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Current Assessment and Future Prediction of Forest Cover Change in Cumberland and Morgan Counties, Tennessee: A Modeling Technique

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To the Graduate Council:

I am submitting herewith a thesis written by Jeffery David Strickland entitled "Current Assessment and Future Prediction of Forest Cover Change in Cumberland and Morgan Counties, Tennessee: A Modeling Technique." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Donald G. Hodges, Major Professor

We have read this thesis and recommend its acceptance:

Steven Knowe, Roger Tankersley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Acceptance for the Council:

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Graduate Studies

Current Assessment and Future Prediction of Forest Cover Change in Cumberland and Morgan Counties, Tennessee: A Modeling Technique

A Thesis
Presented for the
Master of Science
Degree
University of Tennessee, Knoxville

Jeffery David Strickland
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Abstract

Determining the relationship between human disturbance of the environment and natural forest change is critical for sound natural resource planning. Improved land cover modeling techniques that incorporate geographic information systems and statistical models are needed to assist in this analysis. Continued forest fragmentation due to increasing population and urbanization has created a growing interest in forest protection for the Cumberland Plateau of Tennessee. Specifically, Cumberland and Morgan Counties have seen unprecedented population growth over the last two decades, resulting in fragmentation of forestland. This study developed a model to determine the probability of exurbia development and its resulting forest fragmentation. Geographic data used in the research included satellite imagery from 1992 and 2000, U.S. Census population and demographic estimates, and road and water coverages of the two counties.

The first objective of this study was to develop an accurate and efficient procedure for the development of a land cover map for use in a forest change detection system for Cumberland and Morgan Counties, Tennessee. A unique method was developed to generate this procedure by combining post-classification and image differencing. The second objective of the study was to determine the relationship between urbanization and forest loss in Cumberland and Morgan Counties, Tennessee, and to predict current and future land cover patterns. Logistic regression analysis suggested that demographic variables such as education and population along with spatial factors such as slope, distance to water, distance to interstate junctions, and gravity index factors of nearby urban retail centers, significantly influenced the transition of forest to urban cover. Of these parameters, a high gravity index, a suburban designation, and unsloped terrain had the greatest impact on forest to urban conversion. In addition, spatial factors such as parcel distance to water, and parcel distance to interstate junctions significantly influenced the probability of development. Finally, using population density predictions, the model identified the probability that forest land would be urbanized by 2010.

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Chapter I

Introduction

Located in the heart of Tennessee's Cumberland Plateau, Morgan and Cumberland Counties have experienced large increases in population and substantial changes in land cover over the last half-century. Areas once occupied by forest and agriculture are now replaced by residential development. Compared to the national annual population growth average of 1.3 percent (Social Science Data Analysis Network (SSDAN) 2000), Cumberland and Morgan Counties are experiencing above average growth at annual rates of 3.4 and 1.4 percent, respectively (U.S. Census Bureau 2002). At these rates, the appearance of transitional lands and development projects is likely to continue. Due to the area's mild climate, scenic beauty, and affordable cost of living most growth has been associated with retirees favoring the local rural lifestyle, and commuters working in nearby cities. Beginning in the 1970s, when development projects were first appearing, the Forest Service and environmental groups have voiced concern over the negative effects of urbanization (Wear and Greis 2002). With a number of land trust alliances throughout the Cumberland Plateau and mountain regions, many agencies have begun to examine the detrimental impact of changes in natural land cover.

Little research has been conducted on the relationship between demographic information and land cover change. Demographic information pertains to the residents of an area and includes population density, education level, household income, employment rate, and house value. Most existing studies focus on surrounding regions such as the Appalachian Mountain region, neglecting the potential growth of the Cumberland Plateau (Galbraith 2001; Pearson et al. 1998; Pearson et al. 1999; Turner 1990). The two-county region of Cumberland and Morgan Counties are experiencing a steady rate of urban sprawl and an influx of population growth and were selected for this study as representative of the region.

In order to determine forest cover change patterns, this thesis chapter examines forest area and volume information obtained from the USDA Forest Service and demographic data from the U.S. Census Bureau to assess:

1) the relationship between land cover change and demographic trends, and
2) the causes of forest cover change.

Study Area

The study area for this project is Cumberland and Morgan Counties, Tennessee, which is located between 85.3 and 84.3 degrees west longitude and 36.4 and 35.9 degrees north latitude and comprising an area of approximately 3,110 square kilometers (311,745 hectares). Figure 1-1[1] depicts the two-county area and regional location. Located within the Cumberland Plateau, this region consists of an elevated tableland bordered by the Ridge and Valley Province to the east and the Eastern Highland Rim of the Interior Low Plateaus to the west (Vickers and Cunningham 2003). With Cumberland Mountain and Walden Ridge to the west, the area's elevation decreases sharply from northeast to southwest from approximately 900 meters to 400 meters along Bird Mountain and Crab Orchard Mountains then increases slightly to 500 meters. Elevation in northern Cumberland and Morgan Counties around the Catoosa Wildlife Management Area averages 500 meters (Figure 1-2). The undulating topography consists of Ultisols, a soil type characterized as well drained, strongly acidic, and low in natural fertility. These

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[1] All tables and figures are located in the Appendices.

soils are derived from thick horizontal strata of sandstones, siltsones, and shales (Springer and Elder 1980). Due to the inadequate amounts of nitrogen, phosphorous, and calcium found throughout the soil, tree growth is slightly limited (Francis and Loftus 1977). While the terrain consists of highly leached, nutrient poor soils, the temperate climatic zone associated with plentiful rainfall supports a healthy mesophytic hardwood forest community.

Current Land Cover and Land Use

The frequency, extent, and spatial distribution of human impacts on land conversion throughout the southern United States are unprecedented. Land cover change is driven by either land modification or land conversion. Whereas modification is a change in the condition within the cover type, conversion is a change from one cover type to another (Bottomley 1998). This paper specifically examines land cover conversion. In order to describe current land cover characteristics for Cumberland and Morgan Counties, it is important to understand the difference between land cover and land use. Whereas land cover relates to the area's observed physical terrain, land use is the purpose for which the land is being used (McConnell and Moran 2000). All land use activities are affected by the physical properties of the terrain, as well as being influenced by population factors, institutional regulations, and economic conditions.

While other areas throughout the South have experienced a strikingly abrupt alteration in land cover, Cumberland and Morgan Counties have seen a process of steady successional land cover change (Hartshorn 1992; Yang 2002). Changes from forest and cropland cover to urban development in the densely populated suburbs of Atlanta, Georgia, illustrate the magnitude of urban expansion. Within the past 10 years, Gwinnett and Henry Counties of Georgia have experienced population growth rates of over 67 and 118 percent, respectively (Kaplan 2003). Once surrounded by major regions of agricultural production, the urban center of Atlanta directly influenced the sprawling growth of Gwinnett and Henry Counties. Although the Cumberland Plateau is not as closely linked to a large metropolitan center as are the suburbs of Atlanta, the continued growth of Knoxville and Nashville will create a similar pattern.

Cumberland and Morgan Counties presently consist of heavily forested areas, covering approximately 79 percent (247,587 hectares) of the two-county region (Schweitzer 2000). Much of these forests are used for natural resource extraction such as wood production, with mining excavation occurring on portions of the land. Public lands such as Catoosa State Wildlife Management Area, Obed Wild and Scenic River, Frozen Head State Park, and Lone Mountain State Forest comprise approximately 25 percent of the 2 Counties. These public areas accommodate recreational activities such as hunting, fishing, water sports, rock climbing, and all-terrain-vehicle use. Agriculture is the most prominent commercial land cover type covering 10 percent (32,114 hectares) of the 2 counties. This cover type includes cropland and pastureland, used for crop and cattle production. Approximately 50 percent of the agricultural area in this region is harvested cropland (16,053 hectares) while the remaining half (16,062 hectares) is classified as pastureland. The 4 main crops harvested in 2000 were hay, corn, wheat, and tobacco (Tennessee Agricultural Statistics Service 2001).

Only 10 percent (32,028 hectares) of the total area consists of either barren or developed land with a majority of the urbanization located in Cumberland County. Of the 7 major communities located in Cumberland and Morgan Counties, Crossville maintains the largest city population with over 10,000 residents. Wartburg, the county seat of Morgan County, consists of 962 residents. The majority of residents within the study area live in rural settings on large-lot parcels (over five acres) or in typical residential developments. Table 1-1 lists the population figures for 2000 and the population percentages for the total area, indicating that a majority of residents live in a rural setting, outside incorporated or census designated places. Areas along Highway 127 in Cumberland County and Highway 27 in Morgan County illustrate the rural large-lot setting.

Current Forest Cover

The forests of Cumberland and Morgan Counties lie within the Appalachian Mixed Mesophytic Forest ecoregion (Ricketts et al. 1999). These forests are characterized as temperate broadleaf and mixed (deciduous and coniferous) forests covering the Plateau and hills west of the Appalachian Mountains. The ecoregion encompasses the Cumberland Plateau of Tennessee, extending into northwestern Alabama, North Carolina, Kentucky, West Virginia, southeastern Ohio and southwestern Pennsylvania (Ricketts *et al.* 1999). In protected areas, mesic coves, and on northeastern slopes, these forests are composed largely of oaks (*Quercus* spp.), hickory (*Carya* spp.), maple (*Acer* spp.), ash (*Fraxinus* spp.), pine (*Pinus* spp.), yellow-poplar (*Liriodendron tulipifera*), and American beech (*Fagus grandifolia*). In ravine bottoms, eastern hemlock (*Tsuga canadensis*), river birch (*Betula nigra*), and fraser magnolia (*Magnolia fraseri*) are the prevalent species (Ricketts *et al.* 1999).

The forested areas of Cumberland and Morgan Counties support a wide variety of wildlife resources, scenic areas, and unique geological features; they also support the local economy through resource extraction (timber). Forest land is defined as land at least 10 percent stocked by trees of any size; timberland consists of forest land capable of producing at least 20 cubic feet of industrial wood per year and not withheld from timber production (Schweitzer 2000). Currently, Cumberland and Morgan Counties contain 243,540 hectares of timberland. Over 85 percent (208,454 hectares) of this timberland is classified as either mixed or oak-hickory forests (Table 1-2). The remaining timberland is classified as either planted loblolly (*Pinus taeda*) or natural shortleaf pine (*Pinus echinata*) forests. With nonindustrial private forest (NIPF) landowners controlling 76 percent (184,901 hectares) of the total timberland (Schweitzer 2000), the majority of the forests are dispersed throughout the two-county region as fragmented parcels. Of this percentage, farmers and individual landholders control 33,832 and 151,069 hectares, respectively. Timberland owned by forest industry includes 22,541 hectares, or 9 percent of the two-county region. Public agencies representing less than 15 percent of total forest cover hold a small proportion of timberland, consisting of only 36,098 hectares (Schweitzer 2000).

Trends in Forest, Agriculture, and Urbanization

Since the beginning of European settlement, land cover throughout the southern United States has consistently been in transition, changing from heavily forested lands to an agrarian cover, and in certain locations to a densely populated urban setting. Prior to colonization, forests of the Cumberland Plateau consisted primarily of hardwoods including red and white oaks (*Quercus* spp.), hickories (*Carya* spp.), black walnut (*Juglans nigra*), yellow-poplar (*Liriodendron tulipifera*), and American chestnut (*Castanea dentata*). Softwood species also were more prevalent than modern distributions. After the Europeans arrived, the area of forest land throughout the South declined 38 percent, dwindling from 143 million hectares in pre-Columbian forests to 87 million hectares currently. Due to the South's economic dependence on agriculture until the mid 1950s, most of the loss in forests was due to clearing for cropland and pasture (Wear and Greis 2002).

By 1860, Tennessee contained 82,000 farms with 8.5 million hectares of land in crops. With the intense changes initiated by the Civil War, the number of farms throughout Tennessee continued to increase, reaching 253,000 in 1920 (Wheeler 1952). The influx of people, the importance of agriculture, and the lack of forest regeneration continued the decline in forests. By the 1930s, improper farming practices forced many farmers to abandon eroded, submarginal farmland and clear new acreage. Remaining forests were either claimed for new agricultural practices or used for fuel, merchantable timber, or forage for farm animals. In 1935, the Tennessee State Planning Commission indicated that gullying had ruined approximately 1.2 million hectares of cropland along with erosion eliminating surface soil from approximately 4.5 million hectares throughout Tennessee (Wheeler 1952). Poor farming practices, coupled with the Great Depression, resulted in many farmers being either too financially depressed to maintain agrarian practices or too unfamiliar with modern farming practices to prevent soil erosion. Therefore, programs throughout the South including Tennessee were initiated to aid farmers and landowners in the prevention of further soil loss. Programs such as the

Civilian Conservation Corps (CCC) and the Agricultural Conservation Program (ACP) of the 1930s were established to help turn idle farmland and eroded cropland back into forests.

The major cause of land cover change was the rural-to-urban population shift. As a result of the implementation of President Roosevelt's New Deal in the mid 1930s, additional programs pertaining to urban renewal projects began to develop. These programs included the national Housing and Highway Acts of the 1940s and 50s, providing federal funding for urban projects in any major city with at least 50,000 persons. A second project, the Tennessee Valley Authority (TVA), was created to provide electrical power to communities of East Tennessee (Held and Visser 1982). These projects in turn created new job opportunities, enticing residents from rural towns to relocate and establish residence in cities. Job opportunities lured residents, and along with the Plateau's poor soil quality, farming competition, and harsh living conditions added to rural abandonment. Trends in population rates are summarized in Table 1-3.

Total timberland equaled 5 million hectares throughout Tennessee, 1.2 million hectares in the Cumberland Plateau, and 261,711 hectares in the two-county region by 1950 (Table 1-4) (Wheeler 1952). The growth continued in Cumberland and Morgan Counties, reaching 263,329 timberland hectares in 1960. Compared to an increase in forest of over 9 percent (5.4 million hectares) for the state of Tennessee, the change from farmland to timberland was relatively small for the Cumberland Plateau (4 percent or 1.3 million hectares) as well as for the two-county region which observed timberland growth rates of only 1 percent (Sterniztke 1962). Comprising 30 percent of the total forest area in 1950, softwoods counted for only 14 percent in 1960, a majority consisting of planted pine (Hedlund and Earles 1971). Total forest volume for both the Cumberland Plateau and the two-county region increased significantly as well, rising roughly 50 percent to 1.7 billion and 362 million cubic feet, respectively (Sterniztke 1962). Table 1-5 summarizes trends in total growing stock volume for the region.

Between 1960 and 1970, timberland in Tennessee declined by 248,000 hectares, a consequence of farm owners increasing their pasture acreage by clearing forest land. The Cumberland Plateau lost over 40,000 hectares along with the Cumberland and Morgan County region falling 5 percent to 249,327 hectares. While some landholdings were cleared throughout the Plateau, others (approximately 84,000 hectares) reverted to forest (Hedlund and Earles 1971). With property values remaining fairly stable, wooded land containing higher potential profit margin for crops and cattle were converted to harvestable cropland and pastureland. In contrast, inadequate cropland was left idle and reverted back into woodland. The reversion to forest land was insufficient to offset forest lost to cropland resulting in a net loss in total forest acreage. Figure 1-3 illustrates Tennessee land cover changes between 1950 and 2000.

While total forest area declined, growing stock volume increased. By 1970, total forest volume for the Cumberland Plateau and the two-county region increased to 2.5 billion and 455 million cubic feet, respectively. The increase in volume but decrease in total acreage can be explained by the maturation of existing trees. Another reason for volume increases along with decreases in total acreage is due to inconsistent use of "adequate" growing stock, followed by the alteration in sampling techniques made by the Forest Service Forest Inventory and Analysis (FIA). What was once considered inadequate growing stock may be considered adequate in the next sampling period (Wear and Greis 2002).

A sufficient labor supply, coupled with inexpensive land prices, lured manufacturing plants not requiring close proximity to suppliers to the exurban areas of Knoxville and Nashville. Exurbs, located in either metropolitan areas or non-metropolitan counties, are settlements situated outside suburbs but still within the commuting distance of a major city (Wacker 2002). These companies drew workers from Cumberland and Morgan Counties to the larger city of Knoxville, making it possible for people to continue to live in a rural setting but work elsewhere. This created long-distance commuting, where residents of the rural countryside traveled from homes or farms to metropolitan areas. This growth in employment therefore spurred an increasing rural population, creating its own demand, which in turn provided more services, financial opportunities, construction jobs, and governmental positions (Healy and Short 1981).

Based on the increase in amenities as well as jobs, the mid-1970s were characterized by a population surge for southern communities. Many rural areas throughout the South experienced population growth rates exceeding three percent per year (Social Science Data Analysis Network (SSDAN) 2000). The population of the Cumberland and Morgan County region, for example, rose 32 percent over a 10-year period to a total population of 45,280 in 1980. Instead of residents leaving the rural life for a more prosperous career in a major urban area, many families and retirees began to settle in the nonmetropolitan places of Cumberland and Morgan Counties. The movement to exurban areas was motivated by the availability of affordable housing, the improved interstate highway systems, and a growing labor market.

The population growth coincided with a decline in total forest land and timberland and an increase in urbanization. By 1980, total timberland on the Plateau decreased by over 3 percent to 1.2 million hectares. Cumberland and Morgan Counties reflected this trend, with a reduction of over 9,000 hectares leaving a total timberland area of 240,586 hectares. The area of softwood forests throughout the Plateau and the two-county region was at its lowest ever, comprising less than 9 percent while hardwood comprised 78 percent of total forest area. Compared to the stand structure of the 1960s, frequent land activities were triggered by farming and logging practices of the past, and continued to add smaller trees, thereby preventing forests from reaching their maximum potential (Birdsey 1983). Even with these drifts in area, total volume for the Plateau and the two-county region increased to approximately 3 billion and 787 million cubic feet, respectively, due to the natural maturation of trees (Birdsey 1983).

Forestland has increased on the Plateau since 1980. Both forest industry and non industrial private forest (NIPF) landowners increased their total forestland holdings. By 1990, timberland area throughout the state of Tennessee had increased 3 percent in the decade, rising to 5.2 million hectares. The Cumberland Plateau, including Cumberland and Morgan Counties, increased to 1.24 million hectares and 241,395 hectares, respectively (May 1991).

Another major impact on land cover change was the exponential growth in the number of retired persons. Many retirees have returned to the rural area from which they migrated while others have moved to a less expensive, less congested area to escape overcrowded cities. Between 1990 and 2000, the number of retired householders in Cumberland and Morgan Counties increased 50.6 percent, rising from 3,271 persons to 4,926. Along with the growth, retirees' income from pensions and Social Security benefits rose 400 percent providing an aggregate retirement income growth from 31 million to 124 million dollars for the Counties (U.S. Census Bureau 2002). Not only have retired persons become more numerous but they also are increasingly able to afford local products and services. There have been stark changes in employment as well. Due to younger worker migration, total employment in the counties dropped 24 percent, from 18,286 in 1980 to 13,984 by 2000. With population growth rates exceeding 28 percent along with retirement rates reaching 50 percent in 10 years, both Cumberland and Morgan Counties are quickly becoming places of retired living (U.S. Census Bureau 2002).

By 2000, total forest area for Tennessee was close to 5.7 million hectares, rising an additional 5.3 percent since 1990. The Cumberland and Morgan County region increased nearly 1 percent with a total forest acreage of 243,540 hectares (Schweitzer 2000). Softwoods comprised 14 percent of this total. Hardwood acreage decreased 4 percent, from 217,883 hectares in 1990 to 208,859 hectares. Unlike the small increase in forest acreage, both the Cumberland Plateau and the two-county region saw unprecedented growth in forest volume. Between 1950 and 2000, the hardwood timber volume for the Plateau rose 640 percent to 4.2 billion cubic feet and 77 percent to over 1.0 billion cubic feet for softwoods. Approximately 80 percent of this total growing stock volume throughout the Cumberland Plateau represented hardwood timber (Wheeler 1952; Schweitzer 2000).

Overall, Cumberland and Morgan Counties have experienced unprecedented growth, making this region one of the fastest growing areas in Tennessee. Figure 1-4 illustrates population growth rates for Cumberland and Morgan Counties. Due to the overall increasing number of retirees in the U.S. and the fact that the area appeals to retirees, the trend appears likely to continue or intensify. Recent population trends indicate that the population might reach 71,137 by 2010, a 10.7 percent increase over current numbers. While an increase in total timber volume reflects a plentiful forest resource, any excess transition to development could significantly change this upward trend. Not only does an influx in population reflect an increase in urbanization, it also reflects an increase in the number of NIPF landowners. It appears unlikely that both forests and human populations will continue to grow in the region.

The Cumberland Plateau has been in continuous transition for the past 100 years with forest land cover dependent upon the competing prices for timber, pasture, and urban development (Wear and Greis 2002). Considered by ecologists as being a critically endangered ecosystem, this ecoregion has seen a 95 percent conversion from forests to another cover over the last 200 years (Ricketts *et al.* 1999). The majority of forests have become fragmented, separated, and converted into roads, utility structures, urban areas, and agriculture. Multiple land uses, infrastructure, and parcelization of land causes fragmentation of forests, affecting the size and amount of contiguous forest patches as well as the loss of interior habitat and wildlife species (Wear and Greis 2002). Whereas most of the anthropogenic development is irreversible, agricultural land is not. However, the croplands that have failed and have been converted to pioneering and secondary growth forests lack the diversity and structural complexity of old-growth forests (Ricketts *et al.* 1999). With proper forest management, these secondary communities can be regenerated into forests embodying the attributes found in old-growth forests. Significant ongoing threats to the forests of the Cumberland Plateau are urbanization, excessive harvesting, and the conversion from hardwood to pine.

Population growth in Cumberland and Morgan Counties has resulted from natural increases and migration. Since the mid 1970s, the number of residents and rural youth moving to metropolitan cities has declined. Adding to a greater exurbia expansion was the influx of retirees, most of whom desired the rural aesthetic environment. Not only did this influx add to urban expansion but also created an increase in the availability of jobs in suburban and rural reaches of Crossville and other towns of the area. Much of the job growth has been in service, retail, construction, and government, with losses in agricultural occupations (U.S. Census Bureau 1997). Due to parcelization and development, agricultural real estate values rose 40 percent in the last 5 years, the second highest increase in the nation (Derrick 1999). In fact, the influx of people into rural sectors of the Cumberland Plateau has become a growing concern among current landowners and environmentalists. Many speculate that this population expansion contributes to urban sprawl and fragmentation in and among the rural areas surrounding the cities and towns of Cumberland and Morgan Counties.

