aerial perspective, large parts of the city resemble a forest with only occasional glimpses of the homes and

Table 11. User's and producer's accuracy statistics for unique land cover classification system for control points selected within the two study areas.

Area	*N*	Sensor	Accuracy	Cover type: Water	Forest: coniferous	Forest: deciduous	Forest: mixed	Herbaceous	Barren	Urban	Wetlands
Rural	182	Landsat ETM+	User's	70.6	89.0	77.8	73.7	75.0	0.0	100.0	100.0
			Producer's	100.0	96.4	48.3	53.8	92.3	NA	25.0	100.0
	167	SPOT 4	User's	75.0	98.5	60.0	24.2	70.8	0.0	0.0	14.3
			Producer's	75.0	73.3	65.2	50.0	58.6	0.0	0.0	33.3
	239	QuickBird	User's	66.7	87.6	61.9	25.9	23.3	25.0	23.5	14.3
			Producer's	66.7	71.6	35.1	25.0	23.8	53.3	100.0	100.0
Urban	397	Landsat ETM+	User's	100.0	61.1	30.3	90.5	86.4	39.5	88.9	56.0
			Producer's	54.5	95.7	77.1	38.8	60.0	75.0	71.7	77.8
	409	SPOT 4	User's	23.1	80.0	43.2	45.1	59.8	18.2	74.2	34.6
			Producer's	46.2	25.0	45.7	56.1	62.8	28.6	58.2	60.0
	326	QuickBird	User's	33.3	87.5	65.5	72.7	58.7	100.0	70.6	12.5
			Producer's	66.7	53.8	69.1	27.6	76.1	4.3	62.1	75.0
Combined	579	Landsat ETM+	User's	82.8	81.1	38.3	82.5	78.1	32.6	96.3	57.7
			Producer's	70.6	96.3	64.1	44.0	67.6	75.0	70.0	78.9
	576	SPOT 4	User's	32.3	92.5	47.0	39.2	65.3	16.7	72.4	30.3
			Producer's	55.6	60.7	53.4	54.8	61.7	27.3	58.2	55.6
	565	QuickBird	User's	36.4	87.6	64.6	39.5	47.4	27.3	66.1	11.4
			Producer's	66.7	69.7	55.4	26.3	56.6	23.7	63.3	80.0

NA, no sample points.

streets beneath the forest canopy. Landsat ETM+ data and to a lesser extent SPOT 4 data were able to define a large area containing structures, grass, and forest. QuickBird, which only defined a small area, saw either a house or a tree but not the relationship of these objects to each other.

All the land cover maps were more accurate in the fairly homogeneous Hayter Estate (rural) than the City of Nacogdoches (urban). Whereas this result was expected with the poorer spatial resolution sensors, it was not expected with the QuickBird satellite sensor, which has a much higher spatial resolution. A closer examination shows that although QuickBird was able to classify land cover more accurately in the Hayter Estate environment than in the City of Nacogdoches, it still performed way below the standard overall map accuracy of 85.0%. When the modified NLCD 2001 Level I or Unique classification scheme was used, QuickBird performed significantly better in the City of Nacogdoches environment than in the Hayter Estate.

Overall map accuracy was correlated to classification level because more general classifications of land cover types increase the overall accuracy of the resulting land cover maps. This fact echoes the results of Salajanu and Olson (2001), who reported that SPOT and Landsat were more accurate at modified NLCD 2001 Level I (91.5 and 89.2%, respectively) than at modified NLCD 2001 Level II (84.7 and 77.8%, respectively). It is important that a practicing forester knows that Landsat is still capable of creating accurate land cover map products compared with those from high spatial resolution data. It is also very important for a practicing forester to know that the accuracy of the derived land cover map products per classification scheme (NLCD 2001 Level II, NLCD 2001 Level 1, and Unique) does, in fact, vary and that the homogeneous nature of a classification scheme, as is the case with NLCD 2001 Level 1, results in a more accurate land cover map product. In this study, accuracy was lowest for NLCD 2001 Level II and highest for NLCD 2001 Level 1 and Unique was between the two in overall map accuracy.

This study was completed using unsupervised classification methodology. Some local knowledge was used in identifying features for classification. This method did not take into account texture, which at higher spatial resolution becomes just as important as spectral signatures for identifying land cover (Franklin et al. 2001) nor were the data from different sensors merged to take advantage of the best spectral characteristics of Landsat with the improved spatial resolution of QuickBird as Salajanu and Olson (2001) demonstrated with Landsat and SPOT. It is important to point out that high spatial resolution data are expensive, and a practicing forester may not have the funds to obtain and merge coarse and high spatial resolution data sets. From a practical standpoint, it is still important to note that medium spatial resolution data such as Landsat still play a viable role in producing high-quality map products.

Interesting next steps are to stack QuickBird with medium spatial resolution SPOT and Landsat data for the classification to see whether land cover map accuracy improves, especially within the coniferous, deciduous, and mixed forest cover types (Roller and Bergen 2000). A supervised attempt at classification that incorporates texture as well as other ancillary information such as existing land cover or land use maps is also a logical approach. Finally, with the launch of Landsat 8 on Feb. 11, 2013, to continue the data continuity of the Landsat series of satellites at 30-m spatial resolution, the ability of forest managers to produce highly accurate land cover maps using medium spatial resolution multispectral data will continue.

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