An Assessment of Forest Change on the Cumberland Plateau in Southern Tennessee

Small Area Assessment Forestry Demonstration Project
for the Southern Forest Resource Assessment

Final Report

Submitted to:
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Pelkey, N., J.P. Evans, and D. Haskell. 2001. Classification, confusion, and contrast: A comparison of forest estimation techniques for the Cumberland Plateau. Paper presented at the Proceedings of the Southern Forest Science Conference. Atlanta, GA (November 26-28, 2001).

This paper compares plot-based FIA data to three other publicly available data sources that cover our study area: the North America Land Cover Database (based on 1992 Landsat imagery), the Tennessee Wildlife Resource Agency Gap Analysis Landuse Coverage (based on 1997 Landsat imagery), and the U.S. Forest Service and U.S. Geological Survey Forest Resources of the United States 1997 Map (based on NOAA AVHRR data). We discuss the advantages and disadvantages of applying each of these coarse-grain forest assessments to the Southern Cumberland Plateau.

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Project Summary

Background

Native forests of the southern United States are currently undergoing dramatic changes due to shifting patterns in land use. In recent years, urban sprawl and the creation of pine plantations have emerged as dominant forces of change and have been predicted to be major causes of native forest loss in the future (Wear and Greis 2001). In the southeast where the vast majority of the land base is privately owned, the forests change as a function of the many individual land use decisions made over a period of time. These land use decisions involve not only the myriad of forest owners spread across the region, but also the resource professionals who advise them and the government officials who enforce regulations and provide incentives to them. If forest values such as biodiversity, water quality, and wood fiber are to be sustained in such a mosaic of decision-making, then landscape-level information must be made available to all parties in order to guide land use activities in an informed and comprehensive manner. This is the role of a small area assessment.

The Cumberland Plateau in Tennessee contains some of the largest remaining tracts of privately owned, contiguous temperate deciduous forest in North America. Native forests on the Cumberland Plateau, as defined for the purposes of this study, consist predominately of a mixture of oak (*Quercus* spp.) and hickory (*Carya* spp.) species, along with other hardwood species. These forest tracts represent important neotropical migratory songbird habitat and serve as the headwaters to some of the most biologically diverse, freshwater stream systems found in the world (Ricketts et al. 1999). The Cumberland Plateau has some of the highest predicted herpifaunal diversity of anywhere in the state and one of the most diverse communities of woody plants in the eastern United States. (Durham 1995; Ricketts et al. 1999). The drought-prone, sandy soils of the plateau surface have a low nutrient content that limits productivity, making the system highly sensitive to the nutrient removal effects of whole-tree harvesting and acid precipitation (Adams et al. 2000). The hard mast (acorns) associated with the mature oak canopy of the plateau forest serves as a keystone resource within the food web of this ecosystem. The availability of this oak mast resource directly or indirectly affects the survivorship of hundreds of animal species inhabiting the forest (McShea and Healy 2002).

There has been considerable recent debate as to the rate and scope of forest change in Tennessee as well as debate about the impact of such change on forest values. This Small Area Assessment Forestry Demonstration Project used a 7-county, 616,000 acre portion of the Cumberland Plateau in southern Tennessee as a case study to test current methods and technologies for detecting forest change and to examine the ecological consequences of native forest removal in this region. The Project study area encompassed only the forest ecosystem associated with the surface of the Plateau (Figure 1). The Project had the following specific objectives:

Mapping Patterns of Forest Change

a) To generate comprehensive forest change documentation for the Plateau study area (1981-2000) using remotely sensed data and current Geographic Information System (GIS) technology.
b) To assess the ability to generate such information at spatial and temporal scales relevant to local land use decision makers and in a cost-effective and technologically transferable manner.

Aquatic Biomonitoring

a) To use benthic macroinvertebrates and salamanders as indicators of water quality and the resulting biological integrity of watersheds within the study area.
b) To assess the utility of low cost aquatic biomonitoring as a means of tracking the impacts of land use change on water quality.

Bird Community Response to Forest Change

a) To examine the responses of bird communities to changes in forest structure, composition, and spatial distribution that result from land use change on the plateau.
b) To assess the utility of using birds as indicators for tracking the impact of land use change on plateau forest biodiversity.

This study was funded, in part, by the U. S. Environmental Protection Agency and the U.S. Fish and Wildlife Service as a Small Area Forestry Demonstration Project. The effort was initiated as part of these agencies' overall involvement with the Southern Forest Resource Assessment project, specifically to assist in analysis of the effects of land use change at smaller, sub-regional focus areas. Scientists from these agencies served as the peer review panel for this Report.

Findings

Within the last twenty years, native forests on the Cumberland Plateau have been cleared to create plantations of predominately loblolly pine (*Pinus taeda*), a species that is not native to the Plateau. The following information is based on a detailed, quantitative assessment of land use change on this portion of the Cumberland Plateau, with an emphasis on identifying the role of silvicultural activities in driving this change. Conversion of native forest habitats to pine plantations is a focus of this analysis along with other land use transitions.

Forest Change Mapping

Using aerial and satellite imagery, we created computer-generated maps of land use and forest cover for the study area. The major cover categories depicted in these maps included: 1) native forest with an intact canopy; 2) silviculturally thinned native forest; 3) areas that had been recently logged and cleared of trees; 4) pine plantation; 5) areas with partial or no tree canopy in predominately agricultural or residential/urban use. From these maps we were able to track and document patterns of forest change and conversion between 1981 and 2000:

- There was approximately 14% less area with intact native forest canopy on the Southern Cumberland Plateau in 2000 than was present in 1981. This represents a net loss of approximately 65,660 acres of native forest during this time.

- The rate and magnitude of pine conversion and native forest loss varied across counties and watersheds within the study area. However, all counties showed a net loss of native forest, with Van Buren County being the highest at 18% (15,868 acres). Pine conversion activity was highly clustered, causing a concentration of impact in certain counties and watersheds.

- Between 1981 and 1997, intact native forest area decreased at a rate of 3012 acres per year. Between 1997 and 2000 the rate of decrease was almost two times greater at 5823 acres per year.

- Total area in pine plantation increased by 170% (24,947 acres) from 1981 to 2000. Pine plantations and associated lands newly cleared for this purpose were responsible for 74% of native forest conversion.

- Total area of native forest converted to agriculture, residential and other non-silvicultural uses increased by 18% between 1981-2000 and was responsible for 26% of native forest conversion.

- About 80% of all newly created pine plantations that appeared in the study area between 1981 and 2000 were derived from either intact or thinned native forests. Less than 3% were derived from lands associated with agriculture. Between 1981 and 2000, most existing or recently converted pine plantations remained as pine plantations and did not transition to other uses.

- From 1997 to 2000, 90% of all native forest removal resulted from clearings that were greater than 40 acres in size (Forest Stewardship Council (FSC) certification limit). 70% of this native forest removal resulted from clearings that were greater than 120 acres in size (Sustainable Forestry Initiative (SFI) certification average clearcut size limit).

Aquatic Biomonitoring

We surveyed salamanders and aquatic invertebrates (insects, crayfish, etc.) in streams across our study area. We found that streams in clearcuts had significantly lower salamander density than those in intact native forests. However, there were no statistically significant differences between the numbers of salamander species in streams running through clearcuts and streams in intact native forests. Aquatic invertebrates were more abundant in disturbed sites (sites that had some logging around them) than in undisturbed sites (sites surrounded by native forest, perhaps because of increased sediment loads). We calculated several indices of water quality based on the populations of aquatic invertebrates (some invertebrates are more tolerant of water pollution than others, so their populations tell us about water quality). Most of these indices were highly variable and lacked the statistical power to discern any differences in water quality. However, one index of water quality based on the proportions of tolerant and intolerant invertebrates indicated that water quality was significantly lower in disturbed sites. This index of water quality also increased with the width of the buffers of uncut forest that are left around streams in logged areas (known as stream-side management zones, or “SMZs”). This suggests that: (i) SMZs help provide increased water quality, and (ii) that some SMZs in our study area may be too narrow to provide maximal protection.

Bird Community Assessment

Our field surveys of breeding birds found that pine plantations had the lowest bird diversity and had the lowest conservation value, as measured by independently-derived Partners in Flight (PIF) priority scores. The intact native forests had the next highest diversity and PIF conservation value. These intact native forests had some of the highest levels of bird diversity found anywhere in the forests of the south-eastern U.S., indicating that this region offers high quality habitat for forest-dwelling birds. Residential/rural areas (including suburban areas and rural areas with low housing density) and thinned native forests had the highest diversity of breeding birds and the highest PIF conservation value.

Neither pine plantations nor residential areas can support the bird communities found in the native forests of the Cumberland Plateau. However, residential areas provide habitat for several species that are found in no other habitat types on the Plateau. In addition, residential areas, young pine plantations, and thinned native forests all provide habitat for a few specialist bird species that require a more open or grassy habitat. Some of these specialists are also present in patches of natural disturbance in native forests.

Our findings are in broad agreement with field studies conducted elsewhere. There is, however, evidence that the species-rich bird communities of the Cumberland Plateau are more vulnerable to loss of bird diversity when subjected to intensive timber management than are bird communities with relatively low species richness in other regions such as boreal and sub-boreal forests.

Recommendations for Completing Future Small Area Assessments

The primary purpose of this study was to examine changes in land cover and land use over time and the environmental effects associated with those changes at a sub-regional scale. However, another important objective of the study was to develop and identify technologically accessible, cost-effective ways of generating landscape-level information that could be used in future sub-regional focus area assessments across the South. In support of this goal, this study has identified methodologies that governmental and non-governmental organizations can access and afford in their search to generate quantitative, accurate information about current land-use changes occurring in their region. This information should become important pieces of any local, land-use decision-making process. In addition, technologies developed for this project could easily be applied as part of any SFI/SFC certification/verification process for the Plateau, or any other area, to track certain indicators of sustainable forestry operations. The following represents some of the key methodological findings related to completion of future sub-regional focus area assessments with similar project objectives:

Forest Change Mapping

In main Report (Section 2.1 and Appendix E), we present a detailed comparison of the strengths and weaknesses associated with the various assessment techniques we tested for generating digital land use change maps for a small area (less than 1 million acres). While the most expensive to implement, the approach we chose to employ in our study provided the requisite degree of accuracy for our relatively large and complex study area and allowed us to take full advantage of the multiple imagery sources needed to examine a 20-year, historical time frame. The accuracy of any method, however, can be improved by ground verification. This process simply involves individuals traveling to areas that have been classified using remote sensing techniques and visually confirming the calls. Ground verification does not require any computer skills. Thus for a small area, where extensive ground verification is practical, a methodology which is less expensive to implement than ours may provide adequate accuracy. Furthermore, imagery for recent years is available in digital, orthorectified form, so a study whose aim was to only create a base land use layer for the purposes assessing future changes could have considerably lower costs. Additional specific recommendations:

- SAA requires a rigorous post-verification process, including ground assessment by a natural resource professional whose has a good working understanding of the area to ensure appropriate classification of land use or forest cover types from aerial or satellite imagery.

- Simple mensuration in the field such as total tree basal area and canopy height are useful in differentiating cover classes.

- Spectral information from satellite imagery can be useful in speeding up the error assessment process for high resolution aerial photography.

- Farm Service Agency small format slides are useful in identifying cover versus non-cover but are difficult to geocorrect, furthermore FSA slides should be used in conjunction with other data to differentiate between classification calls.

Aquatic Biomonitoring

- Future field studies should, if possible, be conducted after GIS descriptions of the habitat are available. These studies should make use of watershed-based landscape metrics (e.g., fractal dimension, proportion of different habitat types, etc.) to plan field sampling.

- High degrees of replication are required for statistical evaluation of variable datasets.

- The Normalized Differenced Benthic Index (NDBI) developed in this study shows promise for detecting differences in water quality in datasets with low levels of replication and statistical power.

- Our study did not include isolated ephemeral pools. The impact of land use change on these habitats on the Cumberland Plateau is unknown, and we recommend further research on the importance and fate of these habitats.

Bird Community Assessment

- Our study showed very distinct differences in bird communities based on a comparative assessment of land cover in fairly close geographic locations. This suggests that the assessment of a single land cover or very few cover types might not accurately reflect the “true” impact of land use on avian communities. We recommend that future studies continue to make such comparisons across the range of land uses/habitats in an area, rather than studying birds in only one habitat to document the “contributions” of this habitat. We also recommend that all assessments of the effects of urbanization and pine conversion take such comparisons into account.

- There is a need for further information about nocturnal birds, raptors, and bird communities out of the breeding season. Studies of productivity in different habitats would also help evaluate changes in our region.

- An analysis of the effects of variation in bird diversity within the residential-rural habitat class is needed to better understand the effects of different types of housing development.

- The integration of GIS layers with field sampling allowed us to investigate landscape-level effects. The direction of these effects depended on the spatial scale of the analysis; therefore we recommend that spatial analyses continue to be conducted at multiple scales.

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Chapter 1

Project Overview

1.1. Why conduct small area assessments?

Native forests of the southern United States are currently undergoing dramatic changes due to shifting patterns in land use. Historically, agriculture has been the primary cause of forest clearing in the south. In recent years, urban sprawl and the creation of pine plantations have emerged as dominant forces of change and have been predicted to be major causes of native forest loss in the future (Wear and Greis 2001). In the southeast where the vast majority of the land base is privately owned, landscape-level forest change becomes a collective function of the many individual land use decisions made over a period of time. These land use decisions involve not only the myriad of forest owners spread across the region, but also the resource professionals who advise them and the government officials who enforce regulations and provide incentives to them. If forest values such as biodiversity, water quality, and wood fiber are to be sustained in such a mosaic of decision-making, then landscape-level information must be made available to all parties in order to guide land use activities in an informed and comprehensive manner. This is the role of a small area assessment.

A small area assessment generates the information necessary to allow each land use decision to be made within the context of what is happening to the greater landscape and provides this information at an appropriate spatial and temporal scale. For example, land use information produced every ten years with a spatial resolution appropriate only at the state level will have little value to decision-makers operating at the county or sub-county level, particularly in areas of rapid change. The conditions that govern the sustainability of forest resources also vary tremendously from one ecosystem to another. If a small area assessment is used for the purposes of defining forest sustainability in a region, then it must be sensitive to this underlying ecosystem variation. Finally, to be effective and enduring, small area assessments must employ a methodology that governmental and nongovernmental organizations can access, maintain and afford.

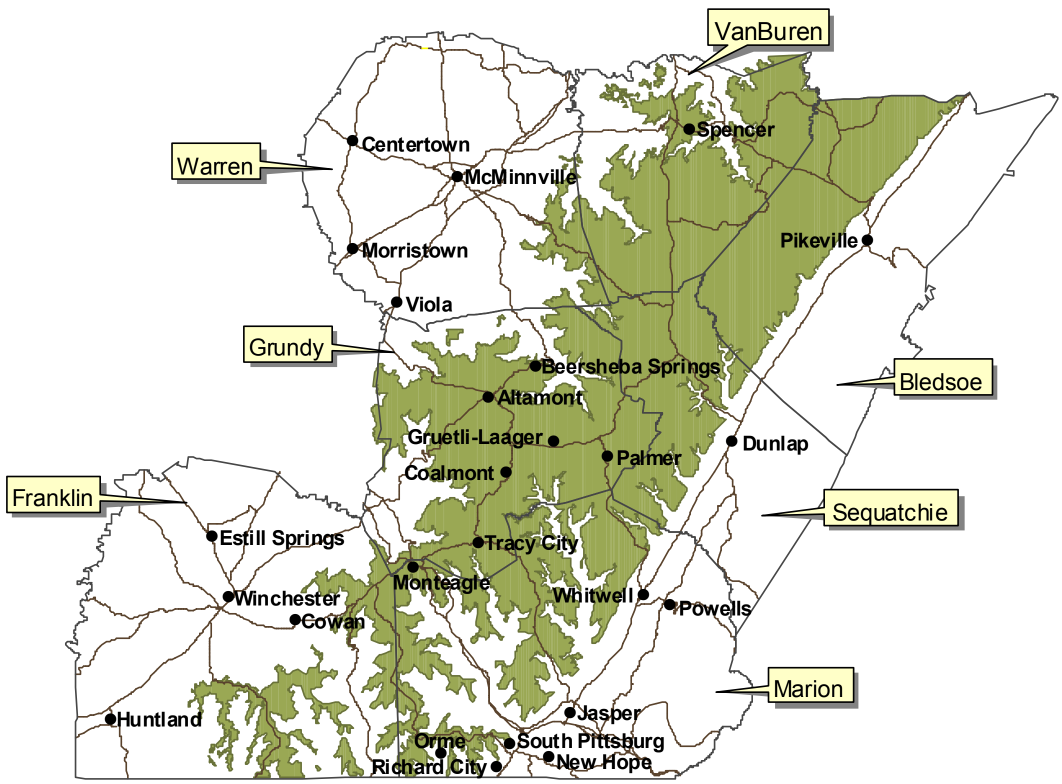
The Small Area Assessment Demonstration Project being reported here developed technologically accessible, cost-effective ways of generating landscape-level information that can be inserted into local, land use decision-making processes. The Project then used this methodology to examine the ecological consequences of land use change on the Cumberland Plateau in southern Tennessee over the last 20 years.

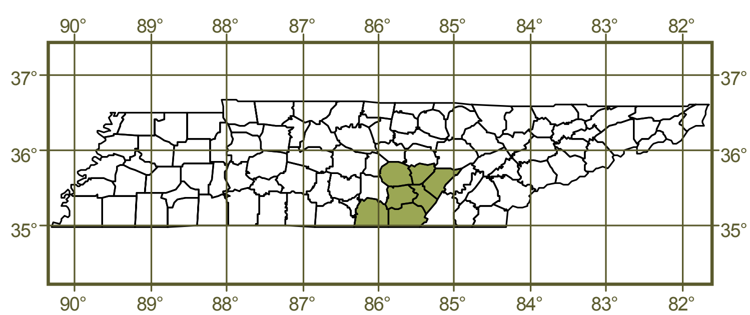
1.2 Plateau Forest Ecosystem

The Cumberland Plateau represents the southern extension of the Appalachian Plateau that extends from West Virginia and Kentucky through Tennessee, terminating in Alabama. It is considered the western-most part of the Southern Appalachian region (SAMAB 1996) bounded by the Ridge and Valley Province to the east and by the Interior Lowland Plateau to the West. The southern portion of the Cumberland Plateau in Tennessee (Fig 1.1) is a flat to gently rolling surface underlain by highly resistant Pennsylvanian sandstones (Pottsville series). Where drainages have breached the sandstone, the less resistant Mississippian limestones underneath have eroded to form extensive steep-sided coves (Fenneman 1938). The eastern escarpment of the Plateau presents a relatively linear front along the Sequatchie Valley, in contrast to the western escarpment and the southern terminus, which are both highly dissected by stream drainages. Watersheds on the Cumberland Plateau in southern Tennessee serve as the headwaters for the Sequatchie River, Tennessee River, Paint Rock River, Elk River, Duck River and the Collins River. The soils of this region reflect their underlying substrate and this, along with topographic position, is responsible for the large compositional differences between the forest of the Plateau surface (hereafter referred to as plateau forest) and that of the coves (hereafter referred to as cove forest). The focus of this Project is the “plateau forest” only. In Chapters 2, 3 and 4 of this report, we refer to the “plateau forest” as the “native forest.”

The plateau forest canopy is composed predominately of a mixture of oak species (*Quercus prinus*, *Q. coccinea*, *Q. velutina*, *Q. alba*, *Q. stellata*), hickory species (*Carya glabra, C. pallida, C. tomentosa*) along with sourwood (*Oxydendrum arboreum*), black gum (*Nyssa sylvatica*) and red maple (*Acer rubrum*) (Ramseur and Kelly 1981). The understory of the plateau forest is composed of a variety of woody shrubs including blueberries (*Vaccinium* spp.), wild azalea (*Rhododendron* spp.), and mountain laurel (*Kalmia latifolia*) along with a large number of grasses, sedges, and fall blooming composites (Clements and Wofford 1991). Shortleaf (*Pinus echinata*) and Virginia pine (*Pinus virginiana*) are the two common pine species native to the plateau forest. Both species tend to be disturbance-dependent, increasing in abundance after fires, agricultural land abandonment, road clearings, and mining events. Shortleaf is also common in shallow soil areas along south facing slopes and bluff edges. Loblolly pine (*Pinus taeda*) is not native to the plateau forest but was introduced in the mid-1900’s and has been planted abundantly in plantations since that time (Hinkle et al. 1993). Pollen analyses from sediment cores indicate that the arboreal flora of the Cumberland Plateau in Tennessee has changed very little over the last 9500 years and that native pine has never been a major component of the Plateau forests (Delcourt 1979).

Figure 1.1. Shaded area represents the Small Area Assessment Forestry Demonstration Project study area with major roads, county boundaries and towns highlighted. This area is upland, oak-hickory forest ecosystem associated with the surface of the Cumberland Plateau in southern Tennessee.





It can be shown from the only two published floras for the Cumberland Plateau in southern Tennessee (Clements and Wofford 1991: Wolf Cove, Franklin County; Wofford et al. 1979: Savage Gulf, Grundy County), that less than 25% of the vascular plant species found in the plateau forest are also found in the cove forest. These studies also reveal that despite this dissimilarity, the plateau forest is just as diverse as the cove forest with plateau forest species representing 48% of the total flora in both study areas.

There has been a tendency in the literature to generalize about the forests of the Cumberland Plateau by lumping the plateau and cove forests together into what has been referred to as the "Mixed Mesophytic Forest Region" (Braun 1950, Hinkle 1993). Braun began this trend with the notion that the plateau forest constituted a "physiographic climax" that would somehow eventually shift to the mixed mesophytic (cove-like) "climatic climax" over time. This concept of a regional climax forest, such as originally espoused by Frederick Clements in the 1920s, is no longer considered valid today (Sprugel 1991). Nonetheless, it has contributed to the false impression that the plateau forest should somehow be more like the cove forest but is not currently manifesting this potential due to its history of human interaction and land use.

Upland plateau forest dynamics are driven to a large degree by limited soil resource availability (Hinkle 1989). This is in distinct contrast to cove forest dynamics, which are controlled to a greater degree by limiting light availability (Martin 1992). The soils of the plateau surface, being derived from the underlying sandstone, have a very high sand content. This condition makes these soils nutrient poor (low ion exchange capacity), drought prone and highly acidic with little buffering capacity (Francis and Loftus 1977; Mays et al. 1991). Most of the fine root matter within the plateau forest soil is located in the upper 5cm of the organic layer. This carpet-like mat of roots suggests that soil resource input (water and nutrients) is mostly coming from above through precipitation and litter turnover. In a study examining the potential impact of increased acid precipitation on cation-poor forest systems, Kelly (1988) found there to be an annual net loss of base cations (principally Ca^{2+} and Mg^{2+}) from two completely forested plateau watersheds (Cross Creek, Franklin County and Camp Branch, Bledsoe County) over a five year period. Kelly (1988) predicted that "in the absence of significant weathering and at current rates of export, exchangeable levels of soil Mg^{2+}, for example, would be substantially reduced in a matter of decades." Calcium has a lower availability than magnesium in plateau soils and Kelly (1988) found it had a higher degree of retention within the plant-soil system.

In a study comparing the effects of whole-tree harvesting on the cation budgets of several forests throughout the United States, Johnson et al. (1988) found that a forest site on the

Cumberland Plateau was one of the few sites studied where cation export from whole-tree removal greatly exceeded loss due to leaching. This was partly attributable to the large amount of stored calcium in the dominant plateau tree species. Federer et al. (1989) examined the effect of whole-tree harvest on change in percent total nutrient pool in six eastern US forest sites and found that the oak-hickory forest type near Oak Ridge, TN was the most sensitive to repeated harvests. They predicted that the combination of leaching loss and whole-tree harvest at short (40-yr) rotations could remove more than 50% of biomass and soil calcium in only 120 years. Adams et al. (2000) note that there is a "serious need" for the creation of soil sensitivity maps for the Cumberland Plateau and Ridge and Valley provinces in Tennessee so as to inform forestry decision-making.

The high plant species diversity in the plateau forest can partly be attributed to the mosaic of habitat conditions created by the continuous variation in soil drainage and soil depth across the plateau (see Smalley 1982). Slow moving stream drainages on the Plateau create swamp forest habitats characterized by a red maple – black gum canopy and a variety of herbaceous species. Shallow depressions in the sandstone substrate can create small ephemeral wetlands that dot the plateau landscape. These bogs and ponds represent critical breeding habitat for plateau amphibians (Haskell, unpubl. data). In a floristic survey of wetland habitats on the Plateau, Jones (1989) found 368 species of vascular plants, 15 of which were considered endangered, threatened or of special concern in Tennessee. Most of these wetland areas are too small in size to show up on wetland maps such as those produced by the National Wetlands Inventory (Cowardin et al. 1979). Shallow soil areas and rock outcrops along ridges and bluff-lines also provide unique habitat for a variety of rare and endemic plant species and a suite of xeric species (Walck et al. 1996).

Both prehistorically and historically, fire has represented an important disturbance regime on the Cumberland Plateau in southern Tennessee. It is believed that natural and anthropogenic fires started by Native Americans have been a constant part of the plateau landscape for thousands of years (Hinkle et al. 1993). With the advent of European settlers and the railroad in the late 1800's and early 1900's, it is believed that fire frequency actually increased across parts of the Plateau (Strohmeier, pers. comm.). Into the mid-1900s and to the present, with the widespread policy of fire suppression, fire frequency has dropped dramatically. This may have contributed to a decrease in the native pine component of the plateau forest and may be contributing to a regeneration failure among certain oak species (Abrams 1992, Evans, unpubl. data). Many of the woody plant species of the plateau forest manifest distinct adaptations associated with fire, such as root sprouts (sassafras, *Sassafras albidum*; black locust, *Robinia pseudo-acacia*) and root collar sprouts (oaks, *Quercus* spp.) (Del Tredici 2001). These same adaptations can promote the regeneration of original genetic individuals following logging events thus leading to less compositional change following a timber harvest as compared to cove forests where sprouting is less common (Evans, unpubl. data). The sprouting nature of overstory and understory woody species on the plateau is one of the reasons for the extensive mechanical and chemical soil treatments that occur in association with site preparation for loblolly pine plantations on the plateau (M. Black, pers. comm.).

It is believed that the high fire frequency on the Plateau may have limited the distribution and abundance of American chestnut (*Castanea dentata)*, which was far more prevalent elsewhere in the Southern Appalachians (Hinkle 1989; White and Lloyd 1998). Chestnut disappeared from the plateau forests by the 1930s with the spread of the introduced chestnut blight. Starting in the 1980s, there has been a dramatic decline in American dogwood (*Cornus florida*), a once prevalent understory tree species in the plateau forest, due to the spread of the introduced dogwood anthracnose blight (Hiers and Evans 1997). Given the role that dogwoods play in mobilizing calcium, Hiers and Evans (1997) believe that their loss could further exacerbate the decline in available calcium in plateau forests and this may have implications for successful egg formation in breeding songbirds.

Other natural disturbance regimes associated with the plateau forest include ice storm damage, localized wind storm blow-downs, and southern pine bark beetle (*Dendroctonus frontalis*) outbreaks. Pine bark beetle outbreaks reoccur on a 10-12 year cycle on the Cumberland Plateau and epidemics have been more spatially extensive in recent years (Price et al. 2001).

The plateau forests have experienced considerable impacts from land use over the last 150 years. Due to the poor, infertile nature of the soils, original attempts by the first settlers to grow crops on the plateau failed and subsequent agricultural activity has been relatively limited (as compared to the extensive clearing of forests for agriculture on the adjacent Highland Rim and Ridge and Valley Provinces) with low intensity pasturing of livestock being the most common (Nicholson 1982). Free-range livestock grazing in the forest was a common practice throughout the plateau in the late 1800s and into the 1900s (Foley 1903). Coal mining during the 20th century - first shaft mines and wildcat mines, then strip mines in the 1950s and 1960s (Nicholson 1982) - resulted in locally intensive forest clearings in specific locations across the plateau (Hinkle et al. 1993).

Some residential and urban encroachment on forests has occurred near the larger established towns, particularly in the Monteagle-Sewanee area. Other forest clearing activity has been associated with the creation of roads, utility corridors and reservoirs. Deer on the southern Cumberland Plateau have been on the rise since their re-introduction in the middle part of last century (TWRA 1997). Locations on the Plateau that represent refuges from hunting, such as forests near residential areas and state park lands, are starting to show signs of overgrazing by deer (Evans, pers. obs.).

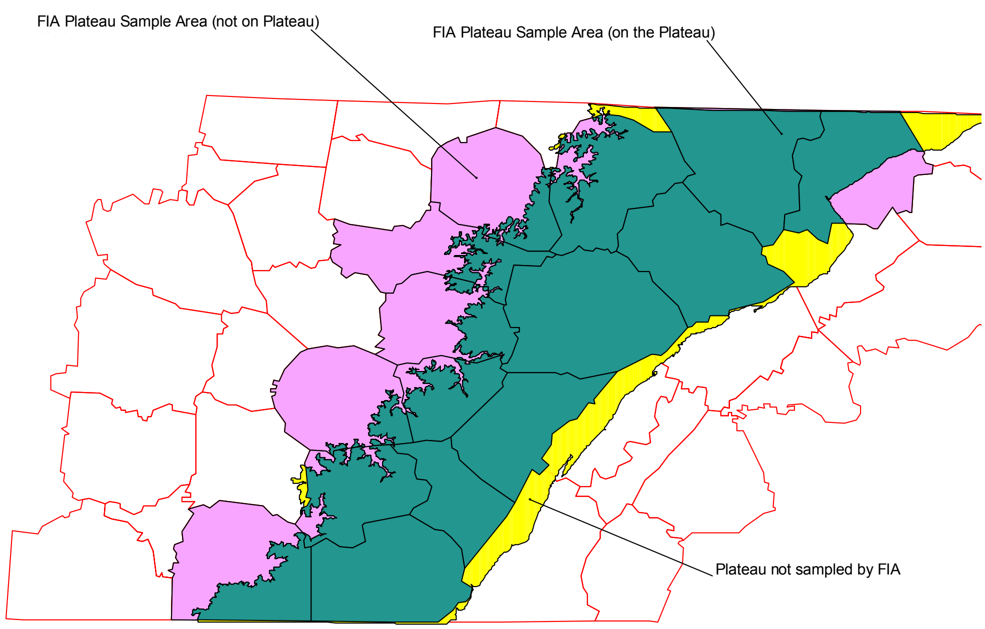
Selective harvesting of timber on the Plateau has been a widespread practice throughout the last 150 years. Given the relative accessibility of much of the landscape, it is not likely that any areas of the Plateau escaped logging activity during this period with some areas having had trees cut multiple times at varying levels of intensity. Clearcut timber harvesting has become a common practice on the Plateau since the 1960s (Strohmeier, pers. comm.). Starting in the 1950's and through to the present, increased amounts of native forest have been converted to loblolly pine plantations (Hinkle et al. 1993). Evans et al. (1999) analyzed 18 years (1981-1998) of forest change for Grundy County Tennessee and found that 13,144 acres of native forest area cleared for pine plantations and 1,161 acres of forest had been cleared for agricultural and residential use. This overall forest conversion resulted in a 12% net loss of privately owned, native hardwood habitat (Evans et al. 1999). The greatest rate of hardwood conversion to pine plantations had occurred since 1994, consistent with the rise in chip mill activity in this general region (Draper 1999).

The Cumberland Plateau in southern Tennessee contains some of the largest remaining tracts of privately owned contiguous temperate deciduous forest in North America. These forest tracts represent critical neotropical migratory songbird habitat (Haney and Lydic 1999) and serve as the headwaters to the most biologically diverse, freshwater stream systems found in the world (Ricketts et al. 1999). The Cumberland Plateau has some of the highest predicted herpifaunal diversity in the state (Durham 1995) and one of the most diverse communities of woody plants in the eastern United States (Ricketts et al. 1999). The hard mast (acorns) associated with the mature oak canopy of the plateau forest serves as a keystone resource within the food web of this ecosystem. The availability of this oak mast resource directly or indirectly affects the survivorship of hundreds of animal species inhabiting the forest (McShea and Healy 2002).

The Cumberland Plateau is currently considered by the media to be a major hotspot of forestry-related, landscape-level change (Starkman 1999). There is considerable debate as to the rate and scope of forest change in Tennessee (Countess and Arney 2001; Pelkey and Evans 2001) and there is concern about the impact of landscape change on the ecological values described above (Ricketts et al. 1999). Prior to this study, there has been little quantitative information available to guide legislators and other decision-makers concerned with forest sustainability on the Cumberland

Plateau (Z. Wamp, Congressman –TN Dist.3, pers. comm.). Information that has been available up until now has been limited in terms of its spatial and temporal applicability (see Appendix A: Pelkey, et al. 2001). For example, the smallest area at which forest assessment was being reported and summarized for this region was the 16 county area in the U.S. Forest Service – Forest Inventory and Analysis (FIA) survey for "Tennessee's Plateau Counties" (Schweitzer 2000). The survey unit in that report was determined by political boundaries rather than ecological parameters and included a large area not actually located on the Plateau (Fig. 1.2).

Figure 1.2. Pink and blue shading together represent the FIA survey area. Pink shading represents that part of the survey area that is not in the Cumberland Plateau physiographic region of Tennessee and yellow shading represents that part of the plateau not included in the survey.



1.3. Project Objectives

This Small Area Assessment Forestry Demonstration Project uses a 7-county, 616,000 acre portion of the Cumberland Plateau in southern Tennessee (see Fig. 1.1; Map 36) as a case study in which to assess 19 years (1981-2000) of forest change and to examine the ecological consequences of this change in the field and at the landscape level through GIS analyses. The project also evaluates the methodologies employed so as to make recommendations about their use in future small area assessments. Our study area encompasses only the forest ecosystem associated with the surface of the Plateau (see description above). Given the various decision-maker jurisdictions at the county, state and federal levels in this region (Figs. 1.3-1.6), it is apparent that the chosen study area is at an appropriate spatial scale for generating information relevant to those concerned with the sustainability of forest resources in this ecosystem.

Figure 1.3. Counties that intersect with the Cumberland Plateau physiographic region in Tennessee. Land use decision-making by county governments affects forest sustainability within the study area.

Counties on the Cumberland Plateau

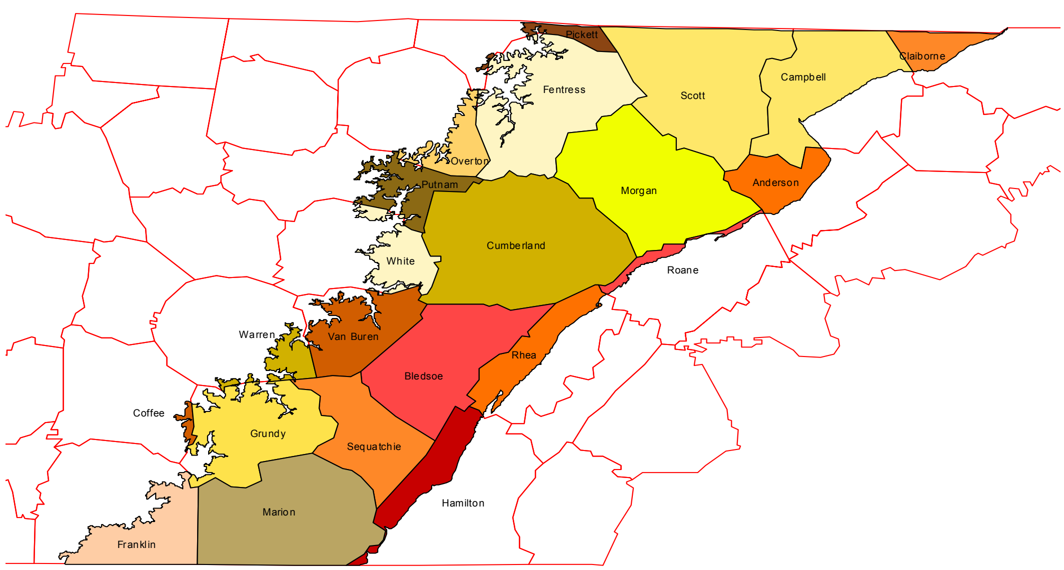


Figure 1.4. Tennessee Division of Forestry Area Forester jurisdictions within the Cumberland Plateau physiographic region of Tennessee.

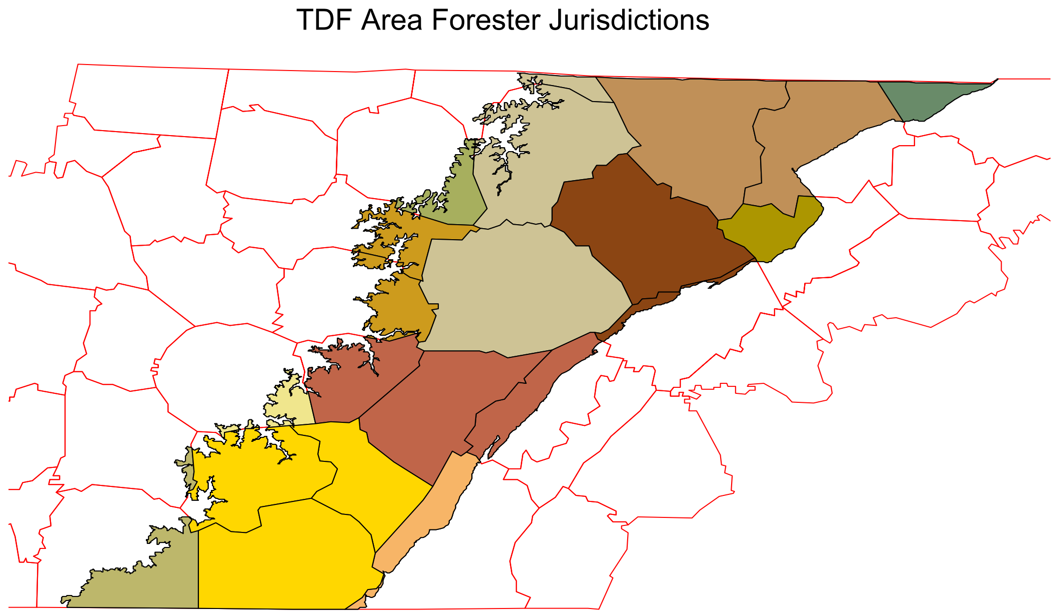


Figure 1.5. Tennessee Division of Forestry (TDF) Districts within the Cumberland Plateau physiographic region in Tennessee.

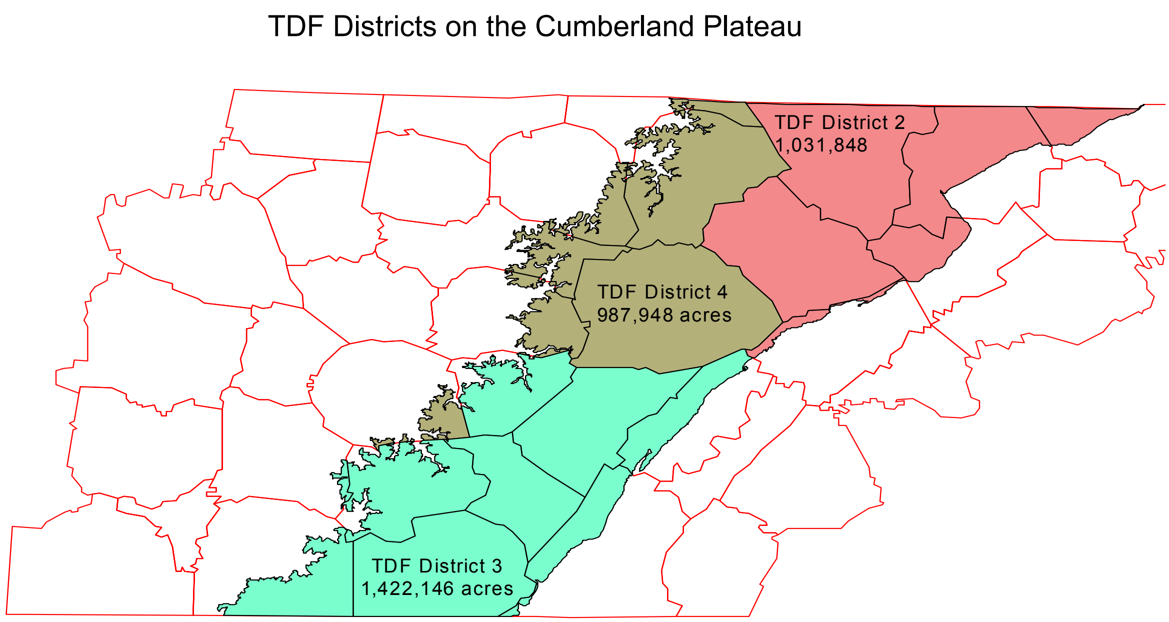
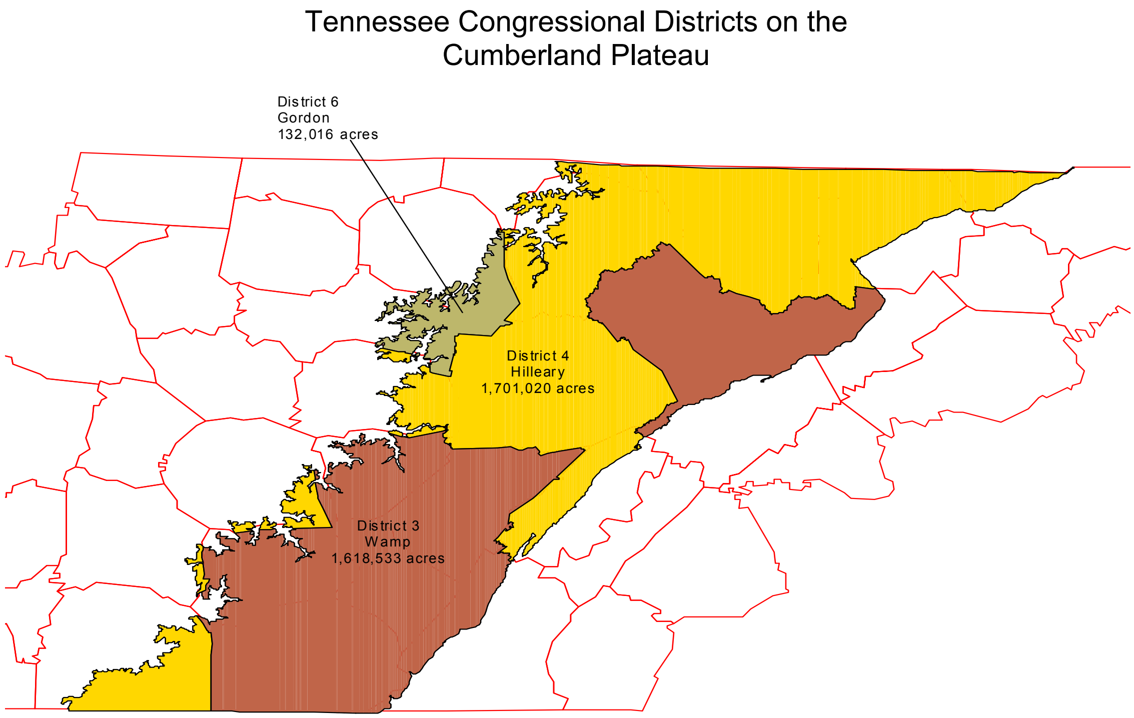


Figure 1.6. Tennessee congressional districts within the Cumberland Plateau physiographic region in Tennessee.



Specific Project Objectives:

Mapping Patterns of Forest Change

a) To generate comprehensive forest change documentation for the Cumberland Plateau in southern Tennessee using remotely sensed data and current GIS technology.

b) To assess the ability to generate such information at spatial and temporal scales relevant to local land use decision makers and in a cost-effective and technologically transferable manner.

Aquatic Biomonitoring

a) To conduct aquatic biomonitoring and water quality assessment within the study area using benthic macroinvertebrates and salamanders as indicators.

b) To assess the utility of low cost aquatic biomonitoring as a means of tracking the impacts of land use change on water quality.

Bird Community Response to Forest Change

a) To examine the responses of bird communities to changes in forest structure, composition, and spatial distribution that result from land use change on the plateau.
b) To assess the utility of using birds as indicators for tracking the impact of land use change on plateau forest biodiversity.

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Chapter 2

Mapping Patterns of Forest Change

2.1. Spatial Database Development and Assessment

2.1.1. Description of Imagery and Software Available for Small Area Assessments

Imagery:

Farm Service Agency Slides

Farm Service Agency (FSA) slides are a source of data for small area studies and are especially useful for distinguishing existing agricultural areas from treeless areas being prepared for pine plantations. FSA Slides are obtainable at no cost in the form of 35mm transparencies from the local FSA office in each county. Since the data is collected annually it is a good source of recent information. Availability of slides for past years depends on local FSA office practices. A slide scanner is required to make digital copies of the slides. Once scanned, the resolution of the imagery is about 1 pixel = 3 meters, but this varies from image to image and can be distorted or changed during resampling. The slides are in color and when scanned in RGB format they produce reasonable size files, which can be used on average desktop computers. The disadvantages of FSA slides are that they are difficult to work with, require time to scan and must be individually georeferenced. This makes it difficult to collect data over large areas, especially when slides cover inaccessible land. (Table 2.1).

National Aerial Photography Program

National Aerial Photography Program (NAPP) imagery can be very versatile and may be used to collect data over a large area. NAPP imagery is available from the USGS at a cost of $10.00 per 9”x9” panchromatic print. NAPP availability varies from region to region but the program started in 1987 and continues to this day. Depending on the weather, some years offer more consistent coverage than others. NAPP imagery provides the required 60% overlap between prints to allow for stereo viewing. It works well with both a stereoscope, or for more accuracy, softcopy stereo software. A large format scanner is required to accommodate the 9”x9” size of the print and the time required to scan each image may be rather long. Each image must then be georeferenced. The 1:24,000 scale of NAPPs allows accurate land use determination while covering a large area. Softcopy stereo viewing will increase the visibility of the land use types but requires more accurate orthorectification and higher resolution scanning (1600 dpi or higher). Both can be very time consuming and may require more expensive equipment. Frame Camera Calibration forms must be obtained to build stereo block models and for orthorectification. (Table 2.1).

National High Altitude Photography

National High Altitude Photography (NHAP) imagery is an inexpensive way to build a historical coverage. It may be obtained from the USGS for $16.00 dollars per 9"x9" color infrared print and is available for dates ranging from 1981 to 1989. A large format scanner is required to accommodate the 9"x9" size of the print. It has many of the same advantages and disadvantages of the NAPP imagery. Since the scale is 1:60,000 the data collected will not be as spatially accurate as data collected from NAPPs. For softcopy stereo viewing in RGB it must be scanned at a high resolution (around 1600 dpi) to be orthorectified accurately making the file size quite large. The resulting stereo images may provide no better data collection accuracy than 2D images. Frame Camera Calibration forms must be obtained to build stereo block models and for orthorectification. (Table 2.1).

Digital Ortho Quadrangles

Digital Ortho Quadrangles (DOQ) are panchromatic Aerial Photo Mosaics of a USGS 7.5 minute area or are divided into 3.75 minute Digital Ortho Quarter-Quads (DOQQ). DOQs are available from a variety of sources including the USGS, state agencies, and commercial companies at little or no cost. Most are created from NHAP or NAPP imagery but they are sometimes made from other aerial photo sources. The quality of the DOQs is determined by the resolution scanned and the accuracy of the orthorectification. Availability of the imagery varies from region to region. DOQs can be an excellent alternative to NAPP or NHAP imagery for non-stereo viewing and data collecting because they are already in a digital format and are orthorectified. They can also be a useful source of ground control points which otherwise may have to be collected with a GPS unit in the field. (Table 2.1).