Since the mid 1970s, exurban sprawl throughout the Cumberland Plateau has slowly expanded in a sequential, multi-step process bringing negative impacts to neighboring farms and forestland (American Farmland Trust 1986). The decision for a landowner depends upon his or her qualitative and quantitative valuation of the property. The qualitative values are based upon the satisfaction the landowner receives from the land, whereas the quantitative values are centered around the income received from the property, the net annual holding costs, and costs associated with shifting to another investment (Patel 1980). As infrastructure improvements spread throughout the rural environment, many of the landowners' future decisions for the property are challenged. These infrastructure improvements usually lead to an influx of residents causing parcelization, which further leads to a rise in property taxes. Farmers and forest landowners faced with higher taxes are enticed to sell and shift to more profitable investments. As rural land transitions to development, many agricultural support companies such as veterinarians, supply stores, storage and trucking companies leave the area (Wacker 2002). This consequence of urbanization affects the land use as well as the price, causing much of the land to fall idle. As a result, farmers are unwilling to make long-term investments in agriculture and forestry due to the expectation of eventual urbanization. This condition, known as the impermanence syndrome, ultimately pressures the landowners to sell. Due to the profitability of development, what was once farm or forestland eventually converts to development (Healy and Short 1981).

Thesis Outline

Although forest volume is increasing exponentially, continued loss in forest acreage will affect available timber volume. Unless reasonable zoning regulations are established and proper forest management practices are continued, the constant increase in urbanization will negatively impact the Plateau's forest ecoregion. Most importantly, this continued land cover change could result in more forest fragmentation, a major concern in the reduction of forest and wildlife biodiversity. The remainder of this thesis describes research conducted to assess the factors driving land cover change in Cumberland and Morgan Counties and to project future land cover patterns.

Chapter Two evaluates a methodology for assessing land cover change in the two-county region on the Cumberland Plateau of Tennessee. This includes the development of a land cover map and a forest cover change detection system using a normalized difference vegetative index (NDVI). The process incorporated the land cover map with the forest cover change detection for the development of an observed classified change in forest cover dataset. This process was then evaluated using an accuracy assessment.

Chapter Three extends the forest change research by developing a model for urbanization in Cumberland and Morgan Counties. Geographic data used in the research included the observed classified change in forest cover dataset created in Chapter Two, the U.S. Census data, and road and water coverages. Using logistic regression, a land cover model was developed to determine the influence of demographic and spatial factors on forest change. In addition, a model was developed for predicted conversion of forest land to another land cover by 2010. Similar procedures used in the first model were followed with some alterations. This included acquiring all predicted population estimates for 2010 from the U.S. Census Bureau and integrating them with a predicted land cover model. As with the original land cover model, all spatial coverages remained constant. Illustrations of estimated and predicted forest conversion to developed lands were included in both sections.

Chapter Four examines the processes taken in the development of a land cover map, land cover change analysis, and the creation of a land cover model. The processes and conclusions derived from the creation of a current and predicted land cover map are also examined. This chapter concludes with an analysis of other procedures that might have been used.

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Appendices

Appendix A

Tables

Table 1-1: 2000 Census for the communities of Cumberland and Morgan Counties, Tennessee

Community	2000 Population	Total Area (hectares)	Percent Study Area
Crab Orchard	1,139	2,875	0.9%
Crossville	10,298	3,818	1.2%
Pleasant Hill	631	401	0.1%
Oakdale	277	236	0.1%
Oliver Springs	56	18	0.01%
Sunbright	616	984	0.3%
Wartburg	962	249	0.1%
Unincorporated	52,580	303,165	97.2%
Total	66,559	311,745	100.0%

Source: U.S. Census Bureau, 2002

Table 1-2: Area (hectares) of timberland by county and type for Cumberland and Morgan Counties, Tennessee, 2000

Forest Type	All groups	White pine	Yellow pine	Mixed	Oak-hickory	Other
	---------- hectares ----------					
Cumberland	129,540	2,347	19,263	29,380	78,347	202
Morgan	114,000	688	12,383	23,634	77,093	202
Total Area	243,540	3,035	31,646	53,014	155,440	405

Source: Tennessee Forest Statistics, 1950-2000

Table 1-3: Estimated and predicted population for Cumberland and Morgan Counties, Cumberland Plateau, and Tennessee, 1950 – 2000

Year	Tennessee	Cumberland Plateau	Two County Region
1950	3,291,718	268,995	34,604
1960	3,567,089	252,556	33,439
1970	3,923,687	262,123	34,352
1980	4,591,120	329,128	45,280
1990	4,877,185	343,106	52,036
2000	5,689,283	389,589	66,559
2010	6,515,255	422,050	71,137

Source: U.S. Census Bureau, 1950-2000

Table 1-4: Comparative growth trends in total timberland area (hectares) by location for Cumberland and Morgan Counties, Cumberland Plateau, and Tennessee 1950 – 2000

Year	**Tennessee**	**Cumberland Plateau**	**Two County Region**
	hectares		
1950	4,999,413	1,237,005	261,711
1960	5,435,908	1,286,093	263,329
1970	5,187,997	1,245,220	249,327
1980	5,211,954	1,202,970	240,586
1990	5,368,285	1,240,242	241,395
2000	**5,651,444**	**1,213,017**	**243,540**

Source: Tennessee Forest Statistics, 1950-2000

Table 1-5: Trends in timberland volume (million cubic feet) for Cumberland and Morgan Counties, Cumberland Plateau, and Tennessee, 1950 – 2000

Year	**Tennessee**	**Cumberland Plateau**	**Two County Region**
	million cubic feet		
1950	4,936.2	1,132.4	227.6
1960	7,209.4	1,736.0	362.0
1970	10,395.8	2,523.6	455.0
1980	12,805.2	2,977.4	579.9
1990	16,682.7	3,796.2	787.0
2000	**22,420.5**	**5,288.8**	**1,132.3**

Source: Tennessee Forest Statistics, 1950-2000

Appendix B

Figures

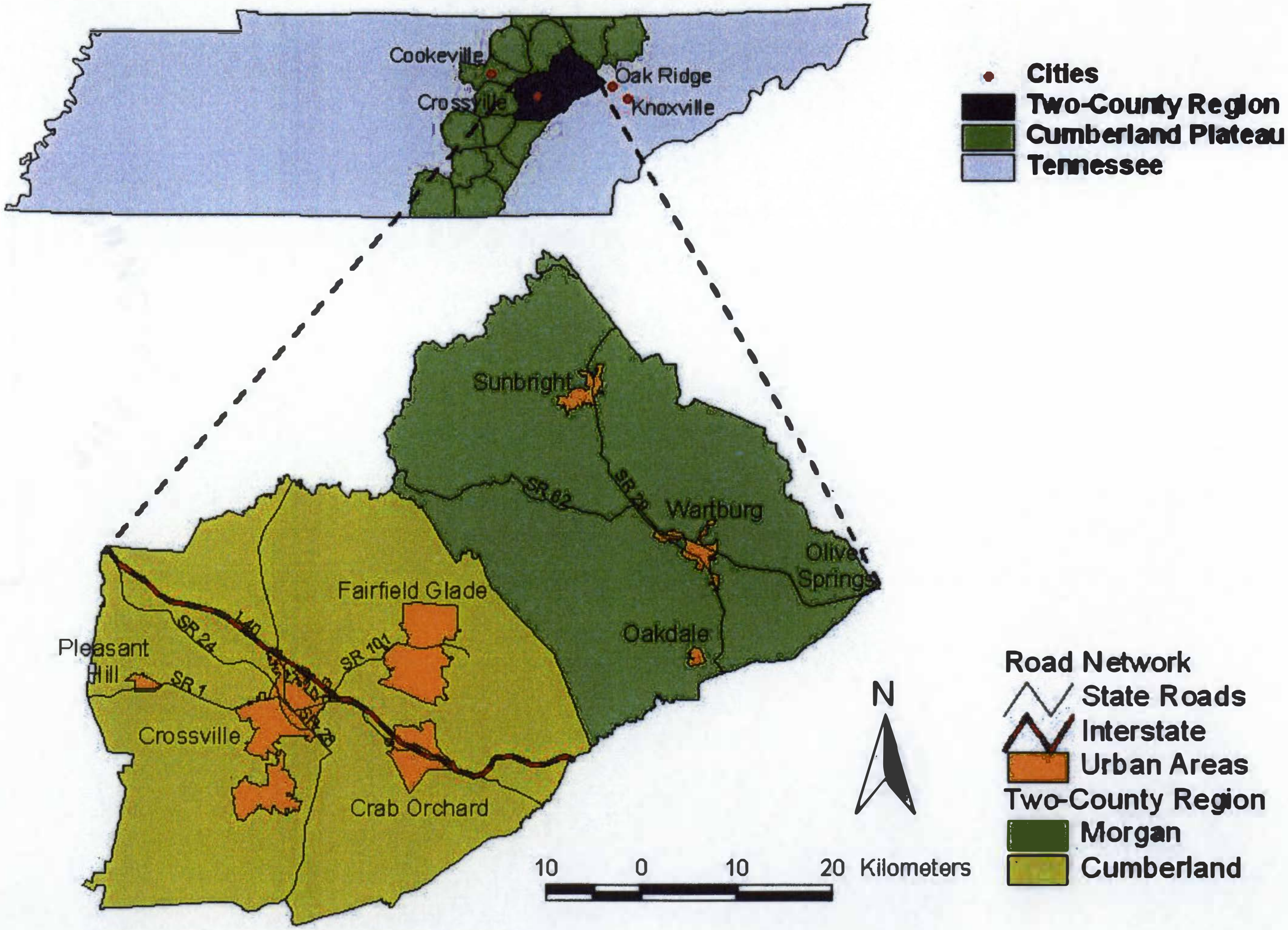

Figure 1-1: Study area: Cumberland and Morgan Counties, Tennessee

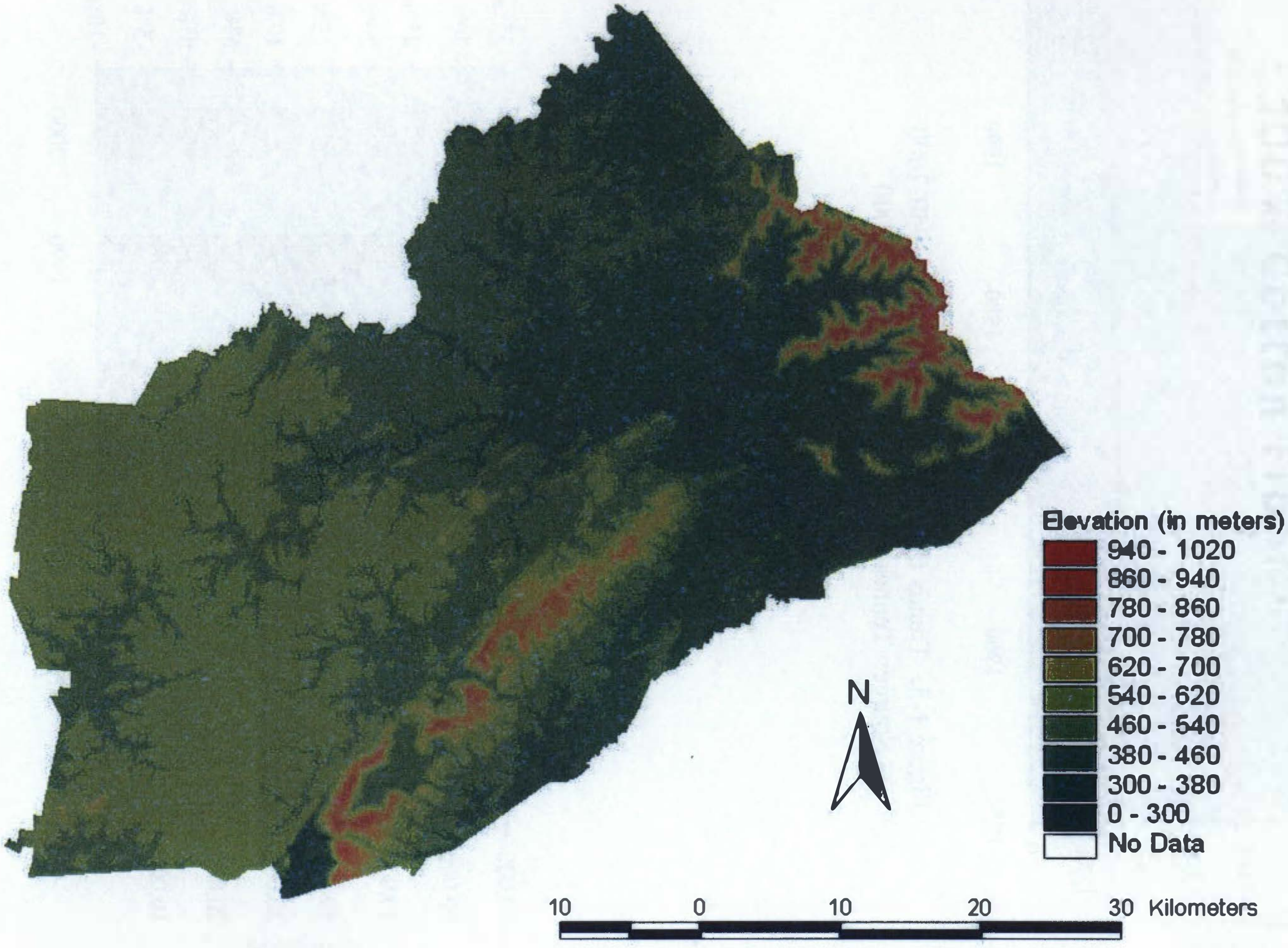

Figure 1-2: Elevation for Cumberland and Morgan Counties, Tennessee

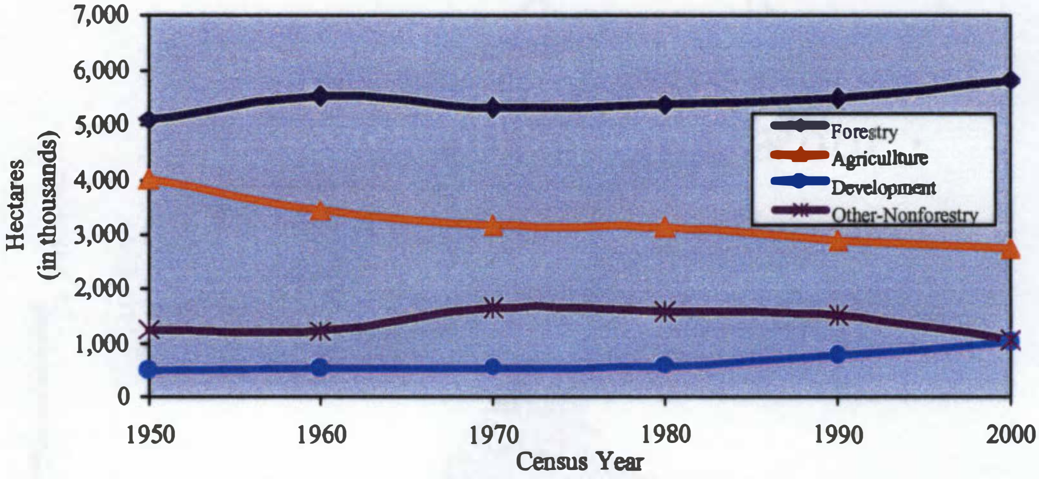

Figure 1-3: Trends in land use for Tennessee, 1950-2000
Source: Tennessee Forest Statistics, 1950-2000

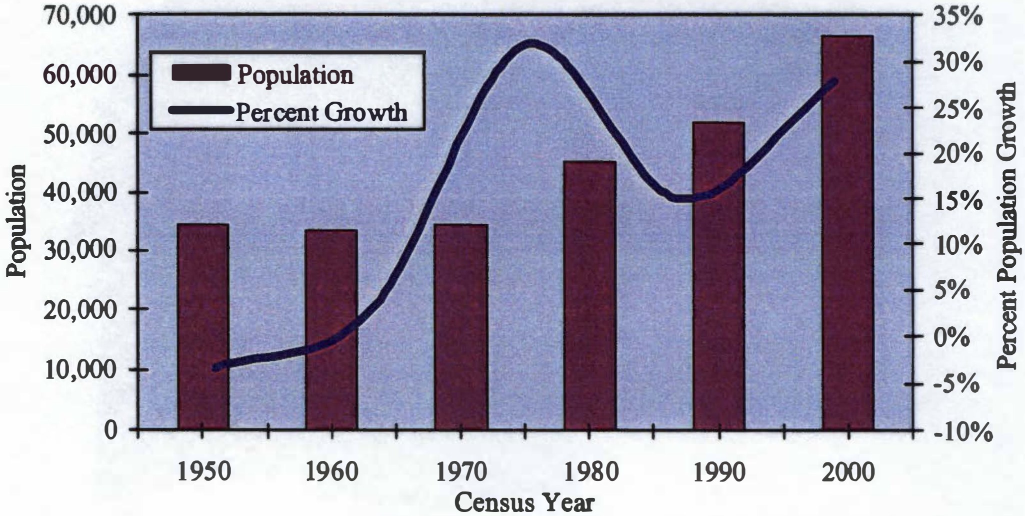

Figure 1-4: Population and Growth Rates for the Cumberland and Morgan County Region, Tennessee, 1950-2000
Source: U.S. Census Bureau, 2000

Chapter II

Developing a Forest Cover Change Map for Cumberland and Morgan Counties, Tennessee

Introduction

Population growth and the resulting urbanization are major threats to forest land in the South (Wear and Greis 2002). The results of the land use change include the loss of forested acres, fragmentation and parcelization, and a reduction in biodiversity. These threats are pertinent for the Cumberland Plateau of east Tennessee due to the rapid population growth and the rich diversity of the region.

Since 1980, the Cumberland Plateau's population has increased 11 percent, rising from 343,000 in 1980 to over 386,000 in 2000 (U.S. Census Bureau 2002). With population increasing and urban areas expanding, much of the forest land in Cumberland and Morgan Counties is threatened by development. Due to lower costs of living, beautiful natural settings, and retirees' growing interest in the area, many analysts believe that the exurban development of Cumberland and Morgan Counties and the rest of the Plateau region will continue to increase dramatically over the next several decades.

With increases in population growth and changes in land cover and land use, planners, ecologists, and resource managers need a reliable and efficient system to assess land cover transition by detecting, monitoring, and quantifying land cover change. Whereas previous research has examined the development of land cover maps (Moore and Bauer 1990; Bolstad and Lillesand 1992; Evans 1994) as well as the creation of land cover change detection maps (Borak et al. 2000; Musaoglu and Ormeci 2000; Lyon et al. 1998), few have created an efficient procedure for developing a temporal change analysis map that integrates a current image of land cover classes.

Study Objectives

This study was designed to develop a methodology for evaluating land cover change in the two-county region on the Cumberland Plateau province of Tennessee. Specific objectives included:

1) develop a land cover map and a forest cover change detection system using image differencing of multiple normalized difference vegetative indices (NDVI),
2) incorporate the land cover map with the forest cover change detection to analyze which cover types replace forest cover, and
3) evaluate the accuracy of the process for the two time periods (1992 and 2000) for Cumberland and Morgan Counties.

Previous Research

Urbanization throughout the Cumberland Plateau as well as for the entire South has long been a major concern for planners, geographers, foresters, and ecologists. With the advent of geographic information systems (GIS), many researchers have used satellite remote sensing systems as an accurate, cost-effective, and reliable system for the development of land cover maps and assessment of land cover change.

Land Cover Classification System

A major component of developing a land cover map involves a land cover classification system. Many current land cover classification maps are derived from satellite imagery with use of computer assisted classification techniques. Multispectral reflectance data for mapping land cover have been a fundamental component of land cover and land use modeling techniques. The Landsat satellite systems of the early 1970s incorporated Multispectral Scanners, which mapped using 3 visible channels along with a near infrared band. By the 1980s, Thematic Mapper was added, incorporating 2 more infrared bands and a thermal long-wave infrared band, allowing for more accurate distinction of landcover as compared to the multispectral bands. In addition, the spatial resolution improved from 80 meters for Multispectral Scanner to 30 meters for Thematic Mapper. In 1999, the Landsat 7 satellite containing the Enhanced Thematic Mapper (ETM+) platform was placed into orbit, providing additional spectral resolution allowing for better interpolation of land cover classes.

Moore and Bauer (1990) compared Multispectral Scanner (MSS) data to Thematic Mapper (TM) data and determined that the TM data was significantly higher in accuracy. The higher accuracy rates are due to the higher spectral and spatial resolution of the TM images. In addition, they determined that at least one band from the visible, near infrared, and middle infrared portions of the spectrum are necessary for the best overall land cover classification. Evans (1994) continued research with Landsat TM data, using supervised classification methods for signature development and classification in the Kisatchie National Forest of Louisiana. All signature training and test polygons were selected from existing GIS, aerial photographs, and Forest Service data deriving an overall classification accuracy rate of 86.2 percent, indicating the necessary procedures for providing the best classification techniques.

Bolstad and Lillesand (1992) examined a process for improving classification of forest vegetation in northern Wisconsin. Using Landsat Thematic Mapper data, they concluded that a combination of soil data, terrain position, and a maximum likelihood ratio test for classification, improve the overall classification accuracies as compared to a traditional maximum likelihood test. However, for the two-county study, soil classification and terrain positions were replaced with digital orthographic quarter quadrangle (DOQQ) maps and GPS verified plot samples.

Land Cover Change Detection

A commonly used procedure for detecting land cover change is comparing changes between two remotely sensed images. Change detection is the technique of comparing two or more separate processed images from different time periods (Jensen *et al.* 1995). This process is important in monitoring urban development and its impact with natural resources. A variety of techniques are available to detect land cover changes from multi-temporal data sets. Previous research has detected land cover change by differentiating areas on digital images that depict change features of interest between two or more image dates (Green et al. 1994; Lyon et al. 1998; Musaoglu and Ormeci 2000). Known as image differencing, this method involves subtracting the brightness values of pixels in one image recorded at a specific date from the brightness values of pixels at the same location in a separate image recorded at another date.

Alternative procedures include post-classification where each image is classified using either supervised or unsupervised classification techniques, then compared to create a change detection map (Pereira et al. 2002). Although this procedure produces a change detection that allows the user to identify what has changed, its accuracy rates tend to be poor. This is due to the combining of errors from both of the classifications (Macleod and Congalton 1998). A procedure developed by Macleod and Congalton (1998), compared several change detection processes including post-classification, image differencing, and principal component technique. Although they examined change for submerged aquatic vegetation, Macleod and Congalton's (1998) results indicated that image differencing produces the highest accuracy readings. The only downfall to image differencing is that it lacks the ability to identify what has changed. Therefore, this study incorporated image differencing with a current classified image to produce a more accurate change detection procedure enabling the reader to identify what cover type replaced the previous forest parcel.

Study Area

The study area for this project was Cumberland and Morgan Counties (two-county region), located within the Cumberland Plateau, which consists of an elevated tableland bordered by the Ridge and Valley Province to the east and the Eastern Highland Rim of the Interior Low Plateaus to the west Figure 2-1[1]. While other areas throughout the South have experienced a strikingly abrupt alteration in land cover, Cumberland and Morgan Counties embody a long-term process of steady successional change. Cumberland and Morgan Counties currently consist of heavily forested areas covering approximately 247,587 hectares (79 percent) of the two-county region. The forests of the region, lying within the Appalachian Mixed Mesophyitic Forest Ecoregion, are characterized as temperate broadleaf and mixed (deciduous and coniferous) forests (Ricketts *et al.* 1999). Of this total, over 85 percent (206,454 hectares) is classified as either mixed or oak-hickory, while the remaining is classified as either planted loblolly (*Pinus taeda*) or natural shortleaf pine (*Pinus echinata*).