Landsat Enhanced Thematic Mapper +

Landsat Enhanced Thematic Mapper + (ETM+) imagery is produced by a satellite-based multispectral scanner. The bands include a 15-meter resolution panchromatic band, a Long Wave Infrared (LWIR) 60-meter resolution band, and six 30-meter resolution multispectral bands. ETM+ availability began in 2000 and continues to the present. Its predecessor, Thematic Mapper (TM), has the same bands but lacks the 15-meter panchromatic band and covers the years 1990 to 1999. ETM+ and TM provide excellent coverages of land change over time using spectral classification techniques. ETM+ scenes can be purchased for $600.00 per scene from the USGS in a variety of formats and they are georeferenced. Each scene covers an area of 106 miles by 115 miles so relatively few images are required for small area assessments. The Landsat satellite retraces its swaths every seventeen days. (Table 2.1).

Digital Elevation Models

Digital Elevation Models (DEM) are raster imagery that allows for the collection of elevation data. This imagery is essential to softcopy stereo viewing and planimetric correction during orthorectification. DEMs can be obtained from the USGS or commercial sources at low cost in 10-meter or 24-meter formats.

Software:

ESRI ArcView 3.2a + Extensions

All of the above imagery can by used in ESRI ArcView 3.2a using a variety of extensions for data collection. ERDAS Image Analysis Extension for ArcView is required for work with any of the above imagery.

ERDAS Imagine 8.4/8.5

All of the above imagery can be used in ERDAS Imagine 8.4/8.5 for data collection. Imagine can be used to more accurately georeference imagery and can also be used to create mosaics of aerial and satellite imagery. Imagine provides an excellent platform for spectral classification of multispectral imagery.

ERDAS OrthoBASE

ERDAS OrthoBASE is software used to create highly accurate orthorectified planimetric imagery and to build large block models for use in softcopy stereo. It requires ERDAS Imagine for full functionality.

ERDAS Stereo Analyst

ERDAS Stereo Analyst (SA) is used for softcopy stereo viewing and data collection. It writes to 3D shapefiles. This is a stand-alone product and does not require either ERDAS Imagine or OrthoBASE and will integrate as an extension into ArcView. SA can be used to build small block models but is not as accurate as ERDAS OrthoBASE.

2.1.2. Assessment of Methods Tested During the Project

This project tested 3 different methods for documenting landscape changes over small areas. In each case a base layer year was selected. Land use polygons were drawn for that year and were then compared to images from other years to determine changes in land usage.

Imagery for land use analysis is available in different forms. This study used FSA slides, NHAP and NAPP images, DOQQ images and ETM imagery. An important factor to consider here is that the latter two formats are available in digital form. FSA images are available only as slides. NHAP and NAPP imagery is currently available from the USGS only as photographs but these images may be available in digital form from commercial sources for some areas. A difficult and time-consuming feature of all three methods is the scanning and rectification of hardcopy images to digital form. Where digital images can be obtained considerable time and effort may be saved. Developing a land use database for recent years where electronic images are more readily available will be less difficult.

The major difference in the three methods was the technique used to establish the initial base layer. Comparison of the base layer with previous and subsequent years to determine landscape changes was done in essentially the same way in each method. Method 1 involved stereoscopic analysis of photographs to establish the base layer. In method 2 we made the initial classification using 2 dimensional digital images and checked it using digital stereo. Method 3 utilized a more advanced form of digital stereo, which permitted us to digitize land use polygons directly on the stereo imagery.

We determined that Method 3 provided much greater accuracy and all the data for this study was collected using that method. The three methods are compared in more detail in appendix E and Method 3 is further described later in this chapter.

2.1.3. Final Land Use/Land Cover Mapping Methodology

The methodology outlined in this section was used to generate the land cover change databases for the study area for the years: 1982, 1997 and 2000. The results from this methodology are reported in Section 2.2. This methodology was chosen so as to provide the greatest possible accuracy (see Sect. 2.12.) while still maintaining a certain level of cost-effectiveness and technological accessibility for users concerned with small areas (less than 1 million acres).

A base layer was created for 1997 where land cover calls and delineations were conducted using 3D visualization of aerial photography on the computer. Land cover differences between 1997 and 1982 were also digitized using softcopy 3D visualization of aerial photography. Land cover differences between 1997 and 2000 were conducted in 2D but employed both satellite imagery and high resolution color photography. Final cover classification calls benefited greatly from examination of imagery across sequential years. Extensive accuracy assessment procedures were followed as outlined in Section 2.1.4.

Ground Control Points

In order to prepare images for use in digitizing land cover, it was first necessary to collect ground control points (GCPs). GCPs are physical points on the ground with known coordinates that can be used to accurately rectify digital images on the computer. GCPs were needed to facilitate the building of 1981 HAPP (High Altitude Photography Program) and 1997 NAPP (National Aerial Photography Program) block models as well as the rectification of 2000 FSA slides. GCPs were collected in the field between May and June 2001 at major road intersections easily identified on the 1997 NAPP aerial photographs. The 1997 NAPP block models typically consisted of 6-8 photos per quad, depending on the extent of the study area in a given quad. An accurate block model required at least 9 GCPs per photo. The 1981 HAPP block models consisted of 3-4 photos per quad and also required at least 9 GCPs per photo. The FSAs required 6-9 control points per image.

Satellite health was checked before going into the field using Quick Plan, satellite visibility software (http://www.trimble.com/support.html). GCPs were collected in UTM using a Garmin III+ handheld GPS unit or a Garmin 12 XL. A Mighty Mouse II antenna was used in conjunction with these units for better reception, although it was found that only the 12XL had better reception with the Mighty Mouse. The GCP collection was performed using an atlas, USGS quad sheets, and FSAs printed with MultiSpec as guides in the field to find major intersections.

The GCPs were stored as waypoints in the GPS units and these waypoints were downloaded in the lab using WayPoint + v1.8.00 software (http://www.tapr.org/~kh2z/Waypoint). Once the GCPs were in WayPoint +, they were saved as comma delimited text files.

Substantial amounts of precipitation in June and July interfered with ground point collection so the collection process was changed. Subsequently, GCPs were found on Digital Orthophoto Quadrangles (DOQ) images using ERDAS Imagine's Orthobase software and saved in a MS Excel table.

Creating Digital Imagery

The 1981 HAPPs and 1997 NAPPs were scanned on a UMAX PowerLook 2100XL flatbed scanner and saved as TIFF files. The photos were scanned as true color RGB/1600dpi and grayscale 256/1600dpi respectively. The associated scanning software Binuscan and MagicScan were used to make setting adjustments. The TIFF files were first imported into ERDAS Imagine and then converted to IMG files. The FSA slides were scanned using a Nikon LS 2000. Some slides were scanned individually while others were scanned in batches. The resolution of the slides was adjusted for best viewing purposes and no standard was used for resolution determination.

Rectification

In order to view the 1981 and 1997 imagery in stereo, it was first necessary to create block models of this imagery. A block model is a digital layer that combines elevation and planimetric positional information for the imagery being rectified. 1981 NHAP and 1997 NAPP block models were constructed using ERDAS Imagine's OrthoBASE software for digitization of the plateau landscape in a 3D environment. The scanned aerial photographs were used in conjunction with GCPs and camera information from the USGS OSL to build the block models. 2000 FSA color slides were also rectified using ERDAS Imagine 8.4 software. Digitization was subsequently performed using ERDAS Imagine's Stereo Analyst 3D software and ESRI's ArcView software.

Canopy Cover Classification

Land cover characterization was conducted according to a predetermined classification scheme that allowed us to track changes in the native forest canopy and to distinguish the impact of silvicultural activities from other land uses. Land cover categories were specifically defined as “canopy cover categories” and hereafter are referred to as such. Canopy cover categories were defined as being a function of both: 1) type of tree cover and 2) percent of tree cover (see Table 2.3 for detailed descriptions). The stereo NAPP imagery used in creating the 1997 base layer was leaf-off (winter) and in black and white. This allowed us to use color and 3D texture to delineate cover differences. For example, the evergreen canopy of a pine plantation showed up distinctly as homogeneous black polygon with smooth texture.

We used five basic cover types: native forest (as defined in Chapter 1), pine plantation, pine stands of mixed origin (PINE-MIX), areas recently cleared of trees (LOGGED-CLEARED) and non-silvicultural, human impacted (OTHER). The native forest category was further refined as being either having an intact canopy (NATIVE-INTACT) or having a canopy that was 30-90% thinned as a result of timber harvesting activity (NATIVE-THINNED). Pine plantations were further refined as being in the process of site preparation/early planting (PLANTATION-PREP), or having greater than 70% canopy closure (PLANTATION-COMPLETE). OTHER was refined as being either treeless (OTHER-NO CANOPY) or partially treeless (OTHER-PARTIAL CANOPY). The OTHER category encompassed most of the agricultural, urban, residential and mining impacted areas. As described in Section 2.2.2, these specific land-uses could be differentiated from within the OTHER category using separately created GIS layers of structures, roads and mining activity.

Within this report we use following category groupings:

- PLANTATION = combination of PLANTATION-PREP and PLANTATION-COMPLETE
- OTHER= combination of OTHER-NO CANOPY and OTHER-PARTIAL CANOPY

The PINE-MIX category was used to differentiate pine or mostly pine stands that appear as discreet polygons on the landscape but lack the distinct signature of a intensively managed plantation. These areas may have been plantations that had received little or no management or they could have been naturally seeded pine stands responding to burn areas, abandoned agricultural fields or strip mine reclamation. Much of the land with this cover type was associated with the area in and around Bledsoe State Forest where the Civilian Conservation Corps planted a large amount of pine in the 1940s (C. Strohmeier, pers. comm.). These lands were not actively managed for pine after planting and subsequently acquired a variable amount of hardwood ingrowth.

Areas of mixed pine/ deciduous or native evergreen (such as sometimes found along stream corridors) that did not form discrete polygons and were continuous in the landscape were considered as NATIVE. The NATIVE category included various aged stands of the plateau forest described in detail in Chapter 1.

Canopy Cover Digitizing

We did not employ a minimum mapping unit for any category as part of the digitizing process. In creating the final map layers, we merged any polygon less than two acres by dividing it equally before combining the parts with adjacent polygons.

The 1997 NAPPs were digitized first in ERDAS Stereo Analyst as a complete coverage for each category type. The background or NATIVE-INTACT was not digitized since all of the other shapefiles in the layer acted as a cutout in this NATIVE-INTACT background. Query categories were used when the cover was indeterminable. A procedure was later implemented for classifying these areas using ground photos.

A duplicate, but empty, set of shape files was created from the 1997 layer to digitize any change occurring in 1981. Change detection between 1981 and 1997 was conducted using the 1997 digitized layer draped over the 1981 HAPP block file in Stereo Analyst. Canopy cover change was characterized exactly as in the 1997 coverage. If portions of polygons changed from 1997 to 1981, those portions were digitized as part of the 1981 layer. If a polygon in 1997 was the same shape in 1981, but yet had a different cover call, then a note was made in a “1981” column in the corresponding 1997 shape file. Also, if new landscape features appeared in 1981 out of the background NATIVE-INTACT in 1997, those features were digitized in the 1981 layer.

For 2000, LandSat imagery was used to identify areas of forest change. To increase accuracy, 2D FSA slide images were used to digitize these areas. The 1997 digitized layer was merged into one shape file then draped over the 2000 FSA slides in ArcView 3.1 and again only change was digitized. A single “change 2000” shape file was created containing “1997” and “2000” columns where the canopy cover call was documented. If a polygon in 1997 did not change in shape, but changed cover, then the new call was documented in a “2000” column in the 1997 shape file.

The plateau boundary was digitized in ERDAS Stereo Analyst using the block models created from 1997 NAPPs. The boundary was digitized as a polyline and later converted to a polygon. The polyline was placed on the edge of the plateau where a significant change in escarpment gradient could be identified.

2.1.4. Verification Methodology

In order to verify land use designations made from NAPP, HAP and FSA aerial photographs a series of ground photographs was taken at selected locations within the coverage area. Additionally, selected land use polygons were observed visually and photographed from an aircraft flying 500 feet above the coverage area.

Ground Photographs

Photographs were taken between February and December, 2001 with a Kodak DC290 Zoom Digital camera which was interfaced with a Garmin GPS III + Navigator. A script (GPS Tag 1.04) installed on the camera’s removable memory card permitted location, elevation, date and time to be determined for each image. These data were watermarked on the image and automatically stored in a CSV file on the camera’s memory card.

Ground photo locations were chosen to reflect a variety of habitat types and canopy cover calls. Canopy cover polygons digitized from 1997 NAPP aerial photographs using ERDAS Stereo Analyst were overlain on DeLorme Tennessee Atlas and Gazetteer 1:150,000 scale maps which were digitized and re-projected using ESRI ArcView GIS 3.2. These maps were then printed out and used as a guide by the photographers. Notes with photographs indicate the direction the photographer was facing (bearing of the land use feature of interest). Bearings were determined using hand-held Suunto magnetic compasses. Bearings were omitted if the photographer was clearly inside a polygon delimiting a feature of interest.

After returning from the field, photographs and associated GIS information were downloaded from the Kodak memory cards to LAL computers. CVS files containing photo position information were converted to dBASE III event tables, which were used to create shapefiles in ArcView GIS 3.2. Individual points in the shapefiles were hot linked to their corresponding photographs. Notes and bearing information obtained in the field were added to the feature tables associated with the photo position shapefiles.

Comparison Methods

In order to compare photographs and canopy cover calls, feature data from the photo position shapefiles was attached to feature data from the 1997 and 2000 land use coverage shapefiles. An ArcView GIS 3.2 project was created using the combined shapefile. The information was also exported to a Microsoft Access database. Hot linked photo position points and canopy cover polygon boundaries were displayed in the ArcView project. Individual photographs could be observed by clicking on the corresponding photo position point symbol.

Canopy cover as observed in the ground photographs was judged to be either consistent or inconsistent with the canopy cover calls made in 1997 and 2000 from aerial photography. Where photographs were taken near the edges of polygons the bearings noted in the field were used to determine the polygon being photographed. In some cases photographs were rejected because it was impossible to determine the polygon they referred to. Where the polygon viewed was unambiguous and the quality of the photograph allowed the land use to be determined with precision, photographs were judged consistent if they showed the same land use as the call or if the change indicated could have taken place in the time elapsed between call and photograph. Results of the comparisons were entered in the Access database and inconsistent calls were reviewed at a later date. Where subsequent review showed land use calls to be incorrect they were changed to reflect the photographic evidence, thus increasing the accuracy of our GIS coverage.

A second set of consistency checks was conducted on queries and inconsistent photos identified in the first round. The photo consistency database table generated in MS Access was joined to the ground photo/aerial photo call table in ArcView. The 1997 and 2000 inconsistencies and queries were extracted from the joined table to build new database tables for each year. These tables were converted to shapefiles and subsequently hot linked to photo image paths. Inconsistent and query photos were examined as in the first round. New calls were made by an expert in canopy cover characterization to determine the usefulness of these ambiguous photos. Inconsistencies and queries were checked and verified or changed to reflect consistency or non-usefulness in consistency analyses. After all inconsistencies and queries were checked, changes were made to original calls as needed in the 1997 and 2000 canopy cover layers.

Aerial Observations

Seventy-nine 1997 canopy cover polygons were selected for aerial observation. A point shape file was created in ESRI ArcView GIS 3.2 for a position within each polygon. Each point was assigned a number, thus providing a means of identifying the polygons. Numbered polygons were overlain on DeLorme Tennessee Atlas and Gazetteer 1:150,000 scale maps which were digitized and re-projected using ArcView. These maps were then printed out and used as a guide by the aerial observer.

Aerial observations were made on 12/03/01 from a Cessna 750 aircraft. The pilot was provided with waypoints which allowed him to fly a series of tracks over the area of interest. Based on the track flown, geographical features identified on the map and the shape of the polygons the observer was able to identify all numbered polygons and note the current canopy cover for each.

After returning from the field the canopy cover observations were added to the feature table associated with the polygon central position shapefile. Feature data from 2000 canopy cover database was judged to be either consistent or inconsistent with the canopy cover calls made in 1997 and 2000. Observations were judged consistent if they showed the same land use as the call or if the change observed could have taken place in the time elapsed between call and observation. Results of the comparisons were entered in a Microsoft Access database and inconsistent calls were reviewed at a later date. Where subsequent review showed canopy cover calls to be incorrect they were changed to reflect the aerial observation.

Aerial Photographs

A number of attempts were made to verify canopy cover determinations from NAPP aerial photographs by flying at low altitudes over the area of interest and taking digital photographs. Technical limitations of the equipment being used rendered this verification method less useful than ground photographs and visual aerial observations.

Three different aerial photography techniques were considered. In each case the pilot of a Cessna 750 was provided with waypoints for a series of flight tracks which were entered into the aircraft GPS navigator. Each track was chosen to fly directly over a number of land use polygons of interest. Test photographs were taken at elevations of 500 and 750 feet. It was determined that photographs taken at 750 feet provided better coverage and sufficient clarity to positively determine the land use status of the polygons on the ground. The photographer leaned out the aircraft's window and aimed the camera directly down toward the ground.

The first technique used was the same as that used for the ground photographs. Photographs were taken on November 07 and 09, 2001 with a Kodak DC290 Zoom Digital camera, which was interfaced with a Garmin GPS III Plus Navigator. A script (GPS Tag 1.04) installed on the camera's removable memory card permitted location, elevation, date and time to be determined for each image. The data was watermarked on the image and automatically stored in a CSV file on the camera's memory card. A problem arose because of the delay between the time the shutter button was depressed, the time the GPS data was downloaded to the camera memory card and the time the camera actually took the picture. It was determined that the photograph was taken as much as 15 seconds after the GPS position information was recorded. At an average flight speed of 85 mph the distance between the position photographed and the position recorded by the GPS could be as much as 600 meters. The delay varied, apparently due to the time required by the camera to resolve focus and exposure variables. Many polygons were less than 600 meters in diameter so this technique proved unreliable as an aerial verification method.

Photographs taken from a fixed position on the ground were not subject to the same errors because the photographer was unable to move any great distance between the photograph and the GPS record and also there appeared to be a significantly shorter delay between the two events. Consideration was also given to a technique involving synchronizing the clocks in the GPS unit and camera and having the GPS unit maintain an independent, timed position track while photographs were taken. Photograph times and position times could then be compared. Unfortunately, the camera in use only recorded times to the nearest minute so errors of up to one minute flying time could be expected.

A more useful but still problematic technique involved operating the camera and GPS unit independently and using the GPS unit's MARK key to enter present position at the moment the photograph was taken. This method was tested on December 03, 2001 under the flight conditions described above. Delays between the photograph position and the GPS position were much reduced but small delays were still experienced. From his position leaning out the aircraft window the photographer had to reach back into the cabin to press the MARK key. A delay of 1-3 seconds was unavoidable. This could permit an error of up to 120 meters between photo position and GPS position.

In conclusion, the flight photo technique as tested was not highly reliable as a canopy cover call verification method and was not used in this study. Nevertheless, use of a slightly more sophisticated camera – GPS interface should eliminate the delay between photograph recording and position recording and allow quick and accurate verification.

Cross Categorization Matrices for Canopy Cover Calls

Verification of change calls from 1997 to 2000 was implemented using a cross categorization matrix. The 1997 canopy cover calls were set up in a cross tabulation matrix against calls made in 2000 for each category. For each canopy cover category in 1997, the number of acres from that category that were converted to other categories was tabulated. This matrix and associated shapefiles were used to check the possibility of one land use converting to another in that time period. Any queries as well as the following conversion categories were checked in ArcView using 1997 DOQs and 2000 FSA slides.

Changes were made as needed and then another cross tabulation matrix for 1997 to 2000 was created and checked for improbable conversions. The final cross tabulation matrix was created for changes occurring from 1981 to 1997 to 2000. All of the above checks were made using imagery available from 1981, 1997 and 2000.

The final 1981-1997-2000 vector layer was converted to a raster file for further data manipulation. Overlap and gaps between polygons resulted from digitizing technique and subsequent flattening of 3D files into 2D files. The overlap area between two polygons was assimilated into the nearest polygon with preference being given to the denser land cover category. Gaps were identified and checked for actual missing polygons or missed digitizing. The remaining gaps were filled in using modal fill. The gap area was approximately 0.2%. Adjacent polygons that were the same calls throughout the years were merged to form a contiguous polygon. The final raster file was checked against the final vector file for database integrity before conversion back into a vector file.

Post Hoc Error Assessment

Post hoc error assessment involved two steps:

1. Comparison of final calls with satellite vegetation indices
2. An independent post hoc field classification check.

The first semi-independent error check was made using Landsat Enhanced Thematic Mapper+ (ETM+) satellite imagery to check for potential error areas. The first approach used the Normalized Differenced Vegetation Index (NDVI) to check for the following error types:

- Areas of high vegetation in the native canopy cover areas for leaf off satellite imagery. This was performed to check for pine in the NATIVE-INTACT background category.
- Areas of low vegetation density in native canopy cover class for leaf-on Satellite imagery. This was done to check for cleared areas in the NATIVE-INTACT background category.

The NDVI layer was created for each of the Landsat scenes from band 3 and 4. The following Algorithm was used:

$$NDVI = \frac{IR - R}{IR + R}$$

The satellite scenes included leaf-on for September 2000, and June 2001, and leaf-off for November 2001 (see Map 13). An area was considered in error if the NDVI was greater than 0.3 for the leaf off imagery when upland hardwoods will typically be well below that value. An area was also considered an error if the NDVI was below 0.2 for leaf-on imagery, when upland hardwoods will typically result in much higher NDVI values.

Additionally, supervised spectral classification of the Enhanced Thematic Mapper + data were used to determine how spectral classification compared to digitized coverages. Those coverages were created in the following way:

1. Training Sites were digitized from the ETM+ scenes to build a list of classification signatures. At least two sites were digitized for each classification, some had more. These were stored in ERDAS Signature Editor.
2. ERDAS Imagine Unsupervised Classification was then run on each scene.

NDVI Results:

A visual inspection revealed no areas of significantly low vegetation in the leaf-on and only one area (approx. 100 acres) of very high vegetation in the leaf-off. That is with the exception of riparian areas where native evergreen hardwood mixes are common.

Spectral Classification Results:

The 2000 leaf-on spectral classification results for NATIVE-INTACT and our call for that category from the aerial imagery had a 90% agreement.

Post Hoc Field Classification Check

Previously described quality checks were not independent of the final data set for the following reasons:

1. All errors or classification disagreements were corrected and modified in the final data set,
2. The error assessment was performed by the same people who did the classification of the aerial imagery
3. No professional forester had assessed the accuracy of the land use calls.

Thus the project contracted Mr. J. H. Burckle—the University of the South Assistant Forester—to perform a field verification of canopy cover calls. During that assessment three additional metrics were collected—basal area of pine, basal area of hardwoods and canopy height. Furthermore a georeferenced digital photograph of the error location was taken and archived.

<u>Assessment Method—Ground Verification</u>

Preparation:

Using Arcview, 20 Polygons from each category were picked from the final coverage using a random sample method. All polygons intersecting useable roads were then selected. Non-randomly selected reachable polygons were added to the categories until each group contained at least 10. The polygons were then numbered. Maps of the area and polygons were printed for use in the field. A survey sheet including ID number, map number, forester's call, forester's comment, pine basal area, Hardwood basal area, tree height, and picture number was created. The GPS coordinates of the center of each polygon were downloaded to a Garmin III.

Field Procedure:

After navigating to the polygon using the maps and GPS, the forester observed the environment and made a call from one of the possible choices. It is important to note that the forester did **not** know the Project staff classification so was not aware of the 'correct' call. The forester also noted any distinctive land use/ cover characteristics in the comment field of the survey sheet. If applicable, separate DBH measurements were taken for pines and hardwoods using a 10 BAF prism. Tree height was then taken using a clinometer. Finally, using a digital camera attached to a GPS unit, a photograph marked with GPS coordinates was taken. The direction in which the picture was taken was recorded in degrees.

The resulting data was compiled and entered in a spreadsheet. The photographs were then hotlinked to a polygon shapefile in Arcview. They were then compared with canopy cover calls and georeferencing information to crosscheck for data entry error.

<u>Assessment Method - Comparison of Statistical Accuracy</u>

Temporal Adjustment

Statistically assessing the misclassification based on ground data was confounded by a two-year lag between the FSA imagery and the forester's ground verification. Thus the call land use calls were upgraded to adjust for temporal consistency:

- If moderate maturation occurred within the same forest type—i.e. PLANTATION-PREP in 2000 was deemed PLANTATION-COMPLETE in 2001.
- If silvicultural operations were recent and would have explained the difference—i.e. PLANTATION or NATIVE-INTACT becoming a LOGGED-CLEARED site or NATIVE-INTACT becoming NATIVE-THINNED where recent thinning activity was evident.

In cases of differences of opinion such as an abandoned Christmas tree farm where the photo interpreters deliberately placed that call in the OTHER-PARTIAL CANOPY classification and the forester placed that call in PLANTATION-COMPLETE, the classification was deemed an error, and remains so in the analysis.

Cross-classification accuracy was then performed using the NCSS Statistical Software. Percentages correctly and incorrectly classified are presented for all categories. The total percent correctly classified and the Kappa statistic which adjusts that percentage for the classification that would have been correct even under random assignment are also presented.

Comparison with Forest Metrics

Given that forest classification calls can differ slightly on a canopy call and occasionally just on the opinion of the rater, we also performed comparisons of the mean basal area for pine and hardwoods as well as canopy height for the classification categories. The data was analyzed using Analysis Of Variance and are presented in both tabular and graphic formats. The Kruskal—Wallis test is presented for all metrics since both of the basal area metrics failed omnibus tests for normality. The canopy height was normal, but Kruskal Wallis Tests are reported for consistency.

Results

The classification accuracy was in general acceptable (see Table 2.4), but should be viewed with some caution due to the low samples size (N~10). The overall percent correct was 80.6% with an adjusted Kappa of 0.78 (t=19.6, p<.001). Three categories exceeded 90% correct classification: LOGGED-CLEARED (100%), PLANTATION-PREP (93%), and OTHER-NO CANOPY (100%). Three categories exceeded 75% correct: NATIVE-INTACT (86%), OTHER-PARTIAL CANOPY (79%), and PLANTATION-COMPLETE (90%).

Two of the categories had low correct percentages: PINE-MIX (41%) and NATIVE-THINNED (50%). Perusal of the misclassified sites presented in Table 2.5 showed two potential problem areas:

1. Native mixed pine/hardwood with substantial pine basal area.
2. Low density urban areas with substantial tree cover.

We addressed problem one by recategorizing our PINE-MIX classification to include both native pine mixes with high pine basal areas, and pine plantations with some hardwood basal areas. This change corrected the inaccuracy associated with the PINE-MIX category and increased our overall classification accuracy to 86.4%, but this is post hoc and no longer independent of the accuracy check.

We addressed problem 2 by presenting a separate analysis of housing and structure affected lands (see Section 2.2.2). Our on-the-ground accuracy assessment of NATIVE-THINNED was limited by the fact that we had to utilize polygons closest to roads (given property access issues) and these polygons had a far greater tendency to be associated with structures than those away roads. In the regional analyses, it turned out that approximately 90% of the land area classified as being NATIVE-THINNED was located away from roads and structures (see Section 2.2.2). We therefore have a high level of confidence that our NATIVE-THINNED category reflected silvicultural activity that was not associated with residential or agricultural activity.

Comparison of Forest Metrics by Canopy Cover Classification

Figures 2.1-2.3 and Table 2.6 show the results of the three metrics across the category types.

The results confirmed the preceding accuracy analysis.

> **Pine Basal Area:** There was higher pine basal area in PLANTATION-COMPLETE than all categories. That difference was significant ($p<.05$) in all but the PINE-MIX categories. The pine basal area was higher in PINE-MIX areas, but was not statistically significant.
>
> **Hardwood Basal Area:** NATIVE-INTACT had significantly higher ($p<.05$) hardwood basal area than all categories. The NATIVE-THINNED category had significantly higher hardwood basal area than, PLANTATION-PREP and the OTHER-NO CANOPY categories, but was lower than PINE-MIX and NATIVE-INTACT categories. The PINE-MIX category had a significantly higher hardwood basal area than all categories save NATIVE-INTACT.
>
> **Canopy Height:** The LOGGED-CLEARED and OTHER-NO CANOPY had significantly lower canopy height than all other categories with the exception of PLANTATION-INTACT which was higher, but not significantly so. PLANTATION-PREP was significantly lower than both NATIVE categories, the OTHER-PARTIAL CANOPY and the PINE-MIX category. The higher canopy cover categories did not significantly differ from one another in canopy height.

<u>Discussion</u>

Three trends emerged in the error assessment:

1. The overall accuracy was very good. Through the ground-based accuracy assessment it was determined that the PINE-MIX category required reclassification and the NATIVE-THINNED category needed to be examined in the context of roads, houses and other ancillary data.

2. The forest metrics showed an overall high consistency of on-ground conditions with the remotely classified cover classifications.
3. Thinned and mixed categories were more difficult to assess using the Farm Service Agency small format slides, and should be accompanied with satellite data or ancillary information such as structure location.

2.1.5. Summary of Findings and Recommendations

In this section (and in Appendix E) , we have presented a detailed comparison of the strengths and weaknesses associated with the various assessment techniques we tested for generating digital land use change maps for a small area (less than 1 million acres). While the most expensive to implement, the approach we chose to employ in our study provided the requisite degree of accuracy for our relatively large and complex study area and allowed us to take full advantage of the multiple imagery sources needed to examine a 20-year, historical time frame. The accuracy of any method, however, can be improved by ground verification. This process simply involves individuals traveling to areas that have been classified using remote sensing techniques and visually confirming the calls. Ground verification does not require any computer skills. Thus for a small area, where extensive ground verification is practical, a methodology which is less expensive to implement than ours may provide adequate accuracy. Furthermore, imagery for recent years is available in digital, orthorectified form, so a study whose aim was to only create a base land use layer for the purposes assessing future changes could have considerably lower costs. Additional specific recommendations:

- SAA requires a rigorous post-verification process, including ground assessment by a natural resource professional whose has a good working understanding of the area to ensure appropriate classification of land use or forest cover types from aerial or satellite imagery.

- Simple mensuration in the field such as total tree basal area and canopy height are useful in differentiating cover classes.

- Spectral information from satellite imagery can be useful in speeding up the error assessment process for high resolution aerial photography.

- Farm Service Agency small format slides are useful in identifying cover versus non-cover but are difficult to geocorrect, furthermore FSA slides should be used in conjunction with other data to differentiate between classification calls.

2.2. Analysis of Spatial and Temporal Trends

2.2.1. Forest Canopy Cover

One of the primary goals of this project was to examine changes in native forest with an intact canopy (NATIVE-INTACT). The study focused on anthropogenic changes and conducted analyses at the landscape-level. Our canopy cover classification methodology (sect. 2.1) was designed to detect changes associated with silvicultural activity (pine plantations, timber harvesting) relative to other major land use changes that impact canopy cover. The land uses most associated with our OTHER category were related to agriculture (largely pasture). Except for the few relatively small urban areas (e.g. Monteagle, Tracy City, Altamont, Spencer), much of the residential area within the study area was low density and found most often in association with agricultural openings (Appendix B - Map 12). Strip mines have been a source of forest change in the past (Map 9) and their influence is still reflected in canopy cover today. In Section 2.2.2, we use a digitized structure (houses, etc.) layer and a surface mine layer along with a roads layer to analyze the relationship of these three factors to our canopy cover types. In the present section, however, our focus is on the relationship of silvicultural activity to changes in NATIVE-INTACT cover within the study area and so for the purposes of this first analysis the OTHER category will remain unrefined.

Methods

The canopy cover ArcView databases for 1981, 1997 and 2000 were queried at the following spatial scales: by the seven-county study area, by county, and by watershed. Study area and county-level canopy cover change maps were produced (Appendix B: Maps 1-8) along with associated charts that present cover transition data between 1981-2000 (Appendix C: Charts 1-8). The watershed boundaries used were the NRCS Twelve Digit Hydrologic Unit Code (HUC) Watersheds (Map 14).

This dataset was obtained from the Tennessee Federal GIS Users Group at http://www.tngis.org/watershed.html. The HUC data were compared to watershed boundaries derived from 10 meter Digital Elevation Models and were found to have very good overlap. Canopy cover data were analyzed at each spatial scale using MS EXCEL pivot tables so as examine cover change trajectories and cross-tabulations among years.

Results and Discussion

Regional-level patterns (Map 1; Chart 1)

Net Changes Within Cover Categories

All categories increased in area between 1981 and 2000 except NATIVE-INTACT and PINE-MIX which both showed net decreases. NATIVE-INTACT represented 74.2% of the total study area in 1981 and decreased to 63.6% by 2000. OTHER represented 12.4% in 1981 and 14.8% in 2000. PLANTATION represented 5.7% in 1981 and 9.8% in 2000. NATIVE-THINNED represented 3.6% in 1981 and 5.2% in 2000. LOGGED-CLEARED represented 1.5% in 1981 and 5.0% in 2000. PINE-MIX represented 2.4% of the study area in 1981 and 1.6% in 2000.

The total amount of NATIVE-INTACT forest present within the study area decreased by 65,660 acres or 14.4% from 1981 to 2000 (Figure 2.3; Table 2.6a). Between 1981 and 1997, the average rate of decrease for NATIVE-INTACT was 3012 acres per year (Table 2.7a). Between 1997 and 2000 the average rate of decrease for NATIVE-INTACT was 5823 acres per year (Table 2.8a). There was 43.0% more NATIVE-THINNED area in 2000 (32,089 acres) than was present in 1981 (22,442 acres) (Table 2.6a).

The total amount of PLANTATION area increased by 24,947 acres or 70.1% from 1981 to 2000 (Figure 2.4; Table 2.6a). There was 237% more LOGGED-CLEARED area in 2000 (30,935 acres) than was present in 1981 (9,185 acres) (Figure 2.4). We can calculate the total acreage of land being intensively managed for plantations by adding to PLANTATION in 1981 the acreage of LOGGED-CLEARED that we know becomes pine in 1997 and then doing the same for 1997-2000. Based on the 19-year transition data, we know there is a 89% liklihood that LOGGED-CLEARED will transition to PLANTATION (Chart 1). This can be used to calculate the percent of 2000 LOGGED-CLEARED associated with the PLANTATION category. If these calculations are made, the new adjusted cover of intensive pine plantation across the study area becomes 43,794 acres in 1981 and 88,208 acres in 2000 representing a

101% increase between 1981 and 2000. Of these 88,208 pine plantation acres in 2000, 47% was in the site preparation or recent planting phase.

The amount of OTHER-NO CANOPY area increased by 6,641 acres (9.6%) and OTHER-PARTIAL CANOPY increased by 7,505 acres (97.9%) from 1981 to 2000 (Table 2.6a).

Transition out of NATIVE-INTACT

In 1981 there were 457,379 acres classified as NATIVE-INTACT within the study area. By 2000, 79,865 of these acres had transitioned to other cover categories (Table 2.6ab): 35% NATIVE-THINNED, 27% LOGGED-CLEARED, 23% PLANTATION, and 15% OTHER (Table 2.6a). NATIVE-INTACT transition to PLANTATION or OTHER can be considered a unidirectional conversion since only a very small percentage of either category transitioned the other way during the 19 year period (see below). If you partition the 2000 LOGGED-CLEARED into PLANTATION and OTHER based on the 19-year liklihood percentages (see above), then pine plantations represent 74% of the NATIVE-INTACT conversion over the 19 year period and agriculture/residential/urban represents 26% of this conversion.

Transition to NATIVE-INTACT

The following is a percentage of each of the categories in 1981 that had transitioned to NATIVE-INTACT by 2000: 52% of NATIVE-THINNED, 4% of PINE-MIX, 2% of OTHER, 2% of LOGGED-CLEARED, < 1% of PLANTATION-PREP and <1% of PLANTATION-COMPLETE (Chart 1). These results suggest that the conversion of NATIVE-INTACT to any category other than NATIVE-THINNED is a unidirectional process on the landscape. Only NATIVE-THINNED had a greater than 4% likelihood of reverting back to NATIVE-INTACT. It is interesting to note that only 52% of that which was NATIVE-THINNED in 1980 had transitioned back to NATIVE-INTACT by 2000 (Chart 1). Of the remaining 48%: 12% was classified from aerial photography as still being NATIVE-THINNED in 2000, 15% was converted to PLANTATION, and 15% to OTHER (Chart 1). These results suggest that the thinning of a NATIVE-INTACT stand creates a much higher liklihood that such a stand will be subsequently converted to PLANTATION or OTHER categories.

Transitions to and from LOGGED-CLEARED

LOGGED-CLEARED is a transitional cover category on the landscape. Of the LOGGED-CLEARED area in 1981, 89% had transitioned to PLANTATION by 2000. In 1997 there were 20,582 acres classified as LOGGED-CLEARED within the study area. Of this acreage in 1981, 62% had been classified as NATIVE-INTACT, 24% as PLANTATION, 7% NATIVE-THINNED and 6% PINE-MIX (Table 2.7). After having been cleared in 1997, this same acreage by 2000 had become 73% PLANTATION, 13% OTHER, and 8% NATIVE-THINNED with 6% remaining in a LOGGED-CLEARED condition. Of the 30,935 acres of land that had been LOGGED-CLEARED in 2000, previous classification in 1997 had been: 58% NATIVE-INTACT, 35% PLANTATION, 3% NATIVE-THINNED, 3% PINE-MIX (Table 2.8a). It is clear from this analysis that LOGGED-CLEARED exists primarily as a transitional category in the conversion of native forest to pine plantations or as a transition between two different plantation rotations.

Size of LOGGED-CLEARED Patches

From 1997 to 2000, 90% of all native forest removal resulted from clearings that were greater than 40 acres in size (Forest Stewardship Council (FSC) certification limit). Seventy percent of this native forest removal resulted from clearings that were greater than 120 acres (Sustainable Forestry Initiative (SFI) certification average clear cut size limit) (Figure 2.12). In looking at the NATIVE-INTACT area that was LOGGED-CLEARED by 2000, 73% was contained in clearings >120 acres. In looking at the PLANTATION area that was LOGGED-CLEARED by 2000, 60% was contained in clearings >120 acres (Figure 2.13). The percent number of clearings larger than 120 acres was 18% for NATIVE-INTACT and 23% for PLANTATION emphasizing the disproportionate area effect of the larger clearings on the landscape (Figure 2.13). In 2000, clearings in NATIVE-INTACT totaled 17,900 acres whereas clearings in PLANTATION totaled 9,900 acres.

Transitions Associated with PLANTATION and OTHER

Only 1% of 1981 OTHER had been converted to PLANTATION by 2000 and only 2% of 1981 PLANTATION had been converted to OTHER by 2000 (Table 2.6; Chart1). Between 1997 and 2000 there was no significant transitioning between these two categories (Table 2.8). Of the newly created PLANTATION area that occurred within the study area between 1981 and 2000, 66.6% was derived from NATIVE-INTACT, 12.6% was derived from NATIVE-THINNED, 18.1% was derived from PINE-MIX, and 2.6% was derived from OTHER (area LOGGED-CLEARED in 1981 was not included in these calculations because the pre-1981 origin of these clearings was not determined in this study). Between 1981 and 2000, most existing or recently converted pine plantations remained as pine plantations and did not transition to other uses (Table 2.6).

County-level patterns (Maps 2-8, Charts 2-8)

A number of patterns emerge from a county-level analysis of the data. First, all seven counties showed a decrease in NATIVE-INTACT (Fig 2.5) and an increase in intensive pine management (combination of PLANTATION-COMPLETE, PLANTATION-PREP and LOGGED-CLEARED) (Figure 2.6). However, counties varied considerably in terms of the percent of the plateau land experiencing an increase in PLANTATION cover (Figure 2.6; Table 2.10) as well as in the rate of conversion to PLANTATION. Sequatchie County had the highest percentage of plateau land PLANTATION and LOGGED-CLEARED in all three years surveyed (Chart 6; Figure 2.6). Van Buren County had the greatest increase in the percentage of land transitioning to these categories, going from 8.8% in 1981 to 20.2% in 2000 (Chart 7; Table 2.9b). Between 1981 and 1997, the highest rate of increase in PLANTATION and LOGGED-CLEARED was found in Grundy and Sequatchie Counties (Figure 2.6). Grundy had the highest rate of NATIVE-INTACT loss during this same period dropping from 78% in 1981 to 66% cover in 2000 (Table 2.9b). Between 1997 and 2000, Warren and Van Buren Counties showed the highest rate of increase in PLANTATION and LOGGED-CLEARED (Figure 2.6). Both of these Counties showed the highest rate of NATIVE-INTACT cover loss during this same time period (Figure 2.5). Warren County in 1981 had less than 1% of its plateau land in PLANTATION and LOGGED-CLEARED and by 2000 this had increased to 10%.

All seven counties showed a constant modest increase in the percent total OTHER cover over the 19 year period (Figure 2.8). The amount of OTHER cover was greater in the more northern counties (Van Buren, Bledsoe) as compared to the southernmost counties (Franklin, Marion) (Figure 2.8).

In 1981, 2 counties (Bledsoe and Van Buren) had average LOGGED-CLEARED patches that were greater than 120 acres. In 1997, 4 counties (Grundy, Sequatchie, Van Buren and Warren) had average LOGGED-CLEARED patches that were greater than 120 acres. In 2000, Sequatchie, Van Buren and Warren continued to have average LOGGED-CLEARED patches that were greater than 120 acres (Table 2.11).

Watershed-level patterns

There were ten HUC-watersheds that had at least 75% of their catchment area on the Plateau in our study area (Table 2.10). Several patterns emerge when forest changes are analyzed within these watersheds. First, as with the county-level data, we see a high level of spatial clustering (Figs. 2.8-2.9). For example, Savage Creek watershed changed from 9% PLANTATION and LOGGED-CLEARED in 1981 to 34% in 2000, whereas Upper Cane Creek watershed declined slightly from 2% to 1.4% (Figure 2.9). In 2000, three watersheds had more than 20% of their surface covered in PLANTATION and LOGGED-CLEARED in 2000, four had between 10% and 20%, and four had less than 10%. In 1981 all but one had less than 10% coverage by PLANTATION and LOGGED-CLEARED.

The second pattern to emerge is that all watersheds in the study area lost NATIVE-INTACT cover. In 1981 seven out of the ten watersheds had 75% or greater native-intact cover, in 2000 that proportion had dropped to two out of ten. Although this loss took place across the landscape, its intensity varied (Figure 2.9). For example, Pockett Creek watershed declined from 80.1% NATIVE-INTACT cover in 1981 to 41.5% in 2000, but Piney Creek watershed declined from 86.6% in 1981 to 83% in 2000 (Table 2.10).

This watershed-level analysis suggests that because forest change is spatially clustered, local effects of these changes cannot be inferred from regional averages. Pine conversion activity was highly clustered, causing a concentration of impact in certain counties and watersheds.

2.2.2. Houses, Roads, and Mines

In the above section, we discuss recent changes in forest canopy that have occurred across the landscape with a focus on silviculture as the major contributor of this change. We also show that there has been a steady but smaller increase in the amount of the OTHER category during the last 19 years. In this section, we refine this category, specifically differentiating agriculture from three other important factors: (1) housing and structure construction, (2) road networks, (3) and mining activity. This section will briefly address the status of those activities and their relationship to forests on the plateau circa 1997-2000. The analysis here is static in that we do not have rates of change for these key variables. Therefore we will use relatively recent conditions to answer basic questions about the effects of human infrastructure on the canopy cover on the plateau:

> **First:** What is in the geographic footprint of structure construction on the NATIVE-INTACT habitat cover type vs. the rest of the cover categories. More specifically, how close is the average piece of NATIVE-INTACT cover to human structures?
>
> **Second:** What is the geographic footprint of roads with respect to NATIVE-INTACT vs. other canopy categories. More specifically how close is the average piece of NATIVE-INTACT on the plateau to a road?
>
> **Third:** What is the geographic footprint of the mining activity on the plateau? This analysis differs from the roads and houses analysis in that mining activity is now covered by other land use types. Current mining activity is replacing past land use type. The mining section will determine how many acres of each canopy cover type have been or are within 100 meters of current or past mines.

Methods

Structures: A structures layer was digitized in from the 3D aerial photography in ERDAS Stereo Analyst. A distance grid from any structure to every 30 meter location in the study area was then calculated. Those distances were then averaged over 200 hectare hexagons to provide a housing impact measure which was then assigned to every canopy cover polygon in the study area. This approach was used instead of counting structures in individual canopy cover polygons to avoid the potential for the Modifiable Unit Area Problem (MUAP) (Openshaw and Taylor 1979). The MUAP problem is essentially geographic gerrymandering. That is, the density in a given polygon can be highly affected by small changes in the boundary of that polygon. If an urban polygon is draw tightly around a group of houses, and then another polygon is drawn tightly around a contiguous forest area, the result is one very high density housing polygon and one very low. The same area of houses and forests could conversely be split into two moderate density polygons. Either approach has the potential to misrepresent the impact of houses on forests. One common approach to overcome the MUAP problem is to interpolate or spread out the housing density using spatial interpolation algorithms. The results from these attempts tend to be highly dependent on the type of interpolator chosen, the clustering of the original data and the grid size chosen, however.

Interpolation techniques also suffer from the interpolation becoming highly unreliable at greater distances from the data.

Our approach overcomes the gerrymandering phenomenon by using a hexagonal grid that:

- is not related to the land use boundaries.
- averages over sufficiently large area to avoid local spikes in structure related impacts on canopy.
- focuses on the key item of importance—the forests, not the structures. Our measure is distance of canopy type from the structure, not the density of the structures.

Roads: The approach for assessing the impact of roads on canopy cover was identical to the housing approach. The distance from any major or district road was used as the initial impact variable. That metric was then averaged over 200 hectare hexagons. Those hexagons were then merged with the canopy cover data.

Mines: The mines data layer was created by combining layers from the Office of Surface Mines, U.S.G.S Digital Raster Graphics, and the National Atlas Abandoned Mines dataset. A one hundred meter buffer was added to each layer and then all three buffered layers were merged to create an overall mining footprint. This data layer was then combined with the canopy cover layer to determine the canopy cover areas affected by mining activity.

Results:

Roads and Structures: Maps 10 and 12 show the areas of NATIVE-INTACT and not NATIVE-INTACT that were affected by structures and roads respectively. It visually and statistically evident that NATIVE-INTACT canopy is closer on average to roads than houses. It is also visually apparent that the bulk of the NATIVE-INTACT is not impacted by houses within 250 meters. The average piece of NATIVE-INTACT forest was closer to roads than it was to structures ($t=37.35$, $p<.0001$). The buffer distance of 250 meters exceeds most recommended buffer zone requirements. Furthermore, Allan and Johnson (1997) recommend using multiple buffers in impact analysis. The results of the multiple distance analyses are presented in Map 11 and Figure 2.11.

Only 0.2% of the NATIVE-INTACT canopy class was within 100 meters of a structure. The bulk of the canopy classes that were structure impacted fell in the OTHER category. Thirty-four percent of OTHER-PARTIAL CANOPY and sixteen percent of the OTHER-NO CANOPY fell within 100 meters of a structure. An additional 37% of the OTHER-NO CANOPY and 21% of the OTHER-PARTIAL CANOPY fell within 100 to 250 meters. Six percent of NATIVE-THINNED category fell within 25 meters of a structure. No other class exceeded three percent. Finally more than two thirds of the land that converted from NATIVE-INTACT to the OTHER category between 1982 and 2000 was **further** than 250 meters from a structure, suggesting that much of this conversion to OTHER was agricultural related rather than residential/urban.

Mines:

The Figure 2.12 and Map 9 show the distribution of canopy cover types in the mine-impacted areas. NATIVE-INTACT is the dominant cover category (59%) with the OTHER-PARTIAL CANOPY cover category a distant second (20%). Pine plantations total less than ten percent of the total mine lands. The suggestion that pine plantation lands dominate the mine affected areas was not supported by our data.

2.2.3. Summary of Findings

- There was approximately 14% less area with intact native forest canopy on the southern Tennessee portion of the Cumberland Plateau in 2000 than was present in 1981. This represents a net loss of approximately 65,892 acres of native forest during this time.

- The rate and magnitude of pine conversion and native forest loss varied across counties and watersheds within the study area. However, all counties showed a net loss of native forest, with Van Buren County being the highest at 18% (15,868 acres). Pine conversion activity was highly clustered, causing a concentration of impact in certain counties and watersheds.

- Between 1981 and 1997, intact native forest area decreased at a rate of 3030 acres per year. Between 1997 and 2000 the rate of decrease was almost two times greater at 5820 acres per year.

- Total area in pine plantation increased by 170% (24,945 acres) from 1981 to 2000. Pine plantations and associated lands newly cleared for this purpose were responsible for 74% of native forest conversion.

- Total area of native forest converted to non-silvicultural (i.e. agriculture and residential) uses increased by 18% in the 1981-2000 period and was responsible for 26% of native forest conversion.

- About 80% of all newly created pine plantations appearing in the study area between 1981 and 2000 were derived from either intact or thinned native forests. Less than 3% were derived from lands associated with non-silvicultural use (such as agriculture). Most existing or recently converted pine plantations remained as pine plantations between 1981 and 2000 and did not transition to other uses.

- From 1997 to 2000, 90% of all native forest removal resulted from clearings that were greater than 40 acres in size (Forest Stewardship Council (FSC) certification limit). Seventy percent of this native forest removal resulted from clearings that were greater than 120 acres in size (Sustainable Forestry Initiative (SFI) certification average clear cut size limit).

2.4. Literature Cited

Allan, J.D., and L.B. Johnson. 1997. Catchment-scale analysis of aquatic ecosystems. Freshwater Biology 37:107-111.

Openshaw, S. and P.J. Taylor. 1979. A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In: Statistical Methods in The Spatial Sciences, Wrigley, N. (ed.), pp: 127-144, London, Routledge & Kegan Paul.

Figure 2.1. Pine basal area and hardwood basal area versus canopy type classification.

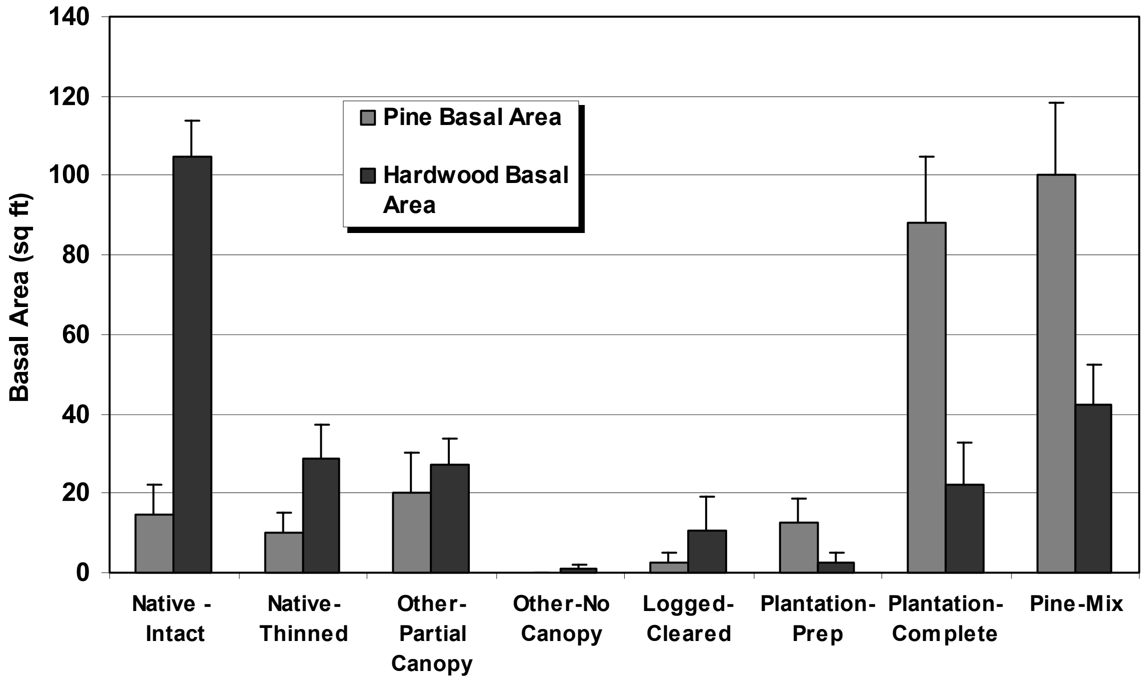

Figure 2.2. Canopy height by canopy type classification.

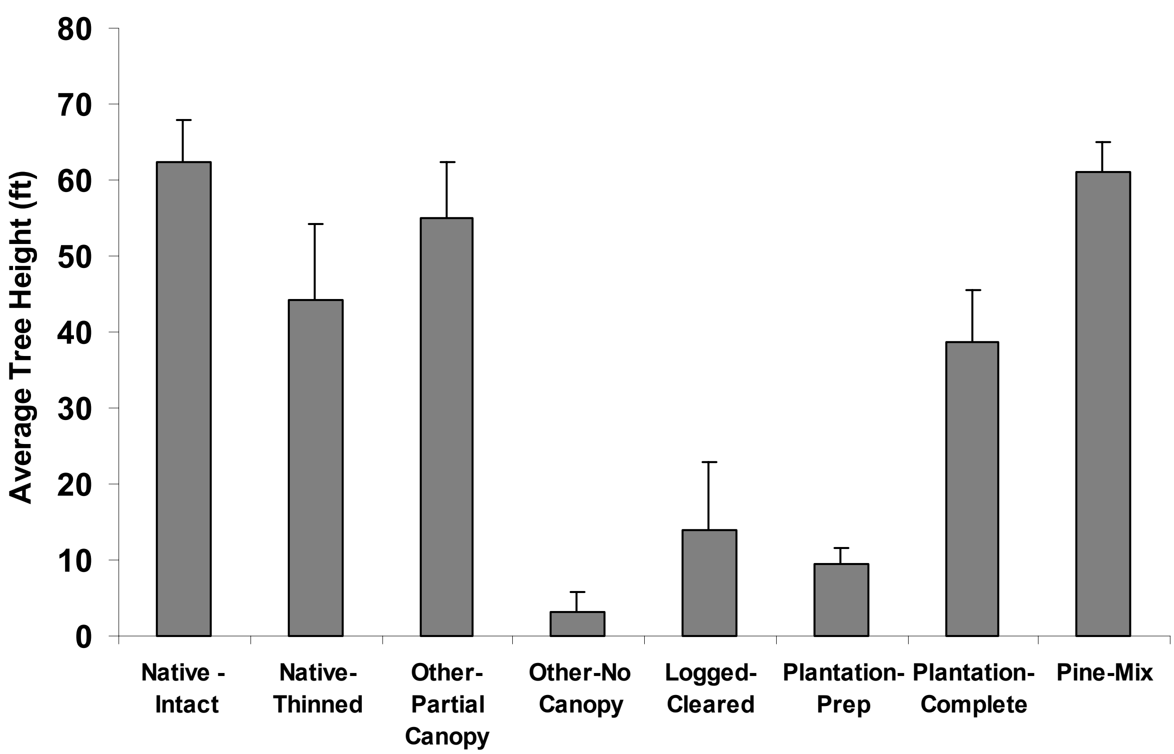

Figure 2.3. 19 year change in NATIVE-INTACT canopy type on the Cumberland Plateau in Southern Tennessee.

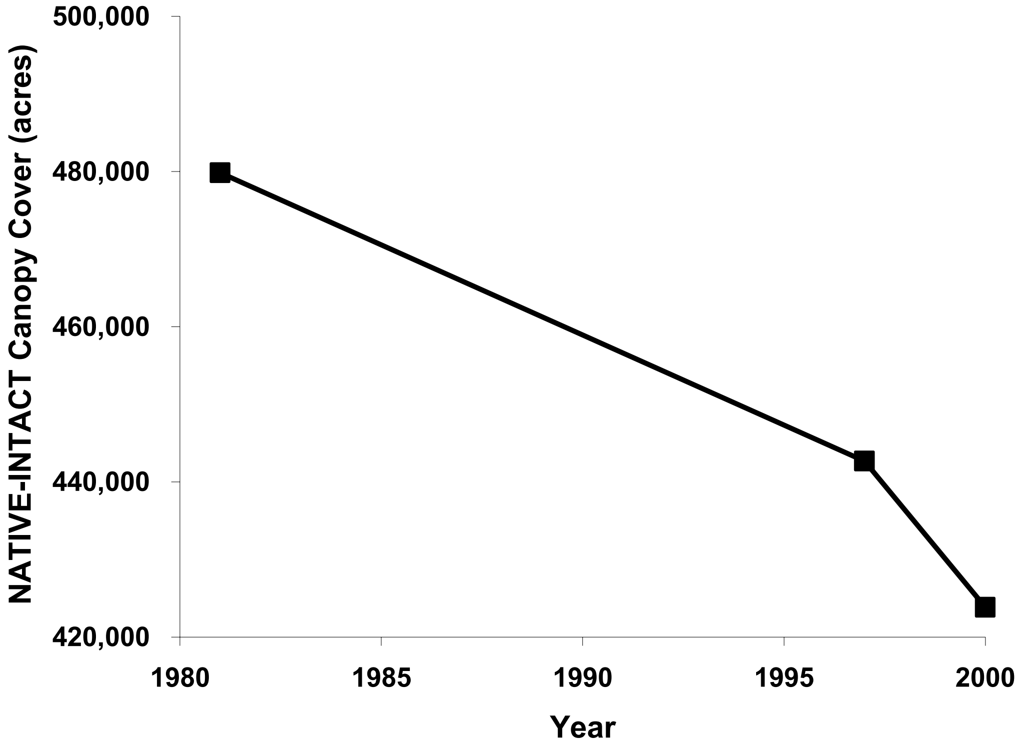

Figure 2.4. Total acreage in PLANTATION and LOGGED-CLEARED canopy types within the study area for the years 1981, 1997, and 2000.

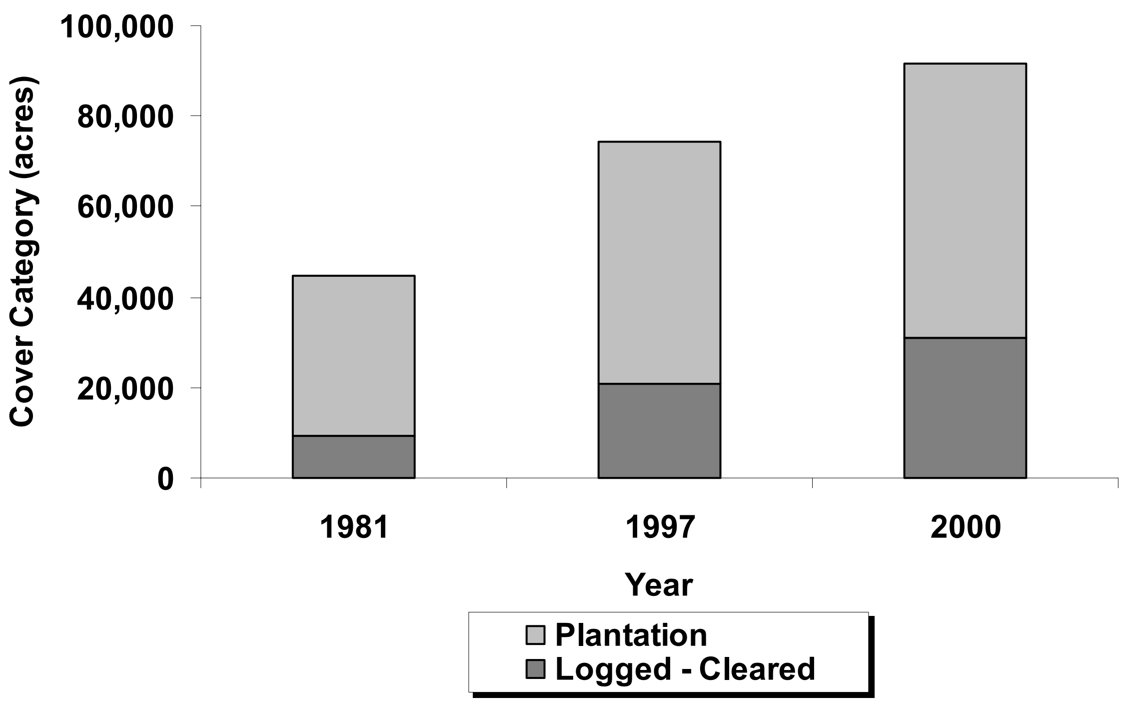

Figure 2.5. Change in percent NATIVE canopy type by county from 1981 to 2000.

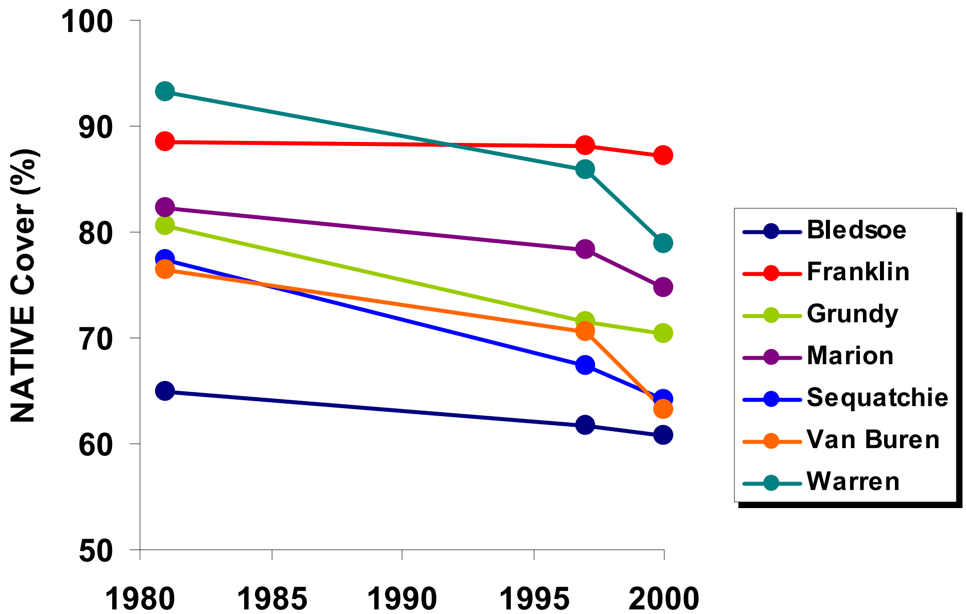

Figure 2.6. Change in percent PLANTATION plus LOGGED-CLEARED canopy type by county from 1981 to 2000.

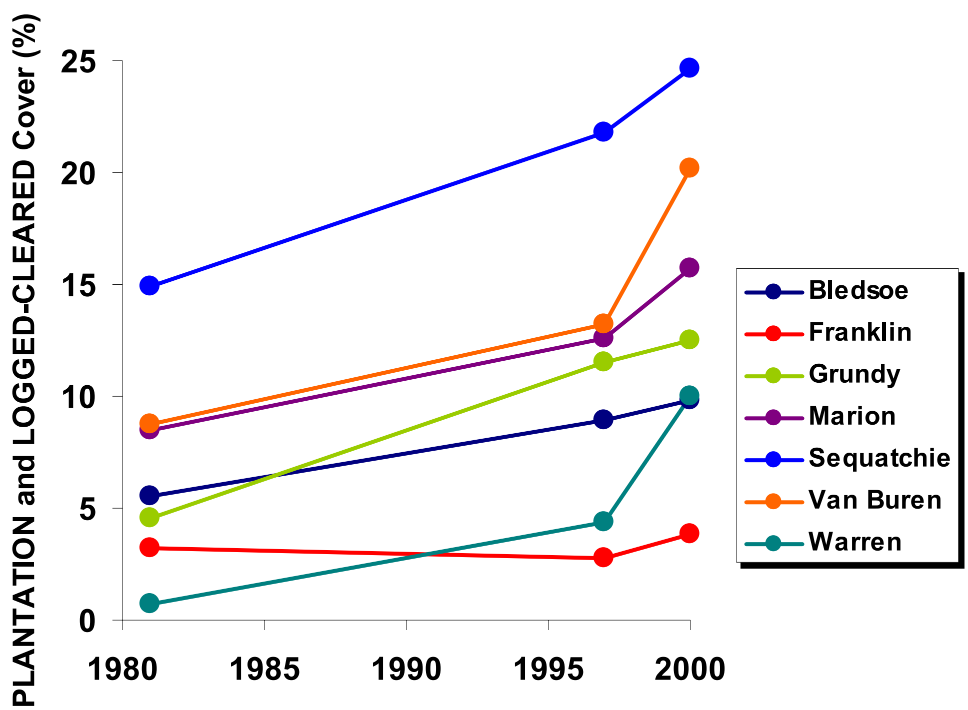

Figure 2.7. Change in percent OTHER canopy type by county from 1981 to 2000.

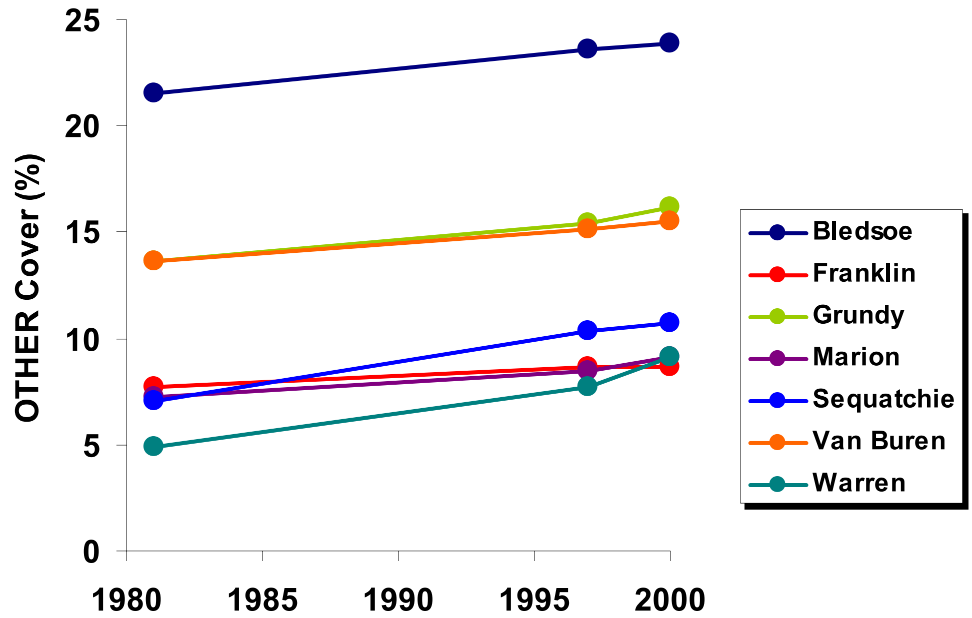

Figure 2.8. Change in percent NATIVE canopy type by 12 Digit HUC Watersheds whose catchment areas are >75% within the study area.

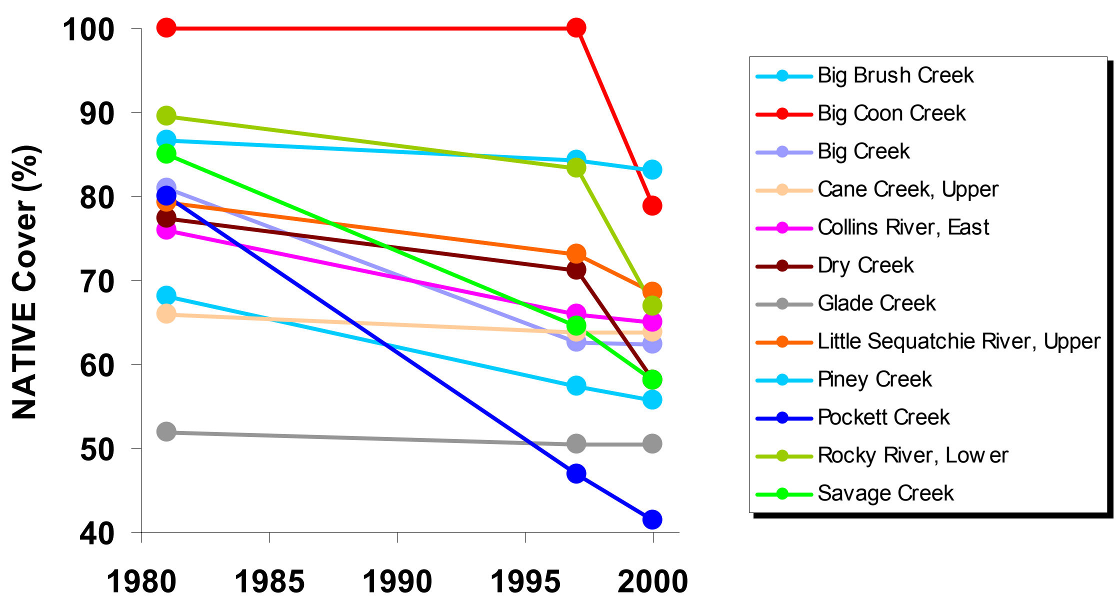

Figure 2.9. Change in percent PLANTATION plus LOGGED-CLEARED canopy cover by 12 Digit HUC Watersheds whose catchment areas are >75% within the study area.

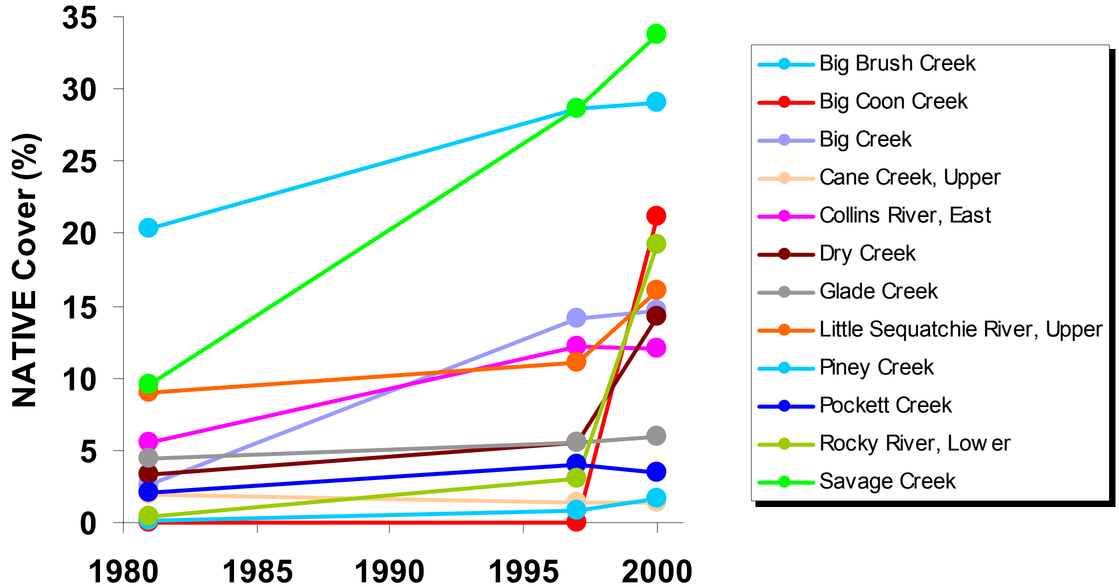

Figure 2.10. Distance of land from structures (digitized from 1997 imagery) by canopy type classification.

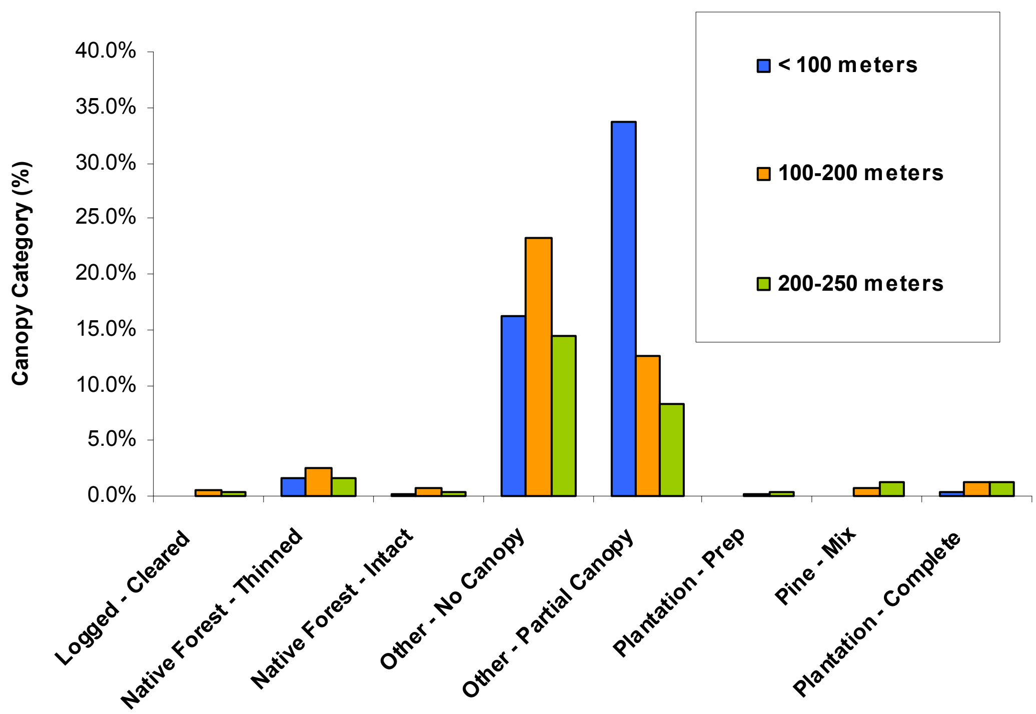

Figure 2.11. Percent of mine lands in canopy type classification for 1997.

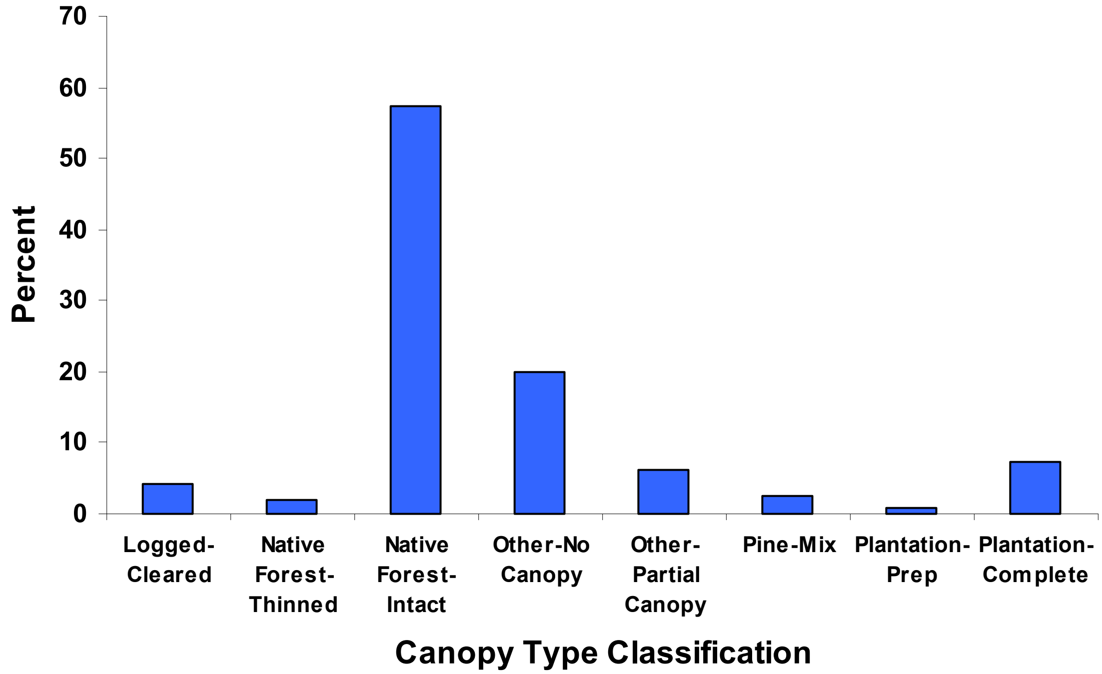

Figure 2.12. Percent total area of LOGGED-CLEARED canopy type for a given year that resulted from clearcuts >40 acres in size or from clearcuts > 120 acres in size.

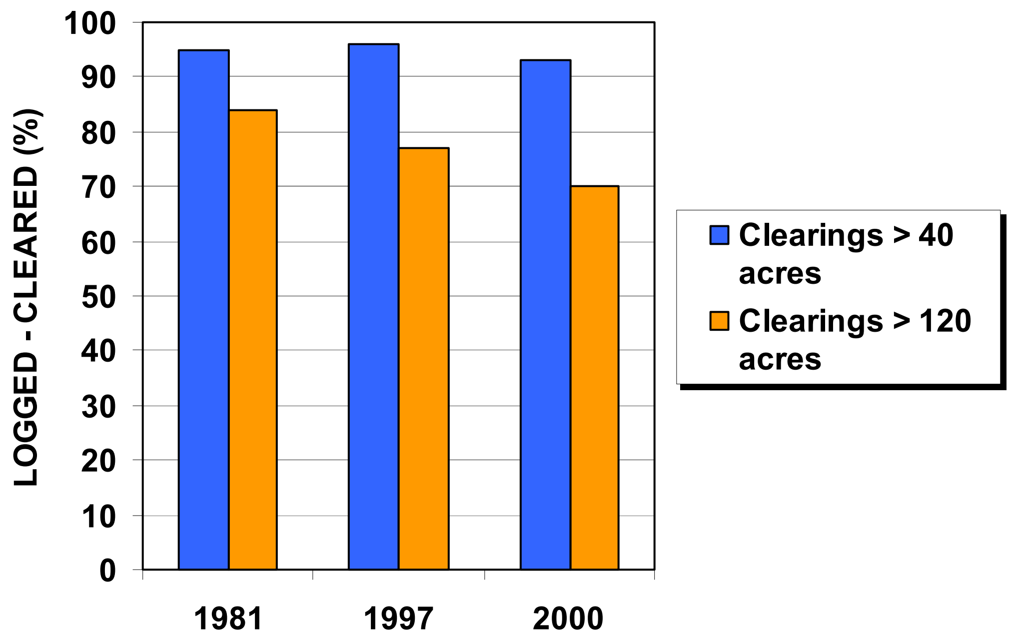

Figure 2.13. This figure indicates the extent in 2000 to which large clearcuts (>120 acres) occurred in NATIVE FOREST versus PLANTATION expressed both as a percent of total LOGGED-CLEARED area and as a percent of total number of clearings.

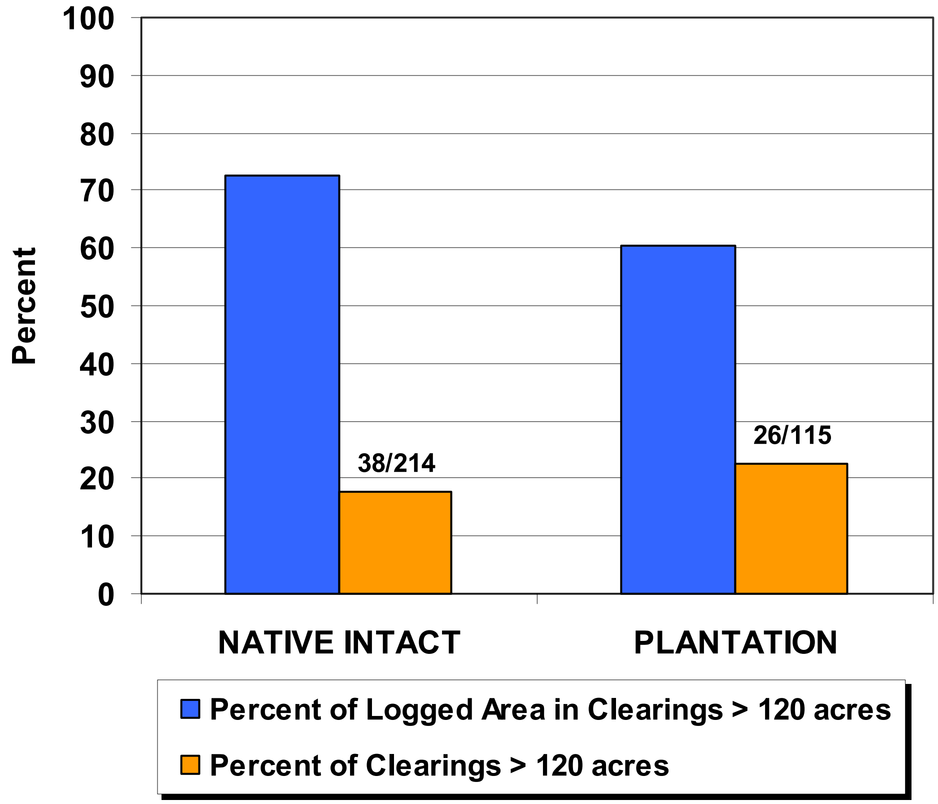

Table 2.1. Summary of available imagery that was borrowed or purchased by the Landscape Analysis Lab.

Year of Data	County: Bledsoe	Franklin	Grundy	Marion	Sequatchie	Van Buren	Warren	All Counties
1980	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	**NHAP**
1981	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	
1982	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	No FSA	
1983	No FSA	No FSA	FSA Available	FSA Available	No FSA	No FSA	No FSA	
1984	FSA Available	FSA Available	No FSA	No FSA	No FSA	FSA Available	No FSA	
1985	FSA Available	FSA Available	**FSA Acquired**	No FSA	No FSA	FSA Available	No FSA	
1986	FSA Available	FSA Available	FSA Available	FSA Available	No FSA	FSA Available	FSA Available	
1987	No FSA	FSA Available	No FSA	FSA Available	No FSA	FSA Available	FSA Available	
1988	FSA Available	FSA Available	FSA Available	FSA Available	No FSA	FSA Available	No FSA	
1989	FSA Available	FSA Available	**FSA Acquired**	FSA Available	No FSA	FSA Available	FSA Available	
1990	FSA Available	FSA Available	FSA Available	FSA Available	No FSA	No FSA	FSA Available	
1991	FSA Available	FSA Available	FSA Available	FSA Available	No FSA	FSA Available	FSA Available	
1992	FSA Available	FSA Available	No FSA	FSA Available	No FSA	FSA Available	FSA Available	**NAPP**
1993	No FSA	FSA Available	FSA Available	No FSA	No FSA	FSA Available	FSA Available	
1994	No FSA	FSA Available	**FSA Acquired**	No FSA	No FSA	FSA Available	FSA Available	
1995	FSA Available	FSA Available	**FSA Acquired**	No FSA	No FSA	FSA Available	FSA Available	
1996	FSA Available	FSA Available	**FSA Acquired**	FSA Available	No FSA	FSA Available	FSA Available	
1997	FSA Available	FSA Available	**FSA Acquired**	**FSA Acquired**	No FSA	FSA Available	FSA Available	**NAPP**
1998	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	
1999	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	FSA Available	
2000	**FSA Acquired**	**FSA Acquired**	**FSA Acquired**	**FSA Acquired**	**FSA Acquired**	**FSA Acquired**	**FSA Acquired**	**Landsat**

No FSA = No slides available at the FSA offices

FSA Available = Slides are available at the FSA offices

FSA Acquired, NHAP. NAPP, Landsat = Imagery has been acquired

and is available at the Landscape Analysis Lab

Table 2.2. Definitions of classification calls used in the project.

Canopy Cover Classification	Vegetation Cover	Canopy Disturbance *Recent Evidence*	Land Uses *Aerial Interpretation*	Notes
Native Forest - Intact	70-100% - Intact forest canopy Upland hardwood; mixed hardwood/pine	Minimal canopy disturbance Small clearings <10 % - Mineral soil exposed	Very low density residential	
Native Forest - Thinned	10-70% - Intact forest canopy Upland hardwood; mixed hardwood/pine Increased early succesional species 10-70% - Mineral soil exposed	Tree removal Logging road and skid trails form obvious network Small clearings	Diameter-limit timber harvest Group selection harvest Clearcut with some trees remaining Low density residential	
Pine - Mix	10-70% - Intact pine canopy Planted pine - low density resulting from mixed deciduous or openings Naturally seeded pine stands in discreet polygons Herbaceous openings	See Pine Plantation Mature if it is a pine deciduous mix See Native Forest Thinned if canopy has been recently thinned	Pine silviculture Low intensity management	May result as response to burned areas or mine reclamation
Pine Plantation Complete	70-100% - Intact plantation canopy Mostly pine, but may contain hardwoods Recognizable polygons of planted pine	Minimal canopy disturbance Small clearings <10 % - Mineral soil exposed	Pine silviculture Intensive management Established planting	
Pine Plantation Prep	Immature planted pine Mostly gramnoid cover Little Bluestem grass common	Complete tree removal and understory cleared evidence of site preparation: Slash rows/burned/bulldozer activity	Pine silviculture Site prep, new planting Intensive management	
Logged - Cleared	<10% - Intact canopy >70% - Mineral soil exposed	Extensive skid trails Clearings, logging roads Complete canopy removal	Upland forest commerical clearcut Pine silviculture Conversion of: Upland forest to Pine Plantation Upland Forest to Other	May include some pine site preparation in 1980, 1992, 1997 (since no color available)
Other - Partial Canopy	10-70% - Canopy Early successional Edge species Exotics	Ongoing human disturbance Understory clearing Grazing, Roads Mining activity Building construction	Residential Agricultural Mining (Non silvicultural)	Mostly residential- agricultural patches
Other - No Canopy	<10% - Canopy Pasture/lawn Ggses Shrubs and occasional trees	Ongoing human disturbance to prevent tree cover	Residential/urban Agricultural Residential Active mining	

Table 2.3. Post hoc accuracy assessment.

Number of Polygons	Ground Data								
Canopy Cover from Aerial Imagery	Logged - Clear	Native - Thinned	Native - Intact	Other - No Canopy	Other - Parital Canopy	Plantation - Prep	Pine - Mix	Plantation - Complete	Total
Logged - Clear	9	0	0	0	0	0	0	0	9
Native - Thinned	0	4	0	1	2	0	0	1	8
Native - Intact	0	1	12	0	0	0	0	1	14
Other - No Canopy	0	0	0	11	0	0	0	0	11
Other - Partial Canopy	0	0	1	0	11	0	0	2	14
Plantation - Prep	0	1	0	0	0	14	0	0	15
Pine - Mix	0	0	5	0	0	0	5	2	12
Plantation - Complete	0	1	0	0	0	0	0	9	10
Total	8	7	18	12	13	15	7	13	93

Percentage in Category	Ground Data								
Canopy Cover from Aerial Imagery	Logged - Clear	Native - Thinned	Native - Intact	Other - No Canopy	Other - Parital Canopy	Plantation - Prep	Pine - Mix	Plantation - Complete	Total
Logged - Clear	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Native - Thinned	0.0%	**50.0%**	0.0%	12.5%	25.0%	0.0%	0.0%	12.5%	100.0%
Native - Intact	0.0%	7.1%	**85.7%**	0.0%	0.0%	0.0%	0.0%	7.1%	100.0%
Other - No Canopy	0.0%	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	100.0%
Other - Partial Canopy	0.0%	0.0%	7.1%	0.0%	**78.6%**	0.0%	0.0%	14.3%	100.0%
Plantation - Prep	0.0%	6.7%	0.0%	0.0%	0.0%	**93.3%**	0.0%	0.0%	100.0%
Pine - Mix	0.0%	0.0%	41.7%	0.0%	0.0%	0.0%	**41.7%**	16.7%	100.0%
Plantation - Complete	0.0%	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**90.0%**	100.0%

Percent Correct: 80.6%
Percent correct no mixed: 90.4%
No Pine - Mix: 86.4%

Table 2.4. Missed classification and ground descriptions.

AERIAL CALL	GROUND CALL	NOTES
Native - Thinned	Other - No Canopy	Griffith Creek Urban Area
Native - Thinned	Other - Partial Canopy	Trailer park, hardwood, cedar, pine
Native - Thinned	Other - Partial Canopy	Griffith Creek Urban Area
Native - Thinned	Plantation - Complete	Loblolly, some virginia, some hardwood. 10-12 yrs old.
Native - Intact	Native - Thinned	Low density residential
Native - Intact	Plantation - Complete	Loblolly pine, some hardwood - widely spaced. Approx. 70% canopy (now thinned)
Other - Partial Canopy	Plantation - Complete	Abandoned white pine christmas trees
Other - Partial Canopy	Native - Intact	Virginia, Shortleaf, and hardwood forest
Plantation - Prep	Native - Thinned	High graded comercial clearcut 3+ yrs old, regrowth
Pine - Mix	Native - Intact	Cedar, Virginia pine, Hemlock, Mountain Laurel, American Holly, Hardwoods
Pine - Mix	Native - Intact	Hardwood Virgiania pine mix
Pine - Mix	Plantation - Complete	Loblolly pine
Pine - Mix	Native - Intact	Mixed virginia and shortleaf pine and hardwood: hickory, oak, black gum (Burned).
Pine - Mix	Native - Intact	Mixed virginia and shortleaf pine.
Pine - Mix	Native - Intact	Virginia pine. Some dogwood, oak. Pine diameter 15"-3" (no rows)

Table 2.5. Kruskal-Willis z values for forest canopy metrics.

Pine Basal Area - Kruskal-Wallis Z Values								
	Logged - Clear	Native - Thinned	Native - Intact	Other - No Canopy	Other - Partial Canopy	Plantation - Prep	Pine - Mix	Plantation - Complete
Logged - Clear	0	0.999	0.8864	0.4128	0.7749	0.8822	**3.9058**	**3.5624**
Native - Thinned	0.999	0	0.2526	1.4724	0.3641	0.1774	**2.8462**	**2.4788**
Native - Intact	0.8864	0.2526	0	1.4381	0.1333	0.067	**3.5809**	**3.1858**
Other - No Canopy	0.4128	1.4724	1.4381	0	1.3175	1.3845	**4.6168**	**4.2736**
Other - Partial Canopy	0.7749	0.3641	0.1333	1.3175	0	0.1875	**3.7015**	**3.31**
Plantation - Prep	0.8822	0.1774	0.067	1.3845	0.1875	0	**3.2323**	**2.8532**
Pine - Mix	**3.9058**	**2.8462**	**3.5809**	**4.6168**	**3.7015**	**3.2323**	0	0.4631
Plantation - Complete	**3.5624**	**2.4788**	**3.1858**	**4.2736**	**3.31**	**2.8532**	0.4631	0

Hardwood Basal Area - Kruskal-Wallis Z Values								
	Logged - Clear	Native - Thinned	Native - Intact	Other - No Canopy	Other - Partial Canopy	Plantation - Prep	Pine - Mix	Plantation - Complete
Logged - Clear	0	1.3924	**4.1072**	0.8556	1.4147	0.7853	**1.9684**	0.6008
Native - Thinned	1.3924	0	**2.5197**	**2.3324**	0.1931	**2.2622**	0.4916	0.9094
Native - Intact	**4.1072**	**2.5197**	0	**5.4348**	**3.2989**	**5.3531**	**2.1528**	**3.8738**
Other - No Canopy	0.8556	**2.3324**	**5.4348**	0	2.542	0.0751	**3.0189**	1.5828
Other - Partial Canopy	1.4147	0.1931	**3.2989**	2.542	0	**2.4591**	0.789	0.8666
Plantation - Prep	0.7853	**2.2622**	**5.3531**	0.0751	**2.4591**	0	**2.9439**	1.5058
Pine - Mix	**1.9684**	0.4916	**2.1528**	**3.0189**	0.789	**2.9439**	0	1.5146
Plantation - Complete	0.6008	0.9094	**3.8738**	1.5828	0.8666	1.5058	1.5146	0

Canopy Height - Kruskal-Wallis Z Values								
	Logged - Clear	Native - Thinned	Native - Intact	Other - No Canopy	Other - Partial Canopy	Plantation - Prep	Pine - Mix	Plantation - Complete
Logged - Clear	0	**1.8708**	**3.5796**	0.7622	**3.0209**	0.1406	**3.0642**	**1.7661**
Native - Thinned	**1.8708**	0	1.3911	**2.8116**	0.8073	**2.1157**	1.0148	0.3255
Native - Intact	**3.5796**	1.3911	0	**5.0006**	0.7598	**4.5513**	0.3499	**2.032**
Other - No Canopy	0.7622	**2.8116**	**5.0006**	0	**4.3904**	1.1256	**4.278**	**2.8592**
Other - Partial Canopy	**3.0209**	0.8073	0.7598	**4.3904**	0	**3.844**	0.3298	1.3574
Plantation - Prep	0.1406	2.1157	**4.5513**	1.1256	**3.844**	0	**3.7144**	**2.0955**
Pine - Mix	**3.0642**	1.0148	0.3499	**4.278**	0.3298	**3.7144**	0	1.5299
Plantation - Complete	**1.7661**	0.3255	**2.032**	**2.8592**	1.3574	**2.0955**	1.5299	0

Regular Test: Medians significantly different if z-value > 1.6449

Bonferroni Test: Medians significantly different if z-value > 2.9137

Table 2.6a. Cross tabulation of canopy cover type acreages (1981-2000).

1981	2000								
	Logged - Cleared	Native Forest - Thinned	Native Forest - Intact	Other - No Canopy	Other - Partial Canopy	Plantation - Prep	Plantation - Complete	Pine - Mix	Total
Logged - Cleared	145	65	167	41	381	250	7,970	168	**9,185**
Native Forest - Thinned	493	3,082	11,640	2,387	878	1,158	2,237	567	**22,442**
Native Forest - Intact	21,303	28,230	377,514	9,277	2,852	9,331	8,641	231	**457,379**
Other - No Canopy	67	51	444	62,766	4,675	13	670	591	**69,278**
Other - Partial Canopy	62	165	1,007	532	5,874	5	23		**7,668**
Plantation - Prep	1,408		59	2		481	9,043	982	**11,974**
Plantation - Complete	6,390	104	231	490	105	3,977	11,829	476	**23,601**
Pine - Mix	1,068	392	657	424	409	828	4,068	6,799	**14,645**
Total	**30,935**	**32,089**	**391,719**	**75,919**	**15,173**	**16,041**	**44,481**	**9,816**	**616,172**

Table 2.6b. Cross tabulation of canopy cover type percentages (1981-2000).

1981	2000								
	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)	Total (%)
Logged - Cleared	1.6	0.7	1.8	0.4	4.1	2.7	86.8	1.8	**100.0**
Native Forest - Thinned	2.2	13.7	51.9	10.6	3.9	5.2	10.0	2.5	**100.0**
Native Forest - Intact	4.7	6.2	82.5	2.0	0.6	2.0	1.9	0.1	**100.0**
Other - No Canopy	0.1	0.1	0.6	90.6	6.7	0.0	1.0	0.9	**100.0**
Other - Partial Canopy	0.8	2.2	13.1	6.9	76.6	0.1	0.3	0.0	**100.0**
Plantation - Prep	11.8	0.0	0.5	0.0	0.0	4.0	75.5	8.2	**100.0**
Plantation - Complete	27.1	0.4	1.0	2.1	0.4	16.8	50.1	2.0	**100.0**
Pine - Mix	7.3	2.7	4.5	2.9	2.8	5.7	27.8	46.4	**100.0**
Total	**5.0**	**5.2**	**63.6**	**12.3**	**2.5**	**2.6**	**7.2**	**1.6**	**100.0**

Table 2.7a. Cross tabulation of canopy cover type acreages (1981-1997).

1981	1997								
	Logged - Cleared	**Native Forest - Thinned**	**Native Forest - Intact**	**Other - No Canopy**	**Other - Partial Canopy**	**Plantation - Prep**	**Plantation - Complete**	**Pine - Mix**	**Total**
Logged - Cleared	182	58	167	22	377	296	7,907	175	**9,185**
Native Forest - Thinned	1,421	3,887	11,104	2,092	674	41	2,647	576	**22,442**
Native Forest - Intact	12,689	29,034	396,986	7,757	1,050	1,301	8,291	271	**457,380**
Other - No Canopy	33		235	62,921	4,780		717	591	**69,278**
Other - Partial Canopy		90	247	566	6,708		56		**7,668**
Plantation - Prep	580		28	2		1,071	9,216	1,077	**11,974**
Plantation - Complete	4,451	99	231	491	28	2,392	15,274	636	**23,601**
Pine - Mix	1,224	159	191	538	176	477	3,943	7,939	**14,645**
Total	**20,582**	**33,327**	**409,188**	**74,390**	**13,793**	**5,577**	**48,051**	**11,265**	**616,172**

Table 2.7b. Cross tabulation of canopy cover type percentages (1981-1997).