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[1] All tables and figures are located in the Appendices.

Methods

The primary purpose of the study was to develop a more efficient procedure for evaluating forest cover change. A map illustrating the observed classified change in forest cover was created by incorporating a current land cover map with the results of a forest cover change detection assessment. The following lists the steps involved in the development and incorporation of a forest cover change image and a current land cover map.

Forest Cover Change Dataset

The purpose of the change detection analysis was to identify natural areas that had sustained substantial forest loss. Contrasting vegetation loss between past and present satellite images and comparing the differences with the area's current land cover was the basis for the change detection analysis. Rather than collecting or acquiring inventory data from other sources, a change detection analysis via remotely sensed data provided a less expensive procedure for analyzing forest area change.

For an accurate vegetative comparison, it was critical that all satellite imagery consisted of high spatial, spectral, and temporal resolution. While spatial resolution refers to the visible detail in an image, spectral resolution refers to the width across the electromagnetic spectrum. Temporal resolution refers to the number of times the satellite returns to a specific location (Verbyla 1995). These attributes along with the accessibility and inexpensive cost of the imagery made Landsat satellite imagery the favored choice. As part of the Multi-Resolution Land Characteristics (MRLC) Consortium, two separate Landsat satellite imagery scenes from September 1992 and June 2000 were purchased from the USGS Earth Resources Observation Systems (EROS) Data Center. These images were scenes from the Cumberland Plateau region in the Landsat World Reference System, path 19 and row 35, and path 20 and row 35. The 1992 imagery data set was in Universal Transverse Mercator (UTM) zone-17 projection, while the 2000 imagery data set was in Albers Conical Equal Area projection system. For comparing data, a program in ERDAS Imagine software automatically overlaid satellite images of different projections without incurring any problems in georeferencing (ERDAS 2001). Therefore, the task of reprojecting either image onto the other was unnecessary.

Whereas the 2000 scene consisted of Enhanced Thematic Mapper Plus (ETM+) data, the 1992 scene consisted of Thematic Mapper (TM) data. Both represented reflected light of the Earth's surface from seven spectral bands ranging from blue to thermal infrared. Six bands (channels 1, 2, 3, 4, 5, and 7) represented 900 square meters spectral data, whereas channel 6, a thermal- infrared band, represented 14,400 square meters ground data (Hurvitz 2002). Even though the September 1992 image was obtained three months later in the season than the 2000 image, the 1992 scene was the most favorable of the 1990's, being that it was cloud free and the closest in season. Conversely, the June 2000 image presented cloud problems, but was acquired because it was the most favorable image for that year. All cloud cover was discarded preceding change classification and evaluation.

Attempts for comparing vegetation change using land cover maps from 2000 and 1992 were compared. However, the land cover processing steps and atmospheric conditions associated with the development of each classified map made it necessary to find an alternative approach. Change detection involved creating and comparing separate temporal vegetation coverages. The extraction of a vegetation source required images with infrared characteristics. This was accomplished by acquiring multi-temporal data sets with vegetational differences but devoid of any variation biased by seasonal change. In order to minimize seasonal and environmental conditions, the imagery was recorded with the same spatial resolution, spectral bandwidths, and viewing geometry. All imagery data had to be acquired during the summer months, when greener, denser canopies were more prevalent ensuring successful vegetational differences between the two time periods (Wilkie and Finn 1996)

The first process involved removing 3 spectral bands (bands 5, 6, 7) from the original 7. The first four spectral bands represent red, green, blue, and near-infrared allowing for clearer distinction of vegetation change. A second process known as vector image transformation involved accentuating and highlighting features by separating the information within the bands (Wilkie and Finn 1996). Examples of vector image transformation are vegetative indices, which use ratios of specific bands to quantify vegetation vigor or "greenness". Vegetative indices enhance differences that cannot be observed at their original color bands. Therefore, it was necessary that the imagery consist of multiple spectral bands with infrared and visible-red bands. The Normalized Difference Vegetation Index (NDVI) determined the density of greenness that separates healthy vegetation with a calculated value near one (1) from unhealthy or sparse vegetation with a value closest to zero (0) (Earth Science Enterprise 2003). Healthy vegetation absorbs more visible light and reflects the majority of near-infrared light. On the other hand, unhealthy vegetation reflects more visible light and less near-infrared light (Earth Science Enterprise 2003). This index is engaged by subtracting the red (Thematic Mapper band 3) band from the near-infrared (NIR) (Thematic Mapper band 4) band. It then divides the two by their sum to normalize the values (Wilkie and Finn 1996). After researching other various vegetative indices, NDVI analysis was selected because it would yield the best results (Musaoglu and Ormeci 2000). The equation for NDVI in Equation 2-1 represents the algorithm used in the ERDAS Imagine program to determine the amount of healthy vegetation in Morgan and Cumberland counties (ERDAS 2001). Using a spectral range of 256 colors, ranging from white to black, areas of dense vegetative cover are illustrative of light areas (values closer to 255).

Equation 2-1:

$$\text{NDVI} = \frac{[\text{band 4 (NIR spectral band)} - \text{band 3 (red spectral band)}]}{[\text{band 4 (NIR spectral band)} + \text{band 3 (red spectral band)}]}$$

Following the creation of NDVI images, a change detection map between the 1992 and 2000 scenes was produced. Change detection involved comparisons between two separate temporal images. This image illustrated the addition or reduction of vegetation over the last eight years. The equation for change detection in Equation 2-2 represents the algorithm procedure used in the ERDAS Imagine program. Similar to the original NDVI images, the change detection image consisted of numbers ranging from 0 to 255, with 0 indicative of no change and numbers closer to 255 designating absolute vegetative change.

Equation 2-2:

$$\text{NDVI Change} = \text{Current Image (2000)} - \text{Previous image (1992)}$$

Due to the fact that these images show large areas with often small changes, a filtering procedure was used to clarify the image. The filtering procedure produced a black and white raster image; black portions representing vegetational change and white representing no change. The final ERDAS raster display was converted to Arc Info polygons representing vegetation loss in white and zero vegetation change in black. After the Arc Info coverages were created, they were then reprojected into UTM zone 16 projection using ARC Info. This image was further converted into an ArcView vector cover, consisting of polygons with a numeric attribute corresponding to change. A value of zero (0) was assigned for no forest change in land cover and a value of one (1) assigned for a loss to another land cover. As illustrated in Figure 2-2, this coverage was referred to as "CHANGE".

Land Cover Dataset

As defined by the Land Use Cover Change (LUCC) Group, land cover is the observed physical cover of existing topography at a specific time and location (McConnell and Moran 2001). Land use, on the other hand, is the purpose for which the land is being used (McConnell and Moran 2000). Instead of quantifying land use data, this project required land cover data. Developing a land cover map necessitated classifying spectral reflectance signatures of current Multi Resolution Land Cover (MRLC) images. The classification system applied for the land cover map was a subset of the Land Use and Land Cover (LULC) classification system developed by USGS. This method known as the Anderson classification system (Anderson *et al.* 1976) uses a hierarchical classification scheme based on four levels: level I, general; level II, descriptive; level III, detailed; and level IV, most detailed. Of the four, the detailed classification level III was preferred, but due to the inability of discerning specific land cover classes from one another, a modified level II was chosen. The following lists the 12 classes: water, mixed barren, pasture/grassland, cropland, transitional (fallow), residential, commercial/transportation, deciduous forest, evergreen forest, mixed forest, beetle infestation, and cloud/cloud shadow cover.

ERDAS Imagine was used to aid in classifying, labeling, and statistically determining land cover types. Due to the rapid processing of preliminary steps, unsupervised classification was selected and processed. In comparison to real life ground features derived from forest plot sampling, this process failed to accurately display land cover types. Except in areas of water, no other land cover type was successfully classified. Therefore, the more effective and detailed supervised classification system was deemed to be the most successful tool for classifying.

Preceding classification, the MRLC satellite images were downloaded and merged using the mosaic feature, then clipped according to the shape of Cumberland and Morgan Counties. Condensing the image used less memory and expedited the classification process, as well as helping the user identify field areas and county boundaries. The classification process demanded that a specific combination of bands be engaged for the user to properly discern vegetation from other cover types for proper classification. Therefore, three spectral bands were used in the classification: green (band 2), middle infrared (Band 5), and thermal infrared (band 6) portions of the spectrum (Hurvitz 2002). Previous research concluded that this combination of spectral bands captures the information in Thematic Mapper data for greater classification accuracy for delineating between vegetation and other cover types (Bolstad and Lillesand 1992).

Based upon aerial photography and field data, supervised classification required the user to identify areas within the imagery known to belong to the particular land cover class found on the aerial representation. These training sites enabled the computer to identify land cover types based on a combination of its spectral reflectance color. Therefore, areas on the image were identified using training sets, which in turn, statistically generated spectral signatures characteristic of each land cover type. Whereas training sets are samples of the image representative of known features, signatures are the spectral properties of that feature (Wilkie and Finn 1996).

Prior to sampling, two constraints had to be addressed: the quality of the reference data and the size and location of the training sets. The first constraint, reference data, needed to be collected at the same minimum mapping unit as the imagery data. Discerning features and cover types on the imagery required downloading digital orthographic quarter quadrangle (DOQQ) maps (1:24,000 scale, July 1997) containing Cumberland and Morgan Counties from a Tennessee GIS spatial server (Tennessee Federal GIS Users Group 2003). These digital maps, a form of aerial photographs, were in a differentially rectified and geocoded format designed to prevent image displacements caused by camera tilt and terrain relief (Tennessee Federal GIS Users Group 2003). Because these DOQQ images were in a different projection, they had to be reprojected into Albers Equal Area projection, so they could be overlaid with the satellite images.

Even with the satellite image's high resolution and specific band combinations, some land cover classes were still indistinguishable. In some areas of the imagery, places of mixed forest, pasture, and cropland needed a second source of verification. This demanded the purchase of winter 2002 satellite imagery, set in the same area and projection system of the previously purchased 2000 imagery. This winter verification allowed the user to differentiate areas of pasture (light-greenish shade in summer and teal color in winter), from cropland (bright-greenish color in summer and light-greenish shade in winter).

Along with the aerial depictions, 150 sampling points were taken during the summer of 2002 throughout Cumberland and Morgan Counties. These sampling points, geographically positioned, detailed the species composition and local features of the area, thereby helping in verification.

The second constraint, training sets, required an appropriate size, location, and sampling intensity for extracting spectral data. Even with a correctly geocoded image, it was necessary to select a cluster of pixels (minimal 9-square pixel area) to minimize registration problems. This made it easier for locating features on reference aerials (Congalton and Green 1999). Secondly, the training sets were placed in homogenous areas avoiding edge effects of stand boundaries. Any selection including two distinctly different spectral characteristics would have yielded spectrally inaccurate samples thereby resulting in an imprecise map (Evans 1994). A third problem existed with the possibility of spatial autocorrelation between adjacent pixels. Spatial autocorrelation occurs when the presence or absence of a specific land cover unit affects the presence of neighboring land cover units (Cliff and Ord 1973). To reduce spatial autocorrelation, all training sets were selected using simple random sampling. Finally, to further increase the accuracy of the land cover map, a large sampling intensity of 550 training fields were selected for classification. This sampling intensity size was derived from Congalton and Green's (1999) guidelines for data collection. Many projects have followed the concept that a minimum collection of 50 samples for each land cover category be statistically sound and practically attainable (Congalton and Green 1999). Whereas the major land cover types were collected with a minimum of 50 samples, non-obligatory cover classes such as cloud and beetle infestation were selected with a maximum of 25 training sets. The 550 selected training sets were selected in each cluster, providing an even distribution of samples, and at the same time improving the efficiency and accuracy of the final image.

Once the training sets were selected, the groups of signatures for each class were statistically calculated for homogeneity. All class signatures were labeled one of the following: water, open, pasture, crop, fallow, residential, urban/industrial, mixed, evergreen, deciduous, cloud, and/or beetle infestation. Any sample with a coefficient of variation greater than 10 percent was deleted from its specific signature group, then replaced with a statistically improved sample (Evans 1994). The final signature selection was then run using a maximum likelihood classification algorithm. This algorithm, computing the probability of pixels belonging to a specific class, determined the true shape of the distribution of each land cover (Wilkie and Finn 1996). The end result produced a thematic map containing 550-signature classes representative of the 12 cover classes. Using the ERDAS recode algorithm, the signature classes were further refined into 12 cover classes producing a final thematic map.

With Arc Info software, the final ERDAS Imagine classification was processed into a grid format and then reprojected to UTM zone 16 projection (Environmental Systems Research Institute (ESRI) 1999). This image was further converted into an ArcView vector coverage, consisting of polygons with a numerical attribute and a classification label equal to the original ERDAS classified image (Evans 1994; Environmental Systems Research Institute (ESRI) 1999). Finally, the polygon cover was labeled 1 through 12 according to the land cover type in 2000 (Gunter *et al.* 2000). To ensure the land cover map's accuracy, an accuracy assessment was instituted. The procedures executed for an accuracy assessment are described below.

Results

Land Cover Accuracy Assessments

Verifying the accuracy of the land cover map required comparing specific sites on the image with their exact reference points. Reference data, another name for ground locations, are the class labels derived from a correct source of information. Similar to the training set field sites, the location of the classified positions was distributed in a simple random pattern throughout the image. Information about the cover type within the land cover map was compared with the reference data, the 1997 DOQQ aerial images. In order to have a reliable land cover map, most sources required a minimum overall accuracy of 85 percent (Congalton and Green 1999). The ability to prove the map's accuracy and its relevance, however, depended on the total number of random points taken. For a statistically accurate sample size, the total number of ground truth locations was based on the desired accuracy rate (Wilkie and Finn 1996). Using a model expressed by Congalton and Green, Equation 2-3 represents the statistical procedure for determining sampling size based on a desired accuracy rate (1999). For an accuracy of 85 percent, a minimum of 500 random points was required for the two-county region.

Equation 2-3:

$$N = \beta \prod_i (1-\prod_i) / b_i^2$$

Where:

β = Derived from chi-square table with 1 degree of freedom and 1 - α / κ Probability one a Type I error (one-tailed)

$\prod_i$ = Percentage of map area covered by a particular class

b_i = Desired precision rate

[Source:(Congalton and Green 1999)]

An error matrix was created to determine overall accuracy, a measure representing the probability that both reference and classified data correctly correspond to each other (Congalton and Green 1999). An error matrix reflects the map's accuracy with columns and rows. The columns represent reference data whereas the rows represent classified data. Any classified data included in an incorrect category or excluded from a correct category decreases the images' overall accuracy rate. In addition to overall accuracy, producer and user accuracies were calculated to determine specific categorical accuracies. Producer's accuracy is the probability that a pixel observed in the field (column data) is correctly depicted on the map (row data). User's accuracy is the probability that a pixel on the map correctly identifies the land cover category as it is represented in the field. A high accuracy ratio depends on the precision of the individual pixel class to their reference positions (Congalton and Green 1999).

The total combined accuracy rate for Cumberland and Morgan Counties was 89 percent (Table 2-1). User's accuracy rates for Cumberland and Morgan Counties were 90.8 and 87.6 percent, respectively. Whereas both overall rates were acceptable, the user and producer ratios signified some specific problems with both counties. Morgan County's user accuracy rates were 33, 53, and zero percent for water, residential, and urban/transportation, respectively (Table 2-2). As represented in Table 2-3, Cumberland County yielded similar results for water and urban/transportation with a user's accuracy of only 50 percent. The reasons for such inaccuracies were the incorrect spectral reflectance of steep terrain and indistinct waterways. In addition, shadow effects created by clouds created inaccurate producer accuracies, giving off a spectral reflectance color similar to residential areas. Rather than being labeled correctly, both the terrain and waterways were labeled as residential. Therefore, additional training sets and spectral signatures were selected in the problem areas. The new spectral signatures were then rerun in the maximum likelihood algorithm, creating a new thematic land cover map averaging an accuracy rate of 91 percent for both counties. This cover is illustrated in Figure 2-3 and Figure 2-4 and referred to as "COVER".

Observed Classified Change in Forest Cover

In order to correctly portray forest loss, it was necessary to compare forest change between 1992 and 2000. Despite the fact that atmospheric conditions distorted the ability to delineate changes in land cover, the combination of the NDVI difference dataset with the land cover map made it possible to delineate the transition from forest to urban cover. Therefore, the combination of the forest cover change detection map "CHANGE" and the land cover map "COVER" resulted in the observed classified change in forest cover "CCFC" (classified change in forest cover). An illustration of CCFC is represented in Figure 2-5

The resultant image of Figure 2-4 illustrates the transition from forest cover to another land cover type between 1992 and 2000. The total change in forest cover represented 13,185 hectares (4.2 percent loss) (Table 2-4). Based on Figure 2-4, the spatial expansion of residential and commercial development is clearly visible along Interstate 40, following a diagonal pattern from Northwest to Southeast Cumberland County. With Crossville's population growth of 30 percent within a 10-year period, expansion in urban and residential development increased 1,915 and 1,062 hectares, respectively.

Another land cover type replacement for forest cover was barren and transitional lands. Mixed barren, representing sandy areas, gravel parking lots, and bare rock totals 3,730 hectares, a 1.2 percent increase from 1992. In addition, transitional lands representing cleared forests occurring primarily in northern Morgan County exhibited increases of 3,796 hectares since 1992.

Discussion and Conclusions

The objective of this study was to develop an accurate and efficient procedure for the creation of a land cover map and a forest change detection algorithm for Cumberland and Morgan Counties, Tennessee. The method used to generate this procedure combined the methods of post-classification and image differencing.

The development of a forest cover change dataset required the process of image differencing by comparing two Landsat images (1992 and 2000). Secondly, using the 2000 Landsat image with digital classification techniques created a current land cover map for Cumberland and Morgan Counties. An Anderson level II land cover classification comprised of water, mixed barren, pasture, cropland, transitional areas, residential, urban/transportation, mixed forest, evergreen forest, deciduous forest, cloud/cloud cover, and beetle infestation was used (Anderson *et al.* 1976). The classified image was then incorporated with the land cover change dataset for the development of a map illustrating the observed classified change in forest cover. The overall classification accuracy of 89.2 percent was achieved by combining ground truth data and aerial photography. It was determined by visual analysis that this procedure provided an excellent indicator of level II forest conversion to another land cover class.

Previous research suggested developing change detection through the process of post-classification (Macleod and Congalton 1998). This enabled the user to determine the cover type prior and subsequent to conversion. Whereas this is helpful for determining exact forest type, for example deciduous or evergreen, accuracy rates tend to be lower than the 85 percent required by the U.S. Geological Survey (Anderson *et al.* 1976). In addition, image differencing involved subtracting the pixels of the 2000 image with the exact location of the pixels of the 1992 image. The only shortcoming to image differencing is that it lacks the ability to identify what has changed (Macleod and Congalton 1998). Therefore, this study incorporated image differencing with a current classified image to produce a more accurate change detection procedure enabling the reader to identify what cover type replaced the previous forest parcel.

This study could be improved by refining upon the classification procedure. Even though cloud cover represented less than one percent of the total area, this could have been completely avoided by proper examination of the satellite images before final purchase. Overall, the procedures for developing a land cover map make it very difficult for agencies to process the results. Therefore, the results of identifying forested areas that have been converted to another cover through the use of combining post-classification and image differencing could be easily transferable to local government agencies, planners, and foresters. The product derived from these techniques could improve future land use plans, allowing local planners and civil engineers more time for the development of better services to growing areas. Secondly, these techniques could help foresters to identify which areas are highly susceptible to possible conversion to urban uses.

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Appendices

Appendix A

Tables

Table 2-1: Overall accuracy assessment for 2000 data set of Cumberland and Morgan Counties, Tennessee

County	Producer's Accuracy°	User's Accuracy*	Total Accuracy**
Cumberland	89.5%	88.1%	90.8%
Morgan	**73.9%**	**79.2%**	**87.6%**
Total Area	79.2%	86.8%	89.2%

° Producer's accuracy - probability that a pixel observed in the field is correctly depicted on the map

* User's accuracy - probability that a pixel observed in the map is correctly depicted in the field

** Overall accuracy - probability that both reference and classified data correctly relate to each other

Table 2-2: Initial accuracy assessment for 2000 data set of Morgan County, Tennessee

		Reference (Field) Data												
	Classification	Water	Open	Pasture	Crop	Fallow	Residential	Commercial	Mixed Forest	Evergreen Forest	Deciduous Forest	Cloud / Cloud Shadow	Beetle Infestation	Row Total	Producer's Accuracy
Classified Data	Water	1							1	1				3	33
	Open		10											10	100
	Pasture			27	1				1					29	93
	Crop				1									1	100
	Fallow					12								12	100
	Residential		1	3	1		19				8	2	2	36	53
	Commercial		1	1				0						2	0
	Mixed Forest								59	5				64	92
	Evergreen Forest									11				11	100
	Deciduous Forest								1		79			80	99
	Cloud / Cloud Shadow										1	1		2	50
	Beetle Infestation												0	0	0
Column Total		1	12	31	3	12	19	0	62	17	88	3	2		
User's Accuracy		100	83	87	33	100	100	0	95	65	90	33	0		
Overall Accuracy =		88.0%													

° Producer's accuracy - probability that a pixel observed in the field is correctly depicted on the map

* User's accuracy - probability that a pixel observed in the map is correctly depicted in the field

** Overall accuracy - probability that both reference and classified data correctly relate to each other

Table 2-3: Initial accuracy assessment for 2000 data set of Cumberland County, Tennessee

		Reference (Field) Data													
	Classification	Water	Open	Pasture	Crop	Fallow	Residential	Commercial	Mixed Forest	Evergree Forest	Deciduous Forest	Cloud / Cloud Shadow	Beetle Infestation	Row Total	Producer's Accuracy
Classified Data	Water	2							2					4	50
	Open		7				1							8	88
	Pasture			31		1	1		2					35	89
	Crop				7									7	100
	Fallow					8								8	100
	Residential	1		1		1	19				3			25	76
	Commercial		1					1						2	50
	Mixed Forest								42	2	1			45	93
	Evergreen Forest									18				18	100
	Deciduous Forest								6		82			88	93
	Cloud / Cloud Shadow											9		9	100
	Beetle Infestation												1	1	100
Column Total		3	8	32	7	10	21	1	52	20	86	9	1		
User's Accuracy		67	88	97	100	80	90	100	81	90	95	100	100		
Overall Accuracy =		90.8%													

° Producer's accuracy - probability that a pixel observed in the field is correctly depicted on the map

* User's accuracy - probability that a pixel observed in the map is correctly depicted in the field

** Overall accuracy - probability that both reference and classified data correctly relate to each other

Table 2-4: Land cover change statistics between 1992 and 2000 for Cumberland and Morgan Counties, Tennessee

Land Cover Type	**Area (Hecares)**	**Percent Change from Forest**
Water	770	0.2%
Mixed Barren	3,730	1.2%
Pasture	689	0.2%
Crop	279	0.1%
Transitional Areas / Fallow	3,796	1.2%
Residential	1,915	0.6%
Commercial/Transportational	1.062	0.3%
Mixed Forest	76	< 0.1%
Evergreen Forest	60	< 0.1%
Deciduous Forest	45	< 0.1%
Cloud / Cloud Shadow	706	0.2%
Beetle Infestation	57	< 0.1%
Total Forest Cover Change	13,185	4.2%
Total Two-County Region	311,730	

Appendix B

Figures

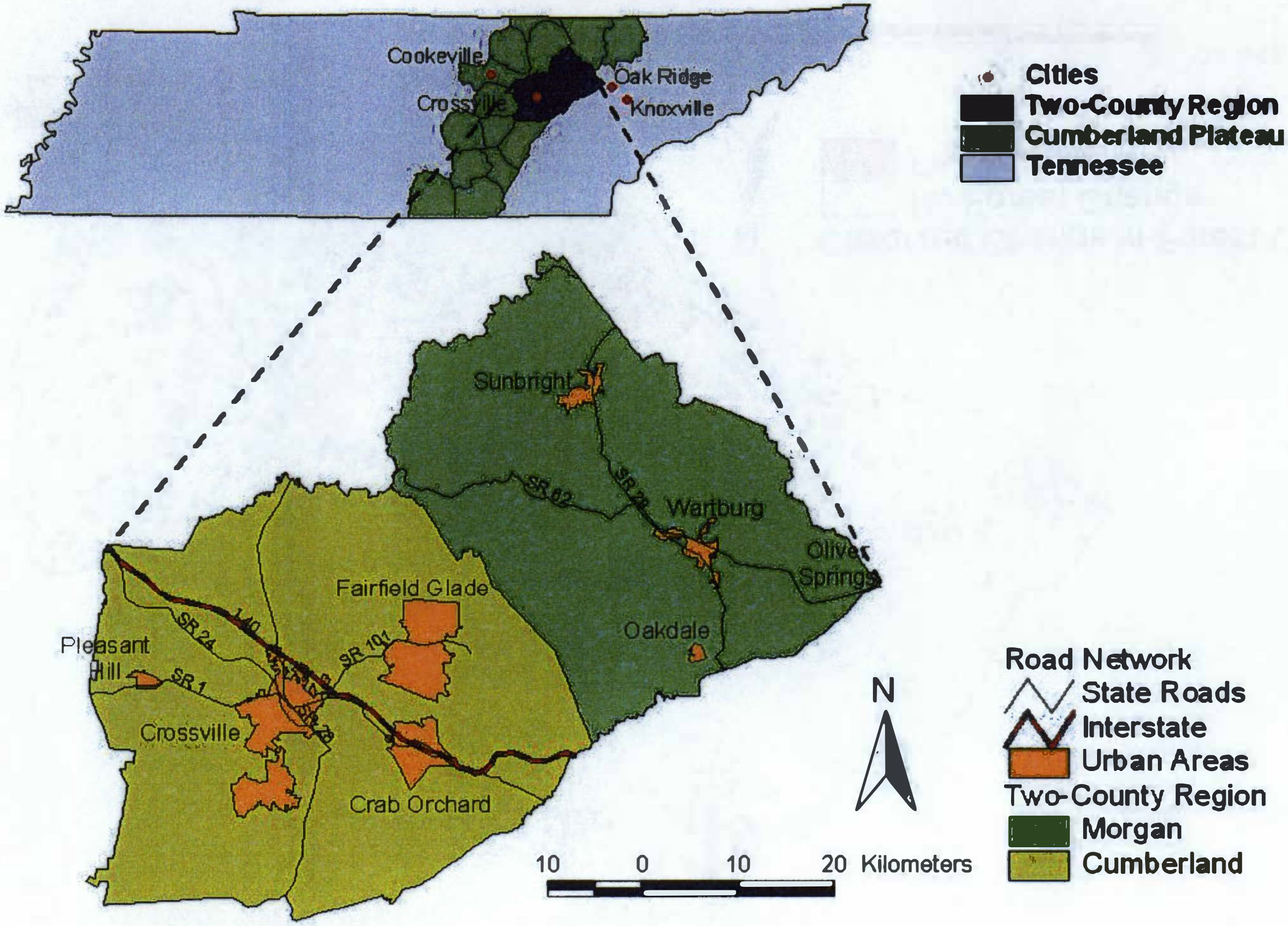

Figure 2-1: Study area with road network system and urban areas, Cumberland and Morgan Counties, Tennessee

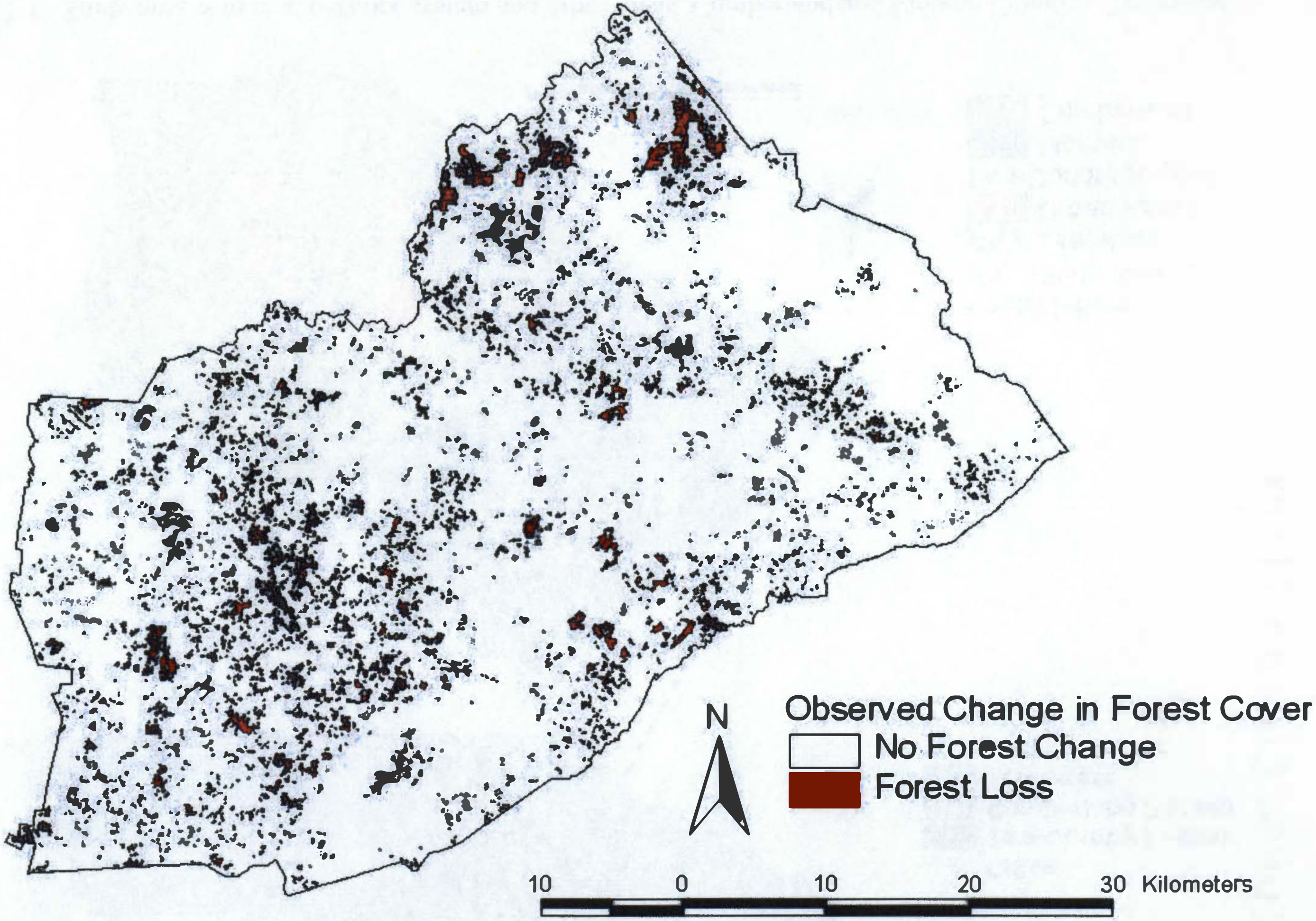

Figure 2-2: Observed forest cover loss between 1992 and 2000, Cumberland and Morgan Counties, Tennessee

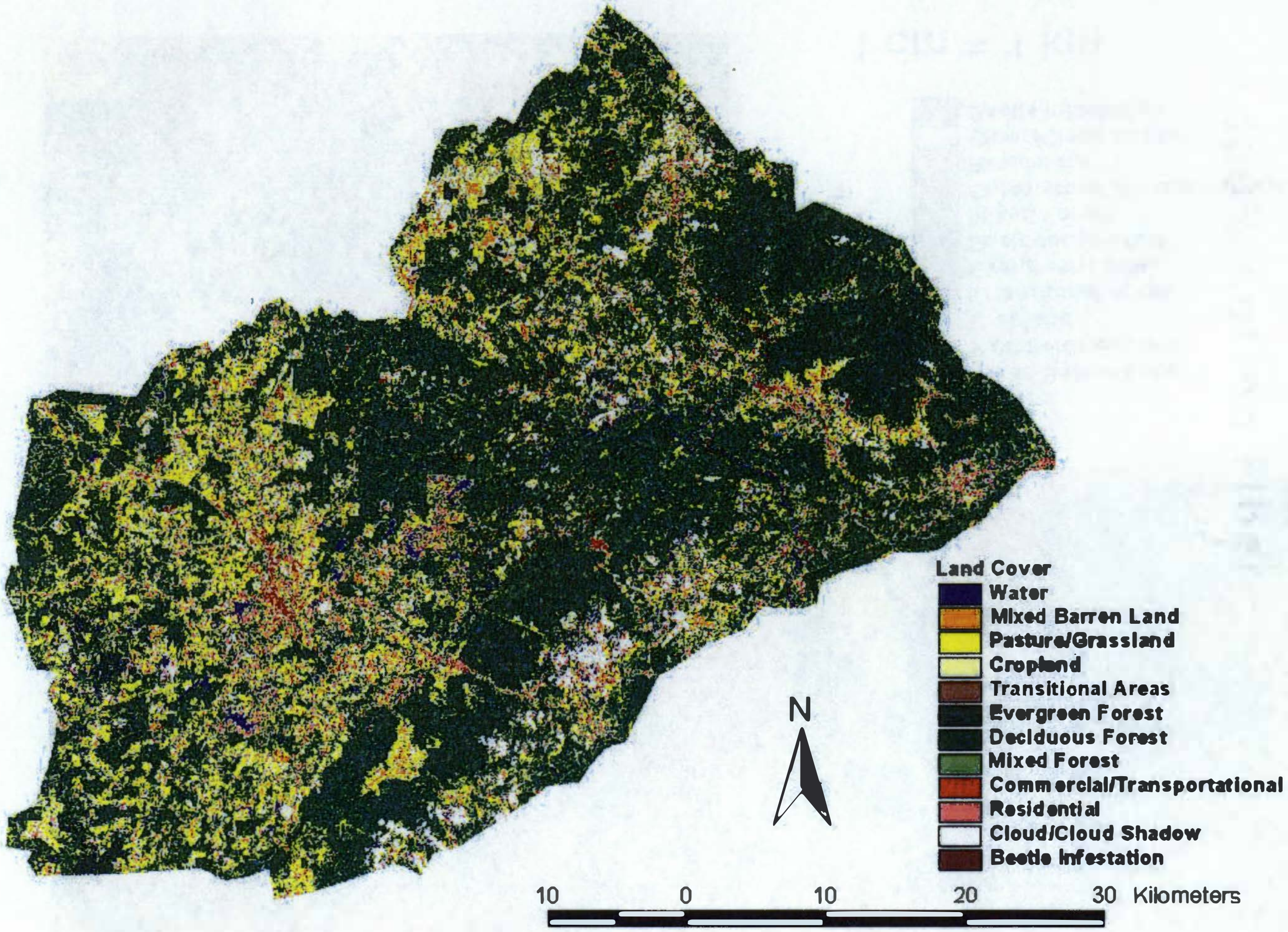

Figure 2-3: Current land cover dataset, Cumberland and Morgan Counties, Tennessee

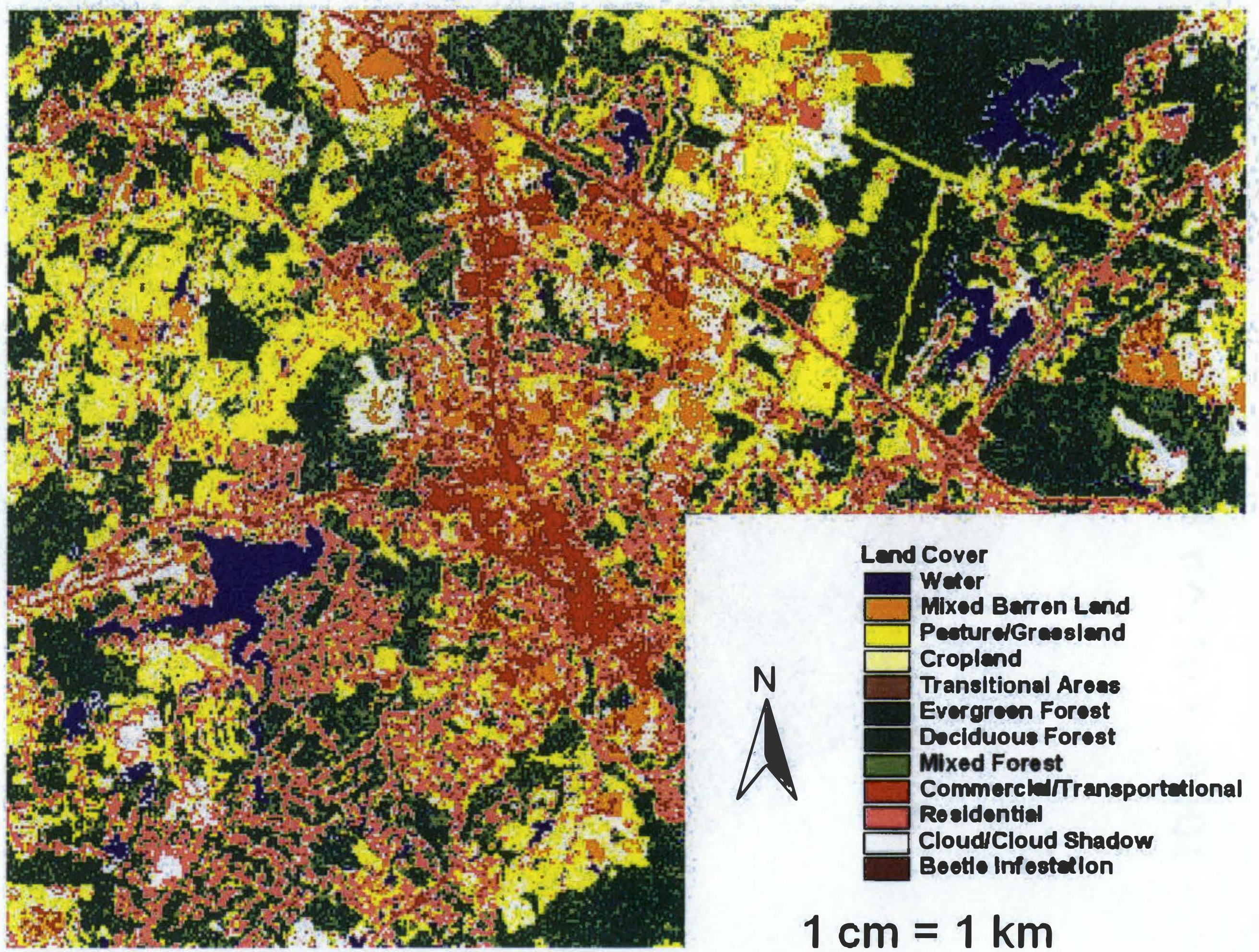

Figure 2-4: Current land cover dataset, city of Crossville, Cumberland County, Tennessee

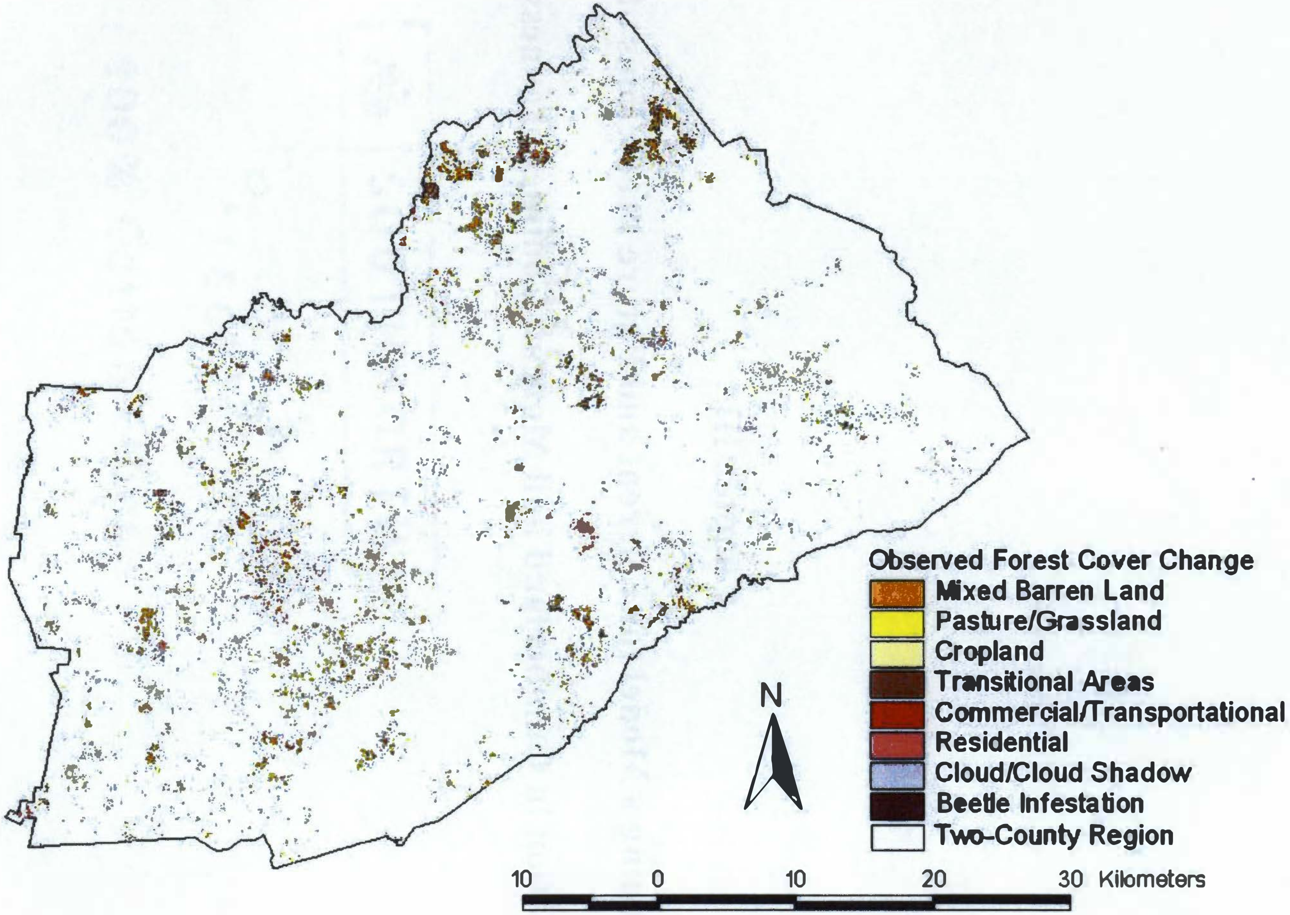

Figure 2-5: Observed change in forest cover to another land cover type between 1992 and 2000, Cumberland and Morgan Counties, Tennessee

Chapter III

Developing a Model for Current and Future Predictions of Urbanization in Cumberland and Morgan Counties, Tennessee

Introduction

The processes for mapping forest cover change are becoming an important research tool for the fields of natural resources, geography, and regional planning. GIS programs allow researchers to quantify and predict these changes through space and time to show the spatial pattern and composition of land cover. It is necessary to integrate factors promoting urban change into a land cover model to better understand and predict forest cover change.

One major impact on land cover change throughout the two-county region was the rapid growth in the number of retired persons. Many retirees have returned to the rural area from which they migrated while others have moved to less expensive, less congested areas to escape overcrowded cities. Between 1990 and 2000, the number of retired households in Cumberland and Morgan Counties increased 22.8 percent, rising from 52,036 persons to a population of 64,258. With population growth rates exceeding 28 percent along with retirement rates reaching 50 percent in 10 years, both Cumberland and Morgan Counties are quickly becoming places of retired living (U.S. Census Bureau 2002).

Due to the increasing number of retirees, the population growth trend will likely continue. Recent population figures indicated that the population might reach 71,137, a 7 percent increase over current numbers. Along with an influx in population is an increase in urbanization and fragmentation. While an increase in total timberland area from 240,586 hectares in 1980 to 243,540 hectares in 2000 is encouraging, any additional development could significantly change this upward trend in area.

With increases in population growth and changes in land cover and land use, planners, ecologists, and resource managers need a reliable and efficient system to predict land cover transition by detecting, monitoring, and analyzing land cover change. Understanding the anthropogenic drivers of landscape change is essential for understanding how and where human pressures may cause fragmentation and urbanization. Therefore, models that predict and forecast land cover change could provide a way to foresee ecological problems before they are occur on the landscape. This study examines the factors that promote land cover change, specifically forest conversion, through the use of a land cover model.

Study Objectives

The purpose of this study was to determine the relationship between urbanization and forest loss in Cumberland and Morgan Counties, Tennessee, and to quantify current and predict future land cover patterns. As a result of the influx of population and the problems associated with urbanization, a land cover change model was created to test land cover transition in these two counties. Land cover transition occurs when the value of the land for a competing use increases beyond the value of the land in its current use. Land will convert from forest to urban use, for example, only when the value for urban use exceeds the value of the land for forest. As long as the land rent for timber is greater than that for other uses, the land will remain forested. Specific study objectives were to:

1. Create GIS layers for land cover, roads, bodies of water, slope, and demographic characteristics (population density, commuter rate, education level, employment rate, and household income value);

2. Incorporate a forest change dataset, representing forest loss between 1990 and 2000;
3. Develop statistical models relating land cover change with physical and demographical factors;
4. Determine the probability that a forest cover parcel would change to a developed parcel; and
5. Project future land cover most likely developed by 2010 using projected population density values and a gravity index value.

Previous Research

Four model types have been combined with GIS to relate a predictive model with temporally static and dynamic information: economic, spatially static, spatially dynamic and gravity index modeling. Economic models link changes in the economy with landscape transition, and are based upon the assumption that various features of the land influence land value and land will be held in its highest value (Kline *et al.* 2001). Spatially static models relate location and physical features to the probability of land cover change. Static features include physical land characteristics, such as slope, waterways, and roads that tend to stay constant over long periods of time. Spatially dynamic models incorporate features that change in a shorter period of time, such as population density, education level, employment rate, commuting distance, and any other non-economic demographic characteristic (Kline *et al.* 2001). Gravity index models measure the ability of cities to attract business trade from surrounding areas (Kline and Alig 2001; Kline et al. 2001; Reilly 1929). In order to forecast land cover change, predictive modeling incorporates economic, spatially static, spatially dynamic, and gravity index models.