1981	1997								
	Logged - Cleared (%)	**Native Forest - Thinned (%)**	**Native Forest - Intact (%)**	**Other - No Canopy (%)**	**Other - Partial Canopy (%)**	**Plantation - Prep (%)**	**Plantation - Complete (%)**	**Pine - Mix (%)**	**Total (%)**
Logged - Cleared	2.0	0.6	1.8	0.2	4.1	3.2	86.1	1.9	**100.0**
Native Forest - Thinned	6.3	17.3	49.5	9.3	3.0	0.2	11.8	2.6	**100.0**
Native Forest - Intact	2.8	6.3	86.8	1.7	0.2	0.3	1.8	0.1	**100.0**
Other - No Canopy	0.0	0.0	0.3	90.8	6.9	0.0	1.0	0.9	**100.0**
Other - Partial Canopy	0.0	1.2	3.2	7.4	87.5	0.0	0.7	0.0	**100.0**
Plantation - Prep	4.8	0.0	0.2	0.0	0.0	8.9	77.0	9.0	**100.0**
Plantation - Complete	18.9	0.4	1.0	2.1	0.1	10.1	64.7	2.7	**100.0**
Pine - Mix	8.4	1.1	1.3	3.7	1.2	3.3	26.9	54.2	**100.0**
Total	**3.3**	**5.4**	**66.4**	**12.1**	**2.2**	**0.9**	**7.8**	**1.8**	**100.0**

Table 2.8a. Cross tabulation of canopy cover type acreages (1997-2000).

1997	2000 Logged - Cleared	Native Forest - Thinned	Native Forest - Intact	Other - No Canopy	Other - Partial Canopy	Plantation - Prep	Plantation - Complete	Pine - Mix	Total
Logged - Cleared	1,175	1,703	53	1,278	1,368	13,453	1,551		**20,582**
Native Forest - Thinned	967	26,172	4,934	629	624				**33,327**
Native Forest - Intact	17,913	4,051	385,401	55	51	1,717			**409,188**
Other - No Canopy			74	73,681	634				**74,390**
Other - Partial Canopy	122	155	873	268	12,370	5			**13,793**
Plantation - Prep	477		31			198	4,872		**5,577**
Plantation - Complete	9,412	8	39		18	640	37,913	22	**48,051**
Pine - Mix	870		313	7	107	28	145	9,793	**11,264**
Total	**30,935**	**32,089**	**391,718**	**75,919**	**15,173**	**16,041**	**44,481**	**9,815**	**616,171**

Table 2.8b. Cross tabulation of canopy cover type percentages (1997-2000).

1997	2000 Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)	Total (%)
Logged - Cleared	5.7	8.3	0.3	6.2	6.6	65.4	7.5	0.0	**100.0**
Native Forest - Thinned	2.9	78.5	14.8	1.9	1.9	0.0	0.0	0.0	**100.0**
Native Forest - Intact	4.4	1.0	94.2	0.0	0.0	0.4	0.0	0.0	**100.0**
Other - No Canopy	0.0	0.0	0.1	99.0	0.9	0.0	0.0	0.0	**100.0**
Other - Partial Canopy	0.9	1.1	6.3	1.9	89.7	0.0	0.0	0.0	**100.0**
Plantation - Prep	8.5	0.0	0.6	0.0	0.0	3.5	87.4	0.0	**100.0**
Plantation - Complete	19.6	0.0	0.1	0.0	0.0	1.3	78.9	0.0	**100.0**
Pine - Mix	7.7	0.0	2.8	0.1	1.0	0.3	1.3	86.9	**100.0**
Total	**5.0**	**5.2**	**63.6**	**12.3**	**2.5**	**2.6**	**7.2**	**1.6**	**100.0**

Table 2.9a. Distribution of canopy cover categories by county.

2000	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (acres)	Native Forest - Thinned (acres)	Native Forest - Intact (acres)	Other - No Canopy (acres)	Other - Partial Canopy (acres)	Plantation - Prep (acres)	Plantation - Complete (acres)	Pine - Mix (acres)
BLEDSOE	104,348	40.1	1,713	988	62,460	22,988	1,885	0	8,554	5,760
FRANKLIN	46,657	12.7	1,315	7,715	32,938	2,454	1,592	0	459	183
GRUNDY	159,246	69.3	5,637	7,113	105,037	19,813	5,879	6,158	8,169	1,439
MARION	97,110	29.6	5,551	11,906	60,708	6,563	2,315	2,884	6,786	397
SEQUATCHIE	73,793	43.1	5,639	2,140	45,153	6,385	1,493	2,439	10,079	466
VANBUREN	117,830	67.1	10,036	2,162	72,341	16,529	1,723	3,904	9,865	1,270
WARREN	14,745	5.3	1,040	81	11,549	1,052	287	302	131	301

1997	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (acres)	Native Forest - Thinned (acres)	Native Forest - Intact (acres)	Other - No Canopy (acres)	Other - Partial Canopy (acres)	Plantation - Prep (acres)	Plantation - Complete (acres)	Pine - Mix (acres)
BLEDSOE	104,348	40.1	120	1,268	63,135	22,867	1,716	230	9,000	6,012
FRANKLIN	46,657	12.7	38	7,470	33,615	2,510	1,540	0	1,259	226
GRUNDY	159,334	69.2	8,302	7,521	106,539	19,311	5,312	579	9,444	2,325
MARION	97,202	29.6	3,350	12,765	63,431	6,125	2,066	509	8,347	609
SEQUATCHIE	73,800	43.2	2,924	2,891	46,766	5,710	1,896	1,822	11,327	466
VANBUREN	117,830	67.1	4,859	1,356	81,767	16,682	1,180	2,200	8,464	1,322
WARREN	14,745	5.3	636	81	12,579	1,052	83	0	10	304

1981	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (acres)	Native Forest - Thinned (acres)	Native Forest - Intact (acres)	Other - No Canopy (acres)	Other - Partial Canopy (acres)	Plantation - Prep (acres)	Plantation - Complete (acres)	Pine - Mix (acres)
BLEDSOE	104,348	40.1	965	1,399	66,281	21,424	1,032	1,837	2,987	8,423
FRANKLIN	46,657	12.7	301	3,662	37,658	2,387	1,199	75	1,132	243
GRUNDY	159,389	69.2	705	3,972	124,429	18,980	2,804	3,634	2,955	1,911
MARION	97,209	29.6	2,430	6,075	73,917	5,583	1,429	745	5,045	1,984
SEQUATCHIE	73,808	43.1	1,468	5,133	52,035	4,655	579	3,267	6,288	384
VANBUREN	117,857	67.2	3,154	1,841	88,209	15,459	555	2,417	4,709	1,513
WARREN	14,745	5.3	0	237	13,504	656	70	0	107	172

Table 2.9b. Percent distribution of canopy cover categories by county and year.

2000	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
BLEDSOE	104,348	40.1	1.6	0.9	59.9	22.0	1.8	0.0	8.2	5.5
FRANKLIN	46,657	12.7	2.8	16.5	70.6	5.3	3.4	0.0	1.0	0.4
GRUNDY	159,246	69.3	3.5	4.5	66.0	12.4	3.7	3.9	5.1	0.9
MARION	97,110	29.6	5.7	12.3	62.5	6.8	2.4	3.0	7.0	0.4
SEQUATCHIE	74,041	43.2	7.6	2.8	61.6	8.8	2.0	3.3	13.2	0.6
VANBUREN	117,830	67.1	8.5	1.8	61.4	14.0	1.5	3.3	8.4	1.1
WARREN	14,745	5.3	7.1	0.6	78.3	7.1	1.9	2.1	0.9	2.0
7-County	**613,976**	**38.2**	**5.3**	**5.6**	**65.8**	**10.9**	**2.4**	**2.2**	**6.3**	**1.6**

1997	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
BLEDSOE	104,348	40.1	0.1	1.2	60.5	21.9	1.6	0.2	8.6	5.8
FRANKLIN	46,657	12.7	0.1	16.0	72.0	5.4	3.3	0.0	2.7	0.5
GRUNDY	159,334	69.2	5.2	4.7	66.9	12.1	3.3	0.4	5.9	1.5
MARION	97,202	29.6	3.4	13.1	65.3	6.3	2.1	0.5	8.6	0.6
SEQUATCHIE	73,800	43.2	3.9	3.9	63.8	7.8	2.6	2.1	15.3	0.6
VANBUREN	117,830	67.1	4.1	1.2	69.4	14.2	1.0	1.9	7.2	1.1
WARREN	14,745	5.3	4.3	0.5	85.3	7.1	0.6	0.0	0.1	2.1
7-County	**613,916**	**38.2**	**3.0**	**5.8**	**69.0**	**10.7**	**2.1**	**0.7**	**6.9**	**1.7**

1981	Total County in Study Area (acres)	(%) County in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
BLEDSOE	104,348	40.1	0.9	1.3	63.5	20.5	1.0	1.8	2.9	8.1
FRANKLIN	46,657	12.7	0.6	7.8	80.7	5.1	2.6	0.2	2.4	0.5
GRUNDY	159,389	69.2	0.4	2.5	78.1	11.9	1.8	2.3	1.9	1.2
MARION	97,209	29.6	2.5	6.2	76.0	5.7	1.5	0.8	5.2	2.0
SEQUATCHIE	74,048	43.2	2.0	5.9	71.9	6.5	0.7	4.0	8.5	0.5
VANBUREN	117,857	67.2	2.7	1.6	74.8	13.1	0.5	2.1	4.0	1.3
WARREN	14,745	5.3	0.0	1.6	91.6	4.4	0.5	0.0	0.7	1.2
7-County	**614,254**	**38.2**	**1.3**	**3.9**	**76.7**	**9.6**	**1.2**	**1.6**	**3.6**	**2.1**

Table 2.10. Percent distribution of canopy cover categories by year and by 12 Digit HUC Watersheds (whose catchment areas are >75% within the study area). HUCs ranked by increasing "Native Forest" cover. The percentages given for canopy cover are for the portion of the watershed within the study area.

2000	Total HUC in Study Area (acres)	(%) HUC in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
Big Brush Creek	36439	81.3	4.5	2.6	55.6	9.8	2.7	2.6	21.9	0.4
Big Coon Creek	139	84.9	21.1	0.0	78.9	0.0	0.0	0.0	0.0	0.0
Big Creek	40131	94.6	4.7	6.6	62.3	12.0	3.0	6.0	4.0	1.4
Cane Creek, Upper	42049	99.2	0.1	1.4	63.8	18.2	3.4	0.0	1.3	11.9
Collins River, East	29127	94.7	2.1	3.3	65.1	15.6	3.3	3.8	6.1	0.7
Dry Fork	15647	84.7	8.7	5.8	58.1	20.4	1.5	1.5	4.0	0.1
Glade Creek	25804	100.0	0.7	0.3	50.5	40.5	0.3	0.7	4.5	2.6
Little Sequatchie River, Upper	31910	76.2	9.6	4.5	68.6	7.1	3.5	0.8	5.7	0.3
Piney Creek	15383	98.4	1.3	1.3	83.0	12.9	1.0	0.0	0.3	0.2
Pockett Creek	8982	88.9	0.0	43.0	41.5	7.2	3.7	0.0	3.4	1.3
Rocky River, Lower	35526	81.9	16.2	2.7	66.9	7.5	1.0	2.1	0.9	2.6
Savage Creek	22246	93.8	12.4	2.7	58.2	4.5	0.5	7.0	14.4	0.1
AVERAGE	25282	89.9	6.8	6.2	62.7	13.0	2.0	2.0	5.5	1.8

1997	Total HUC in Study Area (acres)	(%) HUC in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
Big Brush Creek	36439	81.3	3.5	2.9	57.4	8.6	2.0	1.6	23.6	0.4
Big Coon Creek	139	84.9	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Big Creek	40204	94.6	10.4	7.9	62.6	11.0	1.6	0.0	3.7	2.8
Cane Creek, Upper	42049	99.2	0.1	1.3	63.9	18.6	2.9	0.0	1.3	12.0
Collins River, East	29127	94.7	4.9	2.6	65.9	15.3	3.0	0.6	6.7	0.9
Dry Fork	15647	84.7	1.5	1.4	71.2	20.4	1.4	0.6	3.5	0.1
Glade Creek	25804	100.0	0.7	0.3	50.5	40.5	0.4	0.0	4.8	2.8
Little Sequatchie River, Upper	31910	76.2	2.8	4.9	73.2	6.8	3.5	0.8	7.5	0.5
Piney Creek	15383	98.4	0.5	1.3	84.2	12.9	0.6	0.0	0.3	0.2
Pockett Creek	8982	88.9	0.6	36.8	46.9	7.1	3.9	0.0	3.4	1.3
Rocky River, Lower	35526	81.9	2.6	2.4	83.3	8.1	0.6	0.0	0.4	2.7
Savage Creek	22246	93.8	7.8	1.2	64.6	4.7	0.6	0.6	20.3	0.1
AVERAGE	25288	89.9	2.9	5.3	68.6	12.8	1.7	0.4	6.3	2.0

1981	Total HUC in Study Area (acres)	(%) HUC in Study Area	Logged - Cleared (%)	Native Forest - Thinned (%)	Native Forest - Intact (%)	Other - No Canopy (%)	Other - Partial Canopy (%)	Plantation - Prep (%)	Plantation - Complete (%)	Pine - Mix (%)
Big Brush Creek	36439	81.3	5.7	2.8	68.2	6.5	0.3	6.5	8.2	1.8
Big Coon Creek	139	84.9	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Big Creek	40204	94.6	0.5	3.1	80.9	9.8	0.3	1.6	0.5	3.4
Cane Creek, Upper	42032	99.2	0.0	1.3	65.9	15.4	2.6	0.0	2.0	12.7
Collins River, East	29127	94.7	0.1	0.9	76.0	16.2	0.8	3.0	2.4	0.6
Dry Fork	15647	84.7	2.5	1.3	77.5	17.1	0.8	0.6	0.2	0.0
Glade Creek	25804	100.0	0.0	0.7	51.8	39.0	0.0	1.5	2.9	4.0
Little Sequatchie River, Upper	31910	76.2	0.4	2.2	79.4	8.0	1.2	3.9	4.7	0.1
Piney Creek	15383	98.4	0.0	1.5	86.6	11.3	0.2	0.0	0.1	0.3
Pockett Creek	8982	88.9	3.3	4.3	80.1	8.2	2.9	1.3	0.1	0.0
Rocky River, Lower	35526	81.9	0.0	0.6	89.5	7.6	0.1	0.0	0.4	1.8
Savage Creek	22251	93.8	0.6	1.1	85.0	3.9	0.3	0.1	8.9	0.1
AVERAGE	25287	89.9	1.1	1.7	78.4	11.9	0.8	1.6	2.5	2.1

Table 2.11. Average size of clearing by county. Coefficient of variation in italics.

County	1980	1997	2000
Bledsoe	**121**	**41**	**50**
	1.24	*0.41*	*1.55*
Franklin	**101**	**79**	**94**
	2.43	*1.30*	*1.36*
Grundy	**45**	**210**	**77**
	1.09	*1.21*	*1.68*
Marion	**33**	**38**	**110**
	1.63	*0.00*	*1.62*
Sequatchie	**111**	**137**	**143**
	1.54	*1.11*	*1.30*
Van Buren	**158**	**141**	**186**
	1.15	*0.99*	*1.44*
Warren	**0**	**123**	**282**
	-	*0.63*	*1.08*
All Counties	**101**	**138**	**116**
	1.77	*1.27*	*1.59*

Chapter 3

Aquatic Biomonitoring

3.1. Introduction

The Cumberland Plateau serves as the headwaters for biologically significant watersheds in the Southern U.S. For example, Herring and Shute (2001) identified the region as having the greatest concentration of rare mussels and fish in the South (see Figures 12, 15 in Herring and Shute 2001). The area also supports significant numbers of rare crustacea, snails, and amphibians (see Figures 4, 10, 18 in Herring and Shute 2001). Forestry activities are known to affect the quality and quantity of water flowing from watersheds (reviewed in Fulton and West 2001). Therefore, to assess the potential effects of forest changes on the Cumberland Plateau, we conducted field samples of stream-dwelling salamanders and macroinvertebrates across our study area. Our goals were: (1) to provide a preliminary assessment of patterns of diversity and abundance of these organisms in different habitats, and (2) to evaluate the feasibility of using focused and inexpensive field sampling to assess changes in biodiversity.

3.2. Methods

Salamanders

Salamanders were sampled during the spring (March and April in 2000 and 2001) and summer (June and July in 2001). The springtime samples were taken in the southern portion of the study area (Franklin and Marion Counties) and were conducted in first-order streams whose watersheds were either entirely covered by native forest, or were entirely clearcut (except for stream-side management zone buffers) within the past 12 months. The summertime samples were taken from undisturbed (native forest) and disturbed (clearcut or heavily logged) streams across the study area. To investigate landscape-level effects, these streams drained watersheds that contained a mixture of land cover types (e.g., samples taken in native forests had some upstream clearcuts in their watershed, and vice versa). Salamanders in all samples were identified in the field using Conant and Collins (1991) and Petranka (1998).

The twenty four springtime samples were conducted by intensively searching 30 m segments of stream (45-60 minutes search per 10 m of stream length). Searches were conducted by turning rocks and hand-sifting through gravel and dead organic material. The entire streambed was searched, as was the stream bank and any mossy overhanging vegetation. We also quantified the volume of coarse woody debris (CWD) in two 15 m x 10 m transects perpendicular to the midpoint of the stream survey. We measured the length and width of all CWD that was greater than 10 cm wide. All CWD was classified on a decomposition scale from 1 to 5 (Table 3.1). These surveys were located in either oak-hickory forests that had not been harvested for at least 30 years, or in recently harvested pine plantations.

The fourteen summertime samples were surveyed in a similar manner, except that 90 m stretches of stream were surveyed (3 person hours per 90 m stream). In addition, three 10 m wide by 30 m long bands of terrestrial habitat were searched by turning CWD having a diameter greater than 5 cm. These bands ran perpendicular to the stream and originated at the 15, 45 and 75 m marks on the 90 m length of stream. The diameter and length of all CWD over 5 cm were measured and classified on the decomposition scale (Table 3.1). Care was taken to minimize the impact of search efforts on the habitat by replacing logs, rocks, and leaf litter in their original positions. Photographs and GPS coordinates (UTM) were taken at each stream (at 0 m, 25 m, 50 m, 75 m and 100 m). Four pictures were taken at each point of upstream, downstream, left and right banks (including adjacent habitat), with compass readings for reference to the stream.

We calculated salamander density for each stream by dividing the total number of individuals detected by the product of the average stream width and the length of the stretch of stream that we sampled. We use two-sample Hotelling's T2 tests to compare salamander density, total volume of CWD, and number of species detected per stream. Because the data did not meet the assumptions of the parametric two-sample Hotelling's T2 test, we used p-values derived from randomization tests based on 10,000 Monte Carlo samples. Landscape-level statistics were calculated using our 2000 land cover database. We calculated the proportion of each land cover type upstream from each sampling point and used Patch Analyst 2.2 to calculate landscape metrics for each watershed.

Macroinvertebrates

We used the same fourteen sites that were used for the summertime salamander samples (see above) and one site was resampled for QA/QC purposes. Sample collection and invertebrate identification used a reduced form of the rapid bioassessment protocols established by the U.S. EPA and followed the methods described in the QAPP (Quality Assurance Work Plan) approved by EPA on April 27, 2001. Collection and identification of macroinvertebrates was performed by S. and L. Hamilton (Austin Peay State University). Benthic macroinvertebrates were collected using a 500 µm opening mesh D-net (this is a change from the QAPP -- the streams were too narrow to use the 1.0 m width kick-net). Collection followed the field sampling procedures for single habitat established in EPA's Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers. At each site, a 100 m sampling reach was delineated and 5 riffle areas within the reach were sampled (1 m^2 each) for macroinvertebrates. Prior to sampling, the habitat was evaluated on the EPA protocols. We also measured the total width of the stream-side management zone (SMZ) buffers of uncut forest along each stream. This measurement was made from the midpoint of each sampling transect. GIS coordinates were recorded using a Magellan GPS 315 unit. In addition, a calibrated Hydrolab Quanta was used to measure the following parameters in the water at each reach: temperature, pH, dissolved oxygen and conductivity. All 5 samples from each reach were combined and preserved in 70 percent ethanol in a sealed Rubbermaid box and provided with a label indicating the date, a site-specific identification code, collection site location, and collector name(s).

Once samples had been transported to the laboratory, they were processed for subsampling and macroinvertebrate identification. Subsampling followed the procedure established in the EPA Rapid Bioassessment Protocols. A 300-organism subsample was removed from each sample and preserved separately from the remainder of the sample. Organisms were identified to the genus level by using a variety of taxonomic keys, including Edmunds et al. (1976), Harris et al. (1987), Stehr (1987), Stewart and Stark (1988), Merrit and Cummins (1996), and McCafferty (1998).

We used Appendix B of Barbour et al. (1999) to assign tolerance values and feeding groups to each taxon in our sample. We used values for the Southeast, but when tolerance/feeding group behavior was not included for the Southeast we used Midwest values and when these were missing we excluded the taxon from the analysis. To examine effects of landuse change on macroinvertebrate communities independent of effects on abundance (i.e. based on presence/absence) we created a Normalized Differenced Benthic Index (NDBI) with the structure:

$$\frac{\#Intolerant - \#Tolerant}{\#Tolerant + \#Intolerant}$$

This index will have a range between -1 with totality of pollution tolerant inverts and +1 being a totality of intolerant inverts. Zero signifies balance between the two. Thus the higher the value, the higher the water quality. Invertebrate taxa were assigned as tolerant if the tolerance score from the RBP's was > 5 and intolerant if the score was < 5 (this corresponds to the mean tolerance for the study area which was 5.3).

Landscape-level statistics were calculated using our 2000 land cover database. We calculated the proportion of each land cover type upstream from each sampling point and used Patch Analyst 2.2 to calculate landscape metrics for each watershed. We calculated area-weighted mean shape index, area-weighted mean patch fractal dimension, and edge density. The former two metrics are measures of how the length of edge increases with the area of patches (this is one way of quantifying fragmentation). Both are weighted for area, so that different sized patches are not given disproportional weight in the metric.

We estimated beta diversity by conducting a detrended correspondence analysis (DCA). This analysis is an ordination technique that uses reciprocal averaging of species abundance data to place samples in an ordination space defined by a small number of dimensions. The detrended analysis places samples in the ordination space such that distances between points are equivalent across the entire ordination space, allowing beta diversity to be compared in units of standard deviations of species turnover.

3.3. Results

Salamanders

The springtime surveys showed that streams in clearcuts had significantly lower salamander density than those in native forests (Figure 3.1 (a); Table 3.2). There were non-significant trends indicating streams in clearcuts have lower richness and volumes of coarse woody debris (Figure 3.1 (b), (c); Table 3.2).

When the summer samples were divided according to the condition of the forest immediately surrounding the stream, there were no significant differences between density, richness, or volume of coarse woody debris (Figure 3.1 (a), (b), (c); Table 3.2). This lack of any significant difference persists when the data are analyzed at the landscape level: there were no significant relationships between density or richness and the proportion of the watershed that had been logged or the proportion of the watershed that was covered in native forest (Table 3.3). There was no relationship between richness and the area-weighted mean patch fractal dimension, the area-weighted mean shape index, or edge density, but density increased with all these metrics (Table 3.3). The relationship between density and area-weighted mean shape index was statistically significant ($p = 0.015$) when significance is determined with a cutoff of $p = 0.05$, but not significant when corrections are made for multiple comparisons (cutoff for significance with Bonferoni correction is $p = 0.005$).

Invertebrates

Disturbed sites had a statistically significant higher abundance of macroinvertebrates (Figure 3.2; Table 3.4). The NDBI index was significantly higher for undisturbed than disturbed sites (Fig 3.3; ANOVA: $F = 16.23$, $p = 0.0017$, power = 0.96; Kruskal-Wallis Chi-Square = 7.9, $p = 0.005$; the tests of error term for normality were all negative, so the ANOVA results could be used: Skewness Normality of Residuals $p = 0.30$, Kurtosis Normality of Residuals $p = 0.46$, Omnibus Normality of Residuals $p = 0.45$, Modified-Levene Equal-Variance Test $p = 0.35$). There were no statistically significant differences between disturbed and undisturbed sites for number of taxa (Figure 3.4), the Hilsendorf index (Figure 3.5), number of EPT individuals (Figure 3.6), number of EPT taxa (Figure 3.7), the proportion of chironomid midges (Figure 3.8), the proportion of gatherer/collectors (Figure 3.9), the proportion of filterer/collectors (Figure 3.10), the proportion of scrapers (Figure 3.11), the proportion of shredders (Figure 3.12), or the proportion of predators (Figure 3.13; see Table 3.4 for statistical tests).

Width of stream-side management zone (SMZ) in logged areas also had a significant effect on NDBI, independent of the disturbed/undisturbed effect (linear regression of disturbance against NBDI with SMZ width as interaction term: $p = 0.0003$, R-squared = 0.64, F-ratio = 24, coefficient = 0.013 (this is approximately a 1.3% increase in NDBI for every meter of SMZ)).

At the landscape level, there were non-significant trends for the NDBI to increase with the proportion of the watershed that was native forest, and to decrease with the proportion of the watershed that was in pine plantation or logged (Table 3.5). The R-square values were, however, very low. A Kruskal-Wallis Multiple-Comparison Z-

Value test indicated that those watersheds that had any logging in them or had any pine plantation in them had lower NDBI values than watersheds without these activities (logging: $Z = 1.91$, $p < 0.05$; pine: $Z = 1.65$, $p < 0.05$ (medians significantly different if Z-value >= 1.65)). There were no significant relationships between macroinvertebrate abundance, number of taxa, number of EPT individuals, number of EPT taxa, or the Hilsendorf index and any of the landscape variables examined (area-weighted mean shape index, area-weighted mean patch fractal dimension, edge density) or with proportions of the watersheds covered by different land uses (native (70%-100% cover), pine plantation, logged; Table 3.5).

The detrended correspondence analysis (DCA) indicated that the communities in disturbed sites were more uniform than were the communities in undisturbed sites (Figure 3.14). The site that was resampled for QA/QC purposes clustered very close to the original sample in the DCA analysis.

The abundance of macroinvertebrates did not predict the abundance of salamanders (linear regression, $p = 0.068$, R-squared = 0.25, coefficient = 0.065), nor did the taxonomic richness of macroinvertebrates predict the richness of the salamander fauna (linear regression, $p = 0.514$, R-squared = 0.036, coefficient = 0.033).

Streams in disturbed sites had a greater percentage coverage by sand than streams from undisturbed sites (Figure 3.15, Table 3.6), but did not differ in any other physical characteristics (Table 3.6).

3.4. Discussion

Salamanders

Our field surveys revealed highly variable population densities of salamanders across our study area. The springtime surveys (conducted in watersheds with just two habitat types: clearcut and native forest) indicated that density, but not richness, was lower in streams running through clearcuts. This pattern was not replicated in the summer surveys that were conducted in much more heterogeneous watersheds. Previous studies (e.g., deMaynadier and Hunter 1995; Herbeck and Larsen 1999) have found that clearcutting depresses salamander populations, at least temporarily, thus our springtime finding is in accord with previous work. The lack of pattern in the summer data could be due to: (1) there is no effect of clearcutting on salamanders, or (2) our study design was not powerful enough to detect any effects (either positive or negative). Possibility (1) is intriguing because it contradicts previous research (see references above) and we would therefore require more field sampling to confirm or refute this hypothesis. Possibility (2) is, we believe, likely because our summer samples (n = 14) spanned a large range of habitat types and landscape configurations, thus there may be as many, or more, independent variables as there are datapoints which leads to decreased statistical power.

Invertebrates

The finding that overall abundance of macroinvertebrates was higher in disturbed streams is consistent with previous research. For example, Kedzierski and Smock (2001) studied streams in Virginia and found that whole-stream annual macroinvertebrate production was greater in sections of streams that were surrounded by logging activities than in undisturbed sections of stream. Likewise, Stone and Wallace (1998) found higher benthic invertebrate abundance in disturbed streams. This increased productivity is likely due to increased sediment in the streams (Kedzierski and Smock 2001). We did find more sand in streams from disturbed sites, which suggests that these streams have received more sediment than undisturbed streams.

The Normalized Differenced Benthic Index (NDBI) indicated that the invertebrate community at undisturbed sites had a higher proportion of intolerant taxa than did the disturbed sites which were dominated by more tolerant taxa. NDBI also increased with SMZ width. The SMZ widths in our analysis varied from 16.7 m to 60 m (total width; stream to edge width would be half this amount). Some streams in our study area were not buffered with any SMZs, but macroinvertbrate samples were not taken from these streams. Our data indicates both that SMZs help provide increased water quality, and that some SMZs in our study area may be too narrow to provide maximal protection. Further analysis with a larger sample size would be required to determine exactly which SMZ width offers maximal protection of water quality. Watersheds that had any logging in them or had any pine plantation in them had lower NDBI values than watersheds without these activities. This data suggests that water quality at the disturbed sites was lower than at the undisturbed sites.

In contrast to the NDBI, the tolerance index and comparisons of function feeding groups showed no significant relationship with local conditions or with landscape-level parameters. The interpretation of these data is open to the same two conclusions as the salamander data: that our sample sizes may have been too small to detect differences, or that differences in some indices may not exist (e.g., Stone and Wallace 1998). The statistical power of many of many of our analyses was low (below 10% in some instances). This low power comes about through the combination of a variable dataset and a relatively low sample size.

Assessment of assessment

Our ability to test hypotheses about the effects of land cover change on salamander and invertebrate populations was limited by the short-term nature of this assessment. In particular, we were constrained to conduct field work before accurate GIS coverages were available. Thus, our field sampling design could not take advantage of spatial statistics or broad-scale information about land cover. An ideal protocol would use GIS coverages to come up with a sampling design that sampled the full range of watershed conditions (e.g., land cover, degrees of fragmentation, etc) and that controlled for both local and landscape level effects.

We also recommend that future projects include higher degrees of replication. We encountered highly variable densities of salamanders and invertebrates (e.g., see outliers and interquartile ranges in Figures 3.1, 3.2, 3.4) and this limited our ability to statistically discern whether there were any patterns embedded in this natural variation.

We found that some macroinvertebrate indices had greater statistical power than others. In particular, the Normalized Differenced Benthic Index (NDBI) was able to discern patterns in the data that other indices could not. Any signal present in the other indices may have been swamped by the very large variation in abundance detected across taxa and across samples in our study. The NDBI uses presence/absence data and therefore is not as strongly affected by variation in abundance as some other indices.

3.5. Summary of Findings and Recommendations

Findings:

- Streams in clearcuts had significantly lower salamander density than those in native forests in the spring samples, but not in the summer samples. There were no statistically significant differences in species richness or volume of coarse woody debris.
- Macroinvertebrates were more abundant in disturbed sites than undisturbed sites.
- An index of water quality based on the proportions of tolerant and intolerant macroinvertebrate taxa indicated that water quality was significantly lower in disturbed sites. Other indices showed no statistically significant differences.

- The index of water quality also increased with stream-side management zone (SMZ) width, indicating that: (i) SMZ's help provide increased water quality, and (ii) that some SMZs in our study area may be too narrow to provide maximal protection.
- Most statistical tests for both salamanders and invertebrates had low statistical power.

Recommendations:

- Future field studies should, if possible, be conducted after GIS descriptions of the habitat are available. These studies should make use of watershed-based landscape metrics (e.g., fractal dimension, proportion of different habitat types, etc.) to plan field sampling.
- Higher degrees of replication would allow the statistical evaluation of variable datasets.
- The Normalized Differenced Benthic Index (NDBI) shows promise for detecting differences in water quality in datasets with low levels of replication and statistical power.
- Our study did not include isolated ephemeral pools. The impact of landuse change on these habitats on the Cumberland Plateau is unknown and we recommend further research on the importance and fate of these habitats.

3.6. Literature Cited

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Figure 3.1. Density and richness of salamanders, and volume of coarse woody debris in native and clearcut forests. Boxplots indicate medians and interquartile ranges, points represent outliers.

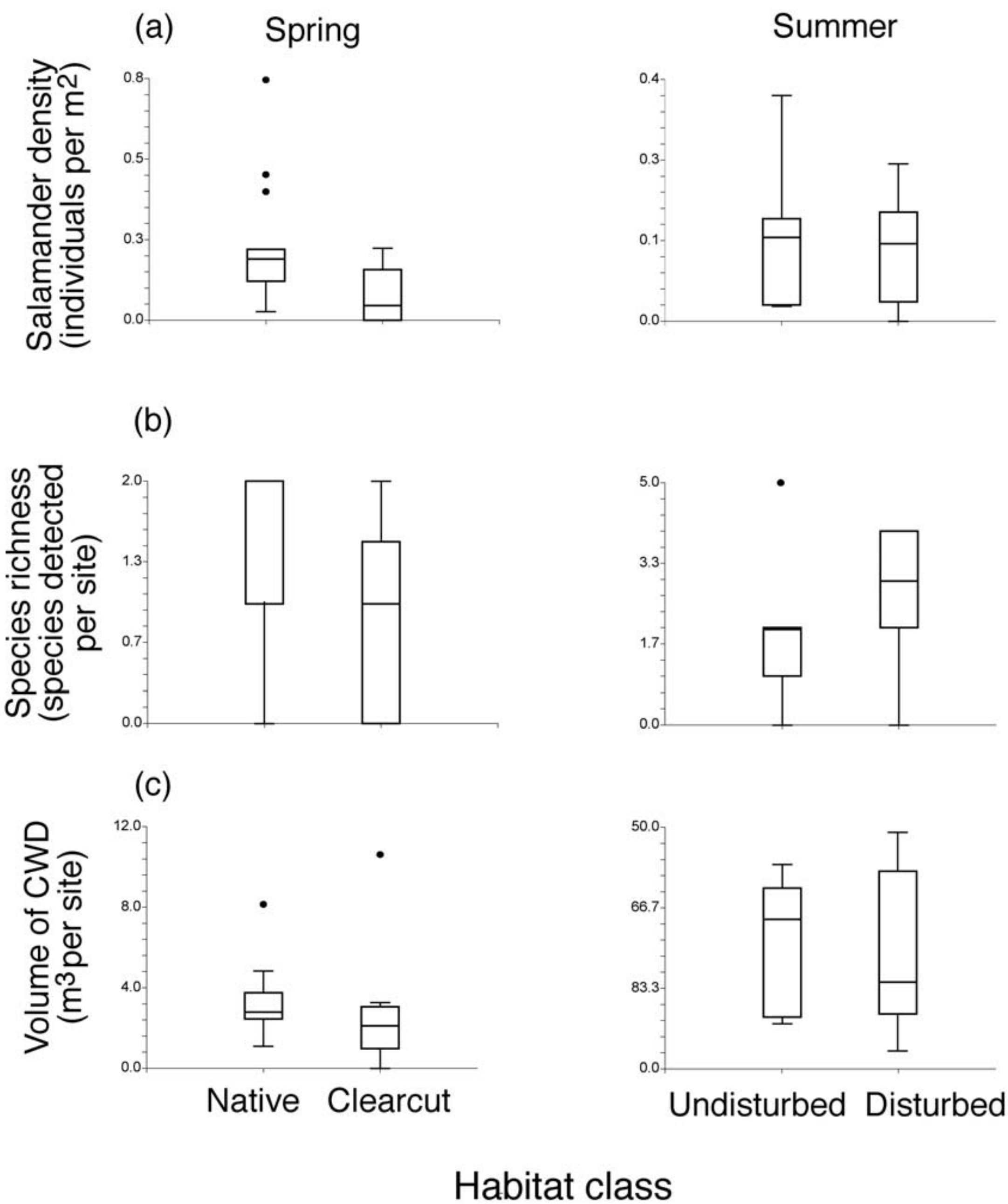

Figure 3.2. Abundance of macroinvertebrates in undisturbed and disturbed streams.

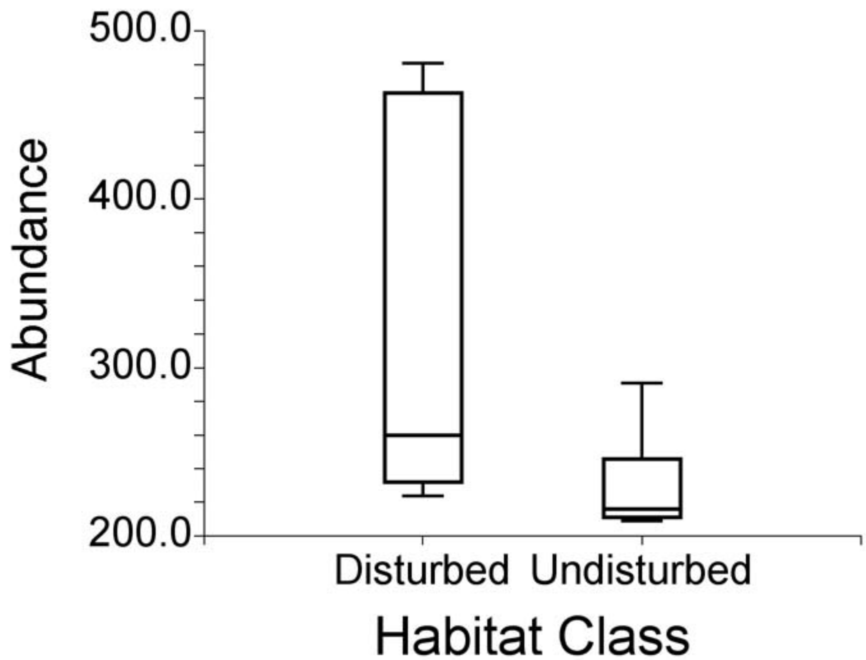

Figure 3.3. Normalized Differenced Benthic Index (NDBI) for disturbed and undisturbed sites. Higher values indicate higher water quality.

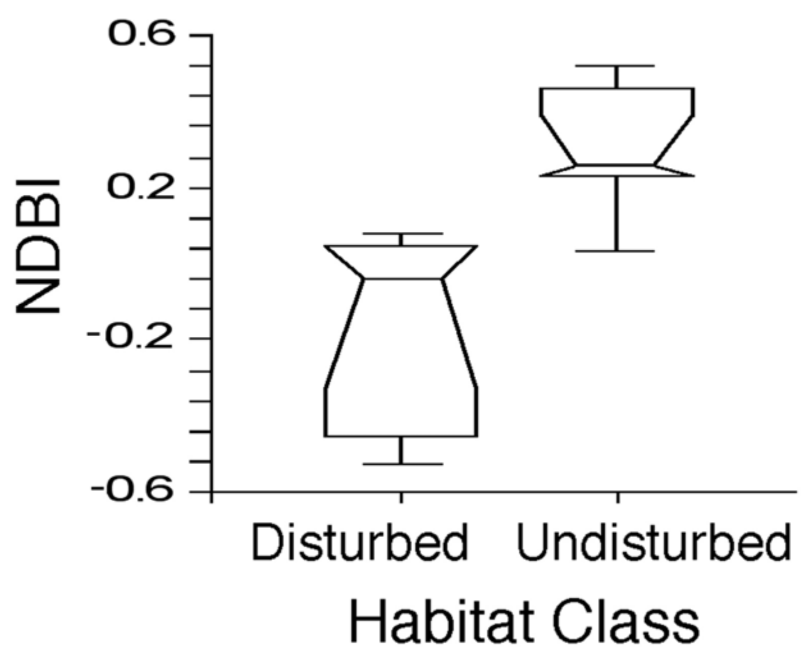

Figure 3.4 Number of taxa of macroinvertebrates in undisturbed and disturbed streams.

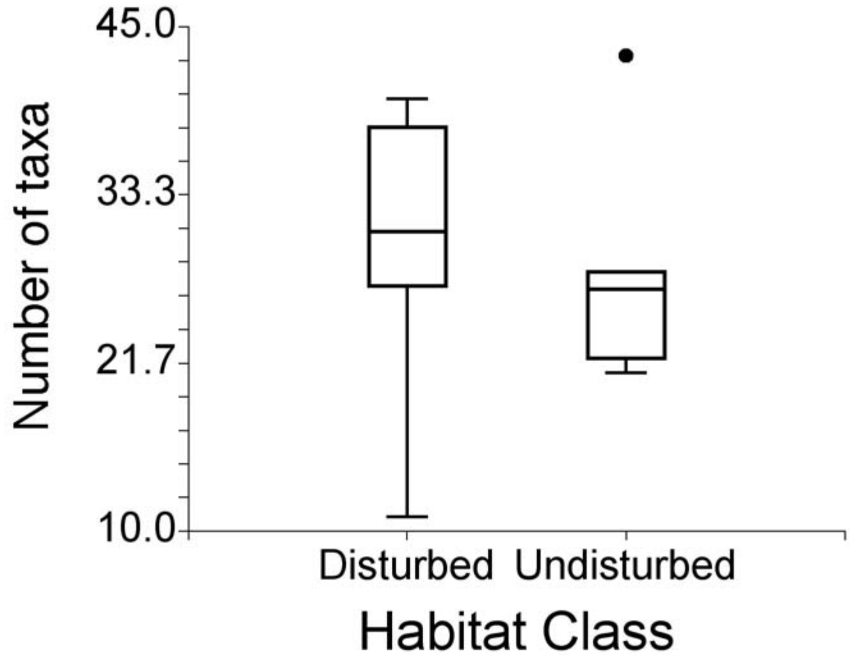

Figure 3.5. Hilsendorf index for of macroinvertebrate communities in undisturbed and disturbed streams.

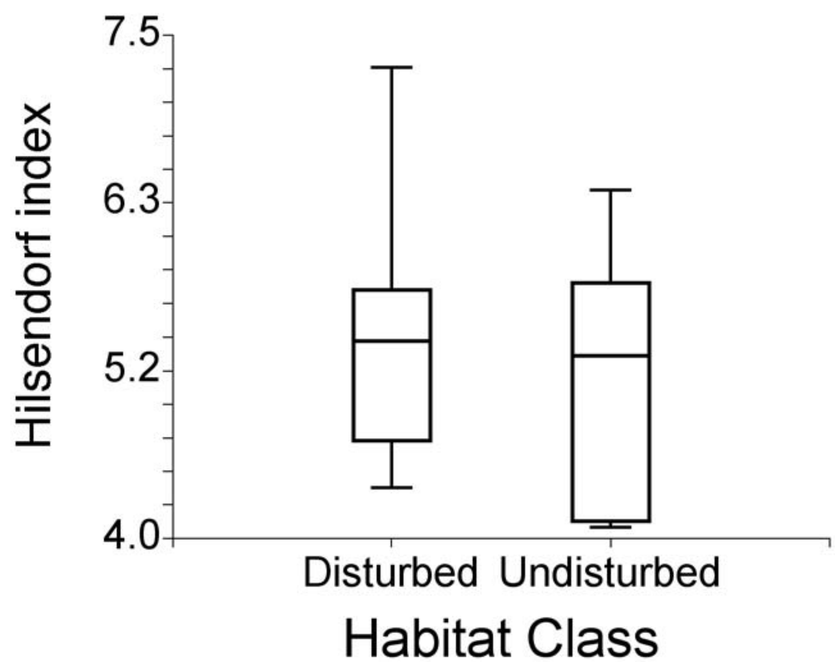

Figure 3.6. Number of EPT individuals in undisturbed and disturbed streams.

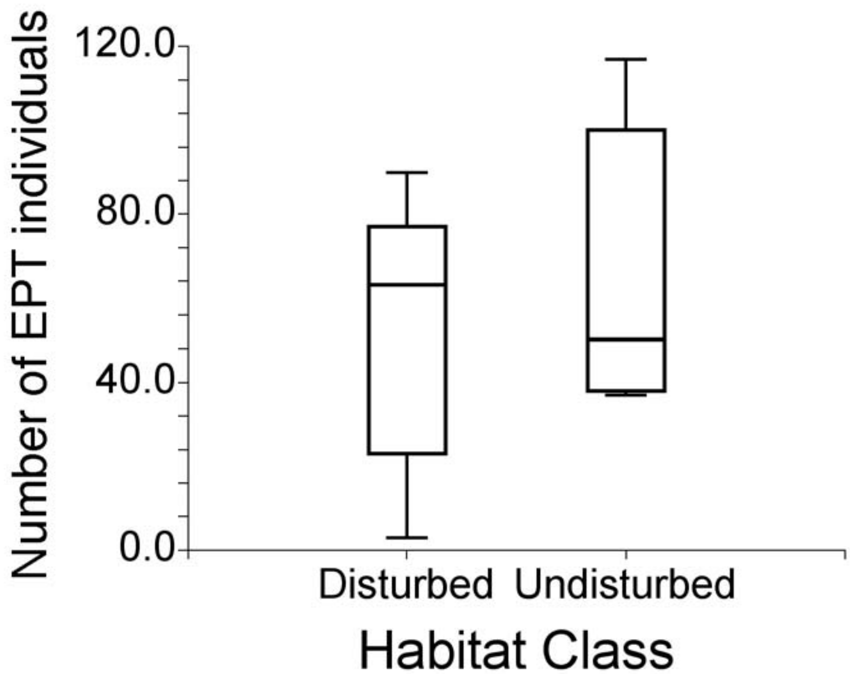

Figure 3.7. Number of EPT taxa in undisturbed and disturbed streams.

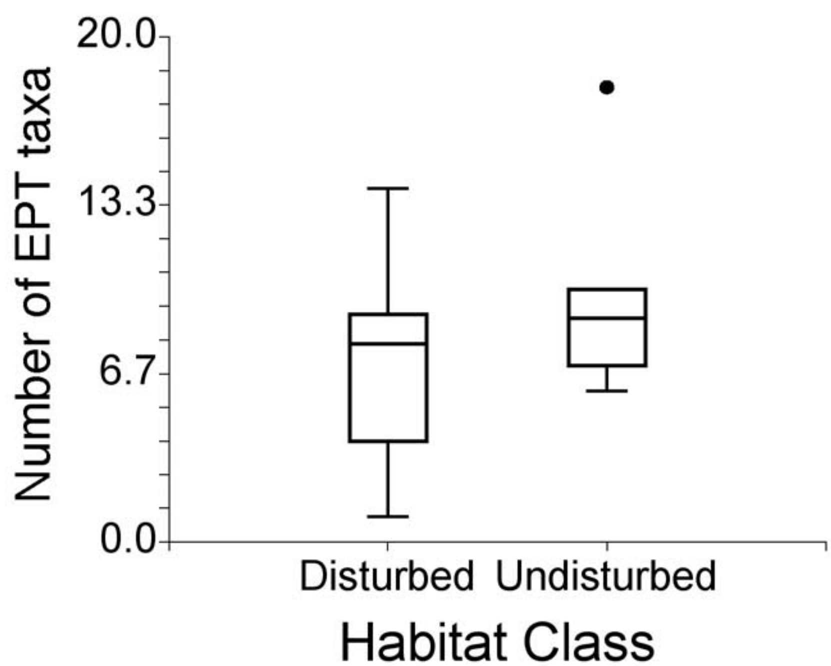

Figure 3.8. Proportion of chironomid midge individuals in undisturbed and disturbed streams.