Predictive Modeling

Similar to determining the relationship between land cover change and physical and demographic features, predictive modeling incorporates statistical models in forecasting changes in forests and urban areas. Whereas an adequate amount of research was found involving modeling techniques, few researchers have used the same models in forecasting forest change. Using satellite imagery and demographic information with logistic regression, Gunter *et al.* (2000) estimated the probability that a forested parcel would be developed. Population density, distance to highways and interstate junctions, and major cities directly influence the probability that a forested parcel will be developed. Similar statistical development procedures were extended to project future timberland locations, therefore illustrating the drastic change urbanization would have on the area's forest land.

Economic Modeling

Economic models that relate an area's economic characteristics to deforestation and urbanization are becoming increasingly popular. For example, Cropper *et al.* (1999) examined the effects of markets, roads, slope, and population on land use change in Thailand. The conversion of a land cover depended on the market situation, physical properties, and the estimated profitability accrued from the predicted land use. In turn, profitability depended upon the slope of the land as well as the costs associated with logging and road construction.

Alig *et al.* (1986; 1987; 1988) analyzed econometric factors influencing land use changes in the Southeast and South-Central United States, and concluded that population and personal income are significant factors in transferring land from farmers to private landowners. A rise in personal income correlates to an increase in urbanization but a decrease in forest cover. In response to urbanization, they noted that government programs on land use promote shifts from agricultural land to forest land. Plantinga *et al.* (1990) examined the economic determinants of land cover changes in private timberland throughout the United States, and found that regions throughout the U.S. with rapid economic growth face rapid declines in farm population but increases in nonindustrial farms. On the contrary, Gunter *et al (2002)* projected that an increase in education level (ED) along with an increase in income level (INC) and house value (HOME) would foster a positive influence on forest conservation, therefore resulting in a negative impact on further development.

Instead of determining land use change based upon population and demographics, Capozza *et al.* (1989) based urban growth on land price. Land price is correlated to the value of agricultural land rent, conversion costs, accessibility value, and the expected increase in future rent, a growth premium. In areas of unprecedented growth, the growth premium accounts for more than half of the land price, causing large differences in the price of urban-bordered and agricultural land (Capozza and Helsley 1989). In addition, Turner *et al.* (1996) examined land attributes in the Southern Appalachians and the Olympic Peninsula and concluded that changes in forest products and agricultural prices (Parks *et al.* 2000), along with changes in laws and policies, force land owners to alter land management procedures. In addition, further results by Hardie *et al.* (2000)

indicated that increases in median household income results in a decrease in urban land use. With higher location rents, expensive housing will be found in more remote, rural areas.

Static Modeling

Spatially static data includes any geographic information that remains constant over a period of time. Turner *et al.* (1996) concluded that changes in slope, elevation, and distance to roads and markets greatly influence land use change. The influence of road network systems was examined by Nelson and Hellerstein (1997), who concluded that road access affects land use. As the cost of accessing roads increases, the probability that a forested parcel will remain forested increases. In addition, Barlow *et al.* (1998) examined the effect of urbanization on timber harvesting in Mississippi and Alabama, and reported that the proximity to roads increases the chance of harvesting, but in areas where development and population are higher, lower harvesting rates are more likely to occur. They also reported that the probability of harvesting timber is greater on industry and privately owned lands; as growing stock increases, the probability of harvesting increases.

Wear and Bolstad (1998) and Wear *et al.* (1998) examined the potential for urbanization and concluded that the highest probability of development occurs on level land and near roads, water sources, and metropolitan centers. Regardless of development pressures, topography is a significant factor in determining land use. If slope is excessively steep, the possibility of development is low. Secondly, location and distance from the site to the nearest road network and major city strongly influences the probability of development.

Dynamic Modeling

The growing use of geographic information systems with the integration of spatially dynamic models has improved the ability to predict the urbanization of forested areas. Turner (1990) examined changing land cover patterns in rural counties of Georgia and determined that forest cover, especially coniferous forests, increased over a 50 year period, whereas transitional lands and deciduous forests decreased in that same period. Moreover, spatial pattern analysis revealed that the rural Georgia landscape is less fragmented today than in 1930. In addition to this research, Sullivan (2002) determined that the suburban areas of today consist of more wooded, fragmented parcels as compared to the same area 50 years ago. Rudis (1995) hypothesized that fragmentation occurs more frequently on drier sites and habitats. He concluded that agricultural proximity along with urban development, ownership, and access to a specific site is the primary factor in determining fragmentation. Compared to sites closely located to roads and urbanized areas, the size of fragmented parcels was smaller near developed roads or towns.

Using multinomial logit regression, Munn and Cleaves (1998) analyzed losses that occurred in southern commercial timberland over a 20 year period. The results revealed that education level, slope, forest size, and distance to the nearest city are negatively correlated to the possibility of conversion of forest land into agricultural land. Representing the second major loss, conversion from forest land to urban uses is negatively correlated to forest size, distance to developed areas, and distance to the nearest city. Moreover, productive timberland, steep terrain, and densely populated areas decrease the probability of being converted into agricultural or urban uses.

Ahn *et al*. (2002) projected future land use in the South Central U.S. by relating forest, agriculture, and urban uses to demographic factors. They concluded that population growth and city proximity has a greater effect on urbanization of private timberland than on conversion to agricultural land. Seto *et al* (2003) indicated that urban expansion might be linked to industrial development. Even though highly productive agricultural land might be developed, urban centers emerge and extend outward from areas where people first migrated. This land might either be cropland or forest land. The continued growth of urbanization therefore attracts more people, adding to more urbanization and population influx. Only through an increase in forest or farming profitability will the conversion from agriculture to urban land cease.

Current and projected population characteristics can affect land use change substantially. Prior research has demonstrated that current population density and historic growth rates are positively related to land use change from forest to urban uses (Gunter et al. 2000; 2002). Wear *et al.* (1998) related more dispersed population distribution to a decrease in the number of persons per household as well as an increase in building density. Wear *et al.* (1999) examined the effects of population growth on timber management and inventories in Virginia and concluded that population density significantly affects the availability of commercial timberland. Similarly, parcels of forests are more likely to be converted to urban or other developed uses as distance to towns and cities decreases and as access to the property by roads increases (Gunter *et al.* 2002).

Gravity Index Modeling

Whereas accessibility models measure the close proximity of forested parcels to cities, they do not relate the influence of population change of surrounding cities. One procedure for determining population growth and its spatial distribution is with a gravity index model, measuring urbanization through population and proximity (Kline et al. 2001). Using an empirical model, Kline and Alig (2001) and Kline *et al.* (2001) determined the probability that forests and farmland in western Oregon and western Washington would be developed into residential, commercial, and industrial uses over a 30 year period. Using a gravity model first developed by Reilly (1929), Kline *et al.* (2001) determined the ability of cities to attract business trade from surrounding areas. Derived from the Newtonian law of planetary attraction, Reilly's Gravity Index Model considers distance and the attractiveness of major retail urban centers. The basis of this concept states that urban centers with greater population and retail numbers draw customers from further distances than smaller populated towns. The potential for urbanization on forest and agricultural lands is the greatest near the more populated cities and the rate at which an area will be urbanized depends on the size of the surrounding population centers (Reilly 1929). Based on these models, it was determined that a similar model could be constructed for use in this project's study area.

Study Area

The study area for this project was Cumberland and Morgan Counties, located within the Cumberland Plateau, which consists of an elevated tableland bordered by the Ridge and Valley Province to the east and the Eastern Highland Rim of the Interior Low

Plateaus to the west Figure 3-1[1]. While other areas throughout the South have experienced a strikingly abrupt alteration in land cover, Cumberland and Morgan Counties embody a long-term process of steady successional change. Cumberland and Morgan Counties currently consist of timberland areas covering approximately 243,540 hectares (79 percent) of the two-county region. The forests of the region, lying within the Appalachian Mixed Mesophyitic Forest Ecoregion, are characterized as temperate broadleaf and mixed (deciduous and coniferous) forests (Ricketts *et al*. 1999). Of this total, over 85 percent (206,454 hectares) is classified as either mixed or oak-hickory, while the remaining is classified as either planted loblolly (*Pinus taeda*) or natural shortleaf pine (*Pinus echinata*).

Methods

The primary goal of the study was to identify the factors that are related to land conversion from forest to other cover types. Specifically, a separate land cover model was created to determine the possibility that forest land would transition to development. The land cover model was designed to provide an accurate estimated relationship between land cover change and physical, geographic, and demographic characteristics. In general form, land cover change (LCC) was hypothesized to be related in the following form in Equation 3-1, through the creation of GIS layers.

Equation 3-1:

LCC = *f* (Demand Factors, Accessibility, Gravity Index, Location, Physical Attributes)

---

[1] All tables and figures are located in the Appendices.

Creating GIS Layers

Random Points

Demographics are a major predictor of land cover and land use change via urban sprawl (Gunter *et al.* 2000). While it was possible to acquire land cover change for the entire study area, it seemed inefficient and less accurate to do a continuous coverage. An inappropriately conducted census can provide less reliable information than a carefully obtained sample. The correlation between demographic change and land cover change required a statistical test that accounted for the sample size needed to provide a chance of detecting an effect of a given size (Agresti 1996). Therefore, a randomly distributed sampling size with at least a 30 meter separation between each sampling point and a 1 meter separation from the two-county border was developed. A 30 meter separation was chosen in relation to the satellite imagery resolution of 30 meters. Using Agresti's model, detailed in Equation 3-3, a sample size of 6,000 random points was required.

Only lands where development was possible were used to compute and forecast change. Public lands were not included because they would not be developed. Therefore, a polygon coverage identified as public lands was deleted from the two-county region. Obtained from the TIGER 2000 data provided by the U.S. Census Bureau, the preserve polygon represented all publicly owned state and federal parks, forests, wildlife refuges, and managed lands. Figure 3-7 illustrates the public lands. With the aid of ArcView's movement extension, 6,000 random points were generated throughout the two-county region where land change was permissible. Figure 3-8 illustrates the random positioning of the sampling points and Equation 3-3 describes the statistical procedures.

Equation 3-3:

$$N = \frac{[Z_{\alpha/2} + Z_{\beta} e(-?^2/4)]^2 (1 + 2\bar{\pi}\delta)}{\bar{\pi}\lambda^2}$$

Where:

$Z_{\alpha/2}$ = Probability one a Type I error (one-tailed)

Z_{β} = Probability of Type II error

$\bar{\pi}$ = Probability of successfully predicting development at the mean value of the continuous independent variable

? = ln (Probability of successfully predicting development at one standard deviation above the mean value of the continuous independent variable)

$$\delta = \frac{1 + (1 + \lambda^2) e^{(-5\lambda 2/4)}}{1 + e^{(-\lambda 2/4)}}$$ [Source: (Agresti, 1996) and (Gunter *et al.* 2000)]

Demand Factors: Demographic Data Set

The probability that a site will be developed is related to population growth and the demand for space. Areas experiencing more population growth and changes in demographic characteristics such as changes in education level, income value, and commuting distance are more apt to change in land use and land cover than areas of declining growth rates (Alig 1986; Alig and Healy 1987; Alig et al. 1988; Cropper et al. 1999; Gunter et al. 2000). Therefore, demand factor coverages were developed using the information from the U.S. Census Bureau on total population (PERS), education rate (ED), employment rate (LAB), income level (INC), house value (HOME), construction rate (BLDG), and the percent of residents commuting outside the two counties (WOC). Population density was mapped by acquiring block maps and total population for each census block for Cumberland and Morgan Counties. Population density (POP) was calculated by dividing the total population of a census block by the square kilometer area of the block. Figure 3-2 depicts the current population density for Cumberland and Morgan Counties. Whereas population data was obtained at the census block level, the other demographic information (total population, education rate, employment rate, income value, house value, construction rate, and commuting percent) was available only at the census block group level. The 1990 and 2000 demographic information representing the strength of the area was downloaded and matched with the census block polygons. The change between the 1990 and 2000 data was calculated as an additional coverage.

Accessibility: Proximity to Cities and Interstate Junctions

Due to transportation costs, residents commuting to work live closer to urban centers or areas of accessibility. Regardless of trip destination, activities located near major cities or freeway junctions have a higher level of accessibility than activities located further away (Landis and Zhang 1997). In order to represent this proximity, distance to cities and interstate connections were calculated. Four major cities having populations greater than 8,000 contributing to urban expansion were examined: Cookeville, Crossville, Knoxville, and Oak Ridge. These cities' features were obtained from TIGER 2000 of the U.S. Census Bureau. Their population values are listed in Table 3-1. Freeway intersections were pulled from TIGER 2000 road data and displayed as ArcView features. Drivable distance from 6,000 random points to either the city or interstate junction destinations were processed using the ArcView's Network Analysis and labeled separately as "CKE_DS" (Cookeville), "CR_DS" (Crossville), "OAK_DS" (Oak Ridge), "KNX_DS" (Knoxville), and "INT_DS" (interstate junction), respectively.

Figure 3-3 illustrates the cities and interstate junctions of Cumberland and Morgan Counties in 2000.

Gravity Index

While distance and demographic variables measured the proximity of land and economic effects to local urban areas, they do not account for the changing influence of cities as their population changes. Another process for conceptualizing population growth and its spatial distribution is the gravity index model (Kline *et al.* 2001). First developed by Reilly (1929), the gravity index model measures the combined economic influence of population and proximity to the nearest metropolitan cities. In this project, the four cities most likely to influence land cover conversion were included in the gravity index, where k represented the four urban areas: Cookeville, Crossville, Knoxville, and Oak Ridge. The higher the gravity index value, the greater the effect of the urbanization of the four cities on the development potential for a parcel. The difference between the gravity index for 1990 and 2000 was calculated into a final gravity index. The final calculated gravity index value for each of the 6,000 parcels was compiled into an Arc View polygon theme file, and then matched to an area based upon their FIPS code, and finally labeled as "G_IND". The gravity index for Cumberland and Morgan Counties for 2000 is depicted in Figure 3-4. The equation for gravity index is listed in Equation 3-2. However, the gravity index equation used in this model incorporated drivable distance to cities along paved roads instead of Euclidean distance to cities. Whereas this was unintentional, it is not notably important and does not significantly change the overall results.

Equation 3-2:

$$\text{Gravity Index} = \sum_{K=1}^{4} \frac{(\text{Population}_k)^{0.5}}{(\text{Distance})_k}$$

Where:

k = Four most influential cities (Cookeville, Crossville, Knoxville, Oak Ridge)

[Source: (Kline et al. 2001)]

Location: County and Area

Parcel location may influence development as well. Other than population and proximity pressures, county location and suburbia factors play an important role in urbanization. A parcel located in a more developed county increases the probability that the parcel will be developed. Moreover, instead of being located within a rural environment, a parcel located in a suburban setting has a greater chance for development. These concepts are based upon previous studies, relating population density and physical structures of the landscape to land cover change (Spies et al. 1994; Wear et al. 1998). Whereas gravity index models account for the external influence of surrounding cities as their populations increase or decrease (Kline and Alig 2001; Kline et al. 2001), the location of a parcel measures the proximity of the land to a city, focusing on distance instead of the external influences of population (Plantinga et al. 1990). In order to represent these location factors, two themes obtained from TIGER 2000 data were created: one theme representing Cumberland and Morgan County delineation, and another theme representing suburban and rural environments. The location of the 6,000 random points was processed using ArcView and finally labeled accordingly as "COUNTY" for county location and "TYPE" for either suburban or rural location.

Physical Attributes: Roads, Slope, and Water Effects

Many areas in the two-county region are constrained by road access, steep terrain, or public ownership. These limitations inhibit development projects and logging. For development to occur, urban services such as roads, sewer, water, telephone, and electrical services need to exist. The development of these services constrained by distance or slope substantially raises the cost of developing the land. As urbanization progresses, however, distance and accessibility to these services are no longer an issue.

To measure distance to roads, a road theme (ArcView feature) representing all local and state roads, as well as interstate highways of the two-county region was obtained from TIGER 2000 data provided by the U.S. Census Bureau. The closer a parcel is to a road, the greater the potential for development. The Euclidean (straight-line) distance to the nearest road from each of the 6,000 points was measured using ArcView's Network Analyst and referred to as "RD_DS".

Areas characterized by steep terrain (slope) limit the possibility of development (Turner et al. 1996). Digital elevation models (DEM's) of Cumberland and Morgan Counties were downloaded from the USGS (2003) seamless website <http://seamless.usgs.gov/> and converted into a slope feature (ArcView theme). This coverage was measured in degrees and referred to as "SLOPE". Figure 3-5 depicts the slope data of Cumberland and Morgan Counties in 2000.

A third attribute, distance to water, may also be related to development. Kline and Alig (2001) determined that forest land located within the Pacific coastal strip had a greater probability for urban conversion. Whether a parcel has a short or long distance to an urban area, the proximity to a water source is an integral part of the decision for development. The recreation and aesthetic opportunities associated with water influences people to live near rivers, lakes, and ocean coastlines. The streams theme (ArcView feature) represented all waterways found throughout Cumberland and Morgan Counties. This theme was obtained from TIGER 2000 data provided by the U.S. Census Bureau and referred to as "HY_DS". The Euclidean distance to the nearest stream from each of the 6,000 points was measured using ArcView's Network Analysis. Figure 3-6 illustrates the stream data of Cumberland and Morgan Counties in 2000.

Observed Classified Change in Forest Cover

The change detection analysis involved contrasting vegetation loss between past and present satellite images, and comparing the differences with the area's current land cover. Change detection involved creating and comparing vegetative coverages for both 1992 and 2000. One specific index, Normalized Difference Vegetation Index (NDVI), quantifies vegetation greenness by subtracting the red (Thematic Mapper band 3) from the near-infrared (Thematic Mapper band 4) bands. Following the creation of vegetative images, a change detection map between the 1992 and 2000 scenes was produced by subtracting the red from the near-infrared bands.

A second process involved the development of a land cover map, quantifying physical cover of existing topography at a specific time and location. Instead of land use data, this project required land cover data. Therefore, the development of a land cover map required classifying spectral signatures of the current Multi Resolution Land Cover (MRLC) images. The classification system applied for the land cover map was a subset of the Land Use and Land Cover (LULC) classification system developed by USGS Anderson Level II. Supervised classification along with training fields and a computer algorithm was used in the analysis to identify land classes based upon the image's spectral reflectance colors (Strickland 2003).

In order to correctly portray forest loss due to urbanization, it was necessary to compare forest change between 1992 and 2000. Despite the fact that atmospheric conditions distorted the ability to delineate changes in land cover, the combination of the land cover change dataset with the land cover map made it possible to delineate the transition from forest to urban cover. This observed forest cover change labeled as "CCFC" (classified change in forest cover) is illustrated in Figure 3-9. More information about the creation of the observed classified change in forest cover is available in Chapter 2 (Strickland 2003).

SAS Preparation

Along with determining the probability of forest to urban conversion, the study also determined the role that demographic and physical attributes play in the process of conversion. This was accomplished by developing a model that described the relationship between the probability of development and a set of explanatory (independent) variables. To accomplish such a task, all coverage data sets (COUNTY, TYPE, POP, PERS, WOC, ED, etc.) were masked with a polygon coverage created from "CCFC". The resulting image contained only information from the randomly selected parcels. The point and polygon coverages were then intersected with "CFCC" to create the coverage "LCC" (land cover change dataset) containing the dependent and explanatory variables needed for the logistic regression analysis. Prior to running the model, it was necessary to have a balance in the number of randomly selected points throughout the two-county region. A well-balanced model ensured that an adequate number of forested and urban parcels were selected for proper statistical analysis. This required a reduction in selected points from 6,000 to 860. Next, "LCC" was exported into an Excel worksheet used in the logistic regression model and further divided into a forest to development (LCC_DEV) model and a forest to forecasted development (LCC_DEV10) model.

Model Development

Logistic regression was used in this project to estimate the probability that a forest parcel would be developed. The dependent variable (land use change) was binary: zero (0) if the parcel of land was forested in 1992 and remained forested in 2000 or one (1) if the parcel of land was forested in 1992 but nonforested in 2000. In order to predict the probability of forest change, the final model included the independent variables described above.

Equation 3-4 describes the logistic model used in analyzing forest change (Hosmer and Lemeshow 1989), where "i" represented each parcel, "$\pi (X_i)$" is the probability that a 0.09-hectare parcel will change from forest to nonforest, and "X_b" is the matrix of independent variables ($b_1 X_1 + b_2 X_2 + \ldots + b_i X_i$).

Equation 3-4: $$\pi (X_i) = \frac{e^{(xb)}}{1 + e^{(xb)}}$$

Equation 3-5: $$X_b = \ln [\pi (X_i)]$$

The logit equation listed in Equation 3-5, is the natural logarithm transformation of the logistic model described in Equation 3-4. For each parcel *i*, ln [$\pi (X_i)$] is the natural logarithm of probability that a 0.09 hectare parcel (30 by 30 meter pixel image) will change from forest to a developed use, and X_b is the matrix of independent variables ($b_1 X_1 + b_2 X_2 + \ldots + b_i X_i$). Equation 3-6 represents the specific logit model with variables used to estimate the log odds that a forested parcel will be developed. Table 3-2 lists the descriptions of variables in Equation 3-6.

Equation 3-6:

LCCi = *f* (COUNTYi, TYPEi, POPi, PERSi, WOCi, EDi, LABi, INCi, HOMEi, BLDGi, SLOPEi, RD_DSi, INT_DSi, HY_DSi, CKE_DSi, CR_DSi, KNX_DSi, G_INDi)

Based upon previous research, it was hypothesized that Cumberland County (COUNTY) and metropolitan area (TYPE) are more likely to develop (Ahn et al. 2002; Seto and Kaufmann 2003). In addition, population density (POP) and total population (PERS) within a census block group were hypothesized to be positively related to the conversion of forest land to another cover. Moreover, an increase in employment opportunities (LAB) would be positively related to development. Residents commuting to larger metropolitan areas outside the counties were expected to have a positive influence on land conversion (Gunter et al. 2000). Proximity to urban centers or metropolitan areas would also have a positive impact on development (Wear and Bolstad 1998). It was hypothesized that the four most influential urban centers, Cookeville (CKE_DS), Crossville (CR_DS), Knoxville (KNX_DS), and Oak Ridge (OAK_DS) would positively influence land conversion. Gravity index measures the combined economic influence of population and proximity with local land cover change (Reilly 1929). Therefore, it is expected that an increase in gravity index (G_IND) would positively reflect a correlation for development. In addition, a forested parcel close in proximity to roads (RD_DS), interstate junctions (INT_DS), and water (HY_DS) would highly influence conversion. Other spatial factors such as a decrease in slope (SLOPE) would promote the possibility of transition to either development. The flatter the terrain, the easier it is for conversion, therefore making any land with gentle slope susceptible to conversion (Munn and Cleaves 1998; Turner et al. 1996).