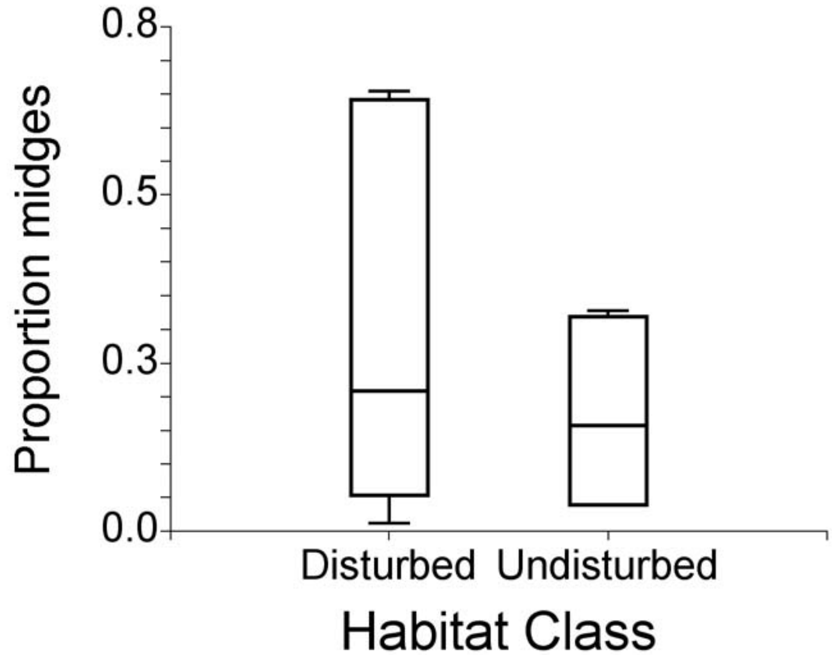

Figure 3.9. Proportion of gatherer/collectors in undisturbed and disturbed streams.

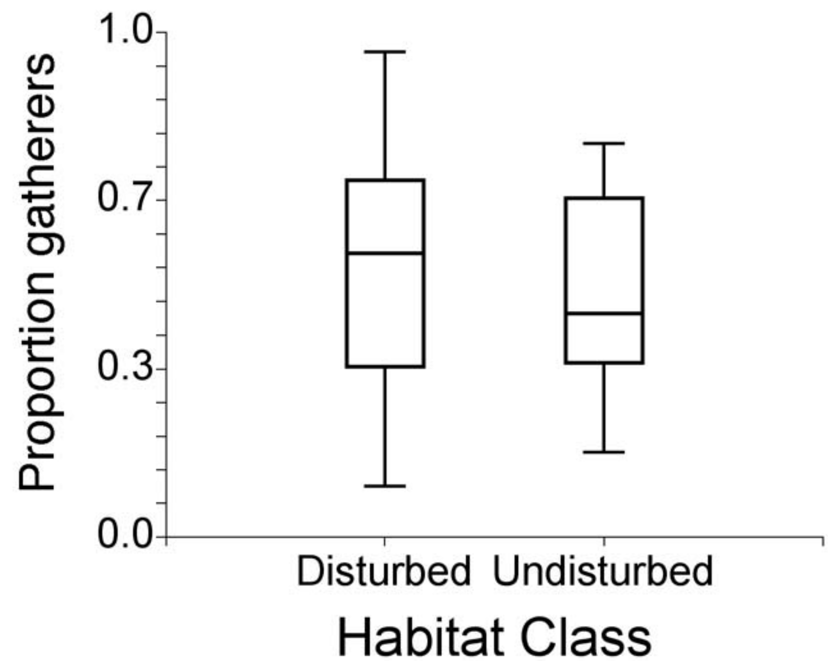

Figure 3.10. Proportion of filterer/collectors in undisturbed and disturbed streams.

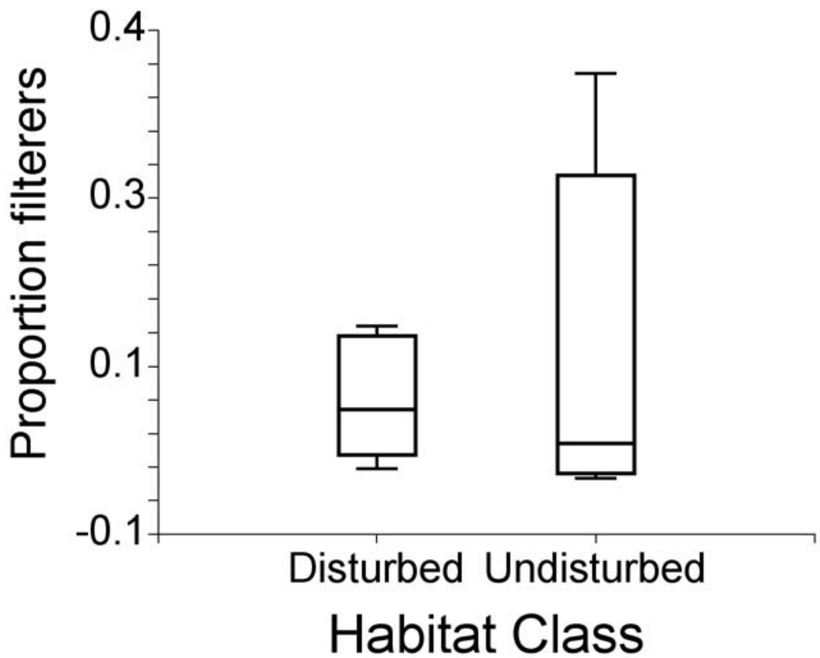

Figure 3.11. Proportion of scrapers in undisturbed and disturbed streams.

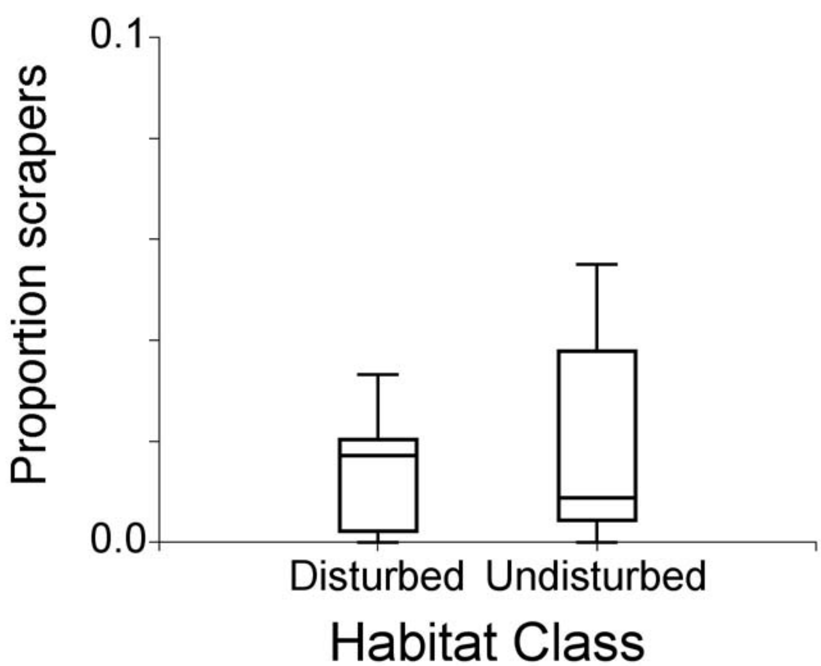

Figure 3.12. Proportion of shredders in undisturbed and disturbed streams.

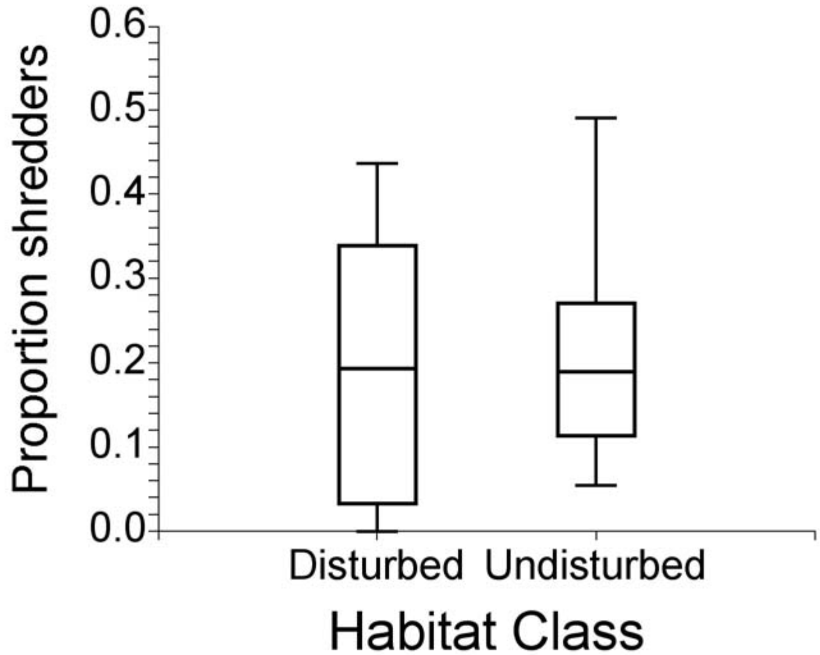

Figure 3.13. Proportion of predators in undisturbed and disturbed streams.

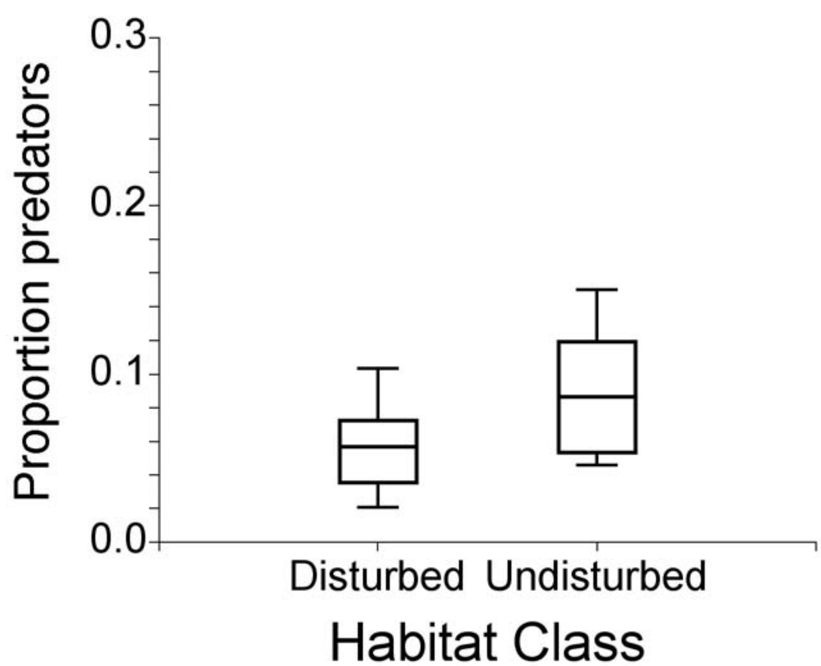

Figure 3.14. Detrended correspondence analysis of macroinvertebrate communities. Each point represents the position in ordination space of the community detected at one stream sample.

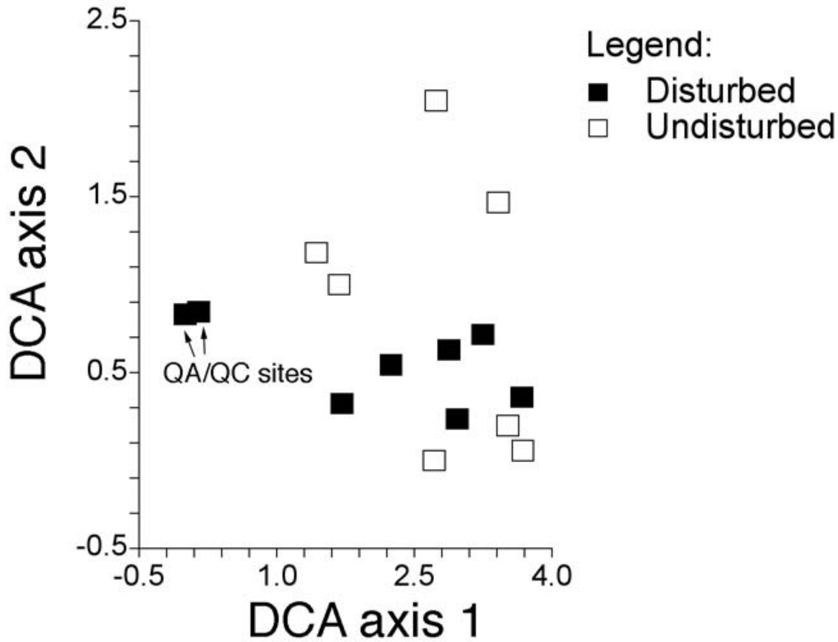

Figure 3.15. Percent of substrate covered with sand in undisturbed and disturbed streams.

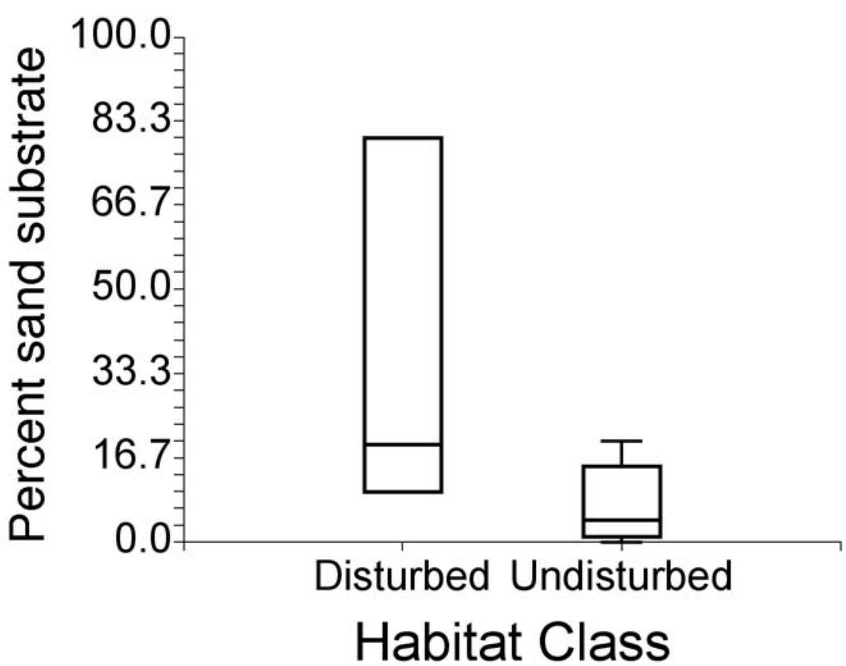

Table 3.1. Decomposition scale for coarse woody debris

Value on Scale	Condition of Coarse Woody Debris
1	No evidence of rot present
2	Start of rot, bark is peeling
3	Some parts are soft, some hard
4	Parts are crumbly, but could still be picked up
5	Wood is entirely crumbled or collapsed

Table 3.2. Comparison of native forests and harvested pine plantations. P-values derived from randomization tests based on 10,000 Monte Carlo samples for the Hotelling's T2 test.

Variable:	T2 value		p value	
	Spring	Summer	Spring	Summer
Salamander density	5.05	0.11	0.026	0.75
Total volume of coarse woody debris	0.283	0.061	0.63	0.81
Species richness	0.82	0.53	0.41	0.50

Table 3.3. Regression statistics for analyses of the effects of upstream watershed composition on the density and richness of stream-dwelling salamanders. Degrees of freedom were 1, 37 for all regressions.

Dependent variable:	Independent Variable	Regression Coefficient	R-squared	F ratio	P value
Density	Proportion Logged	- 8.32	0.031	0.383	0.547
	Proportion Native Forest (70-100% canopy cover)	+ 0.00028	0.000001	0.000	0.997
	Area-weighted mean shape index	2.162	0.400	8.008	0.015
	Area-weighted mean patch fractal dimension	89.92	0.258	4.183	0.063
	Edge density	8474	0.329	5.906	0.0312
Richness	Proportion Logged	+ 2.42	0.081	1.054	0.325
	Proportion Native Forest (70-100% canopy cover)	- 2.50	0.267	4.3751	0.058
	Area-weighted mean shape index	0.120	0.085	1.116	0.311
	Area-weighted mean patch fractal dimension	6.170	0.083	1.096	0.316
	Edge density	747.7	0.176	2.573	0.134

Table 3.4. Mann-Whitney U-tests of biological characteristics of disturbed versus undisturbed invertebrate sampling sites (n = 14).

Response variable	Z-value	P value
Total number of individuals	2.044	0.04
Total number of taxa	1.156	0.247
Hilsendorf index	0.388	0.701
Number of EPT individuals	- 0.967	0.333
Number of EPT taxa	- 0.639	0.522
Proportion chironomid midges	0.511	0.605
Proportion gatherer-collectors	0.388	0.701
Proportion filterer-collector	0.388	0.701
Proportion scraper	0.064	1.00
Proportion shredder	- 0.128	0.898
Proportion predator	- 1.661	0.096

Table 3.5. Regression statistics for analyses of the effects of upstream watershed composition on macroinvertebrate fauna. Degrees of freedom were 1, 13 for all regressions.

Independent variable	Dependent variable	Regression Coefficient	R-squared	F ratio	P value
Proportion Native Forest (70-100% canopy cover)	NDBI	0.31	0.098	1.31	0.27
	Abundance	- 55.47	0.0327	0.406	0.535
	# taxa	- 9.672	0.124	1.7029	0.216
	EPT individuals	- 3.943	0.001	0.0174	0.897
	EPT taxa	- 2.400	0.0336	0.4173	0.091
	Hilsendorf index	0.191	0.004	0.0495	0.827
Proportion Pine Plantation	NDBI	- 0.41	0.041	0.52	0.48
	Abundance	- 43.39	0.005	0.062	0.806
	# taxa	- 6.954	0.016	0.203	0.659
	EPT individuals	- 71.92	0.125	1.715	0.214
	EPT taxa	- 0.41	0.000	0.003	0.956
	Hilsendorf index	1.72	0.0869	1.14	0.306
Proportion Logged	NDBI	- 0.468	0.069	0.89	0.36
	Abundance	- 9.908	0.000	0.004	0.95
	# taxa	13.38	0.077	0.998	0.337
	EPT individuals	53.37	0.085	1.122	0.310
	EPT taxa	4.14	0.032	0.401	0.538
	Hilsendorf index	- 1.800	0.117	1.596	0.230
Area-weighted mean shape index	NDBI	0.0024	0.000	0.0098	0.922
	Abundance	13.49	0.26	4.388	0.058
	# taxa	1.07	0.21	3.25	0.096
	EPT individuals	0.608	0.004	0.054	0.814
	EPT taxa	0.288	0.067	0.865	0.371
	Hilsendorf index	0.0033	0.000	0.002	0.964
Area-weighted mean patch fractal dimension	NDBI	- 1.159	0.067	0.87	0.369
	Abundance	789	0.342	6.25	0.03
	# taxa	60.14	.247	3.95	0.07
	EPT individuals	9.29	0.000	0.005	0.944
	EPT taxa	15.15	0.069	0.889	0.364
	Hilsendorf index	- 0.168	0.000	0.002	0.965
Edge density	NDBI	59.00	0.02	0.312	0.586
	Abundance	16950	0.022	0.278	0.607
	# taxa	2942	0.085	1.117	0.311
	EPT individuals	3090	0.006	0.079	0.782
	EPT taxa	1376	0.081	1.071	0.321
	Hilsendorf index	9.801	0.000	0.001	0.976

Table 3.6. Mann-Whitney U-tests of physical characteristics of disturbed versus undisturbed invertebrate sampling sites (n = 14).

Response variable	Z-value	P value
Temperature	0.929	0.353
pH	- 0.928	0.353
Specific conductance	- 0.788	0.431
Dissolved oxygen	- 1.001	0.316
Turbidity	1.642	0.100
Percent sand substrate	2.326	0.020

Chapter 4

Bird Community Responses to Forest Change

4.1. Introduction

The land cover changes described in the first part of this report may have significant effects on the composition of the bird communities on the Cumberland Plateau. To assess the direction and magnitude of these effects we examined publicly available databases for information on bird communities on the Cumberland Plateau. These datasets include the Breeding Bird Survey (BBS, Sauer et al. 2000), Species Management Abstracts compiled by The Nature Conservancy (SMA-TNC; http://www.partnersinflight.org/birdacct.htm), Birds of North America species accounts (BNA, Poole et al., eds, 1992-2001), and the Atlas of the Breeding Birds of Tennessee (ABBT, Nicholson 1997).

SMA-TNC and BNA provide summary information about the biology of most North American bird species. This information includes overviews of the conservation status of each species and suggestions for management actions to improve habitat. Although these databases provide useful information about general habitat requirements of birds in our region, neither database contained information about the distribution and abundance of birds on the Cumberland Plateau.

The BBS provides information about the abundance of breeding birds along selected roadside survey routes throughout North America. The surveys have been conducted since the 1960's and provide a continent-wide assessment of the status of breeding birds. The BBS surveys are not designed to provide information about bird communities in specific habitat types (each survey route usually crosses many different habitats), so BBS data cannot easily be used to assess the effects of land use change on bird communities across our study area.

The ABBT was constructed using field surveys to map the distribution and abundance of breeding birds at a sub-county level across Tennessee. The Atlas results provide detailed information about the general distribution of birds on the Cumberland Plateau. Because the field surveys encompassed many habitat types, the ABBT does not provide habitat-based quantitative estimates of bird density.

Thus, pre-existing datasets cannot be used to derive specific information about the community structure (e.g., abundance, species richness, species evenness) of birds in different habitat types on the Cumberland Plateau. Therefore, to assess the effects of changing land cover on bird communities we conducted field surveys of breeding birds in the major habitat classes on the Cumberland Plateau.

4.2. Methods

Bird Surveys

The composition of bird communities was quantified using 5 minute point counts arranged in transects. To eliminate among-observer bias all counts were conducted by one observer (DGH). Each transect had 10 counts (unless the size of the habitat patch was too small to fit 10 counts) and a pedometer was used to space counts within each transect 200m apart. The pedometer was calibrated every second transect by walking a 200m measured with a tape. All counts were conducted within 4 hours of sunrise. At each count all birds seen or heard were recorded and the distance between the observer and each bird was estimated using a rangefinder. Counts were not conducted if the wind speed was above 3 on the Beaufort scale or if it was raining or foggy. Each transect was contained within just one habitat class (defined below) and counts were conducted at least 50m from the edge of each habitat class (usually more than 150m).

Each transect was located in one of six distinct habitat classes: mature native hardwood forests (NATIVE), thinned native forests (THINNED), mature loblolly pine (*Pinus taeda*) plantation (LATE), mid-aged loblolly pine plantation (MID), early loblolly pine plantation (EARLY), and residential-rural areas (RES-RURAL). NATIVE sites were dominated by mature trees and showed no evidence of recent logging. They had canopies dominated by oaks (*Quercus* spp.) and hickories (*Carya* spp.), with some Virginia pine *(Pinus virginiana*), shortleaf pine (*Pinus echinata*), and red maple *(Acer rubrum*). These forests had understories of immature trees, blueberries (*Vaccinium* spp.), greenbriar (*Smilax rotundifolia*), and sassafras (*Sassafras albidum*). These understories varied from dense to sparse. THINNED sites had between 50% and 90% of the canopy removed but had not been subject to burning, herbicides, or bulldozing. All had been thinned within two years of the bird counts. LATE plantations had completely closed canopies of loblolly pine and had a sparse understory of sassafras, maple, and blueberry. MID plantations had loblolly trees between 0.5m and 2m high and had not formed a closed canopy. Grasses, forbs, and *Rubus* bushes grew densely between the pines. Trees on EARLY plantations were shorter than 0.5m and were separated by ground that had been bared by a combination of one or more site preparation techniques (burning, herbicides, and bulldozing). They had either no other visible living plants, or sparse growth of ragweed (*Ambrosia artemisiifolia*) and grasses. RES-RURAL sites encompassed areas ranging from suburban (e.g., strip malls, housing developments), through exurban, to rural (farmhouses scattered in a mix of pasture and woodland).

The habitat classes used in this chapter correspond to the canopy cover classes of Chapter 2 in the following way:

- NATIVE = NATIVE-INTACT
- THINNED = NATIVE-THINNED
- LATE or MID = PLANTATION-COMPLETE
- EARLY = PLANTATION-PREP
- RES-RURAL = OTHER

There were no significant differences among habitat classes for the dates on which counts were made (Kruskal-Wallace ANOVA, Chi-squared = 10.4, $p = 0.11$). Counts were made in 2000 and 2001 and all analyses were conducted on data pooled between years. To check for any strong year-to-year variation, we randomly selected three transects from 2000 for repeat sampling in 2001 and found no significant differences in richness or abundance.

Analyses

Richness

We quantified species richness at three spatial scales: at the level of each point count, at the level of each transect (pooling all points within each transect), and at the level of each habitat class (pooling all transects within each class). For the two larger scales we compared richness using rarefaction curves. These curves describe species richness while controlling for the confounding effect of sampling effort and bird density (Gotelli and Graves 1996). We constructed rarefaction curves using EcoSim 6.0 (Gotelli and Entsminger 2001) with 1000 iterations and independent sampling. For the analysis at the level of habitat classes we used the default abundance levels for rarefaction curve construction (S + 3 abundance levels up to a maximum of 42, where S = number of species in sample). For the analysis of transects we constructed rarefaction curves for each transect, then calculated the mean and standard error of all transects within each habitat class. Because transects differed in the number of individuals detected, we truncated each transect's rarefaction curve at the abundance level that allowed comparison across all transects within a habitat class. Thus, we truncated the analysis at 50 individuals for RES and THINNED, 36 individuals for NATIVE, 30 individuals for EARLY and MID, and 24 individuals for LATE.

For the analysis at the level of individual points there were not enough observations per point to construct meaningful rarefaction curves, so we calculated the number of species at each point and performed a nested ANOVA for richness (transect nested within habitat class; ANOVA calculated using MGLM in Systat (1992)). This point-level analysis therefore controls for sampling effort, but not density (samples with more individuals will likely have more species detections).

To check the robustness of our conclusions we calculated two sets of analyses for the data at the level of habitat classes and at the level of individual point counts: one including all the birds encountered (including flyovers), the second using just birds detected within 50m of the count center (a 50m cut-off for is the standard used in previous studies, e.g., Hagan et al. 1997).

Evenness

We used EcoSim 6.0 to calculate Hurlbert's (1971) probability of interspecific encounter (P. I. E.) for each transect and for data pooled within each habitat class. This measure of evenness controls for variation in the number of individuals sampled. We used the same EcoSim settings and datasets as the richness analyses.

Abundance

We used three methods to check the robustness of our conclusions to variation in the technique used to calculate density. First, we produced an index of abundance by summing the numbers of birds detected at each point, regardless of distance from the point. Second, we calculated per-point densities by dividing the number of birds detected within 50m of each point by 0.79 ha (the area of the 50m circle). We performed a nested ANOVA on both the abundance index and the per-point densities (transect nested within habitat class; ANOVA calculated using MGLM in Systat (1992)). Third, we used DISTANCE 3.5 (Thomas et al. 1998) to calculate densities using the shapes of detection functions (estimates of how the probability of detecting a bird changes with distance from the point). We used the analytical approach described in Buckland et al. (1993) and used Chi-squared goodness of fit, Akaike's Information Criterion values, and visual inspection of detection functions to select models that provided the best fit to the data. We used these models to estimate densities and 95% confidence intervals for each habitat type.

Beta diversity and ordination

We estimated beta diversity by conducting a detrended correspondence analysis (DCA). This analysis is an ordination technique that uses reciprocal averaging of species abundance data to place samples (e.g., transects or points) in an ordination space defined by a small number of dimensions. The detrended analysis places samples in the ordination space such that distances between points are equivalent across the entire ordination space, allowing beta diversity to be measured and compared in units of standard deviations of species turnover. We conducted two DCAs: one using all point counts as the sampling units and another using transects as the sampling units (with point counts pooled within each). To assess among-habitat differences in beta diversity we quantified variation along the first axis of the DCA in two ways. In the first, we calculated for each sample (either a point or a transect) the absolute value of the deviation from the median value for the habitat class. In the second, we calculated the square of the deviation from the mean value for the habitat class. Habitat classes with high beta diversity should have large deviations from the mean or median. Because the resulting values could not be transformed to meet the assumptions of parametric tests we used MRPP (multiresponse permutation procedures which make no assumptions about the distribution of the data: Blossom, version W2001.08d) to assess differences among habitat classes in these measures of beta diversity. Because beta diversity measures variation among sites, we excluded thinned native forests from these analyses due to the small sample size (n = 3) of sites.

Life history characteristics

We used Birds of North America species accounts (Poole et al., eds., 1992-2001) and descriptions of nest sites in the literature to code each species by nest site and migratory status. We used Chi-squared analyses to test for differences among habitat classes.

Partners in Flight priority scores

To put our results into a regional and global context we produced indexes using Partners in Flight (PIF) priority scores (Carter et al. 2000; we used PIF scores downloaded in July 2001) for all species and habitats in our samples. First, we calculated the number of individuals of each species detected within 50m of count centers per transect for all habitat classes (a measure of relative abundance), then multiplied this by priority scores derived from PIF. This procedure weighs all PIF scores by relative abundance. Second, we examined PIF scores unweighed by any measure of abundance. Because the resulting data could not be transformed to meet the assumptions of parametric tests we used MRPP to assess differences among habitat classes (multiresponse permutation procedures, which make no assumptions about the distribution of the data: Blossom software, version W2001.08d). We also categorized species according to PIF priority ranks (extremely high priority, high priority, moderate priority) and quantified the numbers of species from each habitat class present in each of these PIF priority classes.

Landscape-level analyses

We used our year 2000 land cover GIS layers to calculate landscape metrics associated with each bird-sampling transect. We buffered each transect at 150 m and 1000 m and computed landscape metrics using Patch Analyst 2.2. We then used linear regression to compare each landscape metric to bird species richness measured at the level of the whole transect. For the RES-RURAL habitat class we quantified housing density by placing 150 m and 1000 m buffers around each point and calculating the number of structures within each buffer.

4.3. Results

The field surveys included 503 indvidual point counts in 52 transects (habitat class breakdown: EARLY, 69 points, 7 transects; MID, 75 points, 8 transects; LATE, 54 points, 6 transects; NATIVE, 85 points, 9 transects; RES, 190 points, 19 transects; THINNED, 30 points, 3 transects). 82 species were detected (Table 4.1(a) and (b)).

The six habitat classes differed significantly in species richness. At the scales of habitat classes and transects, residential-rural areas had highest richness, followed by thinned native forests, then native forests, then all age-classes of pine plantation (Figure 4.1, 4.2). A similar pattern emerged at the level of individual counts, except that native forests did not differ from mid-aged pine plantations in the number of species detected per count (Figure 4.3, Table 4.2).

Evenness measured at the scale of habitat classes was also highest in residential-rural areas, followed by thinned native forests, then native forests, then all age-classes of pine plantation (Figure 4.4). At the smaller scale of transects, the same pattern emerged, except thinned forests had slightly higher evenness than residential-rural areas (Figure 4.5).

The two methods used to estimate abundance gave different estimates of densities with the DISTANCE software consistently estimating higher densities than the method of counting birds within a 50m radius (Figure 4.6). Both methods gave similar ranking of relative abundance, however. Abundance was highest in residential-rural and thinned areas, followed by native forests, mid-aged, and late plantations, followed by early plantations (Figure 4.6, Table 4.2).

The DCA ordination analysis showed that the bird communities were distinct in most habitat classes, especially when these communities were examined at the level of transects (Figure 4.7), but these patterns were also apparent at the level of individual points (Figure 4.8; see also Table 4.1(b) for listings of most abundant species in each habitat class). Residential-rural areas clustered away from all other classes and early and mid-aged plantations clustered next to each other away from all other classes. Native forests and late plantations overlapped each other in ordination space and thinned native forests overlapped some native forests, or sat in the center of the ordination space.

The extent of variation along the first DCA axis (beta diversity) also differed significantly among habitat classes (Figure 4.9, 4.10; squared deviation from mean MRPP standardized test statistic = -21.5, $p = 0.000$; absolute deviation from median MRPP standardized test statistic = -26.0, $p = 0.000$). Residential-rural areas had higher variability among points and transects than did the other habitat classes.

The relative abundance of species with different life history characteristics also differed among habitat classes (Figure 4.11, 4.12; Nest sites: Chi-squared = 73.5, df = 20, $p < 0.05$; Migratory status: Chi-squared = 58.9, df = 10; $p < 0.05$). Pine plantations of all age classes had lower abundances of cavity- and tree-nesters, neotropical migrants, and year-round residents than did all other habitat classes.

The habitat classes differed in their conservation value (as measured by PIF scores). When PIF scores were weighed by relative abundance, residential-rural areas had the highest scores, followed by thinned and native forests, followed by all ages of pine planation (Figure 4.13; MRPP standardized test statistic = -12.17, $p = 0.000$.) The same result was obtained with unweighed PIF scores (Figure 4.14; MRPP standardized test statistic = -24.33, $p = 0.000$). When species were categorized according to PIF priority ranks (extremely high priority, high priority, moderate priority), the same ranking emerges (Table 4.4), except that the only bird found from the “extremely high priority” category was found in a young plantation (this was one individual golden-winged warbler).

The relationship between landscape structure and bird species richness depended strongly on the spatial scale at which the landscape measure were made (Table 4.3). For 150 m buffers, species richness increased with edge density, area-weighted mean shape index (AWMSI), and area-weighted mean patch fractal dimension (AWMPFD) (Figure 4.15, 4.16, 4.17). These trends were reversed for 1000 m buffers (Table 4.3, Figs. 4.18, 4.19, 4.20).

The average number of houses around each point count in the "residential-rural" habitat class was 4.3 (mean) and 3 (median) for 150 m buffers and 93.3 (mean) and 61 (median) for the 1000 m buffers (Figure 4.21). These correspond to mean housing densities of 0.61 houses/ha (150 m buffers) and 0.30 houses/ha (1000 m buffers). The range of housing density is 0 - 3.25 houses/ha (150 m buffers) and 0 - 1.59 houses/ha (1000 m buffers). Using Marzluff et al.'s (2001) definitions, his habitat class therefore spanned sites that included "suburban", "exurban", and "rural" habitats.

4.4. Discussion

Summary of findings

The field surveys show that the breeding bird communities of both pine plantations and residential-rural areas differ from those found in oak-hickory forests (see Table 4.1(b) for listing of the most abundant species in each habitat class). All ages of pine plantations had lower species richness than did oak-hickory forests. In late rotation plantations those species that were still present were similar to those found in oak-hickory forests, whereas early and mid rotation plantations were dominated by early successional specialists. Pine plantations also had lower evenness than oak-hickory forests, meaning that the bird communities in plantations were dominated by a few species, rather than having many species of more equal abundance. Plantations had either similar beta diversity (early and late rotation plantations; beta diversity is a measure of the extent to which community structure changes from place to place) or slightly lower beta diversity (mid rotation plantations) than did oak-hickory forests. Overall abundance of birds in plantations was either lower (for late and early rotation plantations) or the same (for mid rotation plantations). Plantations had fewer cavity- and tree-nesting birds, a proportional loss of neotropical migrant birds relative to oak-hickory forests (especially for early and mid rotation plantations), and a proportional increase in early successional species.

The bird community found in residential-rural areas had higher species richness than that found in oak-hickory forests. The species composition of the bird community in these areas showed some overlap with oak-hickory forests, but some forest-dwelling species were present at lower abundance. Several species were found only in residential-rural areas (e.g., cedar waxwings, barn swallows). Evenness, beta diversity, and overall abundance were also higher in residential-rural areas. There were no pronounced differences in the breakdown of nest site usage or migratory types between the bird community in residential-rural areas and the community in oak-hickory forests, although there was a trend for residential-rural areas to have proportionally more short-distance migrants and year-round residents (residential-rural areas had higher richness, so the actual number of neotropical migrant species was higher).

Thinned forests had higher richness, evenness, and abundance of birds than did oak-hickory forests. The bird community was a mix of early successional species (e.g., prairie warblers) and forest-nesting species (e.g., woodpeckers).

The comparisons of species richness, evenness, and abundance described above provide one approach to understanding the conservation value of habitat types. Another approach takes a continent-wide perspective by using the priority scores developed by Partners in Flight (PIF). These scores are assigned to every bird species based on both objective criteria (e.g., data on changes in abundance through time) and subjective criteria (e.g., assessments made by PIF personnel of perceived threats to habitat). Species with high scores are considered to have higher conservation value than those with low scores. When these scores were used to compare the bird communities assessed in this study, residential-rural areas obtained the highest scores, followed by thinned forests, oak-hickory forests, then pine plantations. This finding was the same irrespective of whether the PIF data was weighed by relative abundance. In addition, when the data are summarized using only birds in high-ranking PIF categories, the same conclusions emerge. Therefore, all habitat classes provide habitat for some species and all habitats provide habitat for at least a few high priority species. However, residential-rural areas provide the most benefit to birds and pine plantations provide the least benefit (as measured by PIF scores). This conclusion is the same as that derived from the comparison of diversity and abundance among habitat types (see above): Residential-rural areas have the highest diversity and abundance and pine plantations have the lowest.

Changes in land cover affect bird populations not only by changing stand-level features (as described above), but by changing the spatial configuration of land covers (e.g., by changing levels of fragmentation). In this study, the direction of landscape effects on breeding bird richness depended on the spatial scale at which we calculated landscape metrics. Increases in edge density, area-weighted mean shape index (AWMSI), and area-weighted mean patch fractal dimension (AWMPFD) were all associated with increases in species richness when the metrics were calculated within 150m buffers of the transects. Thus, at a small scale, increases in edginess and fragmentation increase bird diversity. When the same relationships are examined within 1000 m buffers, the pattern reverses. Larger scale edginess and fragmentation are associated with decreased bird diversity.

Discussion of relationship to previous studies of bird communities

The finding that pine plantations in our study area support lower species diversity of birds echoes the results of some previous studies in other areas of the Southern U.S. (Dickson et al. 1995; Repenning and Labisky 1985). However, there have been no other published studies in the south-east that have compared the bird communities in pine plantations, residential-rural areas, unmanaged forests, and thinned forests. We believe that such comparisons are important because they place the bird community found in each habitat type into a regional context (more such studies are in review and may be published soon, C. Hunter, pers. comm.).

One region for which such comparisons have been published is the boreal and sub-boreal forest in Eastern North America. Hagan et al. (1997) found that timber management had a pronounced effect on bird communities. They found that clearcuts and old growth forest had lower bird diversity than any other forest type. Drapeau et al. (2000) also found differences among land management types, with “industrial forests” having different communities than either natural areas or more residential/agricultural areas. The differences in species richness in both these studies were, however, very small compared to the large differences in richness observed in this study. This suggests that the effects of forest management may differ strongly from region to region. In particular, the species-rich bird communities in the native forests of the Cumberland Plateau seem much more vulnerable to loss of diversity when subjected to intensive timber management than do the bird communities with relatively low species richness in native northern forests. For example, some of the birds that are found at high densities in oak-hickory forests (e.g., white-breasted nuthatch, tufted titmouse) are very rare or absent in pine plantations. Other species that dominate oak-hickory forest bird communities (e.g., red-eyed vireo, scarlet tanager, ovenbird, hooded warbler) are found at much lower densities in plantations. These negative effects extend to rarer species (e.g., Acadian flycatcher, Carolina wren, summer tanager) which are either lost from plantations or found at lower abundance.

The loss of forest-dwelling birds in our region is of special significance because of the very high richness of species found in the native oak-hickory forests. When compared to other studies of birds in southern forests, the bird community in our region had by far the highest species richness, with only the Great Smoky Mountains coming close (Table 4.5). This comparison should be regarded as preliminary and subject to further refinement because comparing across studies with different sampling designs is statistically problematic. However, the comparison does indicate that native oak-hickory forests in our region likely provide very high quality habitat.

We did not sample birds in burned areas nor in areas of old-growth forest. Both these habitat types are currently rare in our study area. It is possible that native forests might support even higher diversity of birds (and perhaps even some very high priority species such as red-cockaded woodpeckers) if old growth conditions were to be restored in some areas and if natural disturbance regimes (such as fire) were reintroduced to the plateau. Whether this hypothesis is correct or not awaits further investigation, but it is clear that even with the present lack of natural burns, the forests of the Cumberland Plateau provide high value habitat for many bird species.

The intensive mechanical and chemical preparation techniques used to prepare land for pine plantations on the Cumberland Plateau involves the removal of all or most of the vegetation. The plantation is then stocked with one species of tree, although some other species resprout to form an understory. These processes reduce the structural complexity of the plantation and remove most cavity trees from the area. Thus, many cavity nesters are lost and the simplified vertical and horizontal structure of the forest may translate into lower bird diversity. This finding is consistent with previous work on the relationship between the structural complexity of habitat and bird diversity (e.g., Roth 1976).

The early stages of pine plantations provide habitat for some early-successional specialist birds such as prairie warblers and yellow-breasted chats. Many of these early-successional species reach their highest densities in young pine plantations. These species were also found (at lower densities) in thinned forests (native forests with 50% to 90% canopy clearing), residential-rural areas, and native forests.

Thinned forests also retained some forest-dwelling species such as woodpeckers, resulting in higher diversity and abundance of birds and higher PIF scores than plantations.

Residential-rural areas had the highest diversity and abundance of birds. This likely results from the very high structural diversity of these areas (e.g., mix of forest, ornamental shrubbery, lawns, and urban areas). Savard and Falls (2001) found that the diversity of birds in residential-rural areas depended, in part, on the maturity and complexity of vegetation. Our study did not include measures of vegetation at each count location, so the small-scale correlates of bird diversity within residential-rural areas await further investigation in our region.

Residential-rural areas provided habitat for both early successional species (e.g., common yellowthroats, chipping sparrows, blue grosbeaks) and for late successional species (e.g., pileated woodpeckers, wood thrushes). This combination of species, many of which have high PIF priority scores, accounts for the high overall “conservation value” of residential-rural areas (as measured by PIF scores). A number of species (e.g., barn swallows, cedar waxwings, red-winged blackbirds, purple martins) were found only in residential-rural areas. This suggests that residential-rural areas provide unique habitats unavailable elsewhere on the landscape. The bird community in residential-rural areas also, however, included species that are generally considered to have low or negative conservation value: exotics (European starling, house sparrow, rock dove) and brood parasites (brown-headed cowbirds). In addition, although residential-rural areas supported many forest-adapted species, the densities of some of these species were lower than in native forests. This suggests that conversion of native forests to residential-rural areas will have negative effects on many of the birds in these forests.

Comparison to previous assessments of bird conservation on the Cumberland Plateau

Two previous assessments are most relevant to this study: the Partners in Flight Bird Conservation Plan for the Cumberland Plateau and the Southern Forest Resource Assessment. The PIF plan (Anderson et al. 2000) describes the birds found in most habitat types on the Plateau, then provides guidelines to help landowners and managers maintain or enhance the conservation value of each habitat type. The bird communities found in our study correspond fairly well with those listed in the PIF plan. However, because the PIF plan was written without extensive field surveys, there are a few discrepancies. For example, the PIF plan states that Eastern wood-pewees, Bachman's Sparrows, yellow-throated warblers, and gray catbirds will all use pine plantations (p. 64 in the plan). We found no wood-pewees or catbirds in any surveys in pine plantations. We detected only one Bachman's sparrow (in a ~3 year old plantation that had burned) and found yellow-throated warblers at low densities in streamside buffers in clearcuts, but in no other plantations (they were, however, abundant in thinned forest, residential-rural areas, and areas of native forest with a large native pine component). Plantations did, however, contain high densities of prairie warblers, yellow-breasted chats, field sparrows, and Eastern towhees, as predicted by the PIF plan.

The PIF plan does not evaluate the relative importance or conservation value of each habitat type, except to describe urbanization as "the most significant bird conservation issue". This conclusion was not based on any quantitative assessment of the spread of urban areas nor did it incorporate any measure of the conservation value of urban areas. Our study indicates that pine plantations occupy a much larger acreage and have spread faster than urban areas on the Cumberland Plateau. Plantations also have substantially lower diversity and are lower "conservation value" habitats as measured by PIF scores. Residential-rural areas have higher diversity at all spatial scales and result in higher "conservation value" habitats as measured by PIF scores. This suggests that bird conservation plans should highlight the accelerating conversion of native forests to pine plantations as a potential conservation problem for most bird species on the Cumberland Plateau. In addition, the low rate of urbanization documented in this study, combined with the high conservation value of residential-rural areas, suggests that the PIF plan should revise its assessment of the impacts of urbanization to mention the potential benefits of urbanization for some bird species. This does not imply that urbanization has no negative effects: our data clearly show that some forest-dwelling species fare poorly in residential areas (Table 4.1).

The Southern Forest Resource Assessment (SFRA, see Wear and Greis (2001) for a summary) reviews the current and projected status of forests in the Southern U.S. The report includes an evaluation of wildlife in the forests of the Southern U.S. and although the SFRA covers the whole south-east, not just the Plateau, the report draws a number of conclusions that can be compared to the results of this study. In particular, the report shows that the two largest changes occurring in southern forests are the conversion of native forests to pine plantations and the intrusion of residential and urban areas into forests.

We suggest that the SFRA report contains some important imbalances and omissions in its discussion of how pine conversion and urbanization affect bird conservation in the Southern U.S. As indicated above, the results of our study suggest that pine conversion and urbanization are not equivalent in their impact on breeding bird communities. The SFRA report, however, places heavy emphasis on the negative impacts of urbanization and has sparse coverage of negative effects of pine conversion. For example, five out of nine factors reviewed in Section 3.3.3, "Effects of Land Use Change", discuss the negative impacts of urbanization on wildlife (especially birds), and the section makes no mention of any impacts (positive or negative) of pine conversion. Similarly, Section 3.3.4, "Effects of Forest Management", concludes by stating that "the ultimate challenge of forest management then is to provide the habitat conditions that support the array of ... species occurring within the same landscape", but the section does not evaluate whether pine plantations can achieve this goal. Our data indicate that managed pine plantations in our study area cannot support the bird communities found in native forests (Figure 4.1, Table 4.1). Thus, the predicted continued conversion of native forests to pine plantations will have a significant negative impact on the majority of forest-dwelling bird species. In addition, our data suggest that intensively managed pine plantations provide less benefit for birds (as measured by overall PIF and diversity indices) than do other types of logging activities in native forests (e.g., thinned forests without intensive site preparation).

Caveats and discussion of potential biases

The following points outline some of the limits of this study and describe some caveats about the interpretation of the data.

1. The bird surveys focused on birds that are visible and audible from morning point counts. Thus, they omit birds that are active at night (e.g., whip-poor-wills, owls), or that are inconspicuous at all times (some raptors). The study also likely under-samples birds that breed in the early spring before the return of most migrants (e.g., brown thrashers). The study also provides no data about the habitat uses of migratory birds, post-breeding birds in late summer, or birds in the winter.

2. The data gathered in this study documents the abundance of birds, not their breeding success. At one level (presence/absence) this does not introduce much bias: birds that are not present in a habitat cannot breed. At another level, studies of abundance can be misleading. For example, this study found several forest-nesting

species singing from narrow (1-15m) buffers around streams in clear-cuts. Whether these buffers offer the same quality nesting habitat as unfragmented forest is unknown. Previous studies have found that edge-dominated forest fragments provide sub-optimal nesting habitat for forest-dwelling birds (Gibbs and Faaborg 1990). If this applies to buffers on the Cumberland Plateau, point count surveys that encompass these very narrow strips of forest may be biased towards overestimating the quality of the habitat for forest-dwelling birds. Habitats may also differ in the abundance of nest predators, parasites, and food. In particular, small patches of forest are often associated with lower food supply (Burke and Nol 1998) and higher nest predation, although the strength of the edge-related predation effect is variable (King et al. 1996; Bayne and Hobson 1997; Flashpohler et al. 2001). Residential-rural areas may also have higher densities of exotic predators such as cats. A study on the Cumberland Plateau found that cats were only found at high densities in the centers of urban areas, not in the more sparsely populated suburbs and rural areas (Haskell et al., 2001).

3. Findings from this study should only be extrapolated to other forest types and contexts with extreme caution. Bird-habitat relationships vary geographically and landscape context can affect the responses of birds to habitat changes. For example, the residential-rural areas in this study occur in a matrix of mostly forested land. In regions were forests occupy a much lower proportion of the landscape, fragmentation effects may be more severe. In addition, the data should not be extrapolated to other organisms with out more field investigations. The motility of birds may mean that they react in different ways to large scale changes in forest cover than many less mobile organisms.

4. The measures of conservation value of birds assume that birds have value. Whether or not this is true is beyond the scope of this paper to discuss. It is, however, important to underscore that “conservation value for birds” does not encompass other values such as the availability of hunting opportunities, the harvesting or mining of forest resources, or the quality of life for human residents.