Similar to previous studies, it was projected that an increase in education level (ED) along with an increase in income level (INC) and house value (HOME) would foster a positive influence on forest conservation, therefore resulting in a negative impact on development (Gunter et al. 2002). In addition, whereas the rate of construction (BLDG) is hypothesized to influence development, it is also subject to discouraging conversion to forests. Furthermore, with the growing influx of retirees into the Cumberland Plateau, it was hypothesized that the influx of retirees will have more education and income, therefore less likely to convert their land to another use based on the need for money. In this region, retirees often move to a secluded environment, desiring areas of less congestion. Therefore, properties owned by retirees are less likely to be further converted. The description of explanatory variables with the hypothetical expected sign is represented in Table 3-2.

Projecting Future Forest Loss

The development of a projected land cover model for 2010 required creating a similar logit model structure. As expressed in Equation 3-5, for each parcel *i*, $\ln[\pi(X_i)]$ is the log odds that a 0.09 hectare parcel (30 by 30 meter pixel image) will change from forest to a developed use by 2010, and X_b is the matrix of independent variables ($b_1 X_1 +$

$b_2 X_2 + \ldots + b_i X_i$). Data for all variables except population density and gravity index were held constant. New values representing population density (POP10_CH), total population (PERS10_CH) and gravity index (GI_10_CH) for 2010 were computed using projected population growth for cities and block groups in the region (U.S. Census Bureau 2002). These data were used to predict the development of forest areas by 2010. Based upon the objectives of the study, only changes in forest to development were evaluated. The expected values for all variables in the conversion to development by 2010 are the same as dictated for conversion from forest to development for 2000.

Results and Discussion

The land cover model predicted the likelihood that a parcel of forest would be converted to a developed land cover type. Three tests were run to determine the significance of the model: 1) the Pearson chi-square statistic and 2) the likelihood ratio test for testing the global null hypothesis. In addition, the statistics for 3) the maximum likelihood estimates were analyzed to test the significance and probability of conversion for each variable. It was hypothesized that the model for the two-county region would be acceptable. Once proven, county- level models were analyzed to determine the significance of each variable at the county level. It was also hypothesized that the county level variables would influence forest conversion. The parameter estimates derived from each county logistic regression analysis were used with the observed values of each randomly selected point to determine the probability of development between 1992 and 2000. The resulting image, a probability surface, was created in GIS by using Equation 3-5 at different probability thresholds and depicted in Figure 3-10.

Forest to Development

The model for detecting conversion to development (LCC_DEV) for the two-county region performed well. The goodness of fit was significant at the 0.05-level. Specifically, since the P-value of the Pearson chi-square (chi-square > 0.9885) statistic was greater than 0.05, the null hypothesis that the model fit was accepted. In addition, the likelihood ratio test (LRT) for testing the global null hypothesis that none of the parameters in the model were significantly different from zero was rejected (LRT chi-square = 113.13 with 12 df and $p < 0.0001$). Prior to testing the model, multicollinearity was tested for all independent variables. Multicollinearity occurs when two independent variables are highly correlated with similar information. When this is the case, neither variable contributes significance to the model after the other one is included. This results in a high P-value implying that the independent variables significantly worsen the model (Maddala 2001). Through the use of SAS, a statistical program, multicollinearity was determined by finding the correlation value between variables (Statistical Analysis System 2002). Parameters with a correlation value greater than 25 percent were either rejected from the model or replaced. This concern posed a substantial problem for several variables, which were omitted from the model: employment rate (LAB), income value (INC), house value (HOME), distance to Cookeville (CKE_DS), distance to Crossville (CR_DS), distance to Knoxville (KNX_DS), and distance to Oak Ridge (OAK_DS).

Of the remaining independent variables, rural or suburban location (TYPE), total population (PERS), commuter rate (WOC), construction rate (BLDG), and distance to roads (RD_DS) were not significantly related to the log-odds of development. However, population density (POP), slope (SLOPE), distance to water (HY_DS), and gravity index (G_IND) were significant at the 0.05-level. In addition, county location (COUNTY), education rate (ED), and distance to interstate junctions (INT_DS) were significant at the 0.10-level (Table 3-3).

Processing the accepted variables' and the intercept's parameter estimates and averages in Equation 3-5 produced the probability of change for the specified variables. In this case, COUNTY, POP, ED, SLOPE, INT_DS, HY_DS, and G_IND were individually processed to determine their effects on the probability of forest to urban conversion. Holding all variables constant at their mean, a 0.25-kilometer increase in distance from a water source (HY_DS) to a parcel increased the probability of urban conversion 61 percent. This direction of influence contradicts the research by Wear and Bolstad (1998). Their research concluded that metropolitan centers and urban development prefer to be near or around water sources for water supply, recreation, and aesthetic purposes. Where this tends to be the case in most areas, the majority of streams found throughout the two-county region are bordered by steep terrain. Figure 3-5 illustrates how some water sources are bordered by terrain of over 30 degrees in slope. Furthermore, a 5 percent increase in slope (SLOPE) consequently decreased urbanization 6 percent. Research by Wear and Bolstad (1998), Wear and Flamm (1993), and Turner *et al.* (1996) concludes that topography, such as slope and elevation, is a significant factor in the influence of land cover conversion. Excessively sloped terrain hinders building construction and septic tank percolation, therefore decreasing any probability of forest to urban conversion (Munn and Cleaves 1998; Turner et al. 1996). While this implied that distance to water (HY_DS) and slope (SLOPE) were related, a correlation analysis determined that neither parameter contained excessive multicollinearity between each other.

A population increase of 10 persons per kilometer (POP) decreased the probability of development 48 percent. Alig *et al.* (1986; 1987; 1988) analyzed econometric factors and concluded that population was a significant factor in transferring forest to urban. However, unlike the exurbia growth of Atlanta where an increase in population density is positively correlated to an increase in development, Cumberland and Morgan Counties exist of retirees preferring less congestion and more land space. Therefore, the retirees are moving into the rural sections of the two-county region, escaping the congested cities but at the same time adding to urban sprawl and habitat fragmentation.

Another major impact on urbanization is the educational level of the residents. Based on Gunter's (2002) research that education was positively related to adopting regulations for the protection of forests, it was hypothesized that residents in Cumberland and Morgan Counties with a higher education were less likely to develop their land. The results suggest that a 10 percent increase in upper education rate (ED) for residents decreased the probability of conversion 37.2 percent. It is assumed that residents with at least some college education tend to have an understanding of the detrimental effects development has on forest habitats. Residents with an advanced degree have a greater chance of adopting local regulations which prevent excessive harvesting (Gunter et al. 2002) and possible urbanization from occurring.

A 10 unit increase in the value of a parcel's gravity index (G_IND) increased the probability of conversion 36 percent. As conducted by Kline *et al.* (2001; 2001), a gravity index model determined the ability an area had in attracting business trade from surrounding cities. The potential for urbanization of forest is greatest near populated cities. The more accessible a parcel was along paved roads to any of the four metropolitan cities (Cookeville, Crossville, Knoxville, and Oak Ridge), the greater the probability for further urbanization. Similarly, the influence of road network systems and proximity to interstate junctions affects land cover and land use (Nelson and Hellerstein 1997; Gunter et al. 2000). For every 5 kilometer decrease in distance to an interstate junction (INT_DS), the probability for conversion to urban increased 35 percent.

Forest to Development County Models

In order to visually represent the probability of forest to urban conversion, it was necessary to develop county level models. County level models were produced to improve the parameters' significance and the overall accuracy for the probability of conversion for each parcel. The county level models for urban conversion (LCC_DEV) proved to be significant in determining the probability that a forested parcel would convert to development. The P-value of the Pearson chi-square (Cumberland County chi-square > 0.5508, Morgan County chi-square > 0.9783) statistics for both county models was greater than 0.05. In addition, the likelihood ratio test (LRT) for testing the global null hypothesis that none of the parameters in the model were significantly different from zero was rejected further indicating acceptable models for both counties.

Unlike the two-county region, fewer variables were significant in the Cumberland and Morgan County models. Only POP, SLOPE, INT_DS, HY_DS, and G_IND were significant at the 0.1 level in the Cumberland County model (Table 3-4). An increase of 10 persons per square kilometer (POP) increased the probability of urban conversion 36 percent. In addition, a 0.25 kilometer increase in the distance from water (HY_DS) to a parcel increased conversion 43 percent. Of the correctly hypothesized variables, a 5 percent increase in slope (SLOPE) and a 5 kilometer increase in the distance to interstate junctions (INT_DS) increased the probability of conversion 17 percent and 30 percent, respectively. In addition the potential for urbanization (G_IND) on a forest parcel in Cumberland County increased the possibility of conversion 38 percent. Of the five significant variables for the Cumberland County model, HY_DS with an estimated maximum likelihood estimate value of 0.87 and SLOPE with an estimated value of -0.19 were the most influential variables in the conversion of forest to development. Conversely, POP (-0.005) and G_IND (0.006) having low maximum likelihood estimates indicated a low influence in the conversion of forest to development.

TYPE, PERS, SLOPE, and INT_DS were significant at the 0.1-level in Morgan County (Table 3-5). Similar to Kline and Alig (2001) and Kline *et* al (2001), urban expansion is linked to the proximity of a city. A parcel located within a suburban or urban area (TYPE) had a 53.8 percent probability of being developed over a parcel located in a rural section. Research concludes that exurbia development tends to sprawl out from existing urban areas (Seto and Kaufmann 2003). An increase of 5 degrees in slope (SLOPE) and an increase of 5 kilometers in the distance to an interstate junction (INT_DS) increased the probability of conversion 25 percent and 17 percent, respectively. Of the five significant variables for the Morgan County model, TYPE with a maximum likelihood estimate value of 1.64 and SLOPE with an estimate value of -0.16 were the most influential variables in the conversion of forest to development.

Conversely, INT_DS (-0.06) and PERS (0.002) having low maximum likelihood estimates indicated a low influence in the conversion of forest to development.

The parameter estimates derived from the county analysis were calculated with the observed values of each randomly selected point to determine the probability of development between 1992 and 2000. The probability surface for development of forest between 1992 and 2000 is depicted in Table 3-6 and illustrated in Figure 3-10. At the 1 to 25 percent threshold, 1,933 parcels were predicted to be developed while 85 parcels were actually developed. The 26 to 50 percent threshold consisted of 331 parcels predicted for development while only 29 were observed. As this threshold increased to 76 and 100 percent, the number of parcels predicted to be developed that were actually developed was distinctly fewer at 1 parcel out of the 12 predicted.

Forest to Development 2010

Projections to 2010 were developed based on the 2000 predicted model. New values representing population density (POP10_CH), total population (PERS10_CH) and gravity index (GI_10_CH) for 2010 were computed using projected population growth for cities and block groups in the region (U.S. Census Bureau 2002). These data were used to predict the development of forest by 2010. However, in evaluating forest to urban conversion, the research was more interested in understanding the location of probability and less interested in predicting a specific land cover type in a particular location.

Similar to the procedures applied in the creation of a current predicted model, the parameter estimates and values of each randomly selected point determined the probability of development between 2000 and 2010. The probability surface for conversion of development of forest between 1992 and 2000 is depicted in Table 3-7 and illustrated in Figure 3-11. At the 25 percent threshold, 5,380 parcels were predicted to be developed. As this threshold increased to 50 percent, the number of parcels predicted to be developed declined to 578 parcels. Between the 51 and 75 percentile, 29 parcels are projected to develop. In addition, only 13 parcels are projected between the 76 and 100 percentile.

Whereas the 2010 projected image (Figure 3-11) reflected similarities to the 1992 and 2000 predicted image (Figure 3-10), slight differences were acknowledged. The average predicted percentile of change for 2000 was 14 percent, while the 2010 prediction was 12 percent; much of which is due to the decrease in the rate of population growth. As depicted in Figure 3-9, the difference in population change was greater between 1990 and 2000 than what was projected to occur between 2000 and 2010, resulting in a lower probability of urbanization.

Conclusions

The purpose of this study was to determine the relationship between urbanization and forest loss in Cumberland and Morgan Counties, Tennessee and to quantify current and predict future land cover patterns. Through the use of GIS, a land cover model investigated the relationship between the conversion of forest to urban cover along with spatial and demographic variables of the region. With population growth rates for the two-county region exceeding 28 percent within the last decade, this continual exurbia growth forewarned the possibility of persistent urbanization and habitat fragmentation. The development of a land cover model makes it possible for natural resource professionals to evaluate future growth patterns based on economic, social, and demographic changes.

The results indicated that the modeling approach could be useful in explaining current land cover and land use trends as well as predicting future land use scenarios. The results suggested that the demographic variables such as education (ED) and population (POP and PERS) along with spatial factors such as slope (SLOPE), distance to water (HY_DS), distance to interstate junctions (INT_DS), and gravity index (G_IND) measuring the urbanization potential of nearby urban retail centers significantly influenced the transition of forest to urban cover. Of these parameters, a high gravity index (G_IND), an urban and suburban setting (TYPE), and unsloped terrain (SLOPE) had the greatest impact on forest to urban conversion. As the gravity index value for a parcel increased, the probability of conversion to development increased. In other words, the closer a parcel is to urban retail accessibility, the greater the tendency for conversion. Population growth is more likely to sprawl into an area that has close proximity to neighboring cities, allowing for the accessibility of business transactions (Kline and Alig 2001; Kline et al. 2001; Reilly 1929). However, the slope of the terrain can hinder any possibility of conversion. Along with an increase in slope comes a greater difficulty in construction accessibility, costs, and especially the placement of septic tanks. An area of steep terrain hinders the percolation of septic tanks, eliminating any possibility for development. Therefore, development is more likely to occur in valleys consisting of a low degree in slope (Munn and Cleaves 1998; Turner et al. 1996).

Overall, the patterns of forest to urban conversion represent the success of predicting the probability of urban sprawl throughout the two-county region. Areas along

Interstate 40 and portions around Northeast Morgan County contain forested parcels consistent with a high probability of conversion. However, improvements could be made upon the land cover model. While the land cover change analysis was examined over an 8 year period, a spatial analysis over a 30 year time span could have improved the change analysis and the model. Population along with structural changes in accessibility and development increased greatly between 1970 and 1990. Having satellite images of this time period would have allowed a better analysis of change, therefore improving the overall significance of the model.

With the continual improvements made in technology, it may be possible to acquire historic imagery and data at a better resolution. Currently, satellite imagery with a 30 meter resolution has some limitations, inhibiting the ability to discern specific patches of forest. The advancements made in the development of finer resolution images will solve this problem and improve the accuracy of land cover detection and modeling analysis.

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Appendices

Appendix A

Tables

Table 3-1: Total population in 2000 for the four cities affecting accessibility in Cumberland and Morgan Counties, Tennessee

Tennessee City	1990 Population	2000 Population
Cookeville	21,744	23,923
Crossville	6,930	8,981
Knoxville	169,761	173,890
Oak Ridge	27,310	27,387

Table 3-2: Descriptions of explanatory variables tested in logit model with data type

Variable	Variable Description	Developed Expected Sign
LCC_AG	Land Cover Change between 1992 and 2000, Parcel remaining forested = 0, parcel converted to agricluture = 1	+
LCC_DEV	Land Cover Change between 1992 and 2000, Parcel remaining forested = 0, parcel converted to development = 1	+
COUNTY	Cumberland or Morgan County, TN in 2000, Morgan County = 0, Cumberland County = 1	+
TYPE	Suburban or rural areas in 2000, Rural = 0, Urban = 1	+
POP	Change in population density in census block group between 1990 and 2000 (persons per square km)	+
PERS	Change in total population in census block group between 1990 and 2000	+
WOC	Change in percent of residents commuting outside Cumberland and Morgan counties between 1992 and 2000, TN	+
ED	Change in percent of residents with some college education between 1990 and 2000 (in percent)	-
LAB	Change in employment rate between 1992 and 2000 (in percent)	+
INC	Change in average household income between 1990 and 2000 (Year 2000 dollars)	-
HOME	Change in average house value between 1990 and 2000 (Year 2000 dollars)	-
BLDG	Change in construction between 1990 and 2000 (in percent)	+
SLOPE	Slope of sample point (in degrees) in 2000	-
RD_DS	Euclidean distance from sample point to nearest road (km) in 2000	-
INT_DS	Distance from sample point to nearest interstate four intersection (km) in 2000	-
HY_DS	Distance from sample point to nearest water (km) in 2000	-
CKE_DS	Distance from sample point to Cookeville, TN (km) in 2000	-
CR_DS	Distance from sample point to Crossville, TN (km) in 2000	-
KNX_DS	Distance from sample point to Knoxville, TN (km) in 2000	-
OAK_DS	Distance from sample point to Oak Ridge, TN (km) in 2000	-
G_IND	Index equal to the average of Cookeville, Crossville, Knoxville, and Oak Ridge, TN, each computed as the ratio of the square root of the city's population divided by the city's proximity to the plot between 1990 and 2000	+

Table 3-3: Descriptive statistics of estimated signs, estimated maximum- likelihood parameters, standard errors, Wald statistics, probability of a greater chi-square, and predicted probability for the conversion of forest to development for both Cumberland and Morgan Counties, Tennessee

Variable	Parameter Estimate LCC	Standard Error	Probability > Chi-square	Predicted Probability
INTERCEPT	-0.0130	0.5437	0.9809	
COUNTY °	-0.7932	0.4668	0.0893 **	22.0%
TYPE	0.5310	0.3351	0.1130	
POP °	-0.0051	0.0025	0.0409 *	47.8%
PERS	-0.0001	0.0003	0.7898	
WOC	0.0071	0.0098	0.4683	
ED	-0.0268	0.0163	0.0999 **	37.2%
BLDG	-0.0002	0.0011	0.8935	
SLOPE	-0.1743	0.0282	<.0001 *	11.9%
RD_DS	-0.2101	0.3031	0.4883	
INT_DS	-0.0259	0.0138	0.0612 **	35.2%
HY_DS °	0.7796	0.3742	0.0372 *	60.5%
G_IND	0.0036	0.0016	0.0258 *	51.7%
Total Probability	11.4%			
Rest Max Log L:	954			
Unrest Max Log L:	847			
No. of Observations:	860			

Note: ° indicates that parameter estimate contradicts null hypothesis

Note: * indicates significance at alpha = 0.05 level.

Note: ** indicates significance at alpha = 0.1 level.

Table 3-4: Descriptive statistics of estimated signs, estimated maximum-likelihood parameters, standard errors, Wald statistics, probability of a greater chi-square, and predicted probability for the conversion of forest to development in Cumberland County, Tennessee

Variable	**Parameter Estimate LCC**	**Standard Error**	**Probability > Chi-square**	**Predicted Probability**
INTERCEPT	-0.5515	0.4074	0.1758	
TYPE	0.1933	0.3984	0.6275	
POP °	-0.0050	0.0029	0.0827 **	35.8%
PERS	-0.0004	0.0004	0.3273	
WOC	0.0178	0.0233	0.4446	
ED	-0.0128	0.0246	0.6025	
BLDG	-0.0009	0.0022	0.6853	
SLOPE	-0.1941	0.0441	<.0001 *	16.7%
RD_DS	-0.5174	0.4336	0.2328	
INT_DS	-0.0317	0.0189	0.0925 **	30.3%
HY_DS °	0.8736	0.4964	0.0784 **	42.8%
G_IND	0.0058	0.0023	0.0111 *	38.2%
Total Probability	10.6%			
Rest Max Log L:	548			
Unrest Max Log L:	485			
No. of Observations:	497			

Note: ° indicates that parameter estimate contradicts null hypothesis

Note: * indicates significance at alpha = 0.05 level.

Note: ** indicates significance at alpha = 0.1 level.

Table 3-5: Descriptive statistics of estimated signs, estimated maximum-likelihood parameters, standard errors, Wald statistics, probability of a greater chi-square, and predicted probability for the conversion of forest to development in Morgan County, Tennessee

Variable	Parameter Estimate LCC	Standard Error	Probability > Chi-square	Predicted Probability
INTERCEPT	0.1116	1.0173	0.9127	
TYPE	1.6381	0.7500	0.0290 *	53.8%
POP	-0.0085	0.0075	0.2603	
PERS	0.0016	0.0008	0.0376 *	75.2%
WOC	-0.0326	0.0279	0.2428	
ED	-0.0203	0.0352	0.5638	
BLDG	0.0037	0.0023	0.1072	
SLOPE	-0.1585	0.0402	<.0001 *	24.8%
RD_DS	0.1261	0.4593	0.7836	
INT_DS	-0.0562	0.0315	0.0738 **	16.6%
HY_DS	0.8382	0.6038	0.1651	
G_IND	0.0014	0.0018	0.4402	
Total Probability	11.1%			
Rest Max Log L:	407			
Unrest Max Log L:	351			
No. of Observations:	363			

Note: ° indicates that parameter estimate contradicts null hypothesis

Note: * indicates significance at alpha = 0.05 level.

Note: ** indicates significance at alpha = 0.1 level.