4.5. Summary of Findings and Recommendations

Findings:

- All ages of pine plantations had lower species richness and evenness than did oak-hickory forests. Plantations had either similar beta diversity or slightly lower beta diversity than did oak-hickory forests. Abundance of birds in plantations was either lower or the same as oak-hickory forests. Plantations had fewer cavity- and tree-nesting birds, a proportional loss of neotropical migrant birds relative to oak-hickory forests, and an increase in birds that specialize on early successional habitats.

- The bird community found in residential-rural areas had higher species richness, evenness, beta diversity, and abundance than that found in oak-hickory forests. Residential-rural areas provided habitat for some birds that occurred nowhere else on the landscape, but many forest-dwelling species were less abundant in this habitat class.
- Thinned forests had higher richness, evenness, and abundance of birds than did oak-hickory forests.
- Residential-rural areas obtained the highest PIF scores, followed by thinned forests, oak-hickory forests, then pine plantations.
- We found very high species richness in the native oak-hickory forests. When compared to other studies of birds in southern forests, the bird community in our region had by far the highest species richness, with only the Great Smoky Mountains coming close.
- The direction of landscape effects on breeding bird richness depended on the spatial scale at which we calculated landscape metrics. At a small scale, increases in edginess and fragmentation increase bird diversity. Larger scale edginess and fragmentation are associated with decreased bird diversity.

Recommendations:

- Assessment of the effects of land use change on bird communities depends on our ability to compare bird communities in different land uses. We recommend that future studies continue make such comparisons, rather than studying birds in only one habitat to document the “contributions” of this habitat. We also recommend that assessments of the effects of urbanization and pine conversion take such comparisons into account.
- There is a need for further information about nocturnal birds, raptors, and bird communities out of the breeding season. Studies of productivity in different habitats would also help evaluate changes in our region.
- An analysis of the effects of variation in bird diversity within the residential-rural habitat class is needed to better understand the effects of different types of housing development.
- The integration of GIS layers with field sampling allowed us to investigate landscape-level effects. The direction of these effects depended on the

spatial scale of the analysis; therefore we recommend that spatial analyses continue to be conducted at multiple scales.

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Figure 4.1. Species richness rarefaction curves calculated at the scale of habitat classes. Thick lines indicate the mean richness at each abundance, thin lines indicate 95% confidence intervals. Overlapping confidence intervals have been merged for clarity. Curves include all birds detected during counts. The same analysis conducted with data including only birds detected within 50m provides qualitatively similar results.

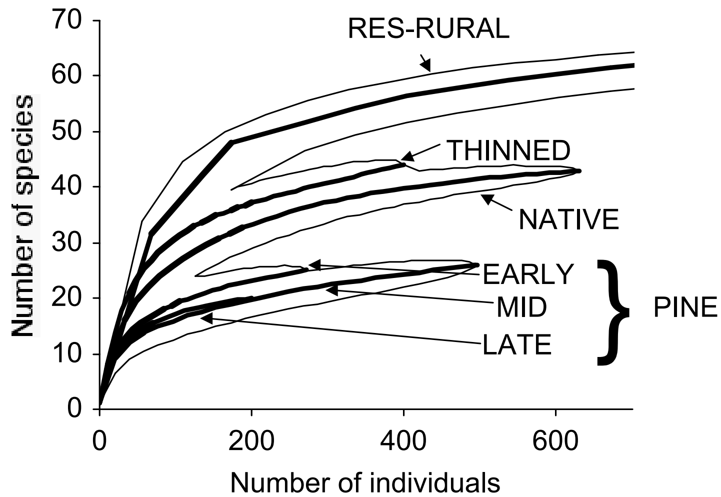

Figure 4.2. Species richness rarefaction curves calculated at the scale of transects. Thick lines indicate the mean richness at each abundance, thin lines indicate standard errors across all transects within the habitat class. Overlapping standard errors have been merged for clarity. Curves include all birds detected during counts. The same analysis conducted with data including only birds detected within 50m provides qualitatively similar results.

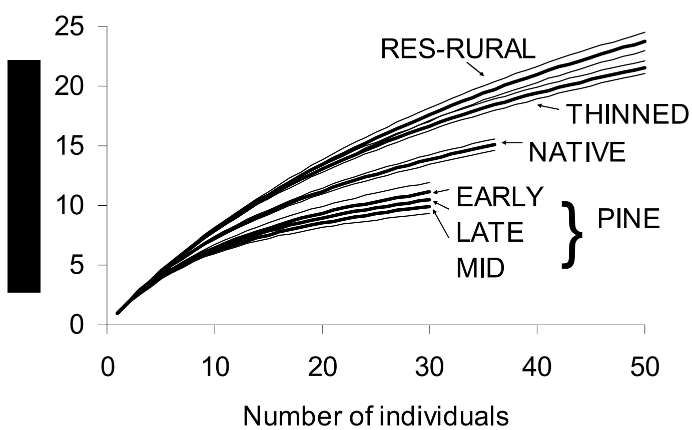

Figure 4.3. Richness measured at the scale of individual points in six habitat classes. Means and SE are presented. Numbers in parentheses indicate the number of point counts in each habitat class. Habitat classes with the same letter are not significantly different from one another in a Tukey HSD multiple means comparison.

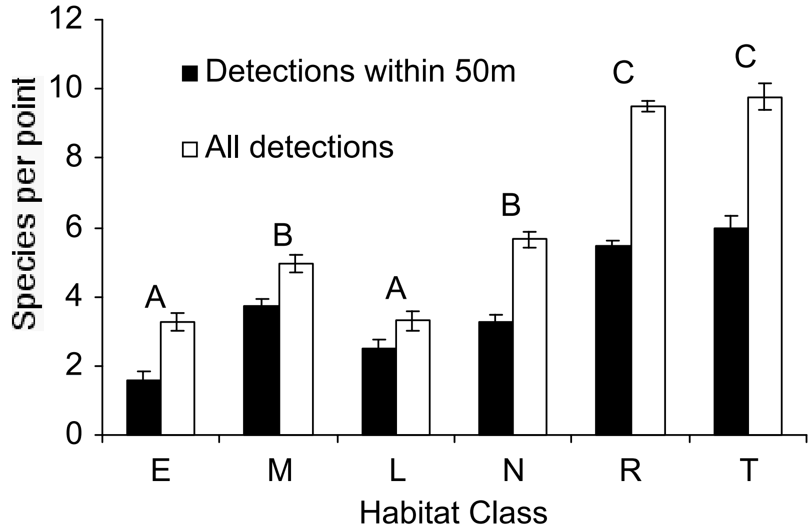

Figure 4.4. Species evenness (probability of interspecific encounter) rarefaction curves calculated at the scale of habitat classes. Thick lines indicate the mean richness at each abundance, thin lines indicate 95% confidence intervals. Overlapping confidence intervals have been merged for clarity. Curves include all birds detected during counts. The same analysis conducted with data including only birds detected within 50m provides qualitatively similar results.

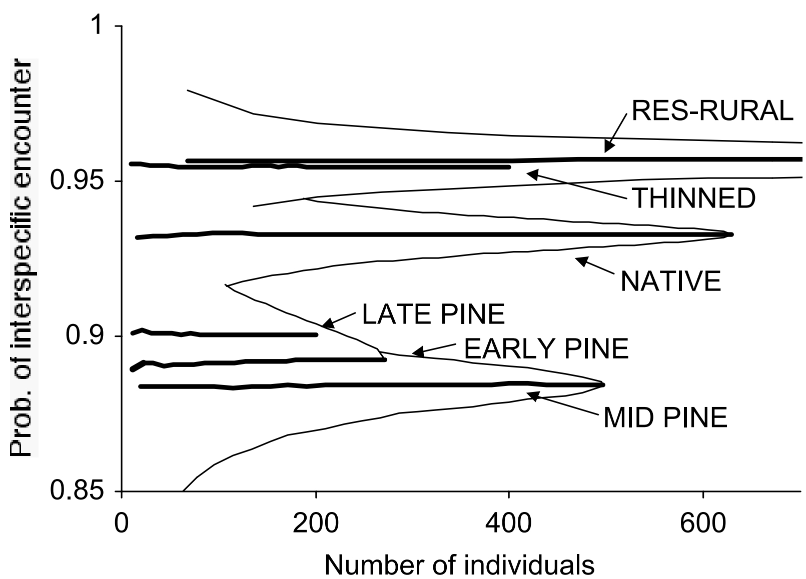

Figure 4.5. Species evenness (probability of interspecific encounter) rarefaction curves calculated at the scale of transects. Thick lines indicate the mean richness at each abundance, thin lines indicate standard errors across all transects within the habitat class. Overlapping standard errors have been merged for clarity. Curves include all birds detected during counts. The same analysis conducted with data including only birds detected within 50m provides qualitatively similar results.

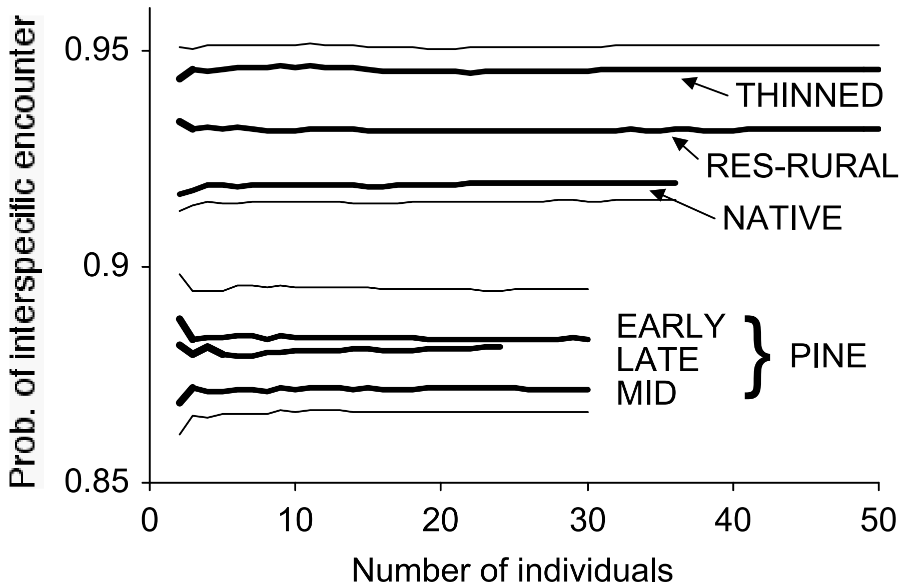

Figure 4.6. Density in six habitat classes. Filled bars show means and SE of densities calculated counting all birds within 50m of each count center. Habitat classes with the same letter are not significantly different from one another in a Tukey HSD multiple means comparison calculated using this data. Open bars show estimated densities with 95% confidence intervals from DISTANCE software using all birds detected up to 150m.

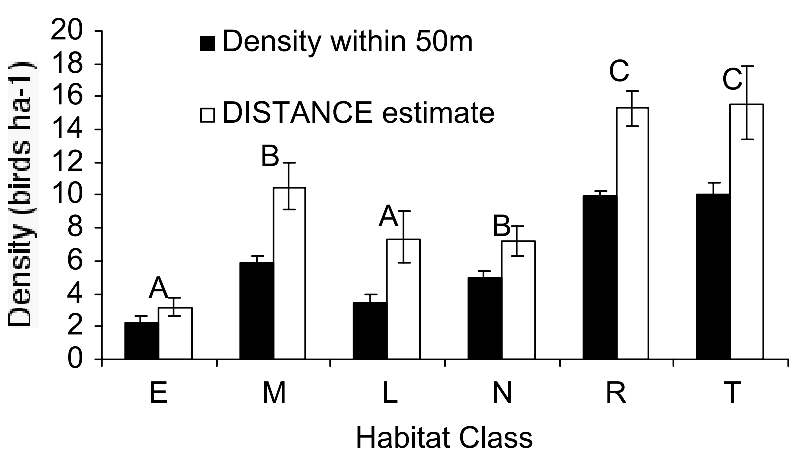

Figure 4.7. Detrended correspondence analysis of bird communities calculated at the scale of transects. Each point represents the position in ordination space of the bird community detected at one transect.

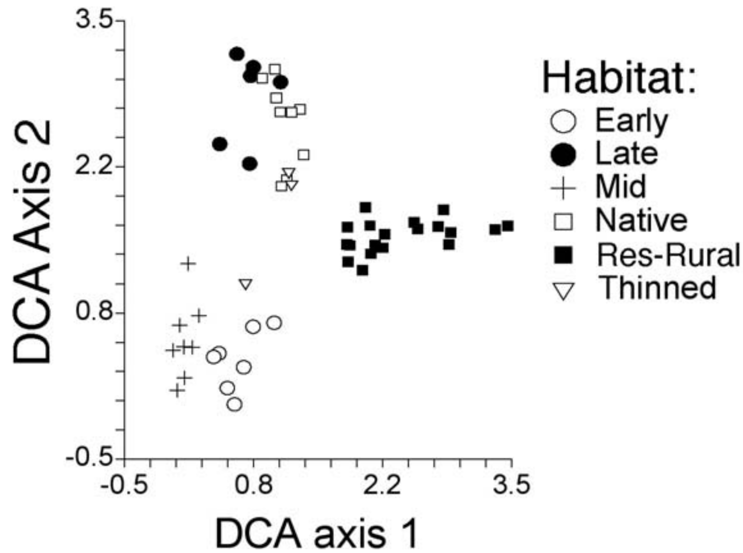

Figure 4.8. Detrended correspondence analysis of bird communities calculated at the scale of point counts. Each point represents the position in ordination space of the bird community detected at one point count.

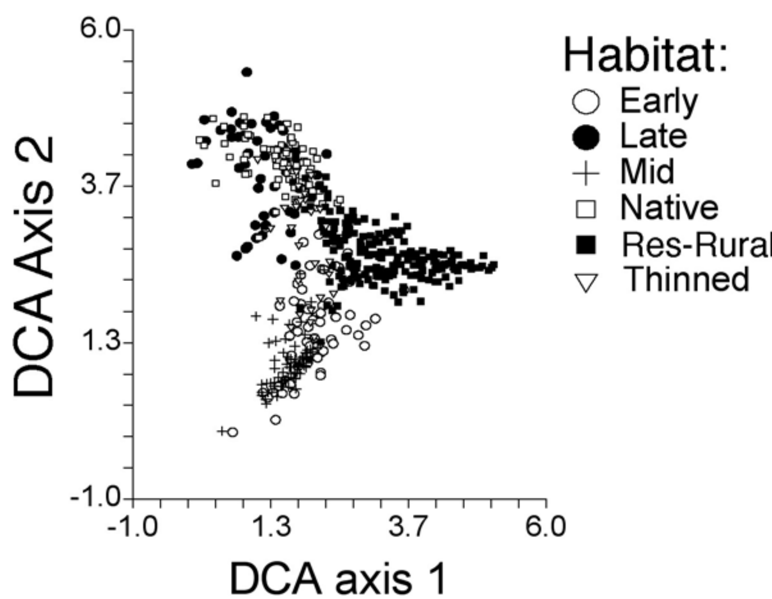

Figure 4.9. Beta diversity measured as the squared deviation from the mean value of the first DCA axis in each habitat class. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas.

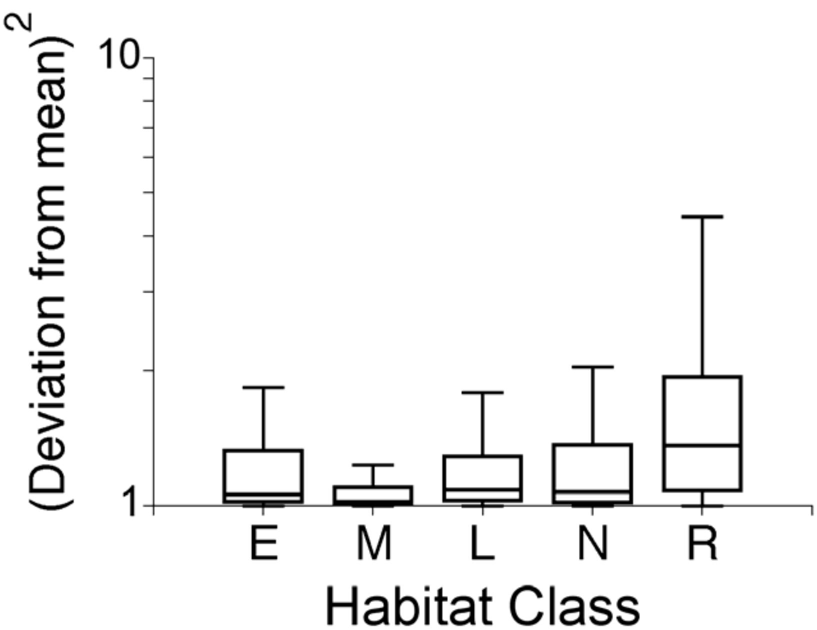

Figure 4.10. Beta diversity measured as the absolute deviation from the median value of the first DCA axis in each habitat class. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas.

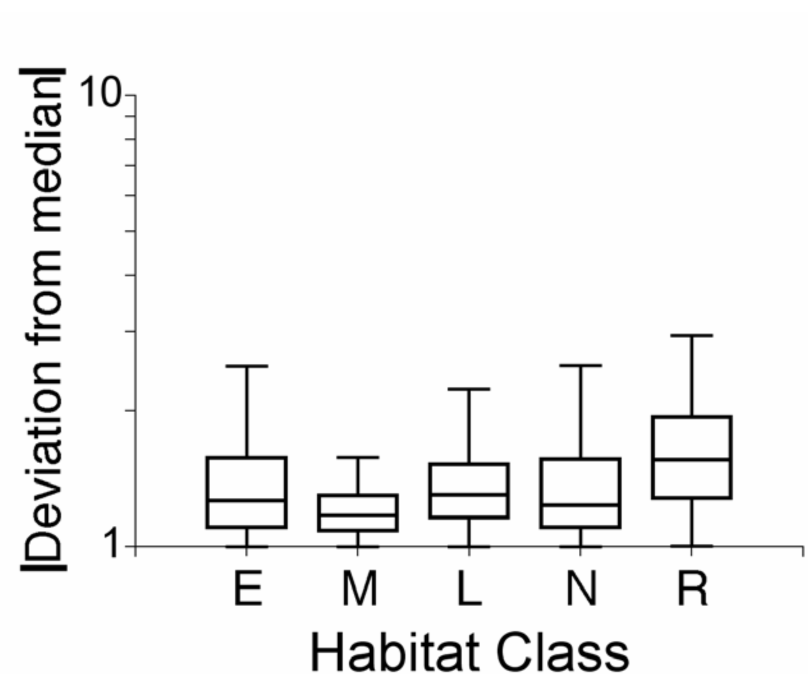

Figure 4.11. Numbers of species nesting in different nest site types in each habitat class. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas, T = thinned native forest.

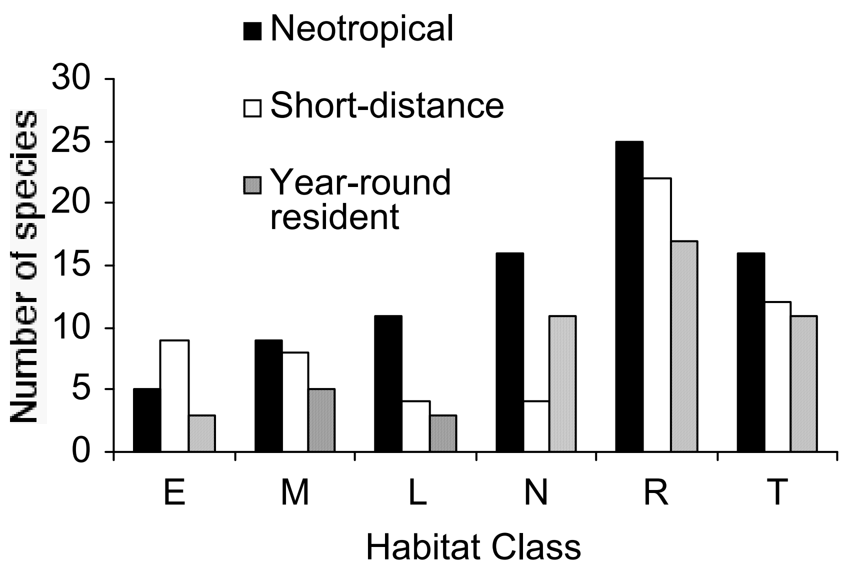

Figure 4.12. Numbers of species with different migratory patterns in each habitat class. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas, T = thinned native forest.

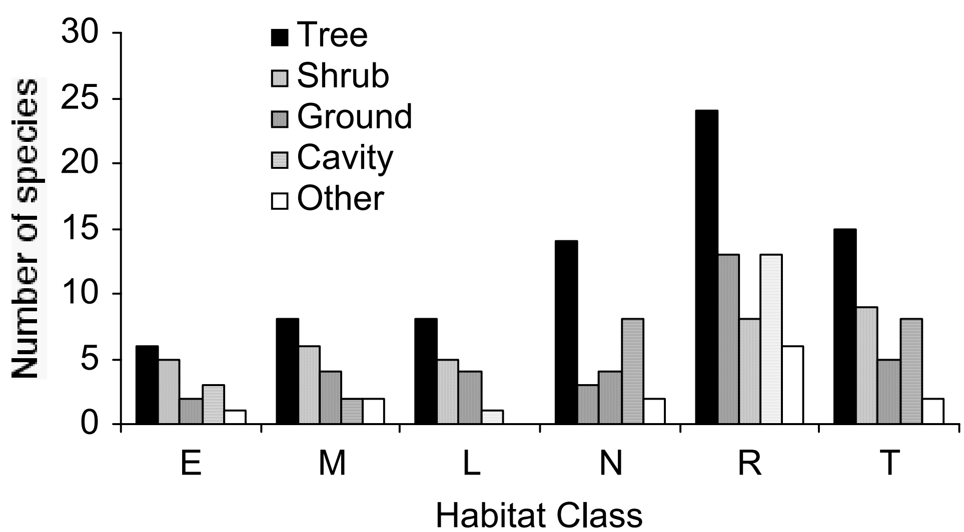

Figure 4.13. Partners in Flight priority scores weighted by relative abundance of birds. Boxplots indicate medians and interquartile ranges of values for each species found in each habitat class. Note log scale on y-axis. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas, T = thinned native forest.

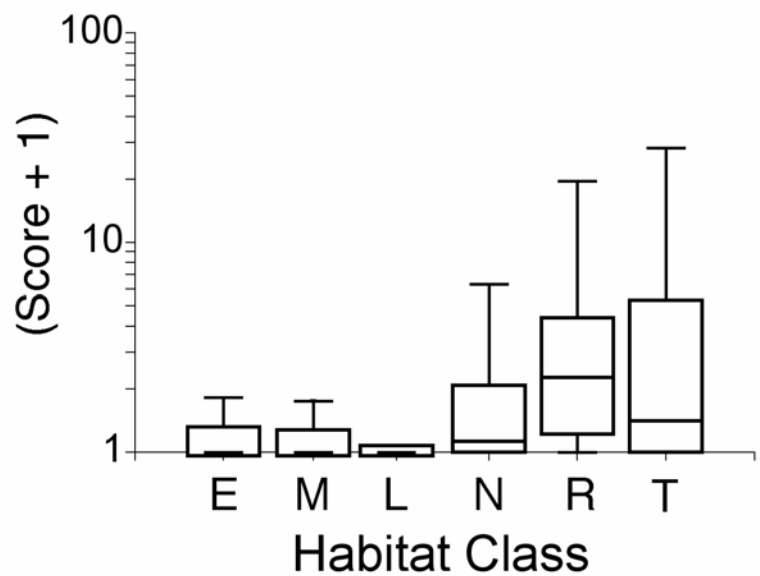

Figure 4.14. Partners in Flight priority scores without weighting by abundance. Boxplots indicate medians and interquartile ranges of values for each species found in each habitat class. E = early pine, M = mid-aged pine, L, = late pine, N = native forest, R = Residential-rural areas, T = thinned native forest.

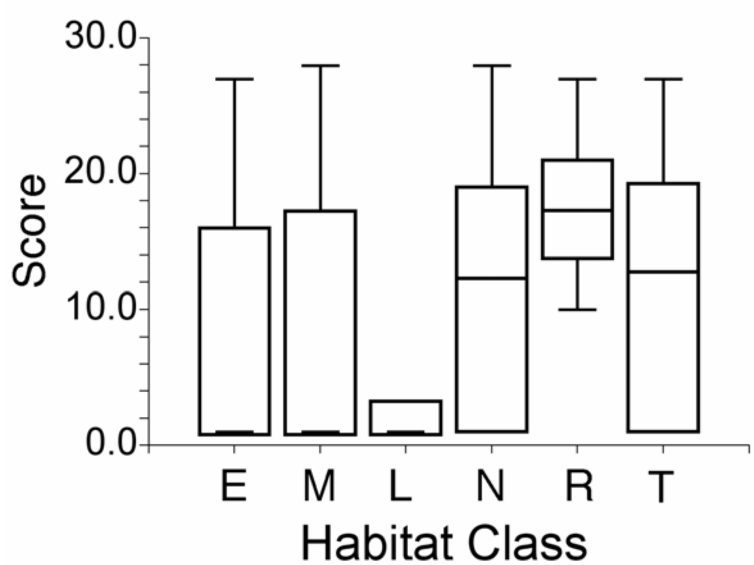

Figure 4.15. Relationship between bird species richness and edge density calculated within 150 m transects. Each point is one transect. The line is a least-squares regression line.

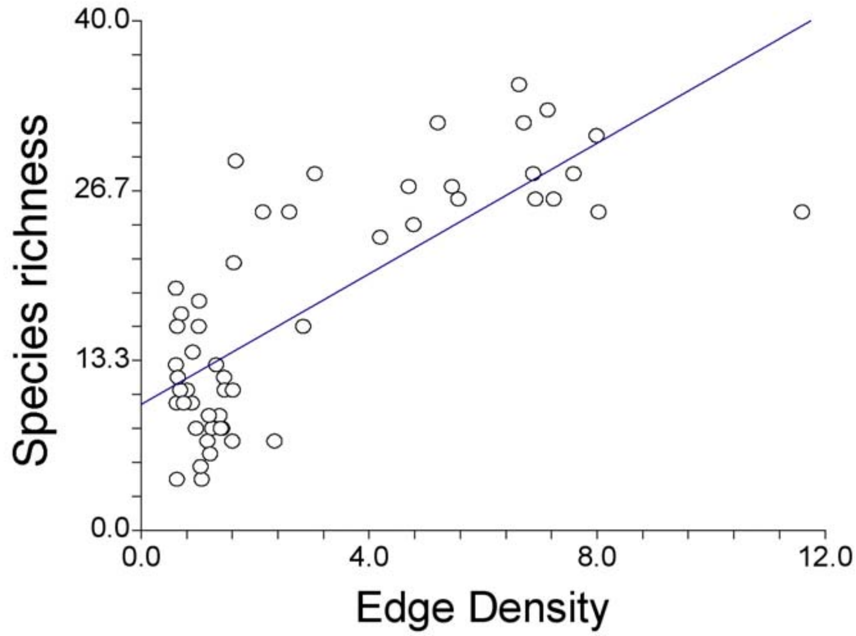

Figure 4.16. Relationship between bird species richness and area-weighted mean shape index calculated within 150 m transects. Each point is one transect. The line is a least-squares regression line.

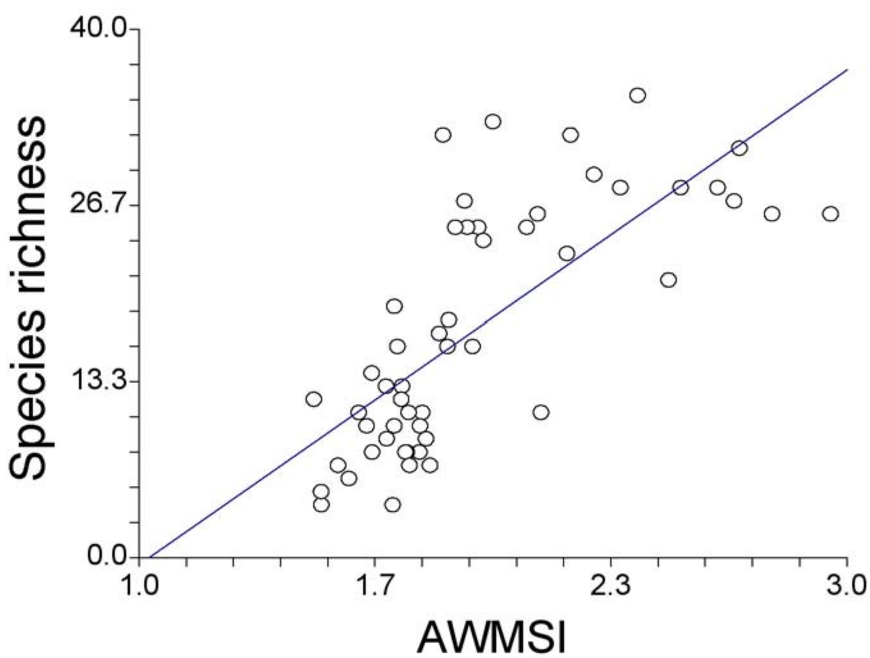

Figure 4.17. Relationship between bird species richness and area-weighted mean patch fractal dimension calculated within 150 m transects. Each point is one transect. The line is a least-squares regression line.

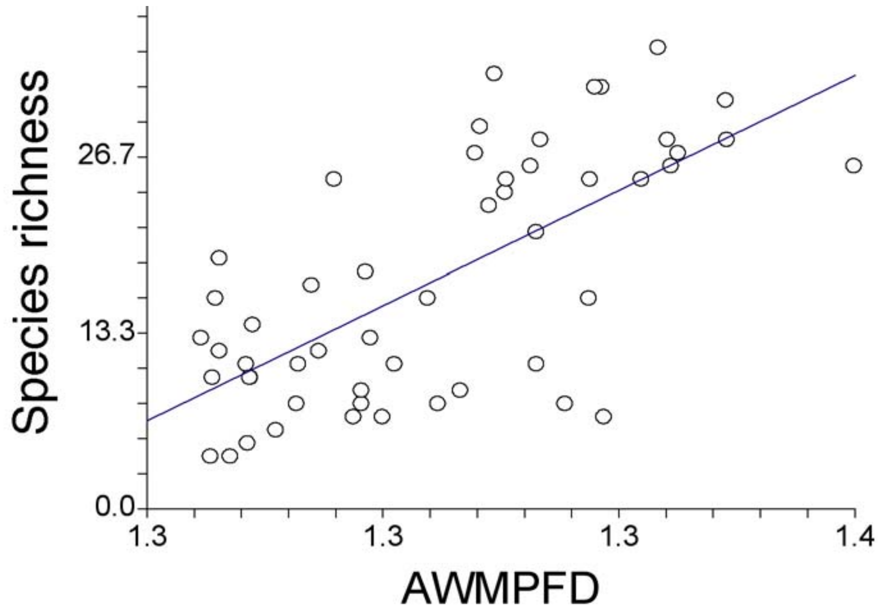

Figure 4.18. Relationship between bird species richness and edge density calculated within 1000 m transects. Each point is one transect. The line is a least-squares regression line.

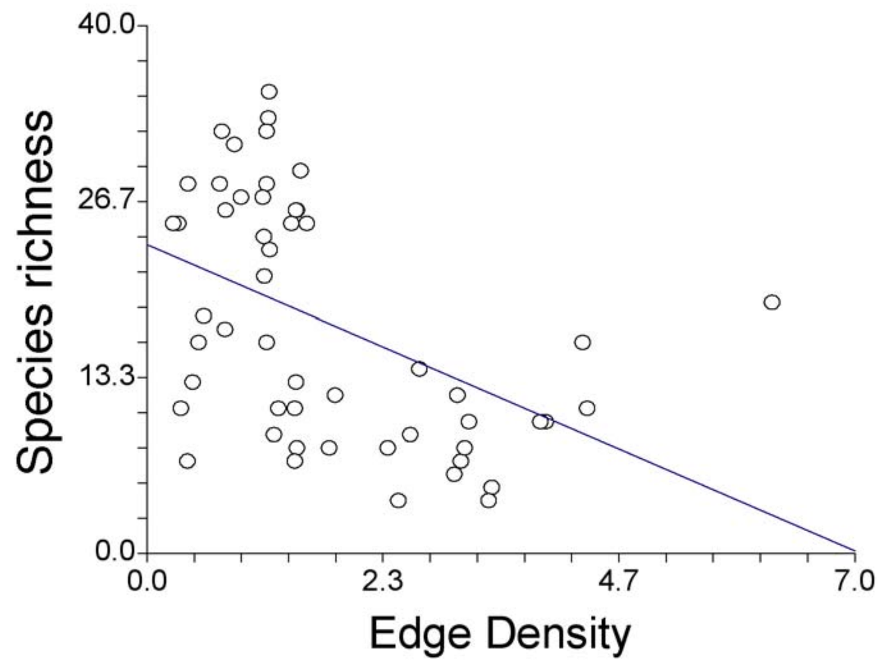

Figure 4.19. Relationship between bird species richness and area-weighted mean shape index calculated within 1000 m transects. Each point is one transect. The line is a least-squares regression line.

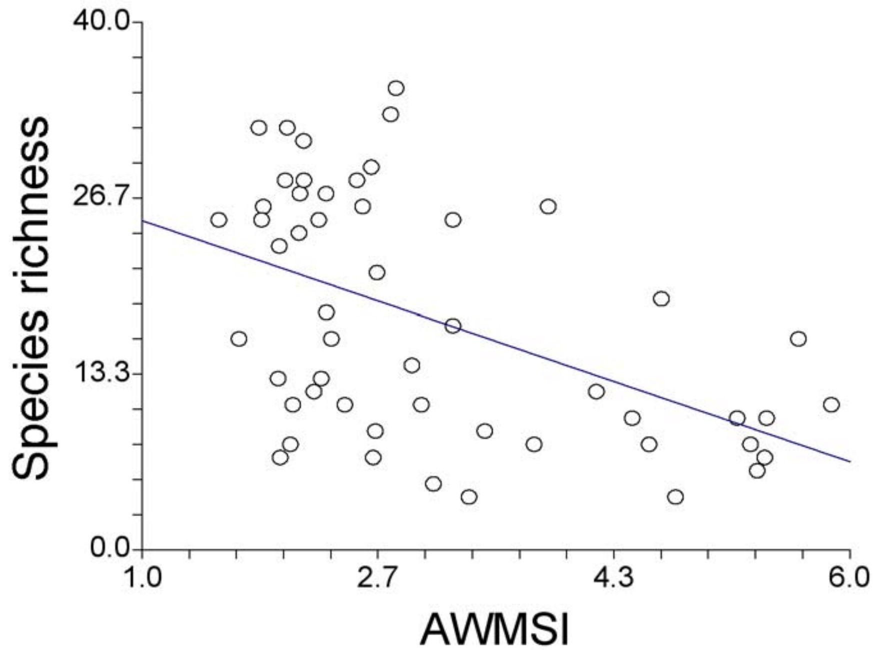

Figure 4.20. Relationship between bird species richness and area-weighted mean patch fractal dimension calculated within 1000 m transects. Each point is one transect. The line is a least-squares regression line.

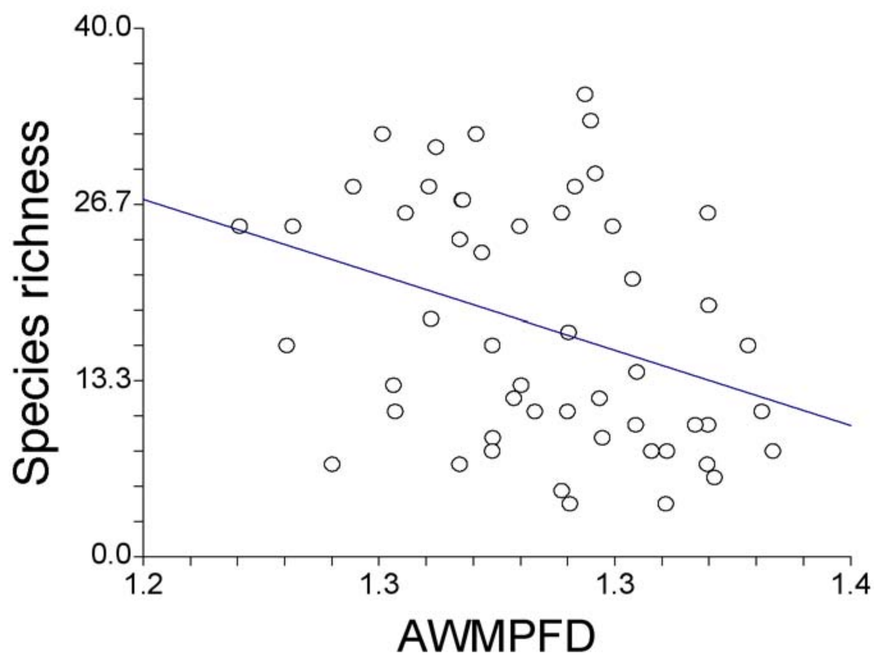

Figure 4.21. Numbers of houses around each point for the "residential-rural" habitat class. Boxplots indicate medians and interquartile ranges of values for each buffer radius.

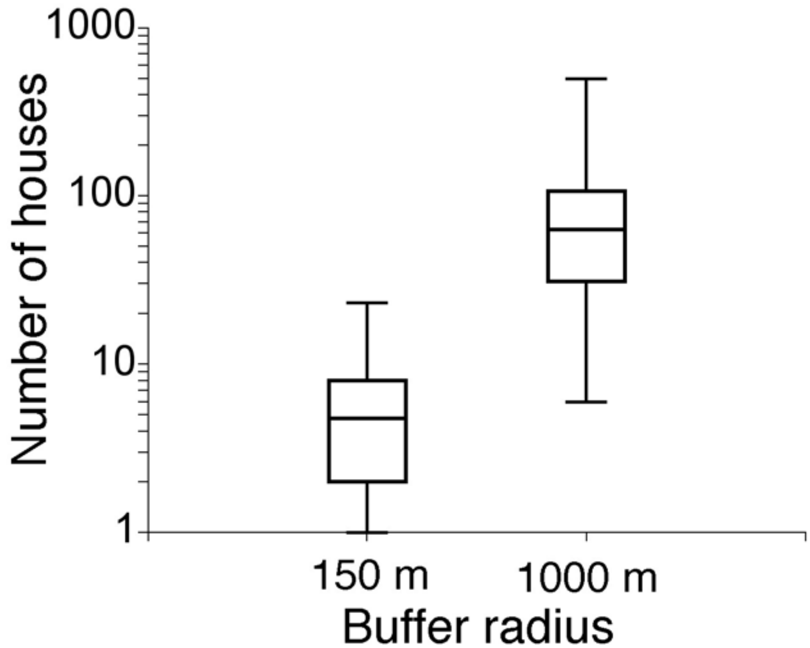

Table 4.1(a). Relative abundance (number of birds detected within 50m each per point) for all species in all habitat classes. * indicates species detected while traveling between point counts, but not detected during any point counts. These were not included in any statistical analyses in this report.

Common Name	Scientific Name	Early	Mid	Late	Native	Res-Rural	Thinned
Acadian Flycatcher	*Empidonax flaviventris*	0.00	0.00	0.00	0.04	0.00	0.00
American Crow	*Corvus brachyrhynchos*	0.20	0.15	0.26	0.54	0.70	0.80
American Goldfinch	*Carduelis tristis*	0.23	0.41	0.06	0.27	0.31	0.30
American Kestrel	*Falco sparvarius*	0.00	0.00	0.00	0.00	0.00	0.03
American Redstart	*Setophaga ruticilla*	0.00	0.00	0.00	0.00*	0.01	0.00
American Robin	*Turdus migratorius*	0.00	0.00	0.00	0.01	0.58	0.03
Barn Swallow	*Hirundo rustica*	0.00	0.00	0.00	0.00	0.28	0.00
Barred Owl	*Strix varia*	0.00	0.00	0.00	0.01	0.00*	0.00
Belted Kingfisher	*Ceryle alycon*	0.00	0.00	0.00	0.00	0.01	0.00
Black-and-white Warbler	*Mniotilta varia*	0.00	0.01	0.04	0.11	0.04	0.13
Black-throated Green Warbler	*Dendroica virens*	0.00	0.00	0.00	0.04	0.00	0.03
Blue Grosbeak	*Cyanocompsa parellina*	0.00	0.00*	0.00	0.00	0.02	0.00
Blue Jay	*Cyanocitta cristata*	0.01	0.00	0.26	0.21	0.22	0.33
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.00	0.04	0.00	0.06	0.18	0.43
Blue-headed Vireo	*Vireo solitarius*	0.00	0.00	0.02	0.06	0.00	0.00
Blue-winged Warbler	*Vermivora pinus*	0.00	0.01	0.00	0.00*	0.00	0.00
Broad-winged Hawk	*Buteo platypterus*	0.00	0.00	0.00	0.00	0.01	0.03
Brown Thrasher	*Toxostoma rufum*	0.01	0.00	0.00	0.00	0.07	0.00
Brown-headed Cowbird	*Molothrus ater*	0.01	0.01	0.00	0.01	0.22	0.07
Canada Goose	*Branta canadensis*	0.00	0.00	0.00	0.00	0.02	0.00
Carolina Chickadee	*Poecile carolinensis*	0.04	0.15	0.28	0.34	0.29	0.40
Carolina Wren	*Thryothorus ludovicianus*	0.04	0.04	0.00	0.06	0.35	0.50
Cedar Waxwing	*Bombycilla cedrorum*	0.00	0.00	0.00	0.00	0.08	0.00
Chimney Swift	*Chaetura pelagica*	0.00	0.01	0.00	0.01	0.34	0.03
Chipping Sparrow	*Spizella passerina*	0.00	0.00	0.00	0.00	0.47	0.20
Common Grackle	*Quiscalus quiscula*	0.00	0.00	0.00	0.05	0.39	0.00
Common Yellowthroat	*Geothlypis trichas*	0.30	0.33	0.06	0.00	0.31	0.20
Downy Woodpecker	*Picoides pubescens*	0.00	0.01	0.00	0.05	0.15	0.20
Eastern Bluebird	*Sialia sialis*	0.17	0.07	0.00	0.00	0.17	0.00
Eastern Kingbird	*Tyrannus tryannus*	0.03	0.00	0.00	0.00	0.06	0.00
Eastern Meadowlark	*Sturnella magna*	0.01	0.00	0.00	0.00	0.15	0.00
Eastern Phoebe	*Sayornis phoebe*	0.00	0.00	0.00	0.01	0.03	0.00
Eastern Towhee	*Pipilo erthyrophthalmus*	0.16	0.47	0.04	0.01	0.15	0.53
Eastern Wood-pewee	*Contopus virens*	0.00	0.00	0.00	0.06	0.27	0.13
European Starling	*Sturnus vulgaris*	0.00	0.00	0.00	0.00	2.06	0.00
Field Sparrow	*Spizella pusilla*	0.58	0.61	0.00	0.00	0.09	0.20
Golden-winged Warbler	*Vermivora chrysoptera*	0.00	0.01	0.00	0.00*	0.00	0.00
Gray Catbird	*Dumetella carolinensis*	0.00	0.00	0.00	0.00	0.03	0.00
Great Blue Heron	*Ardea herodias*	0.00	0.00	0.00	0.00	0.01	0.00
Great Crested Flycatcher	*Myiarchus crinitus*	0.00	0.00	0.00	0.05	0.12	0.07
Green Heron	*Butorides virescens*	0.00	0.00	0.00	0.00	0.01	0.00
Hairy Woodpecker	*Picoides villosus*	0.00	0.00	0.00	0.05	0.00	0.00
Hooded Warbler	*Wilsonia citrina*	0.00	0.07	0.20	0.69	0.04	0.53
House Finch	*Carpodacus mexicanus*	0.00	0.00	0.00	0.00	0.14	0.00
House Sparrow	*Passer domesticus*	0.00	0.00	0.00	0.00	0.37	0.00

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House Wren	*Troglodytes aedon*	0.00	0.00	0.00	0.00	0.01	0.03
Indigo Bunting	*Passerina cyanea*	0.96	0.93	0.24	0.21	0.88	1.60
Kentucky Warbler	*Oporornis formosus*	0.00	0.00	0.06	0.09	0.03	0.03
Killdeer	*Charadrius vociferus*	0.09	0.00	0.00	0.00	0.10	0.03
Mourning Dove	*Zenaida macroura*	0.14	0.32	0.06	0.02	0.19	0.20
Northern Bobwhite	*Colinus virginianus*	0.03	0.04	0.00	0.00	0.09	0.03
Northern Cardinal	*Cardinalis cardinalis*	0.00	0.03	0.00	0.02	0.41	0.13
Northern Flicker	*Colaptes auratus*	0.00	0.00	0.00	0.00	0.01	0.00
Northern Mockingbird	*Mimus polyglottos*	0.00	0.00	0.00	0.00	0.09	0.00
Northern Parula	*Parula americana*	0.00	0.00	0.00	0.04	0.01	0.03
Orchard Oriole	*Icterus gularis*	0.00	0.00	0.00	0.00	0.02	0.00
Ovenbird	*Seiurus aurocapillus*	0.00	0.00	0.56	0.74	0.10	0.63
Pileated Woodpecker	*Dryocopus pileatus*	0.00	0.00	0.02	0.16	0.17	0.23
Pine Warbler	*Dendroica pinus*	0.04	0.01	0.56	0.33	0.03	0.60
Prairie Warbler	*Dendroica discolor*	0.28	1.40	0.07	0.00	0.03	0.67
Purple Martin	*Progne subis*	0.00	0.00	0.00	0.00	0.13	0.00
Red-bellied Woodpecker	*Melanerpes carolinus*	0.00	0.00	0.00	0.02	0.15	0.03
Red-eyed Vireo	*Vireo olivaceus*	0.22	0.05	0.65	1.14	0.45	1.10
Red-headed Woodpecker	*Melanerpes erythrocephalus*	0.01	0.01	0.00	0.00*	0.02	0.00
Red-shouldered Hawk	*Buteo lineatus*	0.00	0.00	0.00	0.05	0.04	0.03
Red-winged Blackbird	*Agelaius phoeniceus*	0.00	0.00	0.00	0.00	0.32	0.00
Rock Dove	*Columbia livia*	0.00	0.00	0.00	0.00	0.03	0.00
Ruby-throated Hummingbird	*Archilocus colubris*	0.00	0.00	0.00	0.02	0.01	0.00
Scarlet tanager	*Piranga olivacea*	0.03	0.00	0.24	0.61	0.07	0.30
Song sparrow	*Melospiza melodia*	0.00	0.00	0.00	0.00	0.63	0.00
Summer tanager	*Piranga rubra*	0.00	0.00	0.00	0.04	0.01	0.00
Tufted Titmouse	*Baeolophus bicolor*	0.00	0.00	0.00	0.40	0.46	0.27
Turkey Vulture	*Cathartes aura*	0.00	0.00	0.00	0.00	0.03	0.00
White-breasted Nuthatch	*Sitta carolinensis*	0.00	0.00	0.00	0.21	0.29	0.23
White-eyed Vireo	*Vireo griseus*	0.00	0.33	0.00	0.00	0.08	0.20
Wild Turkey	*Meleagris gallopavo*	0.03	0.00	0.00	0.00*	0.01	0.00
Wood Thrush	*Hylocichla mustelina*	0.00	0.00	0.02	0.21	0.18	0.20
Worm-eating Warbler	*Helmitheros vermivora*	0.00	0.00	0.00	0.06	0.00	0.00
Yellow-billed Cuckoo	*Coccyzus americanus*	0.00	0.00	0.00	0.19	0.12	0.27
Yellow-breasted Chat	*Icteria virens*	0.26	1.08	0.04	0.00	0.15	0.67
Yellow-throated Vireo	*Vireo flavifrons*	0.00	0.00	0.00	0.02	0.01	0.00
Yellow-throated Warbler	*Dendroica dominica*	0.03	0.00	0.00	0.07	0.10	0.57

Table 4.1(b). Most abundant bird species in each habitat class. All species with an abundance greater than 0.1 birds/transect (from Table 1(a)) are listed for each habitat class.

Native	Residential-rural	Thinned
Red-eyed Vireo	European Starling	Indigo Bunting
Ovenbird	Indigo Bunting	Red-eyed Vireo
Hooded Warbler	American Crow	American Crow
Scarlet tanager	Song sparrow	Yellow-breasted Chat
American Crow	American Robin	Prairie Warbler
Tufted Titmouse	Chipping Sparrow	Ovenbird
Carolina Chickadee	Tufted Titmouse	Pine Warbler
Pine Warbler	Red-eyed Vireo	Yellow-throated Warbler
American Goldfinch	Northern Cardinal	Hooded Warbler
Indigo Bunting	Common Grackle	Eastern Towhee
White-breasted Nuthatch	House Sparrow	Carolina Wren
Blue Jay	Carolina Wren	Blue-gray Gnatcatcher
Wood Thrush	Chimney Swift	Carolina Chickadee
Yellow-billed Cuckoo	Red-winged Blackbird	Blue Jay
Pileated Woodpecker	American Goldfinch	Scarlet tanager
Black-and-white Warbler	Common Yellowthroat	American Goldfinch
	Carolina Chickadee	Tufted Titmouse
	White-breasted Nuthatch	Yellow-billed Cuckoo
	Barn Swallow	White-breasted Nuthatch
	Eastern Wood-pewee	Pileated Woodpecker
	Blue Jay	Wood Thrush
	Brown-headed Cowbird	Downy Woodpecker
	Mourning Dove	Mourning Dove
	Wood Thrush	Chipping Sparrow
	Blue-gray Gnatcatcher	Common Yellowthroat
	Pileated Woodpecker	Field Sparrow
	Eastern Bluebird	White-eyed Vireo
	Downy Woodpecker	Black-and-white Warbler
	Red-bellied Woodpecker	Eastern Wood-pewee
	Eastern Towhee	Northern Cardinal
	Yellow-breasted Chat	
	Eastern Meadowlark	
	House Finch	
	Purple Martin	
	Yellow-billed Cuckoo	
	Great Crested Flycatcher	
	Ovenbird	
	Yellow-throated Warbler	
	Killdeer	

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	Pine plantation:	
Early	**Mid**	**Late**
Indigo Bunting	Prairie Warbler	Red-eyed Vireo
Field Sparrow	Yellow-breasted Chat	Pine Warbler
Common Yellowthroat	Indigo Bunting	Ovenbird
Prairie Warbler	Field Sparrow	Carolina Chickadee
Yellow-breasted Chat	Eastern Towhee	American Crow
American Goldfinch	American Goldfinch	Blue Jay
Red-eyed Vireo	Common Yellowthroat	Indigo Bunting
American Crow	White-eyed Vireo	Scarlet tanager
Eastern Bluebird	Mourning Dove	Hooded Warbler
Eastern Towhee	American Crow	
Mourning Dove	Carolina Chickadee	

Table 4.2. Results of nested ANOVA on the number of species (richness) and number of individuals (density) detected per point in six habitat classes. Results are presented for birds detected within 50m of the count center and for all birds detected regardless of distance from count center.

Dependent variable	Source	df	F	P
Richness (50m cut off)	Habitat class	5	74.16	<0.001
	Transect nested in habitat	46	2.52	<0.001
	Error	451		
Richness (all detections)	Habitat class	5	176.12	<0.001
	Transect nested in habitat	46	2.79	<0.001
	Error	451		
Density (50m cut off)	Habitat class	5	77.38	<0.001
	Transect nested in habitat	46	3.06	<0.001
	Error	451		
Density index (all detections)	Habitat class	5	151.31	<0.001
	Transect nested in habitat	46	3.75	<0.001
	Error	451		

Table 4.3. Summary of regression statistics for analyses of the effects of landscape structure and composition on the total species richness of birds detected on transects. AWMSI = area-weighted mean shape index, AWMPFD = area-weighted mean patch fractal dimension. Degrees of freedom were 1, 50 for all regressions.

Dataset:	Independent Variable	Regression Coefficient	F ratio	P value
Landscape metrics within 150m buffers	Edge density	+ 2.56	71.50	0.000
	AWMSI	+ 8.74	58.99	0.000
	AWMPFD	+ 261.4	43.62	0.000
Landscape metrics within 1000m buffers	Edge density	- 3.31	13.68	0.000
	AWMSI	- 3.64	16.14	0.000
	AWMPFD	- 85.42	6.70	0.012

Table 4.4. Numbers of birds in each Partners in Flight priority class, arranged by habitat class. = early pine, M = mid-aged pine, L, = late pine, N = native forest, = Residential-rural areas, T = thinned native forest. Numbers in the first column indicate ranges of PIF scores (e.g., species with scores over 28 fall into the Extremely high class). The last column indicates the ranking (from high to low) of habitat classes (e.g., for High species, R has the most species present, E has the fewest).

Priority class (numbers indicate range of PIF scores)	E	M	L	N	R	T	Ranking of habitats within priority class
Extremely high (28-35)	0	1	0	0	0	0	M
High (22-27)	4	5	6	8	9	8	R, N/T, L, M, E
Moderate (19-21)	3	4	5	7	11	7	R, N/T, L, M, E

Table 4.5. Species richness from this study (includes only birds detected within 50m of count centers) and from previously published studies of birds in southern forests. Only studies that looked within a relatively homogeneous forest type are included -- studies that reported species richness by combining several different habitat types (e.g., logged areas and unlogged areas) were excluded. Caution should be used in interpreting this table: these studies had different sampling designs.

Authors	Location	Species richness (ranges in parentheses)
This study	Oak-hickory forest on Cumberland Plateau in Tennessee	43 in native forest (20-73)
Childers et al. 1986	Virginia. Second growth native forest and pine plantation.	11 in second growth (8-12)
Conner and Adkinson 1975	Virginia. Mature native forest and logged areas.	16 in mature (8-21)
Crawford et al. 1981	Virginia. Native forests with different degrees of canopy closure.	21
Dickson and Segelquist 1979	Texas. Pine-hardwood and pine plantation.	18 in saw timber pine-hardwood (3-19)
Greenberg et al. 1995	Florida. Sand pine scrub.	22 in mature (12-22)
Repenning and Labisky 1985	Florida. Slash pine plantation and longleaf pine forest.	24 in mature longleaf (9-24)
Robinson and Robinson 1999	Southern Illinois uncut and selectively cut native forest.	21-34
Rodewald and Smith 1998	Arkansas. Uncut and harvested oak-hickory forests.	26 in uncut (21-26)
Thompson et al. 1992	Missouri. Uncut and cut oak-hickory pine.	12 or 14 on uncut (12-16)
Wilcove 1985	Smokey Mountains. Cove, hemlock-deciduous, oak-beech forests	31-37

Appendix A

Classification, Confusion, and Contrast: A Comparison of Forest Estimation Techniques for the Cumberland Plateau

Paper presented at:

Southern Forest Science Conference
Atlanta, GA (November 26-28, 2001)

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Abstract: This paper compares the consistency of forest cover classification in four existing land-use or forest cover assessments. Those assessments include the plot-based forest estimation from the U.S. Forest Service FIA data, the North American Land Cover Database from United States Geologic Survey, the GAP Analysis coverage from the GAP Analysis Program and the Tennessee Wildlife Resources Agency (TWRA), and the United States Forest Service' "State of the Forest—1997" coverage. The results show that the plot based FIA coverage was intermediate between the NALC and TWRA coverages for most classifications at all scales. The exception was pine-evergreen cover where FIA reported significantly higher evergreen cover than the other assessments. The results also suggest that while the coverages may be similar in the average, that the location to location differences may be substantial and masked by comparing averages.

I. Introduction:

This is the first in two-part paper comparing forest assessment techniques for small area assessments—that is for areas less than a million acres. This first section will address the consistencies in currently available forest assessments. Those assessments include the plot-based forest estimation from the U.S. Forest Service FIA data, the North American Land Cover Database from United States Geologic Survey, the GAP Analysis coverage from the GAP Analysis Program and the Tennessee Wildlife Resources Agency (TWRA), and the United States Forest Service' state of the forest coverage. We chose to focus this paper on existing publicly available coverages for the following reasons:

- Their public availability leads to there use and citation in planning, managing, research and consulting,
- There is currently pressure to move to 'better' methods that combine high resolution satellite imagery, LIDAR, and other 'remote' sources of information,
- There is some tension between providing data sources that meet the needs of foresters vs. those which meet the needs of county planners, and
- The existing coverages allow comparison of land use differences at different scales that will not be possible with the 'new methods for at least 4-5 years.

II. Data

The data sources used in the paper were chosen for their public availability and ease of use. The recent NASA /USGS MODIS land coverages, while quite good, are only available in HDF-EOS format and thus are not accessible a wide variety of users. Thus this paper will compare the following four forest assessments:

a. **The 1999 Forest Inventory and Analysis (FIA) database for Tennessee:** This is a plot-based forest estimation process where small large number of tree type, condition, and regeneration data were collected on an X kilometer grid by the USFS and the Tennessee Department of Forestry between 1996 and 1999. The data are available from the USFS FSFIA in Starkville MS (http://fia.fs.fed.us/).

b. **The North American Land Cover Database (NALC) for Tennessee and Kentucky:** This coverage was joint project between USGS and EPA. This coverage was based on 1992 Landsat thematic mapper data nominally at 30 meter pixel resolution. Forest type categorization was accomplished via ground data aerial imagery. The data are available from: http://landcover.usgs.gov/natllandcover.html.

c. The Tennessee Wildlife Resource Agency National Biological Survey, Gap Analysis Landuse Coverage (TWRA): This is also a landsat based coverage based on imagery from 1997. Grand data was used for verification. Other ancillary data such as slope and aspect from digital elevation models were used to improve forest type classification.

d. **The United States Forest Service and United States Geological Survey "Forest Resources of the United States, 1997" Map:** This raster data source was based on the National Oceanographic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) data at 1 kilometer pixels. The dataset is available from http://nationalatlas.gov/atlasftp.html

Only the NALC dataset lists classification accuracy in the metadata—the accuracy is about 80% for the study area. The four coverages are presented in Figure 1.

III. Methods

Given that each of the assessments was performed for the individual needs of each of the projects, they are not directly comparable across pixel locations or forest cover categories. Thus the data needed to be aggregated both spatially and by forest type. These aggregations will be discussed in limited detail.

a. Comparing Broad Forest Categories

The paper compares fro broad forest categories that were similar across the four coverages. These are:

i. *Forest vs. Non-Forest:* This is the percentage of land area classified as forest of any type compared to not forest areas.

ii. *Pine—Evergreen:* The Pine and evergreen categories varied across each of the coverages, so they were aggregated to single pine/evergreen category for analysis here.

iii. *Hardwoods:* All non-evergreen forest types were aggregated into a hardwood category.

iv. *Mixed Hardwood Conifer Stands:* This is an aggregation of all mixed hardwoods conifer types by dataset.

The original categories can be seen in figure 1 with the exception of the FIA data which had over 50 categories and thus was aggregated for presentation purposes.

b. Proportional Coverage—why aggregate

Point to point comparisons of the forest assessments is not wise since they can be affected by a variety of error sources including:

i. *Different projection types in the pixel data make are comparisons slightly tricky:* the NALC coverage was in the Albers Projection, the TWRA and FIA coverages were in the Geographic Projection (.i.e. latitude longitude or Platte Carre), and the USFS coverage in the Lambert Conformal Conic projection.

ii. *Reprojection can change cover types:* While reprojecting the imagery is not difficult, the reregistration and resampling procedures can cause a variety of problems including--changing cover types from pixel to pixel, and misregistration from pixel to pixel for example. The resampling errors can lead to differences that are not real.

iii. *FIA data tend to change county areas depending on assessment:* The seven plateau counties increased by a total of 24, 832 acres between 1989 and 1999 assessment—the state of Tennessee by over 500,000 acres).

iv. *The FIA are plot based and must either be aggregated over and area or interpolated:* Given that the choice of interpolators can dramatically affect the outcome of such comparisons, this uses the spatial aggregation option to avoid conflating spatial aggregation and interpolation difficulties.

Given these considerations, the paper aggregates the data spatially at three scales (See figure 2):

- County: These are USGS County Boundaries
- Quad on Plateau: These are the USGS Quadrangle boundary clipped by the surface of the Cumberland Plateau. This was done to focus the finer resolution assessment on areas that are predominantly forest covered.
- Four Kilometer Hexagonal Grid: Three grid sizes were tested—2km, 4km, and 8km—the 4km size was chosen to provide an area smaller than the quad area, but large

enough to encompass sufficient numbers of FIA plots for cover estimation[1].

We then calculated the proportion of land area in each cover category. These proportions are then further aggregated into the coarser aforementioned cover categories. These proportions were then tabulated by area and the mean and standard errors were calculated for each spatial aggregation by each cover type for each of the four assessments. Each cover type proportion was then differenced from the FIA proportions. The USFS coverage was only included in the analysis at the county level of aggregation because of its large pixel size and predominance of mixed cover types.

IV. Results

The results are presented in table 2 for the mean coverages by spatial aggregation, and in table 3 for the mean absolute deviation from FIA. This section will first address the coverage comparisons and then the deviations from FIA.

a. Average Cover Characteristics:

County: At the broadest aggregation—i.e. the county level—the percent forest cover ranged from a low of .64 for the TWRA coverage to a high of .77 for the NALC coverage. FIA was intermediate at .675. FIA was also intermediate for hardwood and mixed cover, but was higher for the proportion of pines and evergreen types.

Quadrangle: The FIA data once again give intermediate results (.86) compared to the NALC coverage at the high end (.94 for forest cover) and the TWRA coverage at the low end (.82). FIA was also intermediate for hardwoods and mixed cover type while estimating the highest proportion of pine and evergreen cover (.14 or 14%).

4km Hexagonal Grid: The FIA data give intermediate results at the hexagonal grid level as well--(.75) compared to the NALC coverage at the high end (.87 for forest cover) and the TWRA coverage at the low end (.76). FIA was also intermediate for hardwoods and mixed cover type while estimating the highest proportion of pine and evergreen cover (.087).

b. Mean Absolute Deviation from FIA Assessment:

The analysis of mean absolute deviation at a point of aggregation will focus on the different cover types since that is the focus of the error in this analysis. That is, we are trying to determine if the cover types remain similar as we move to finer levels of aggregation.

[1] The FIA documentation strongly warns against using FIA data on area less than million acres, but it is used for those purposes in practice. That is furthermore one of the key points of this paper—how much does FIA differ from the other sources for smaller area assessments.

Forest Cover: The mean absolute deviation of FIA from the other coverage is statistically identical for both the NALC and TWRA coverages. That difference begins at a proportion around .3 for the counties as a whole. The deviation grows to .15 for the quadrangle level of aggregation, and finally to .25 for the hexagonal grid. In terms of percentage differences[2], this is about 4% for the county, about 22% for the quadrangle, and about 37% for the grid.
Pine and Evergreen Cover: The deviance in pine coverage, while only slightly higher in proportion terms move to about 50% deviation at the county level, 120% deviation at the quadrangle level, and 100% deviation at the grid level.
Hardwood Cover: The deviance in hardwood coverage was about half that of the pines and other evergreens. The deviation at the county level was 10% for the NALC coverage and 15% for the TWRA coverage. At the quadrangle level, the deviation moved to about 40%. Finally at the grid level, the deviation moved to over 60%
Mixed Cover: The mixed hardwood pine cover deviated by over 30% for both NALC and TWRA at the county level increasing to 140% at the quadrangle level, and 160% at the grid level.

V. **Discussion**

This paper has shown that the overall percent forest cover characteristics of four publicly available forest assessments differ by only about 13% at the maximum. The subcategory differences are somewhat larger, but still acceptable for county level assessment. It has also shown that the plot based-FIA approach is intermediate to two satellite-based pixel counting approaches on average. As the resolution becomes finer both spatially and by cover category, the deviation from the plot based approaches become substantial and punctuates the need to heed the FIA metadata warnings about using FIA data for estimation in areas less than several counties. The results here also suggest that the small area percentage deviations in FIA data may be substantially larger than those reported using the percentage error formula in the FIA manuals. Finally, this is not intended to suggest the superiority of any of these coverages, but rather that they differ and differ substantially as the spatial resolution increases and the cover categories become less aggregated.

[2] The percentage difference is the mean absolute deviation in proportion divided by the average proportion. This is not weighted by area, so it may be exaggerated for the quad by plateau coverage which has a few small areas with large deviation. For the other coverages, they are roughly equal area. A 100% deviation at a proportional coverage of .1 implies that the cover percentage regularly deviated to zero and to .20.

VI. References:

U.S. Geological Survey National Land Cover Characterization, Reston Virginia http://landcover.usgs.gov/natllandcover.html (2001)

U.S. Department of Agriculture, Forest Service. 2001. Forest inventory and analysis national core field guide, volume 1: field data collection procedures for phase 2 plots, version 1.5. U.S. Department of Agriculture, Forest Service, Washington Office. Internal report. On file with: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, 201 14th St., Washington, D.C., 20250.

Zhu, Z. and Evans, D.L., 1994, U.S. Forest Types and Predicted Percent Forest Cover from AVHRR Data: Photogrammetric Engineering and Remote Sensing, v. 60, No. 5, p. 525-531.

VII. Tables and Figures:

Table 1: Changes in total size of the county in acres between the 1989 FIA assessment and the 1999 assessment: This table presents the differences in acreage for the seven county area as assessed in the 1989 FIA assessment and the 1999 assessment carried out between 1996 and 1999. Data are from USFS 2001.

County	Change in Acres 1989-1999
Bledsoe	307
Franklin	20155
Grundy	-459
Marion	884
Sequatchie	337
Van Buren	1333
Warren	2275
Total	**24832**

Table 2: Mean Proportion in Cover Category of the FIA, NALC, TWRA and USGS Coverages: The values here are the average proportion of area covered from each coverage by county, the area in the USGS quadrangle on the Cumberland Plateau, and a four kilometer hexagonal grid created as a GIS coverage for the purpose of this study. The 4k grid has no legal or administrative significance. Values in parentheses are standard errors. The FIA coverage is based on the 1999 Forest Inventory and Analysis Data from USGS. The NALC coverage is the North American Land Cover (NALC) database distributed by USGS. The TWRA database is the from the Tennessee GAP program. The USFS coverage is from the United States Forest Service' State of the Forest Report 1997.

Proportion with forest cover				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=109/106)**
FIA	Plot-based Sampling	.675 (.072)	.86 (.049)	.75 (.032)
NALC	30 Meter Pixels from Landsat TM	.77 (.057)	.94 (.0088)	.87 (.011)
TWRA	30 Meter Pixels from Landsat TM	.64 (.062)	.82 (.017)	.76 (.015)
USFS	1 Km Pixels from NOAA AVHRR	.71 (.093)		

Proportion Pines-Evergreens				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=109/106)**
FIA	Plot-based Sampling	.097 (.098)	.14 (.047)	.087 (.021)
NALC	30 Meter Pixels from Landsat TM	.075 (.042)	.10 (.021)	.074 (.0078)
TWRA	30 Meter Pixels from Landsat TM	.05 (.03)	.073 (.017)	.052 (.0067)
USFS	1 Km Pixels from NOAA AVHRR	.001(.002)		

Proportion Hardwoods				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=109/106)**
FIA	Plot-based Sampling	.50 (.10)	.67 (.059)	.61 (.035)
NALC	30 Meter Pixels from Landsat TM	.57 (.09)	.70 (.033)	.67 (.017)
TWRA	30 Meter Pixels from Landsat TM	0.55 (.14)	.74 (.026)	.69 (.017)
USFS	1 Km Pixels from NOAA AVHRR	.41 (.13)		

Proportion Mixed Pine-Hardwood Mosaics				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=109/106)**
FIA	Plot-based Sampling	.08 (.03)	.051(.018)	.050 (.012)
NALC	30 Meter Pixels from Landsat TM	.13 (.04)	.14 (.014)	.13 (.007)
TWRA	30 Meter Pixels from Landsat TM	.04 (.012)	.0072(.0091)	.011 (.0011)
USFS	1 Km Pixels from NOAA AVHRR	.29 (.14)		

Table 3: Mean Absolute Deviations of the FIA Coverage from the NALC, TWRA and USGS Coverages: The values here are the average of the absolute deviations of the listed coverage from the Forest Inventory and Analysis of the U.S Forest Service proportion of area covered by county, The area in the USGS quadrangle on the Cumberland Plateau, and a four kilometer hexagonal grid created as a GIS coverage for the purpose of this study. The 4k grid has no legal or administrative significance. Values in parentheses are standard errors. The NALC coverage is the North American Land Cover (NALC) database distributed by USGS. The TWRA database is the from the Tennessee GAP program (cite). The USFS coverage is from the United States Forest Service' State of the Forest Report 1997.

Proportion with Forest Cover				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=106)**
NALC	30 Meter Pixels from Landsat TM	.03 (.008)	.15 (.024)	.25 (.018)
TWRA	30 Meter Pixels from Landsat TM	.033 (.01)	.13 (.023)	.25 (.019)
USFS	1 Km Pixels from NOAA AVHRR	.084 (.025)		

Proportion Pines-Evergreens				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=106)**
NALC	30 Meter Pixels from Landsat TM	.045 (.013)	.13 (.02)	.11 (.01)
TWRA	30 Meter Pixels from Landsat TM	.051 (.014)	.13 (.02)	.11 (.01)
USFS	1 Km Pixels from NOAA AVHRR	.079 (.0022)		

Proportion Hardwoods				
Coverage	**Type**	**County (N=7)**	**Quads on Plateau (N=30)**	**Four Kilometer Hexes (N=106)**
NALC	30 Meter Pixels from Landsat TM	.049 (.016)	.22 (.03)	.31 (.02)
TWRA	30 Meter Pixels from Landsat TM	.077 (.025)	.20 (.03)	.30 (.02)
USFS	1 Km Pixels from NOAA AVHRR	.10 (.031)		

Proportion Mixed Pine-Hardwood Mosaics				
Coverage	**Type**	**County (N=7)**	**Quads on Platea u (N=30)**	**Four Kilometer Hexes (N=106)**
NALC	30 Meter Pixels from Landsat TM	.028 (.008)	.07 (.01)	.09 (.008)
TWRA	30 Meter Pixels from Landsat TM	.025 (.009)	.07 (.01)	.083 (.0075)
USFS	1 Km Pixels from NOAA AVHRR	.081 (.027)		

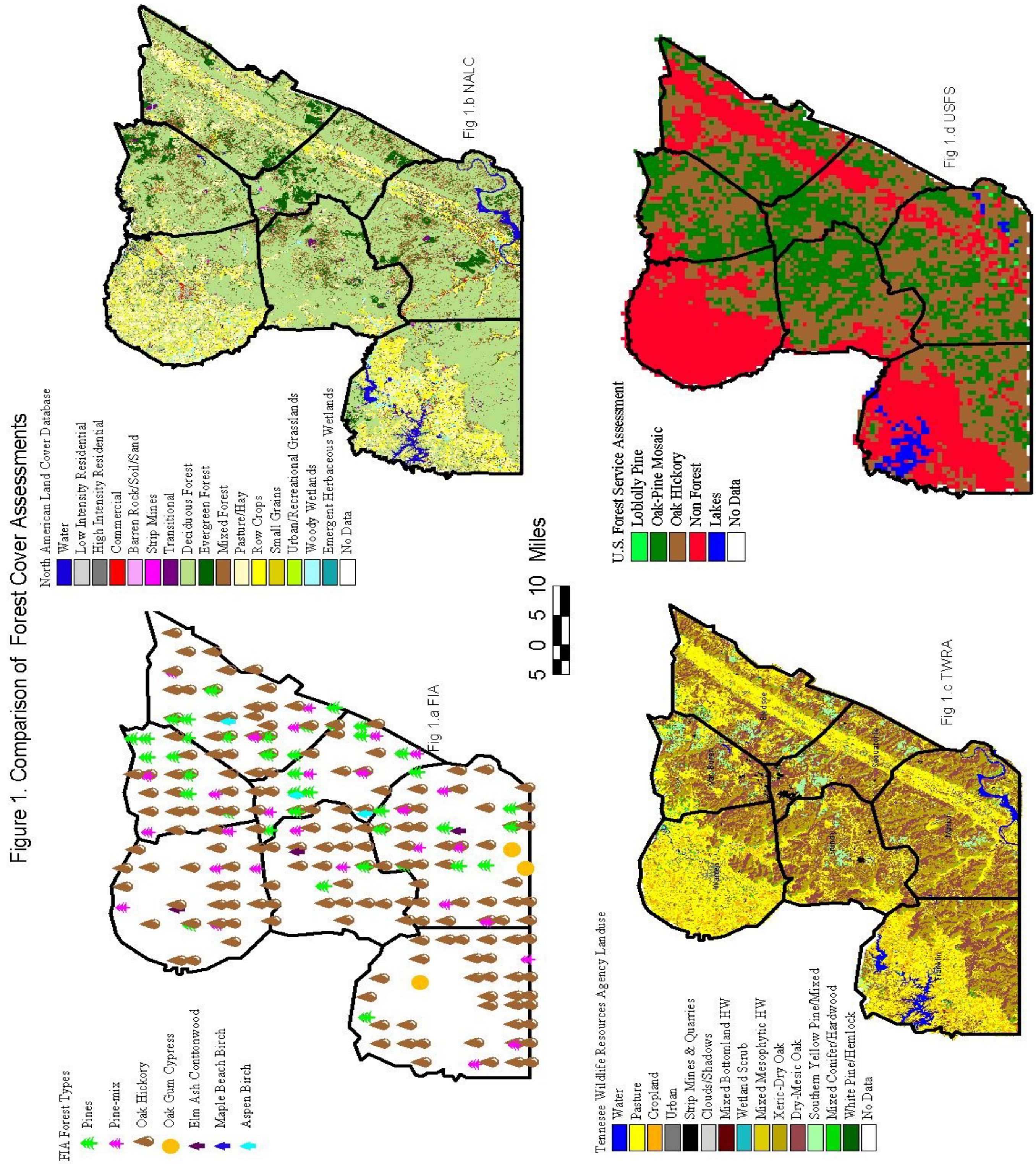


Figure 1: Comparison of Forest Cover Assessments: This figure presents the four coverages assessed in this paper. The FIA coverage is based on the 1999 Forest Inventory and Analysis Data from USGS. The NALC coverage is the North American Land Cover (NALC) database distributed by USGS. The TWRA database is the from the Tennessee GAP program. The USFS coverage is from the United States Forest Service' State of the Forest Report.

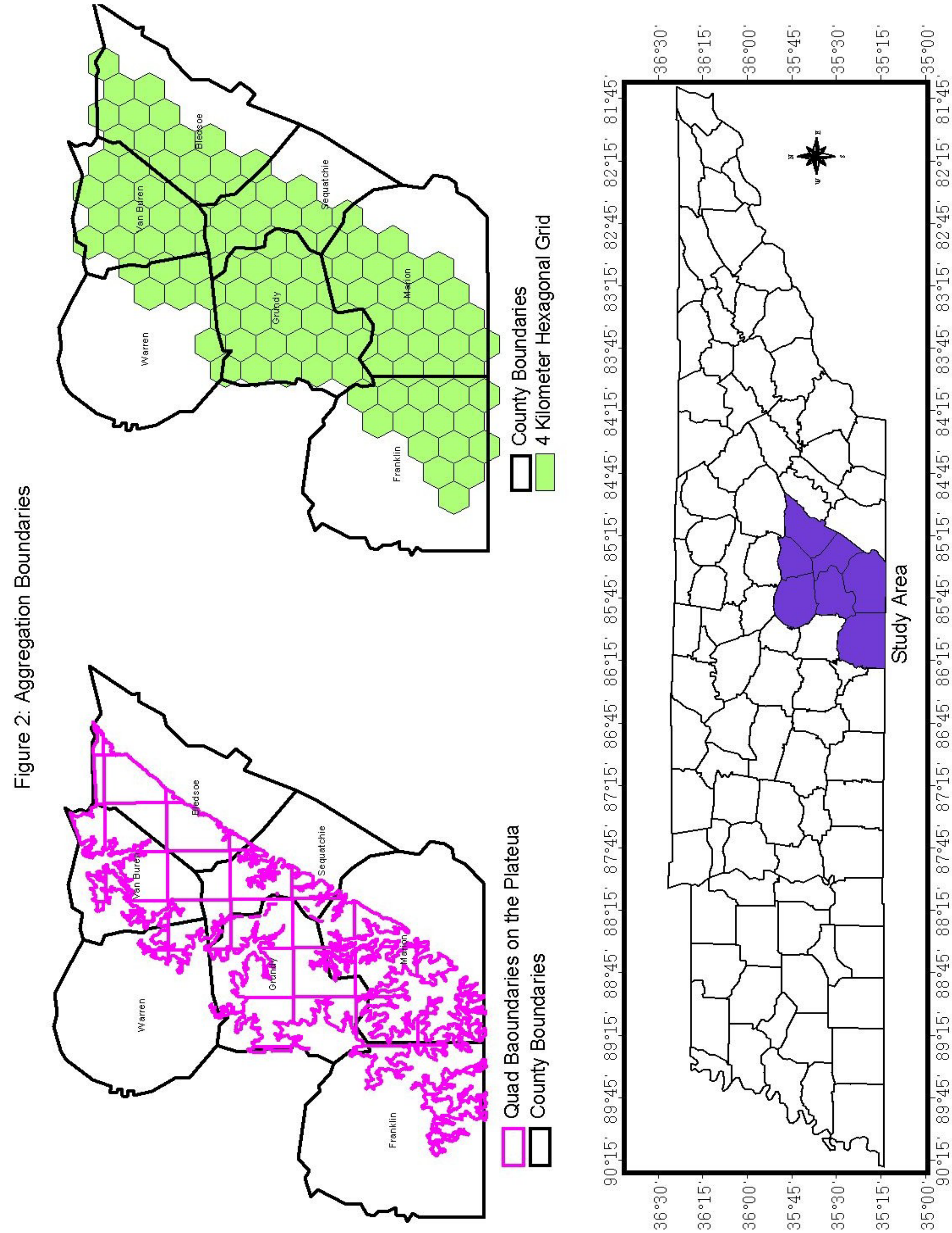


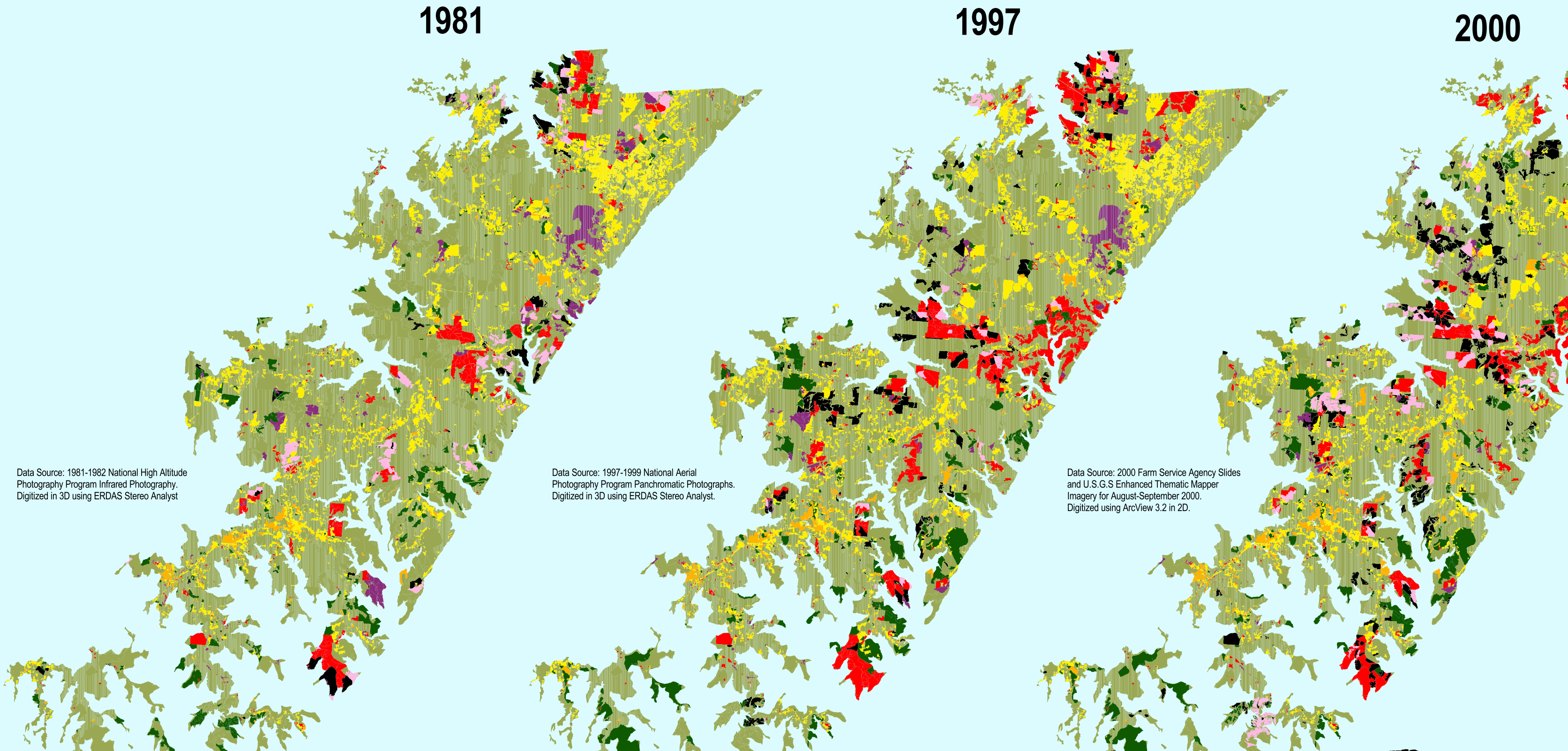
Figure 2: Aggregation Boundaries for Comparing Land Cover Assessments: The three levels of aggregation are 1. the county boundaries, 2. the boundaries of the USGS quadrangles for the sections of those quadrangles on the Cumberland Plateau, and 3. a four kilometer hexagonal grid for areas contiguous with the plateau boundary. The county and quad data are from USGS. The plateau boundary was digitized from stereo models based on the 1997 National Aerial Photography Program (NAPP).

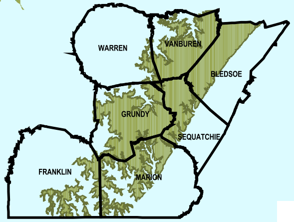
Appendix B

Map Index

NUMBER	TITLE	DATE
Map 1	Canopy Cover Change - Cumberland Plateau of Southern Tennessee	1981-2000
Map 2	Canopy Cover Change - Bledsoe County	1981-2000
Map 3	Canopy Cover Change - Franklin County	1981-2000
Map 4	Canopy Cover Change - Grundy County	1981-2000
Map 5	Canopy Cover Change - Marion County	1981-2000
Map 6	Canopy Cover Change - Sequatchie County	1981-2000
Map 7	Canopy Cover Change - Van Buren County	1981-2000
Map 8	Canopy Cover Change - Warren County	1981-2000
Map 9	Mine Impacted Areas	Various
Map 10	Roads and Forest Cover	2000
Map 11	Distance of Land from Structures	1997
Map 12	Structures and Forest Cover	1997-2000
Map 13	Normalized Difference Vegetation Index	2000-2001
Map 14	NRCS 12 Digit HUC Watersheds	2000

Canopy Cover Map of the Cumberland Plateau Surface in SouthernTennessee





Map 1

LEGEND

- Native Forest - Intact
- Native Forest - Thinned
- Plantation - Complete
- Plantation - Prep
- Pine - Mix
- Logged - Cleared
- Other - Partial Canopy
- Other - No Canopy

("Other" includes agriculture, residential/urban and mining activity)

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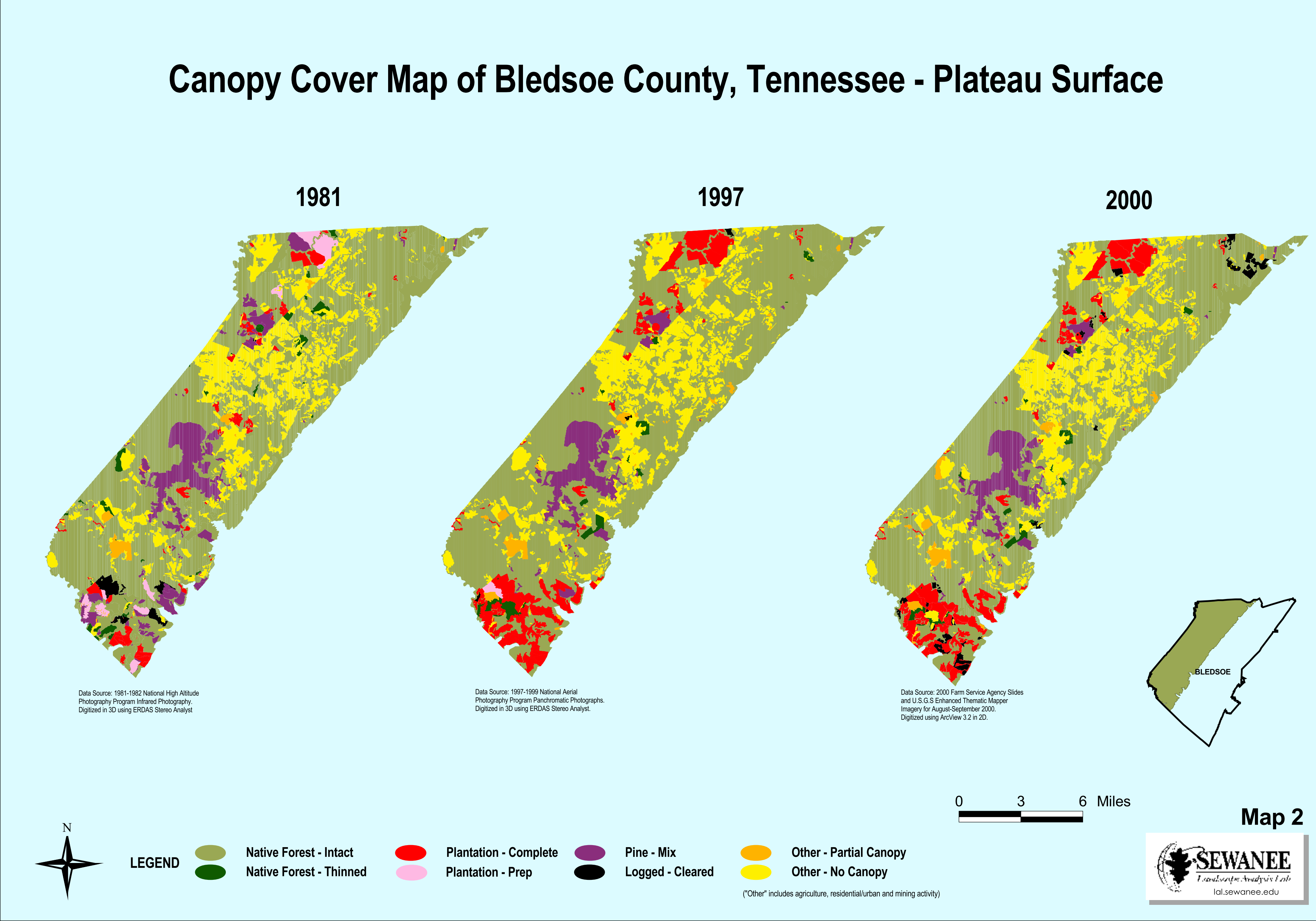

Canopy Cover Map of Bledsoe County, Tennessee - Plateau Surface
1981
1997
2000
Data Source: 1981-1982 National High Altitude Photography Program Infrared Photography. Digitized in 3D using ERDAS Stereo Analyst
Data Source: 1997-1999 National Aerial Photography Program Panchromatic Photographs. Digitized in 3D using ERDAS Stereo Analyst.
Data Source: 2000 Farm Service Agency Slides and U.S.G.S Enhanced Thematic Mapper Imagery for August-September 2000. Digitized using ArcView 3.2 in 2D.
BLEDSOE
0
3
6
Miles
Map 2
N
LEGEND
Native Forest - Intact
Native Forest - Thinned
Plantation - Complete
Plantation - Prep
Pine - Mix
Logged - Cleared
Other - Partial Canopy
Other - No Canopy
("Other" includes agriculture, residential/urban and mining activity)
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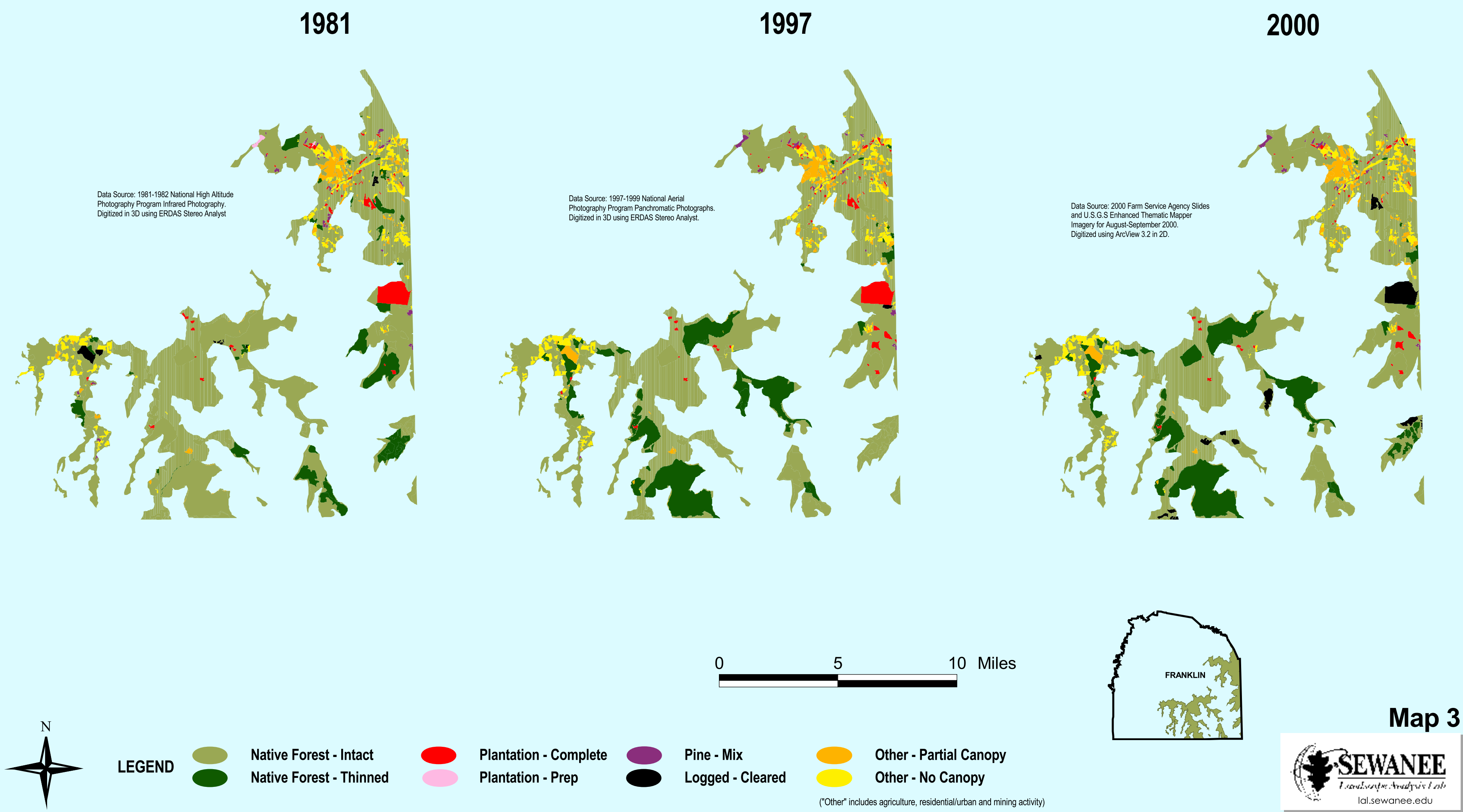
Canopy Cover Map of Franklin County, Tennessee - Plateau Surface



Map 3

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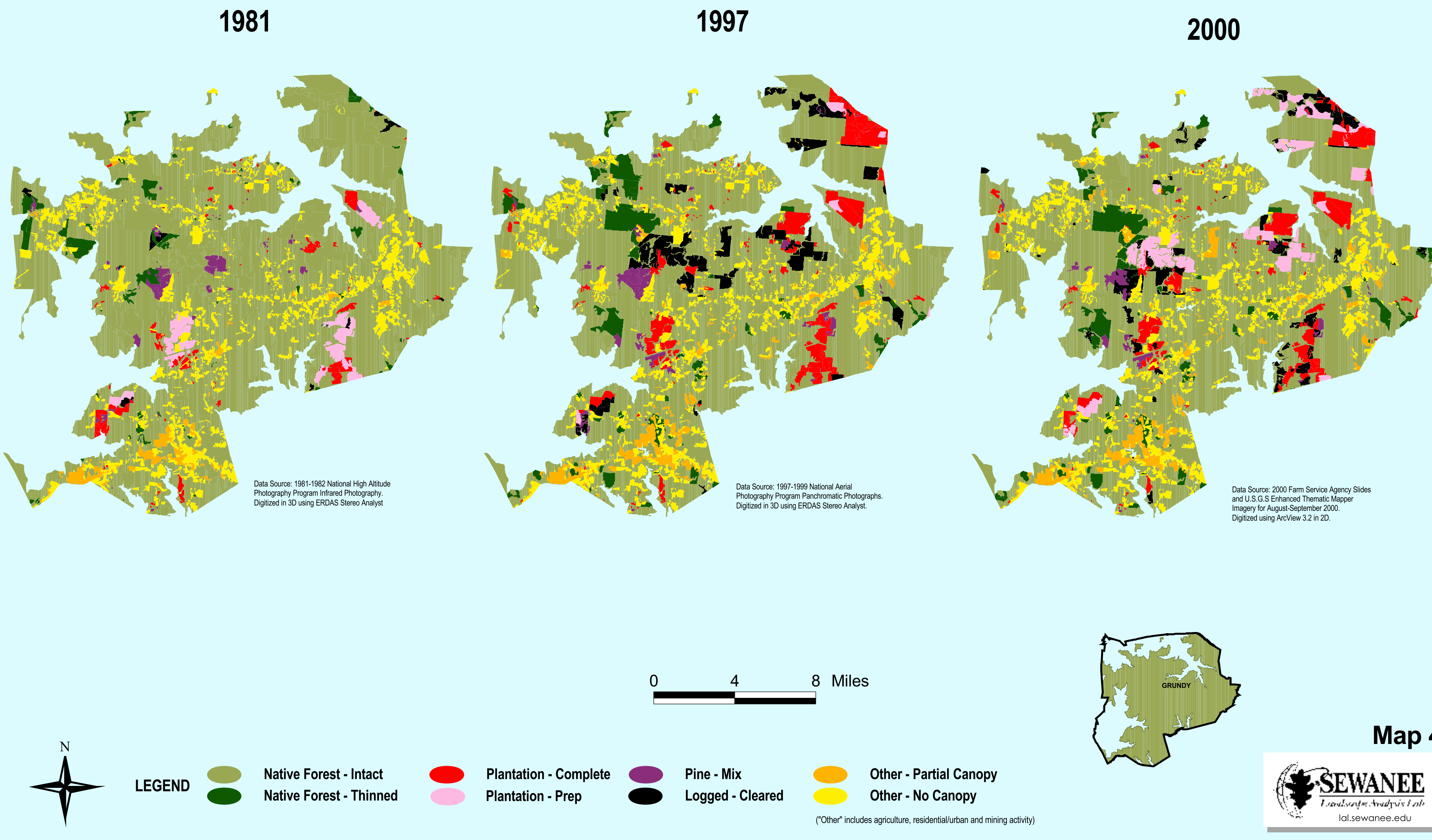
Canopy Cover Map of Grundy County, Tennessee - Plateau Surface