Table 3-6: Contingency table for four probability thresholds for forest to urban conversion between 1992 and 2000

		Predicted Number of Parcels
Observed Number of Parcels	**Probability Level = 0 - 25%**	Developed
	Developed	85
	Remaining Forested	1,848
	Total	1,933
	Probability Level = 26 - 50%	
	Developed	29
	Remaining Forested	302
	Total	331
	Probability Level = 51 - 75%	
	Developed	2
	Remaining Forested	33
	Total	35
	Probability Level = 76 - 100%	
	Developed	1
	Remaining Forested	11
	Total	12

Table 3-7: Four probability thresholds for forest to urban conversion between 2000 and 2010

Probability Level	Developed	Remaining Forested	Percent of Total
0 - 25 Percent	5380	620	89.7
26 - 50 Percent	578	5422	9.6
51 - 75 Percent	29	5971	0.5
76 - 100 Percent	13	5987	0.2
Average Percentile =	12 percent		

Appendix B

Figures

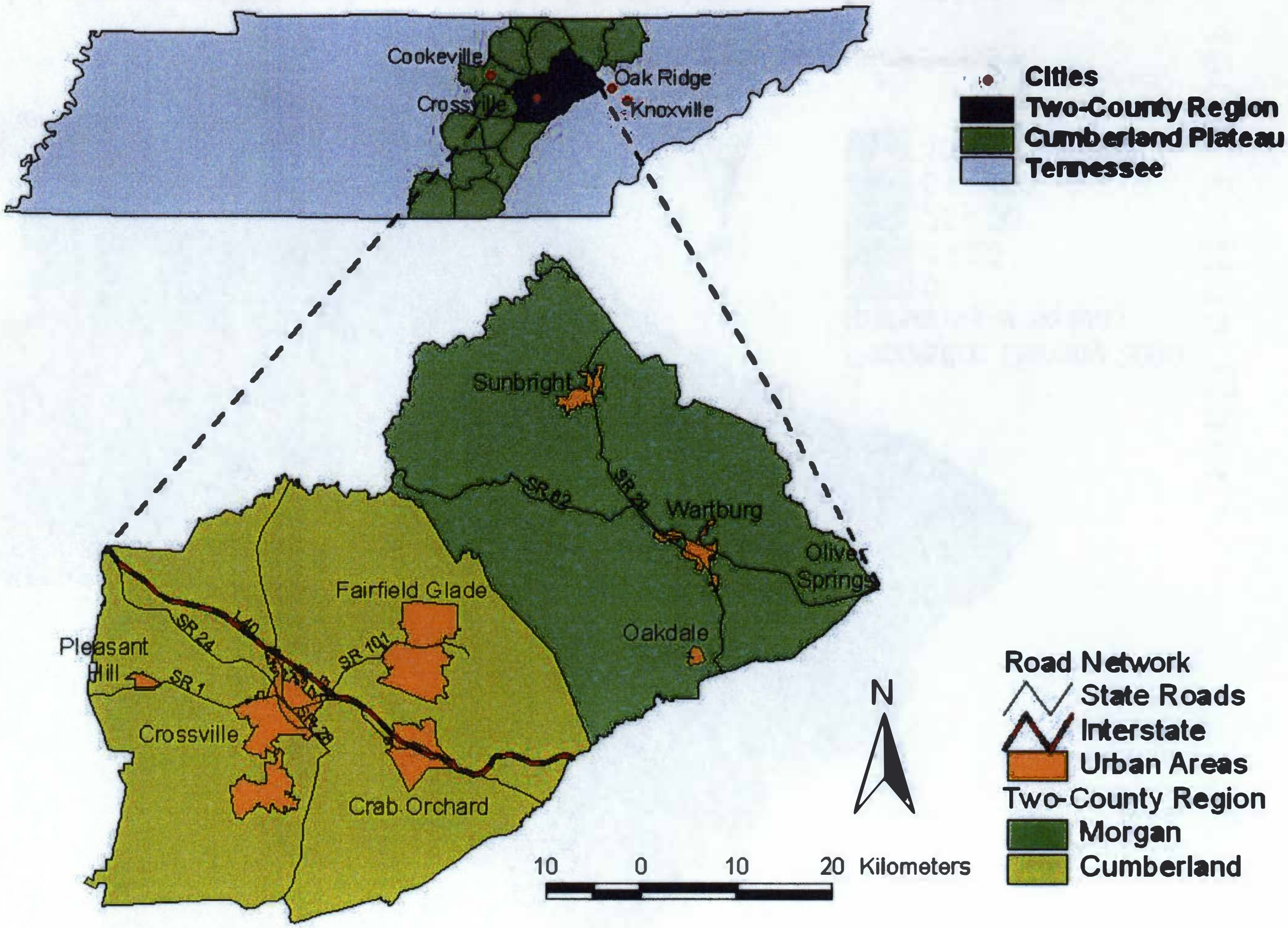

Figure 3-1: Study area with road network system and urban areas, Cumberland and Morgan Counties, Tennessee

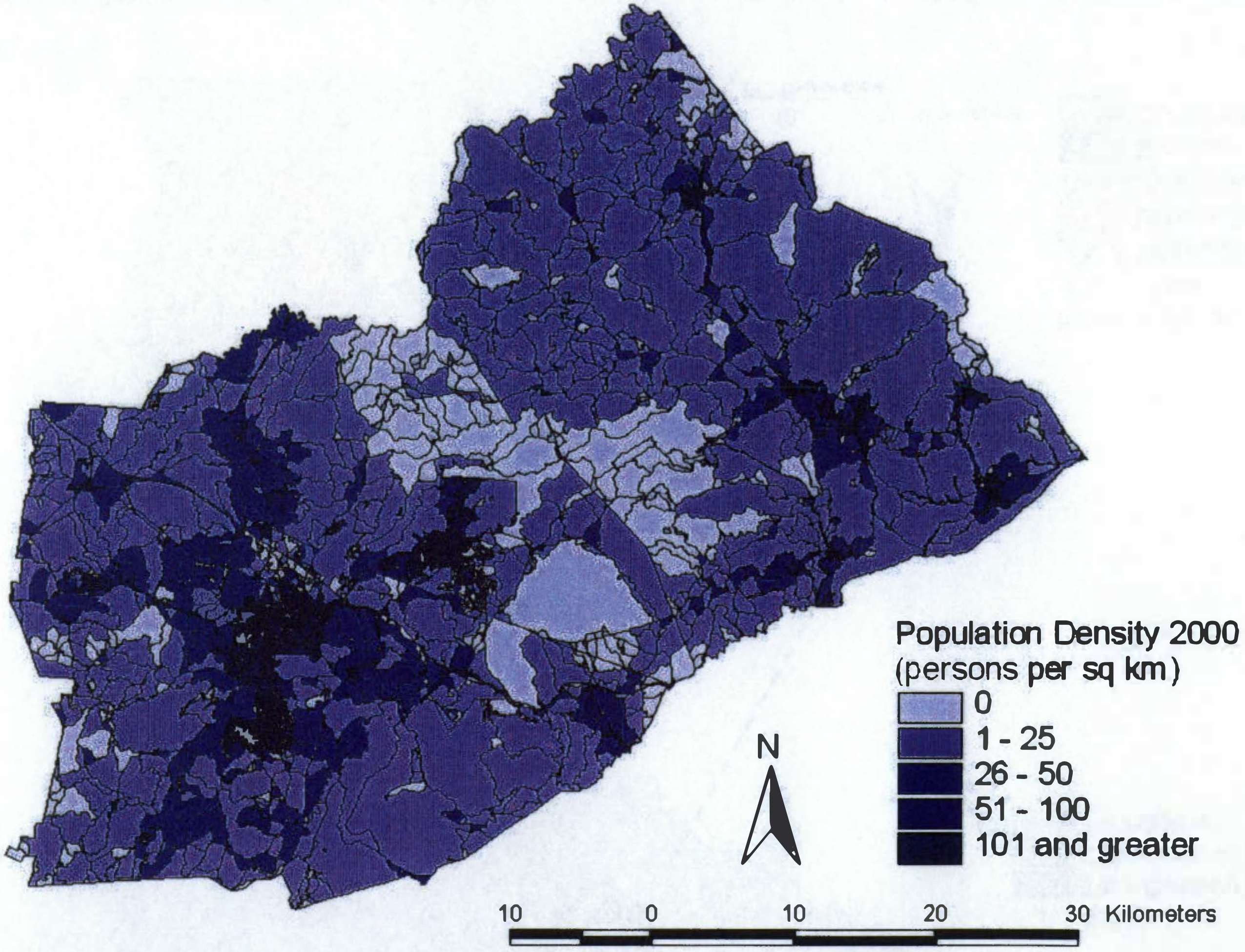

Figure 3-2: Current population density per census block for Cumberland and Morgan Counties, Tennessee

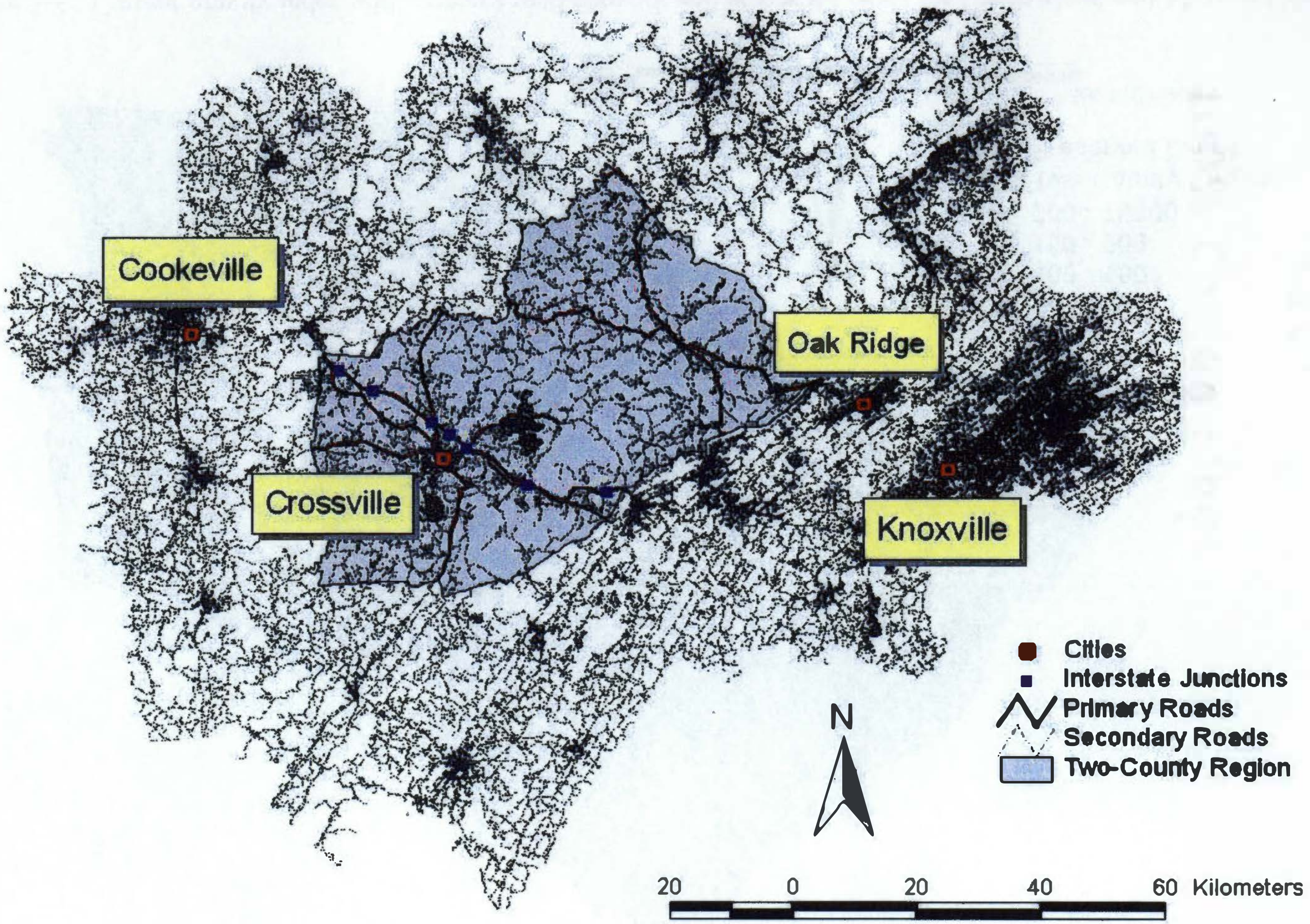

Figure 3-3: Road network system, interstate junctions, and urban areas for Cumberland and Morgan Counties, Tennessee

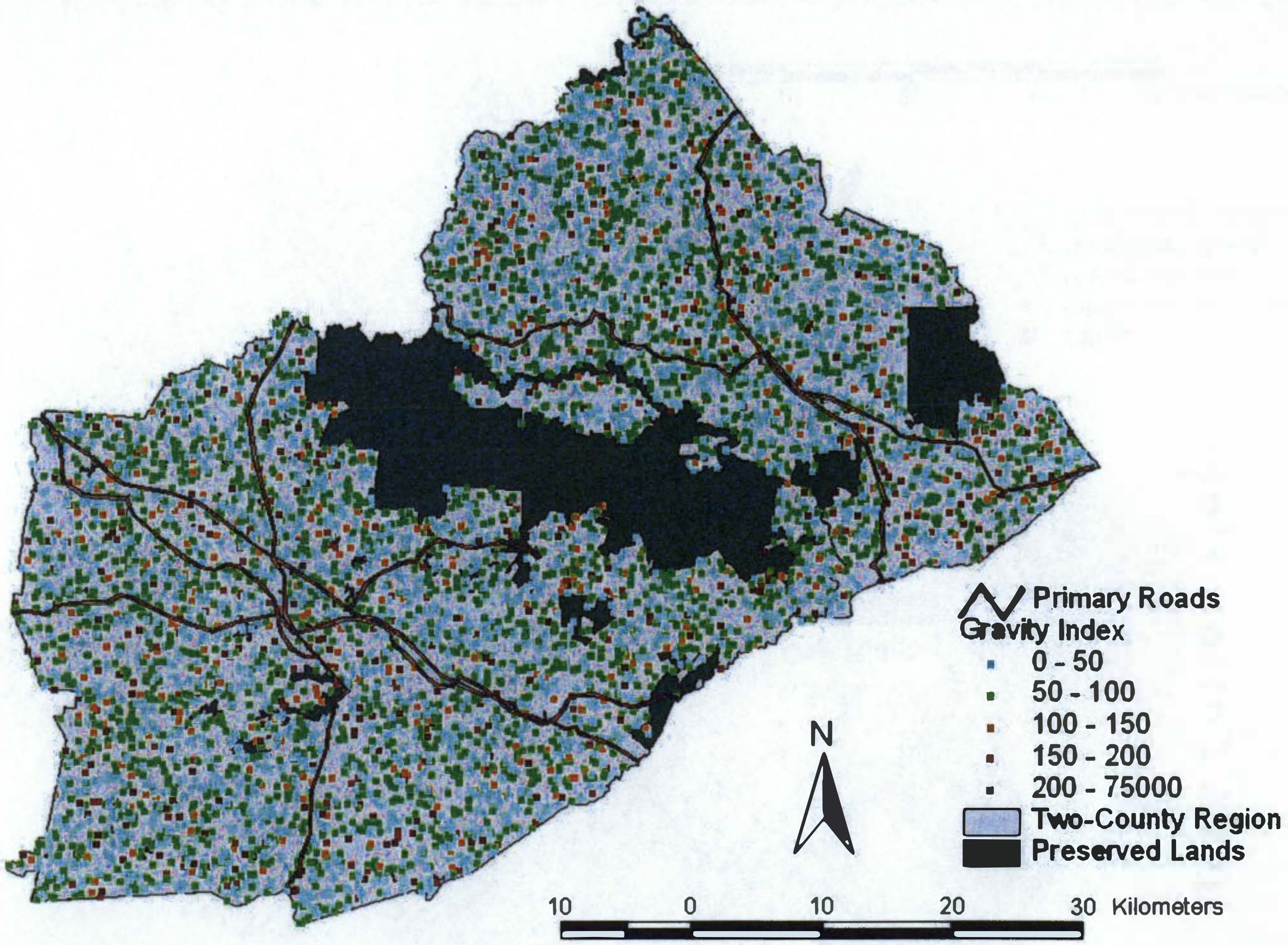

Figure 3-4: Current gravity index with primary road network and preserved lands for Cumberland and Morgan Counties, Tennessee

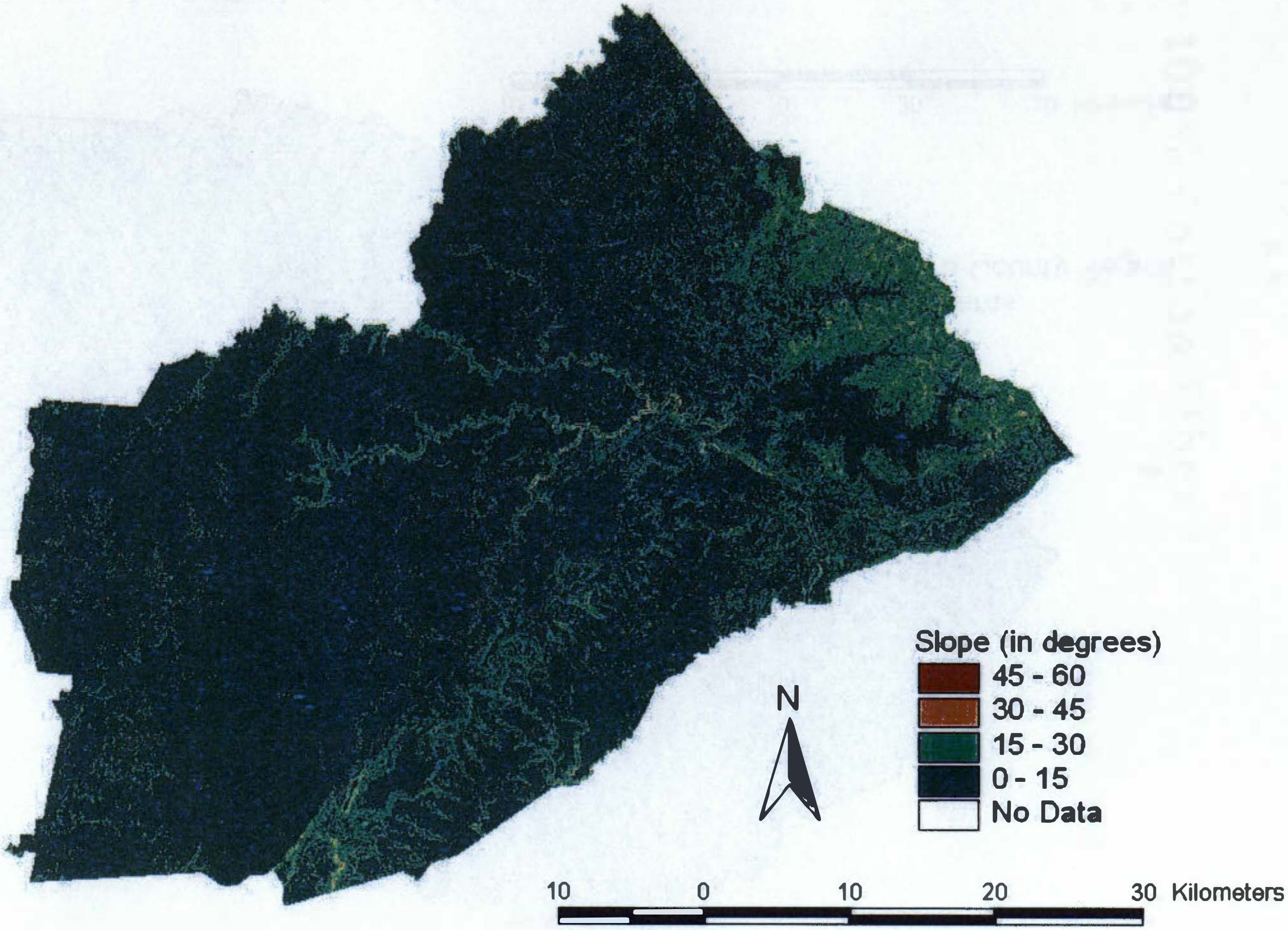

Figure 3-5: Slope for Cumberland and Morgan Counties, Tennessee

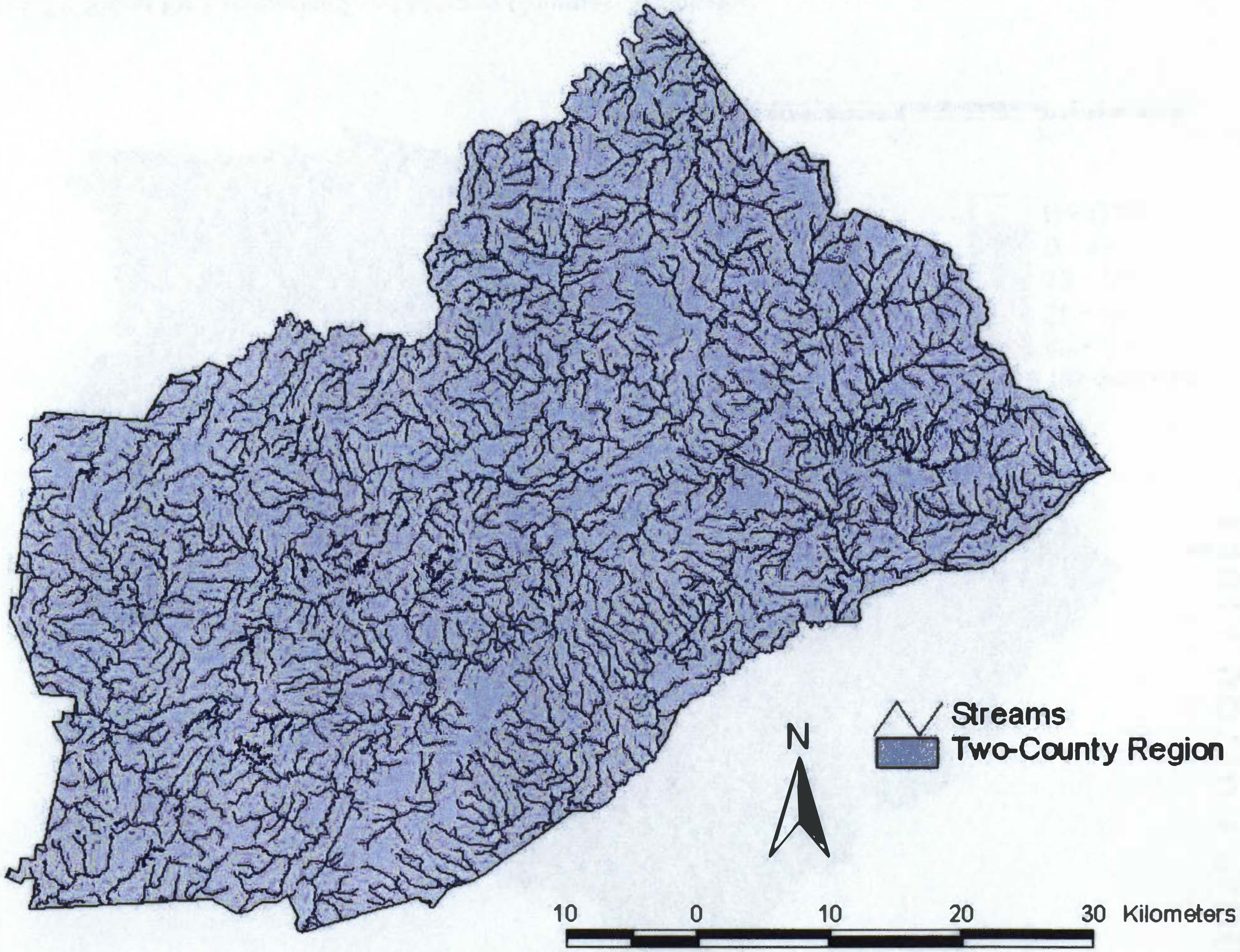

Figure 3-6: Stream data for Cumberland and Morgan Counties, Tennessee

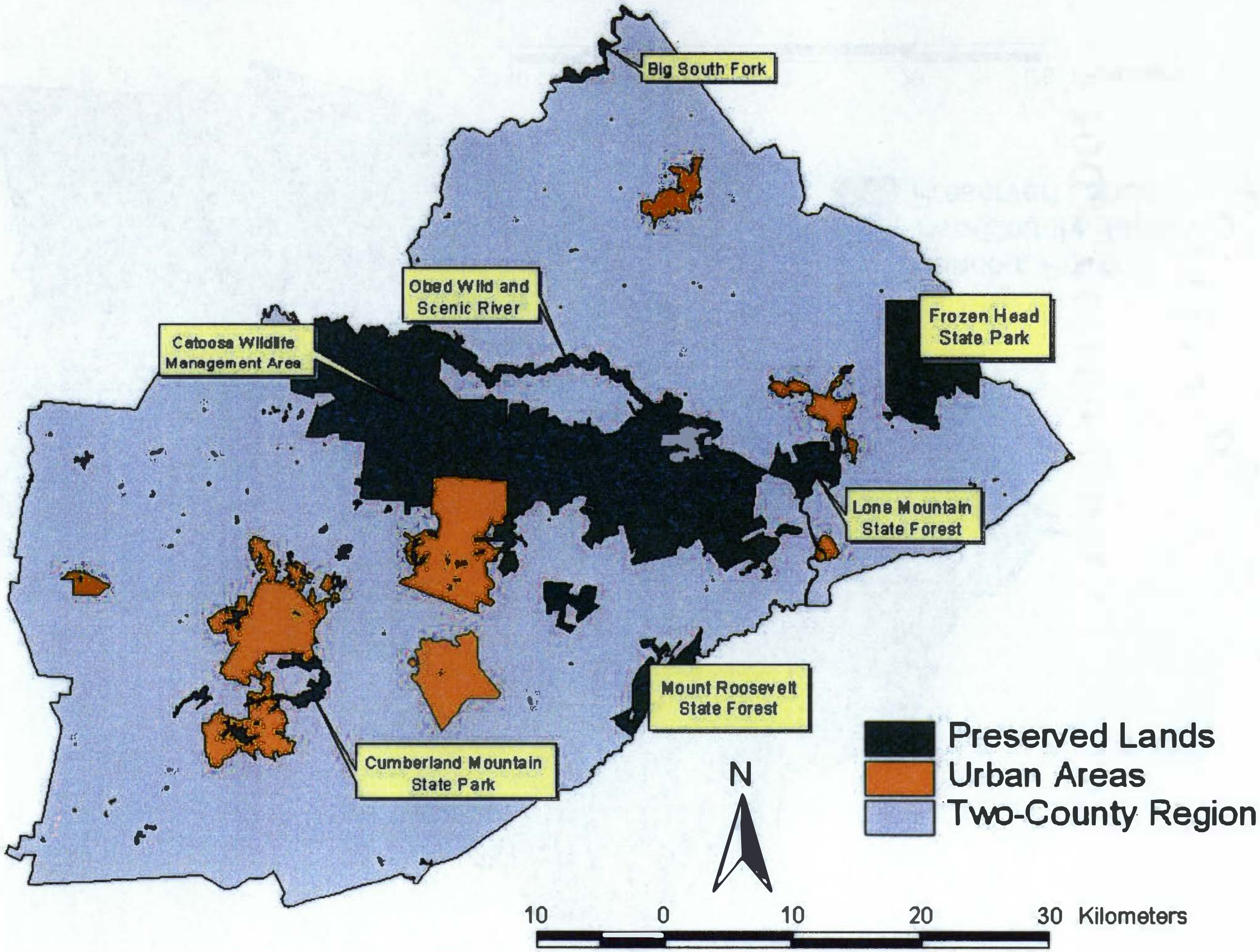

Figure 3-7: Preserved lands for Cumberland and Morgan Counties, Tennessee

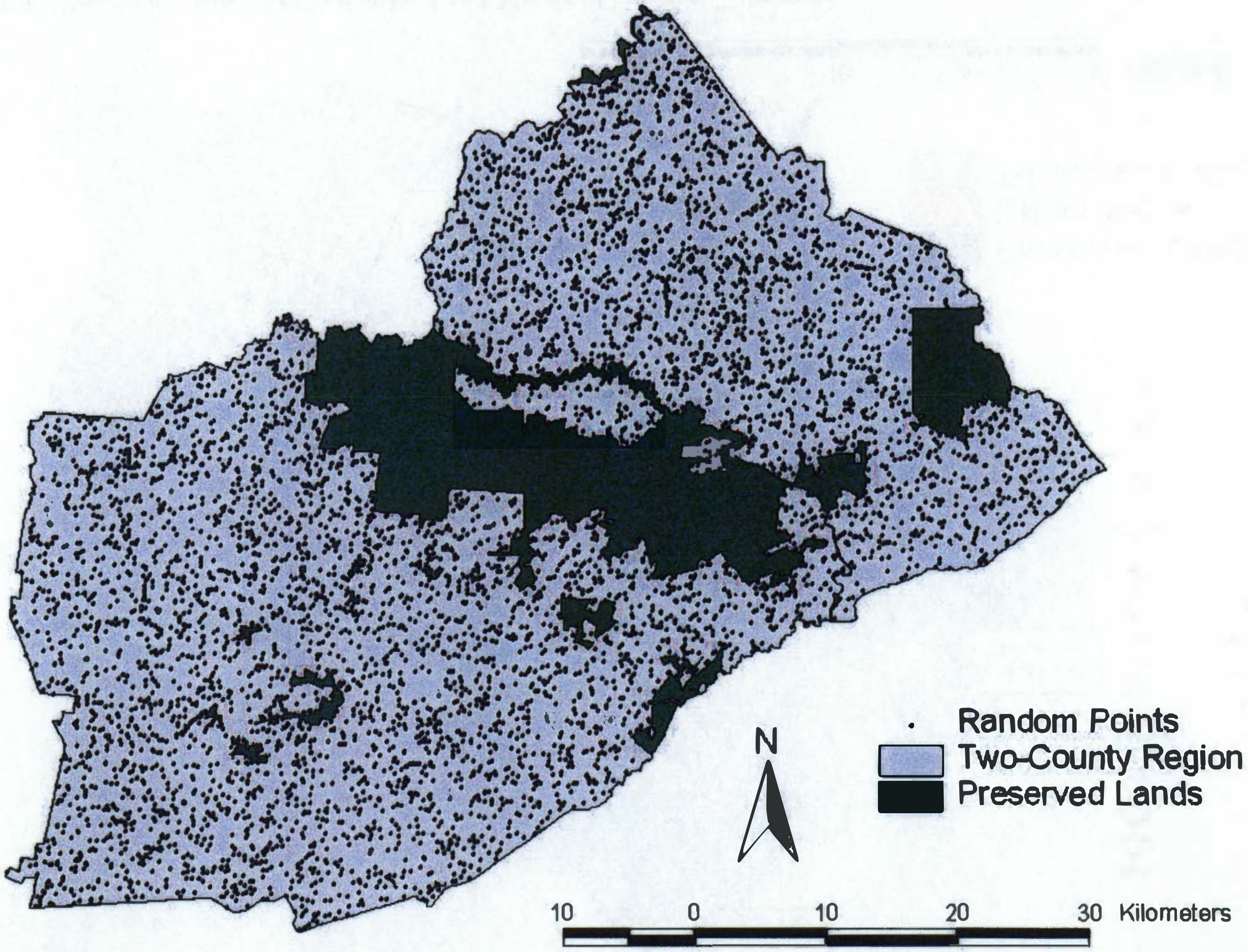

Figure 3-8: Randomly selected points for Cumberland and Morgan Counties, Tennessee

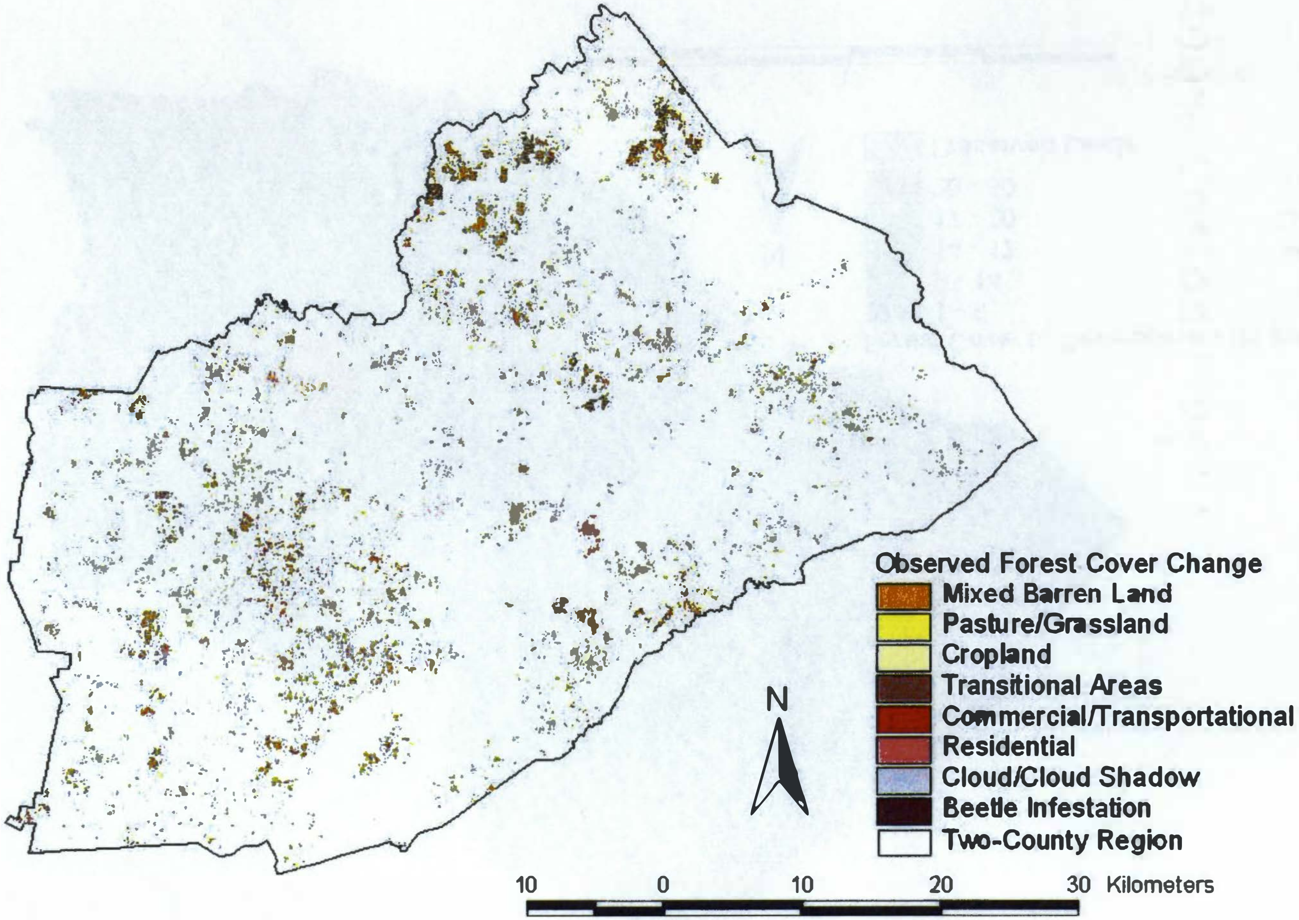

Figure 3-9: Observed change in forest cover to another land cover type between 1992 and 2000, Cumberland and Morgan Counties, Tennessee

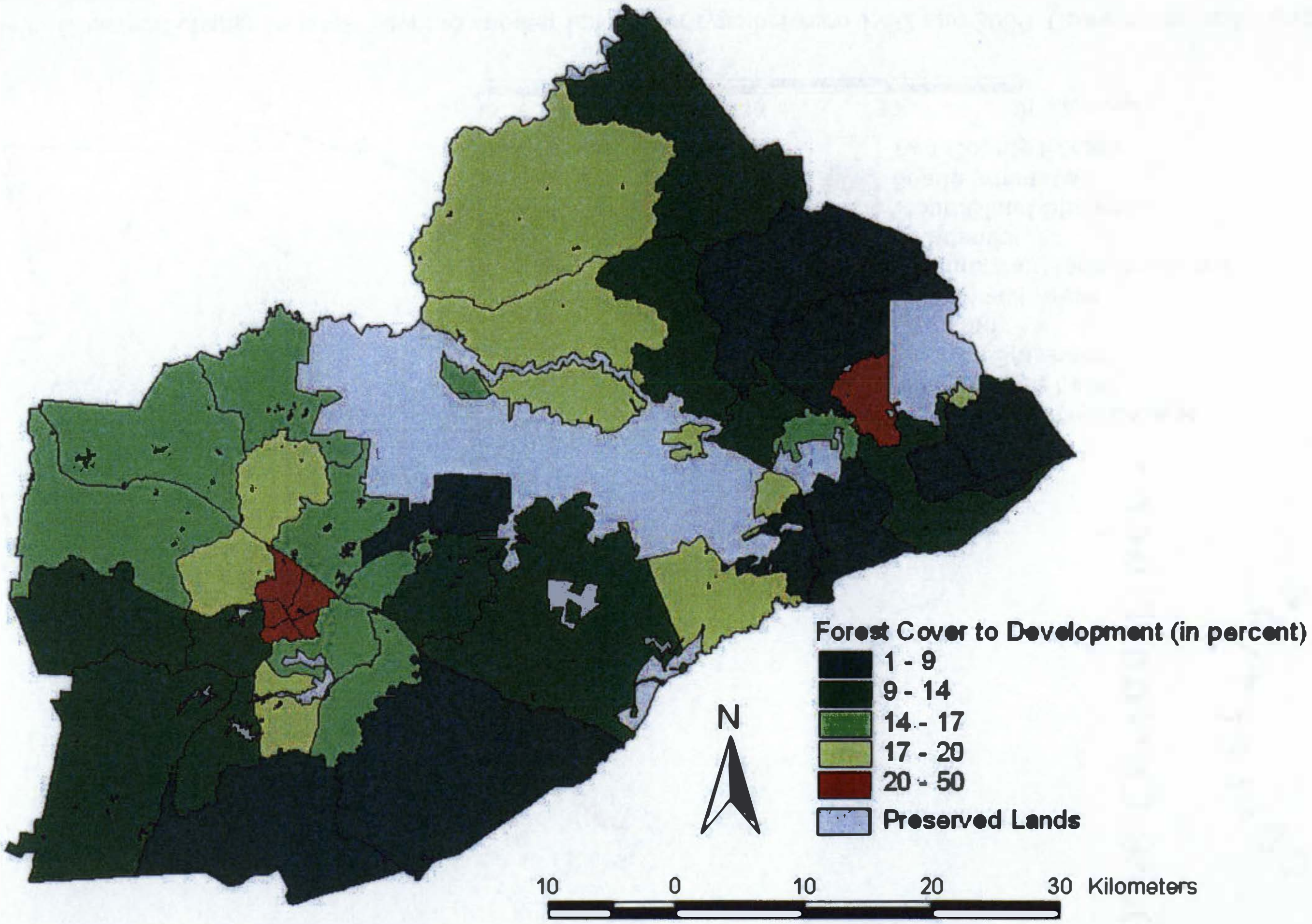

Figure 3-10: Probability of development of forest cover between 1992 and 2000 for Cumberland and Morgan Counties, Tennessee

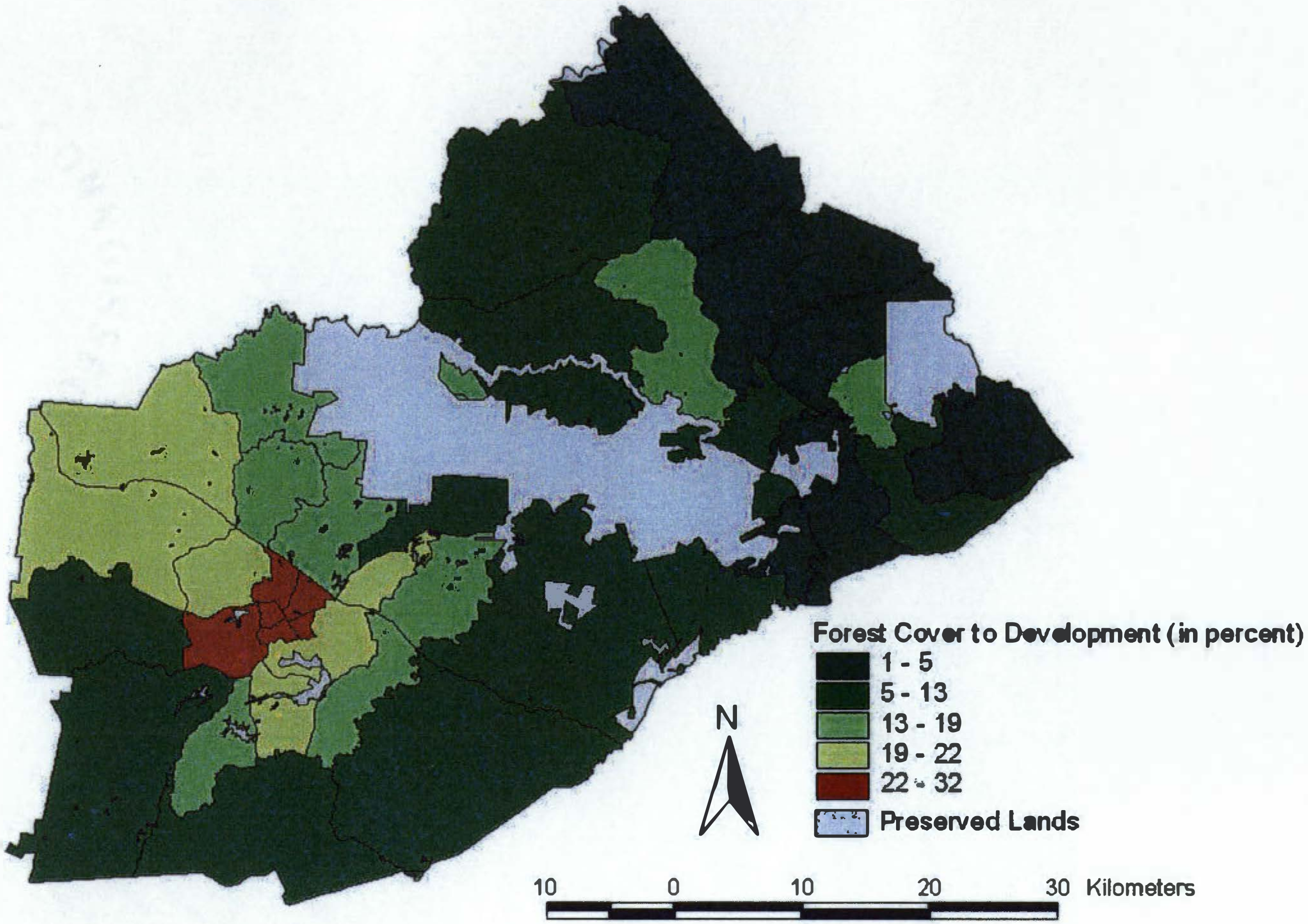

Figure 3-11: Probability of development of forest cover between 2000 and 2010 for Cumberland and Morgan Counties, Tennessee

Chapter IV

Conclusions

This study was designed to test a methodology for evaluating land cover change and projecting future land cover patterns in a two-county region on the Cumberland Plateau province of Tennessee. The region has experienced substantial population growth during the past 20 years. It is uncertain how the resulting land use and land cover change will affect the region's ability to support resource-dependent activities such as logging and biodiversity.

The first objective of this study was to develop an accurate and efficient procedure for developing a land cover map and forest change detection system for Cumberland and Morgan Counties, Tennessee. The method used to generate this procedure combined the methods of post-classification and image differencing. The second objective was to use the forest change analysis to determine the relationship between urbanization and forest loss in Cumberland and Morgan Counties, Tennessee and to predict current and future land cover patterns.

Using the 2000 Landsat image with digital classification techniques, a current land cover map was created for Cumberland and Morgan Counties. An Anderson level II land cover classification comprised of water, mixed barren, pasture, cropland, transitional areas, residential, urban/transportational, mixed forest, evergreen forest, deciduous forest, cloud/cloud cover, and beetle infestation resulted from this effort (Anderson *et al.* 1976). The classified image was then combined with the land cover change dataset to develop a map representing the observed classified change in forest cover. The overall classification accuracy of 89.2 percent was achieved by combining ground truth data and aerial photography. It was determined by visual analysis that this procedure was an excellent indicator of level II forest conversion to another land cover class.

The development of a land cover change dataset employed comparing two Landsat images (1992 and 2000) through a process of image differencing. Previous research suggested developing change detection through the process of post-classification (Macleod and Congalton 1998). This enabled the user to determine the cover type prior and subsequent to conversion. Whereas this is helpful for determining exact forest type, for example deciduous or evergreen, accuracy rates tend to be lower than the required 85 percent by the U.S. Geological Survey (Anderson *et al.* 1976). In addition, image differencing involved subtracting the pixels of the 2000 image from the same pixels of the 1992 image. The only downfall to image differencing is that it lacks the ability to acknowledge what has changed (Macleod and Congalton 1998). Therefore, this study incorporated image differencing with a current classified image to produce a more accurate change detection procedure enabling the reader to identify what cover type replaced the previous forest parcel.

Improving the classification procedures could enhance the study's results. Even though cloud cover represented less than one percent of the total area, this could have been completely avoided by proper examination of the satellite images before final purchase. Overall, the procedures for developing a land cover map make it very difficult for agencies to process the results. Therefore, the maps developed that show forested areas that have been converted to another cover through the use of combining post-classification and image differencing could be easily transferable to local government agencies, planners, and foresters. These techniques could improve future land use plans, allowing local planners and civil engineers more time for the development of better services to growing areas. Secondly, these techniques could help foresters to identify which areas are highly susceptible to possible conversion to urban uses.

The second objective of the study was to determine the relationship between urbanization and forest loss in Cumberland and Morgan Counties, Tennessee and to predict current and future land cover patterns. Through the use of GIS, a land cover model was used to investigate the relationship between the conversion of forest to urban cover and spatial and demographic variables of the region. With population growth rates for the two-county region exceeding 28 percent within the last decade, this continual exurbia growth forewarned the possibility of persistent urbanization and habitat fragmentation. The development of a land cover model makes it possible for natural resource professionals to evaluate future growth patterns based on economic, social, and demographic changes.

The results suggested that the modeling approach is useful in explaining current land cover and land use trends as well as predicting future land use scenarios. Demographic variables such as education and population, along with spatial factors such as slope, distance to water, distance to interstate junctions, and gravity index measuring the urbanization potential of nearby metropolitan areas, significantly influenced the transition of forest to urban cover. Of these parameters, gravity index, population density, and slope had the greatest impact on forest to urban conversion. As the gravity index value for a parcel increased, the probability of conversion to development increased. In other words, the closer a parcel is to a metropolitan area, the greater the tendency for conversion. Population growth is more likely to sprawl into an area that has close proximity to neighboring cities, allowing for the accessibility of business transactions. However, the slope of the terrain can hinder any possibility of conversion. Along with an increase in slope comes a greater difficulty in construction accessibility and costs. Therefore, development is more likely to occur in valleys consisting of a low degree in slope.

Overall, the predicted patterns of urban sprawl dictated the success of the land cover model. Areas along Interstate 40 and portions around northeast Morgan County contain forested parcels consistent with a high probability of conversion. However, improvements could be made upon the land cover model. While the land cover change analysis was examined over an eight-year period, a spatial analysis over a thirty-year time span could have improved the change analysis and the model. Large population growth and accompanying structural changes in accessibility and development occurred between 1970 and 1990. Having satellite images of this time period would have allowed a better analysis of change, therefore improving the overall significance of the model.

As improvements in technology continue, it will be easier to acquire historic imagery and data at a better resolution. Currently, satellite imagery with a 30-meter resolution has some limitations, inhibiting the ability to discern specific patches of forest. The advancements made in the development of more efficient images will solve this problem and improve the accuracy of land cover detection and modeling analysis.

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VITA

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