Map 4

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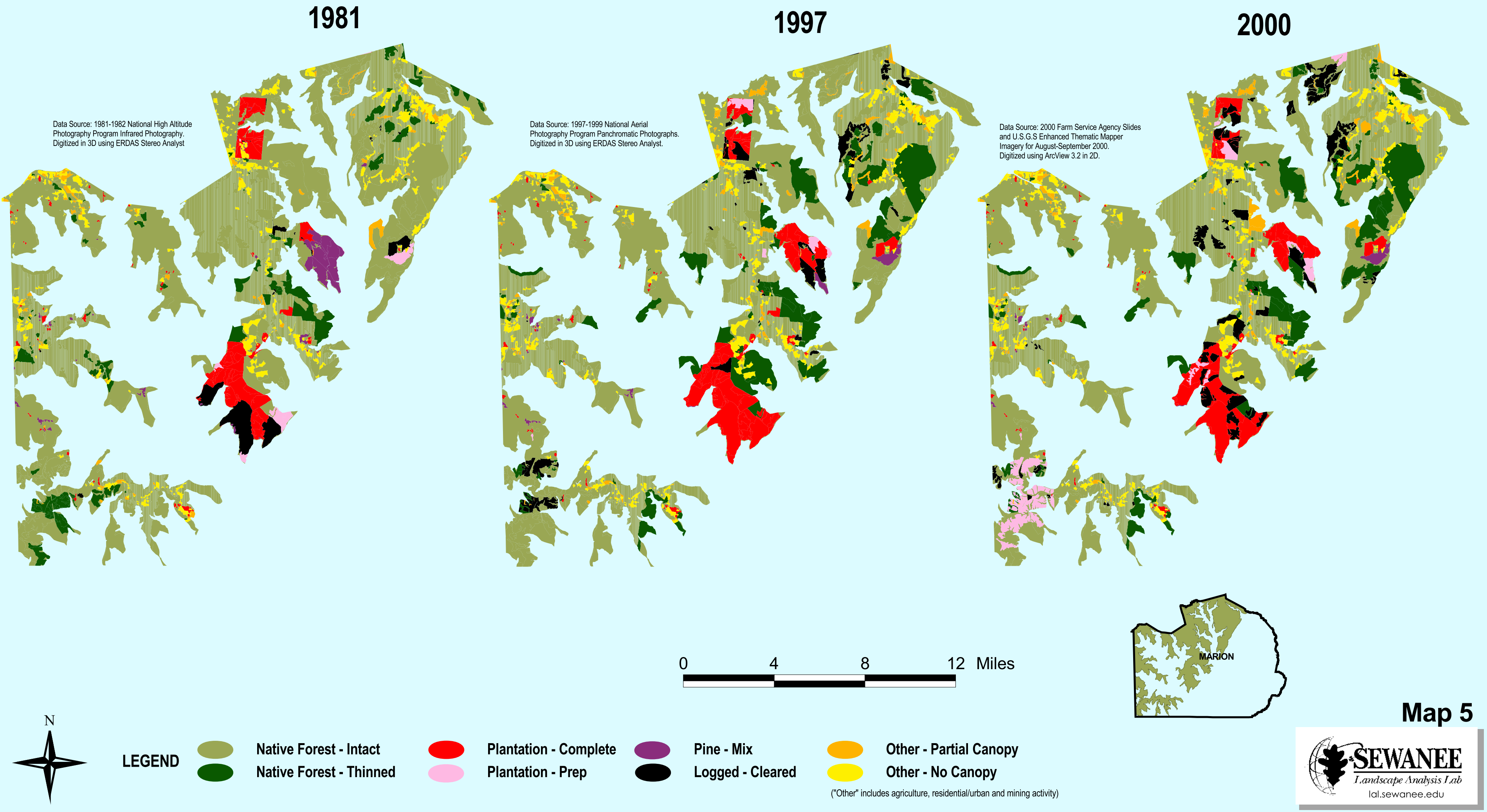
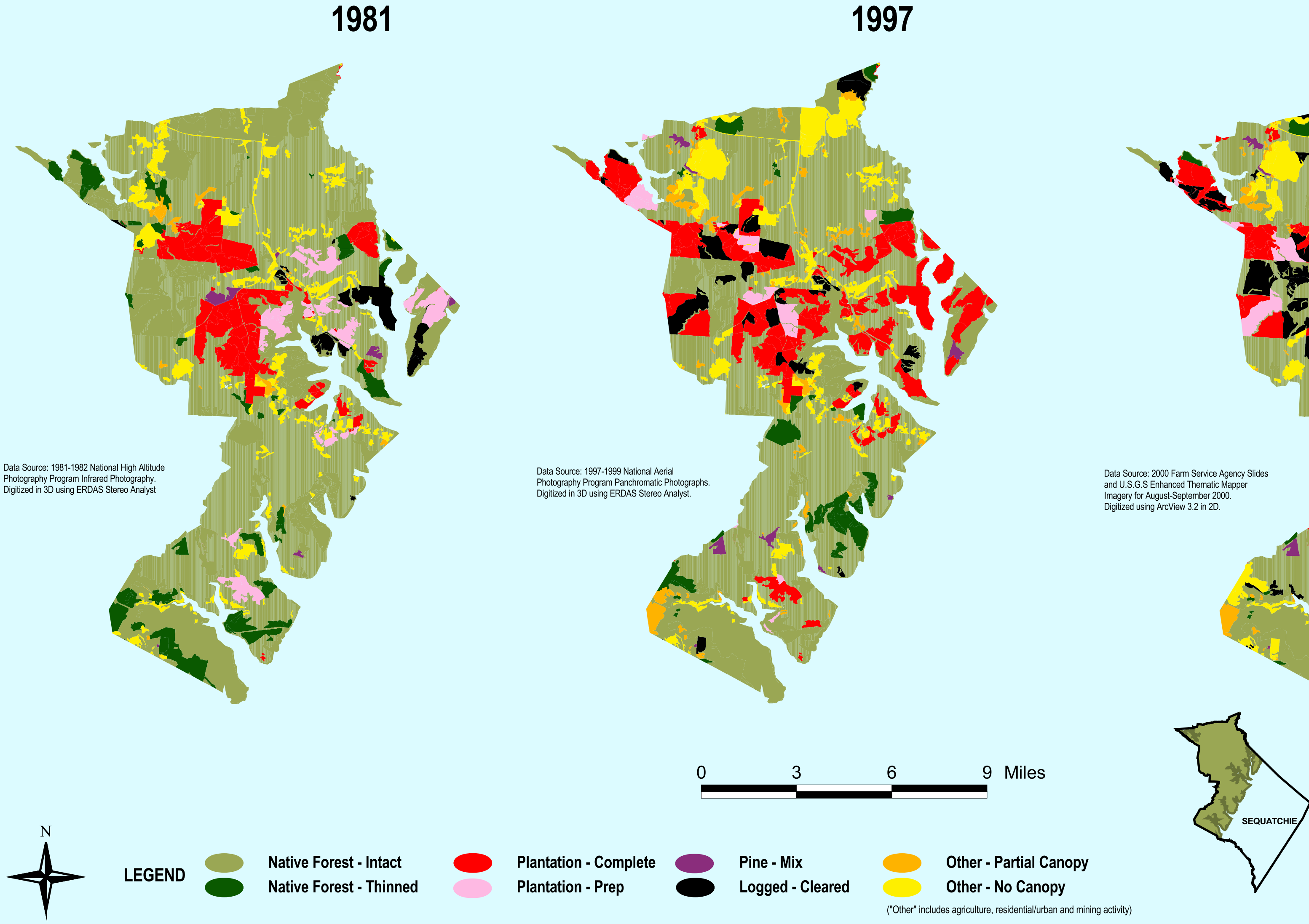
Canopy Cover Map of Marion County, Tennessee - Plateau Surface



Canopy Cover Map of Sequatchie County, Tennessee - Plateau Surface



Map 6

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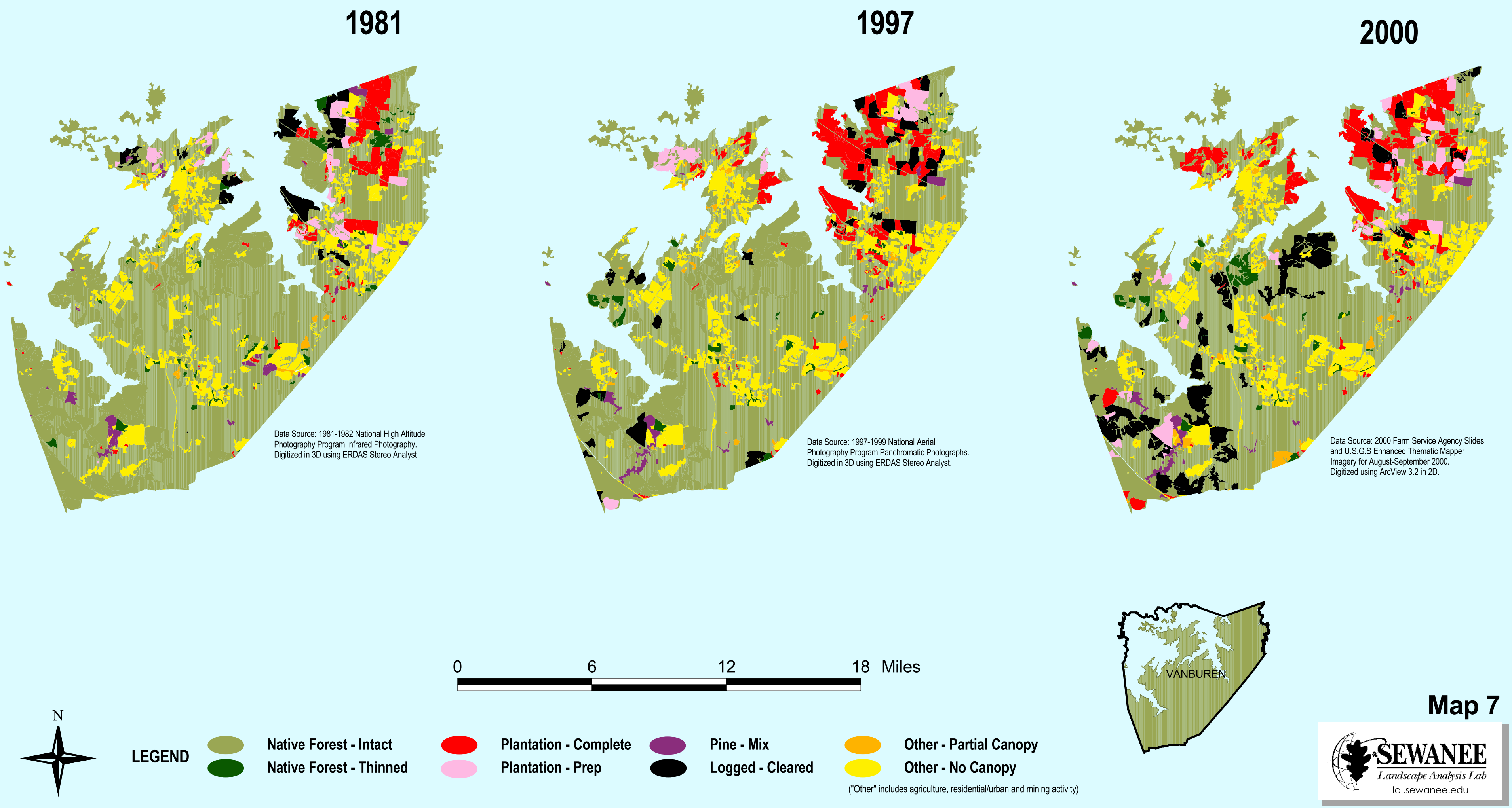
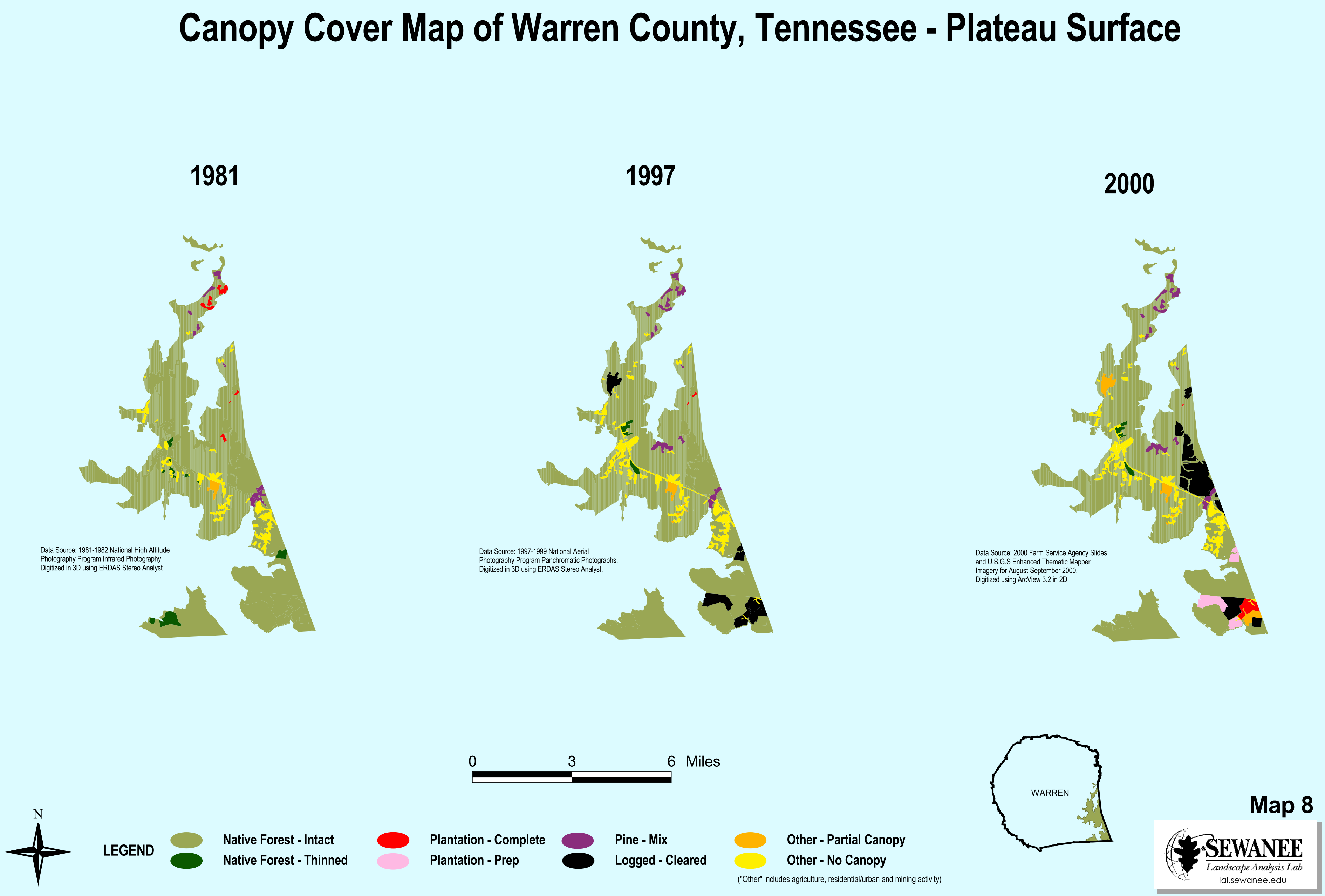
Canopy Cover Map of Van Buren County, Tennessee - Plateau Surface





Canopy Cover Map of Warren County, Tennessee - Plateau Surface
1981
1997
2000
Data Source: 1981-1982 National High Altitude
Photography Program Infrared Photography.
Digitized in 3D using ERDAS Stereo Analyst
Data Source: 1997-1999 National Aerial
Photography Program Panchromatic Photographs.
Digitized in 3D using ERDAS Stereo Analyst.
Data Source: 2000 Farm Service Agency Slides
and U.S.G.S Enhanced Thematic Mapper
Imagery for August-September 2000.
Digitized using ArcView 3.2 in 2D.
0
3
6
Miles
WARREN
Map 8
N
LEGEND
Native Forest - Intact
Native Forest - Thinned
Plantation - Complete
Plantation - Prep
Pine - Mix
Logged - Cleared
Other - Partial Canopy
Other - No Canopy
("Other" includes agriculture, residential/urban and mining activity)
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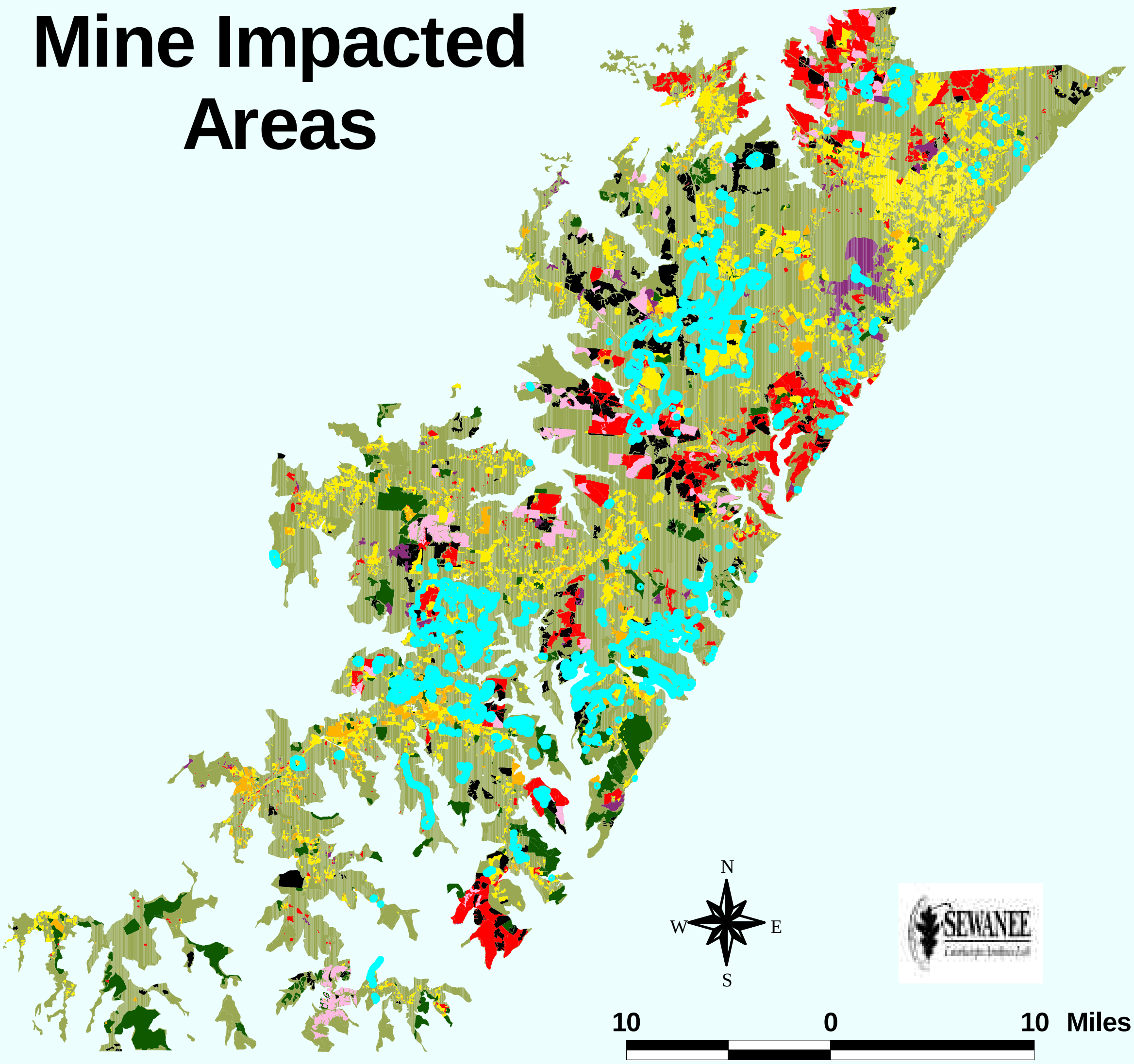
Mine Impacted Areas



Key:

Mine Affected

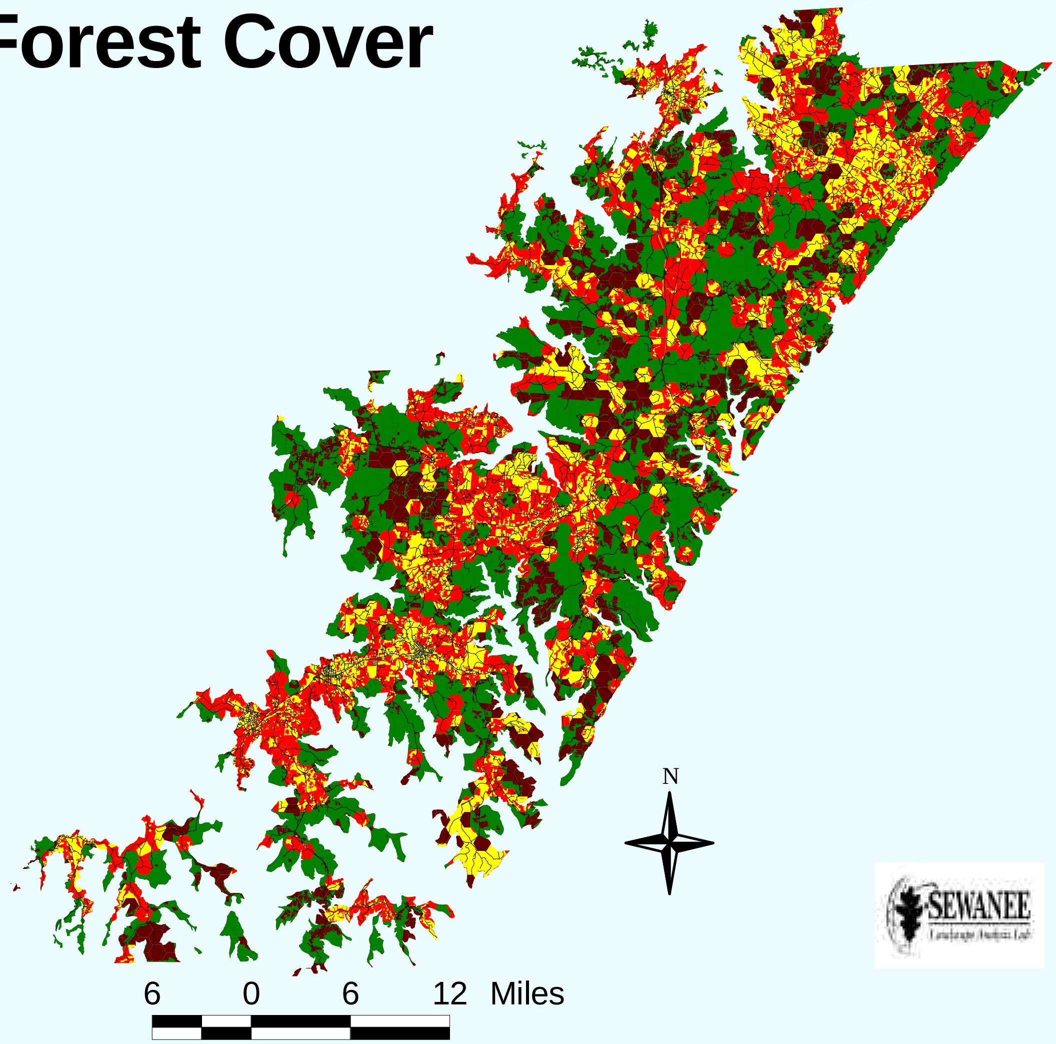
Canopy Cover Classes

- Native Forest
- Native Forest - Thinned
- Plantation - Mature
- Plantation - Mix
- Plantation Prep
- Logged - Cleared
- Other - Some Canopy
- Other - No Canopy

Notes: This map combines mine layers from the Office of Surface Mines and U.S.G.S.--colored in light blue. This is combination of past and current activity.

Map 9

Roads and Forest Cover



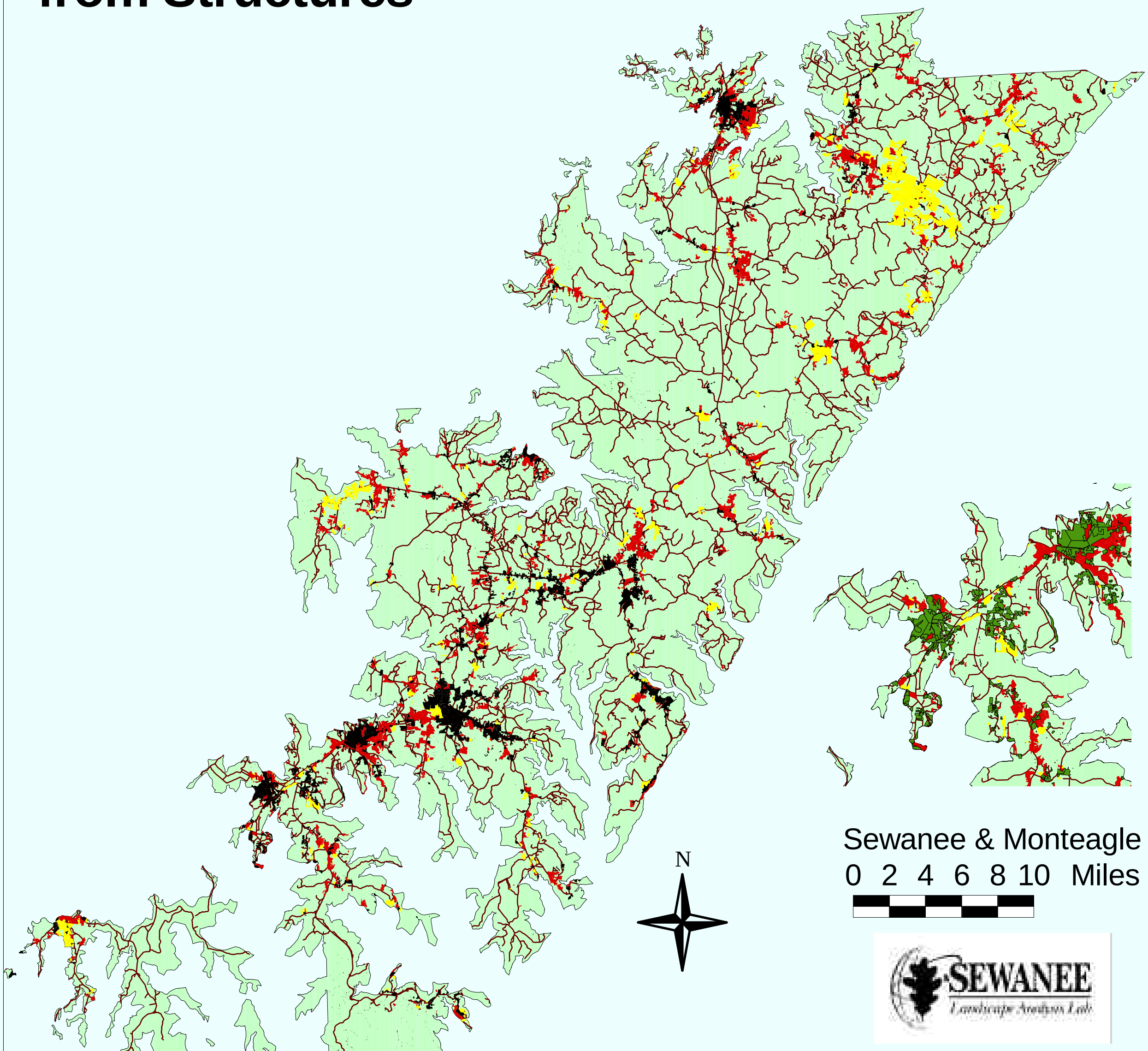
Key

Road Impacted Native
Nonimpacted Native
Road Impacted Non-Native
Nonimpacted Non-Native

Notes: This map shows the areas of dense native forest that are within 250 meters of a road in red. The yellow regions show land areas that are closer than 250 meters on average for other land cover types. The distances were averaged for every 200 hectares of plateu. This was done to more accurately represent areas of high and low housing density.

Map 10

Distance of Land from Structures



Key

Canopy Distance

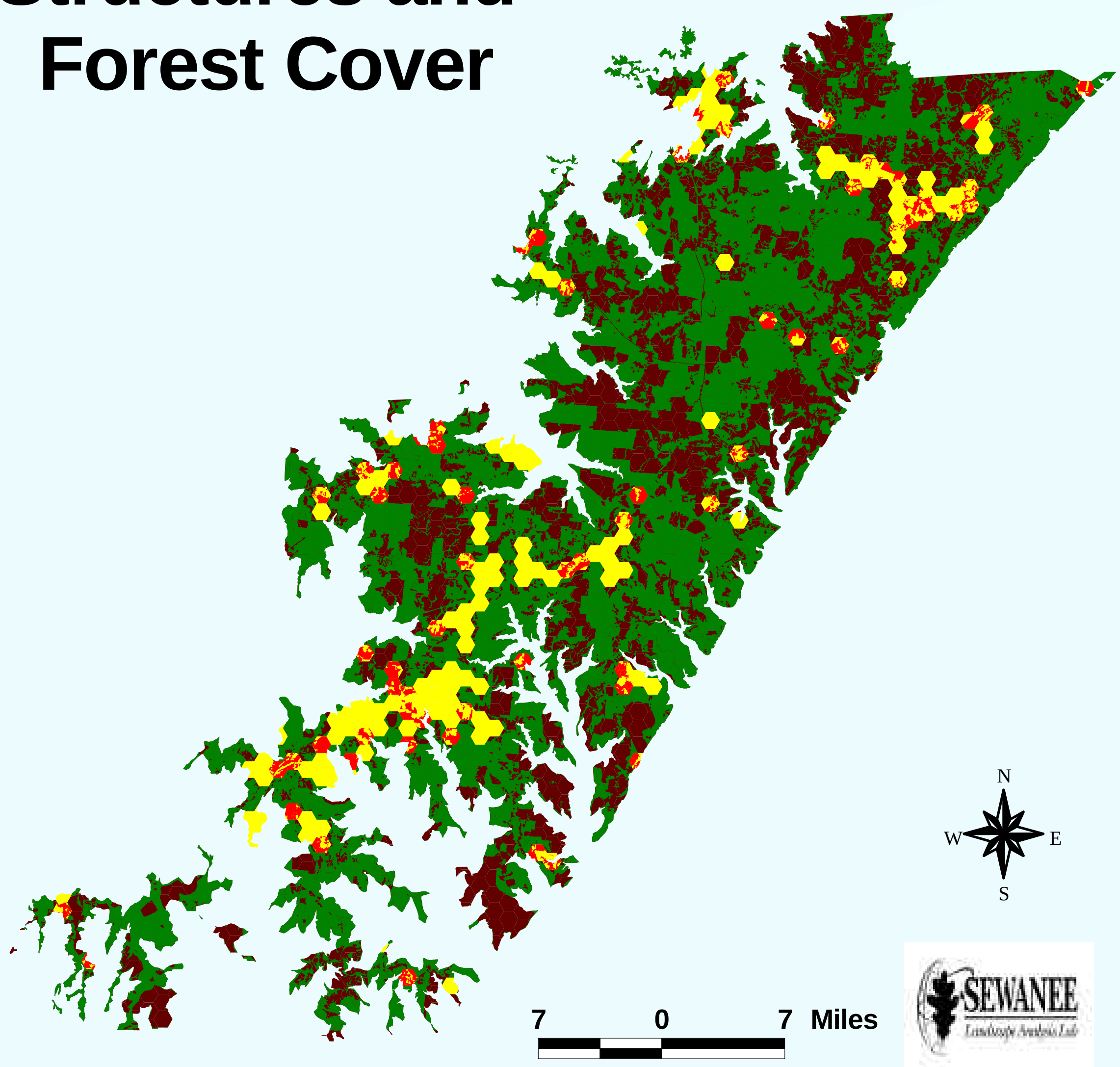
- < 100m from structure
- 100 - 200 m from structure
- 200-250 m from structure
- > 250m from Structure

Roads

Plateau

Map 11

Structures and Forest Cover

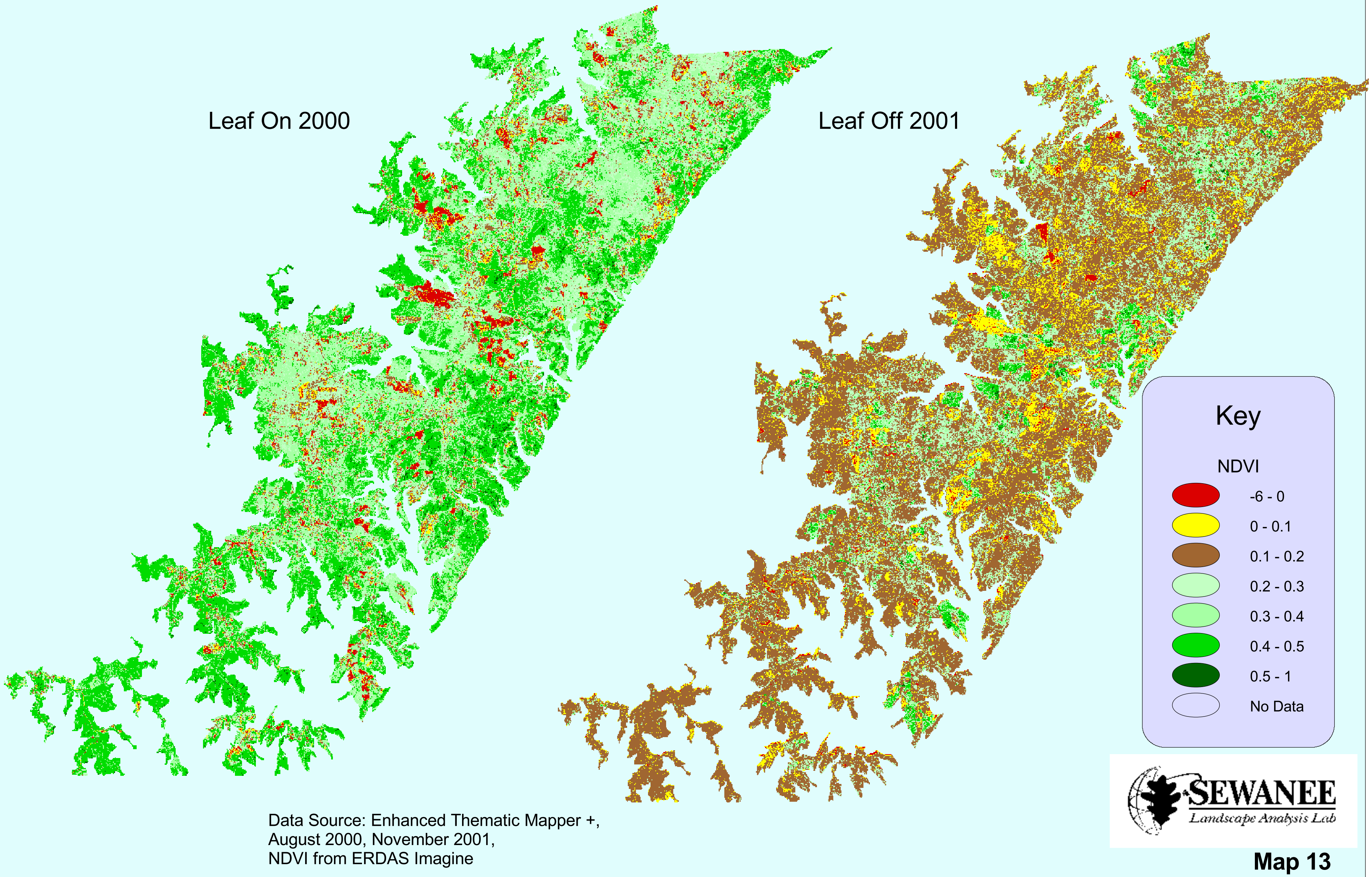


Key

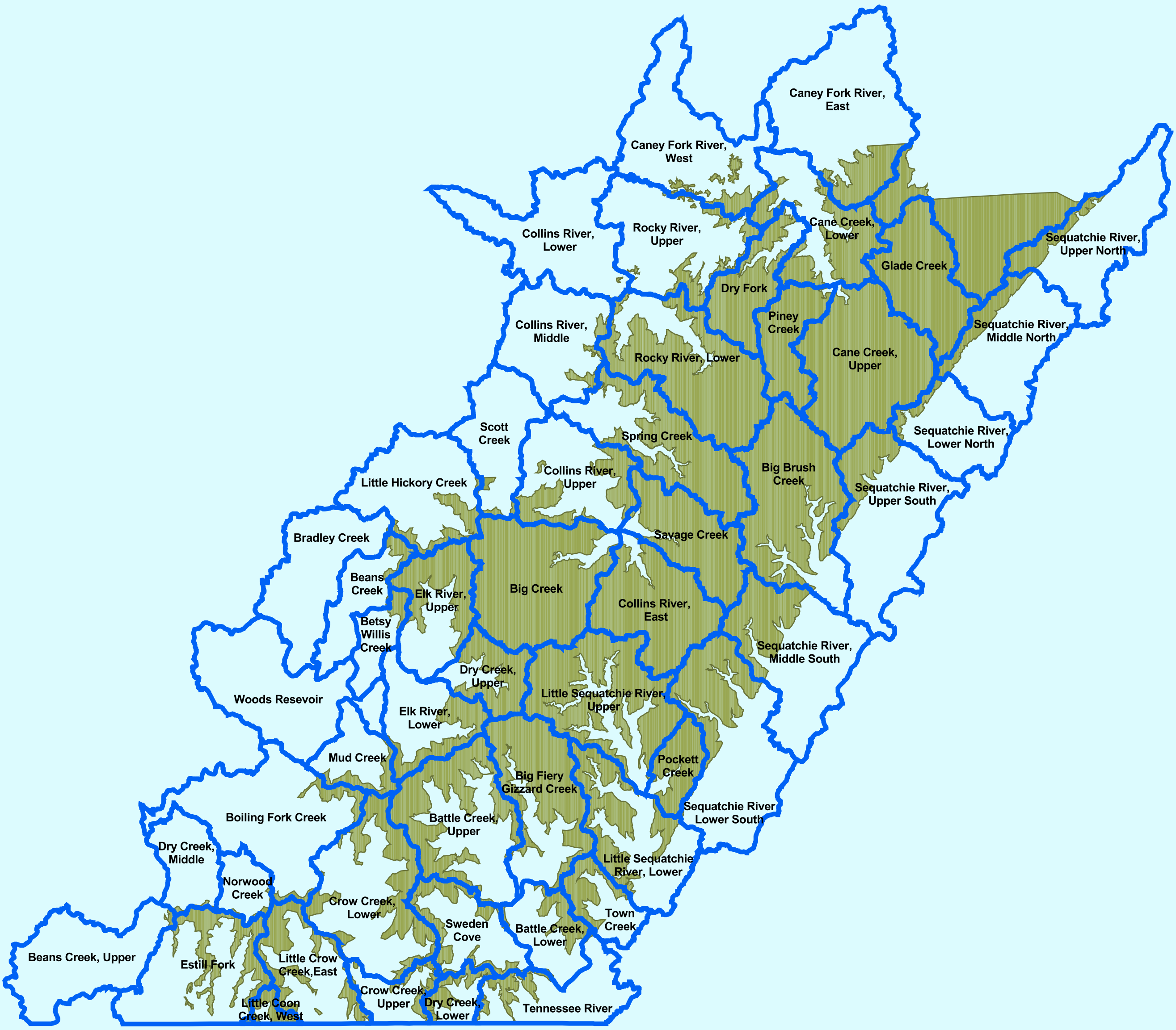
Structure Impacted Native
Nonimpacted Native
Structure Impacted Non-Native
Nonimpacted Non-Native

Notes: This map shows the areas of native intact forest that are within 250 meters of a human built structure in red. The yellow regions show parcel areas that are closer than 250 meters on average for other land cover types. The distances were averaged for every 200 hectares of plateu. This was done to more accurately represent areas of high and low housing density with respect to canopy cover.

Southern Tennessee Cumberland Plateau Study Area
(Normalized Differenced Vegetation Index: Leaf On vs. Leaf Off)



NRCS 12 Digit HUC Watersheds



N

Legend

NRCS 12 Digit HUC Watersheds

Study Area

0 5 10 15 20 Miles

Data Source: National Resources Conservation Service (NRCS) 12 Digit Hydrologic Unit Code. Obtained from the Tennessee Federal GIS Users Group.

Map 14

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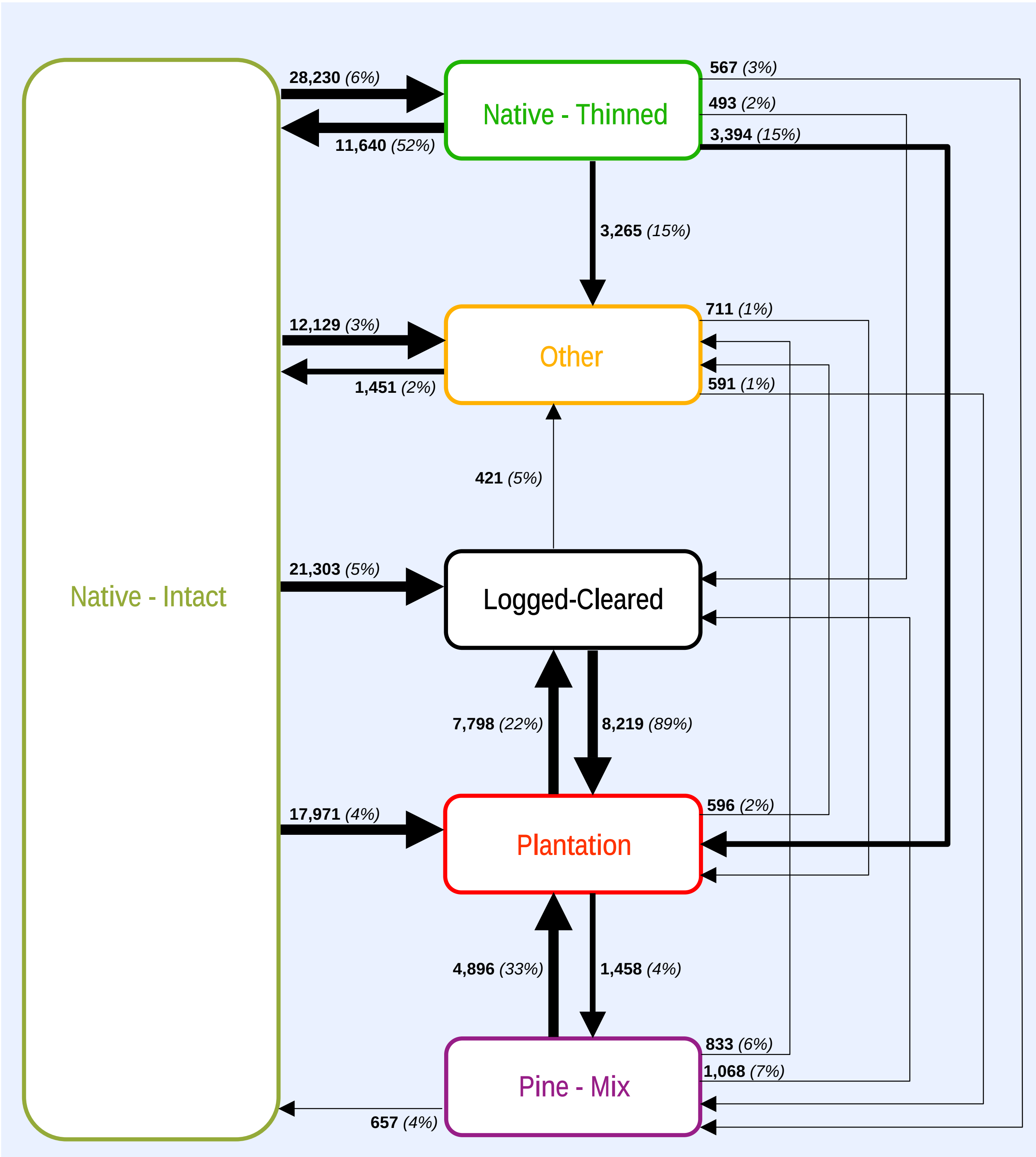
Appendix C

Chart Index

The Cumberland Plateau in Southern Tennessee

(Canopy Cover Transitions 1981-2000)



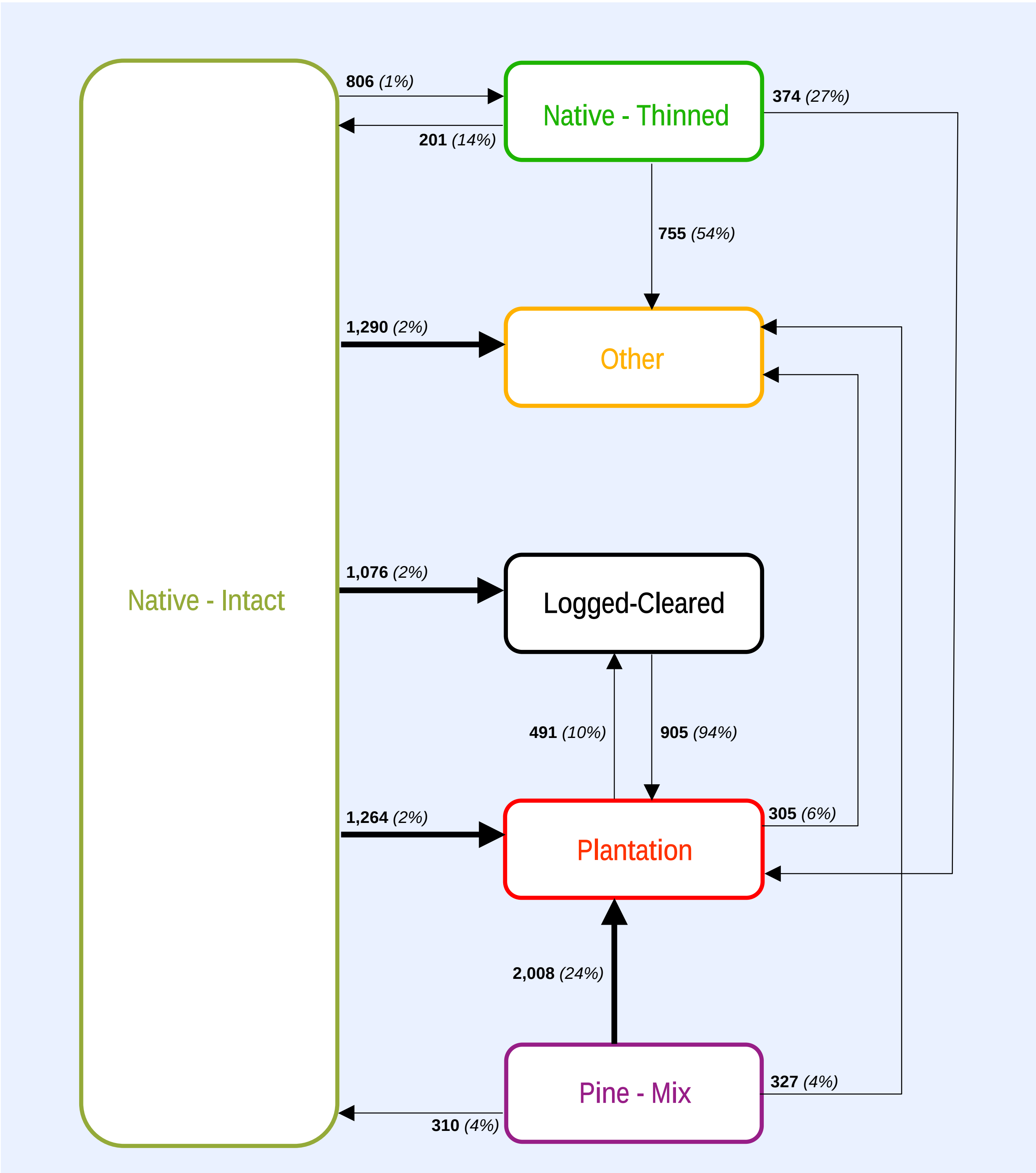
Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

- >7,400 acres
- 1,400 – 7,400 acres
- 400 – 1,400 acres

Chart 1

Bledsoe County

(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

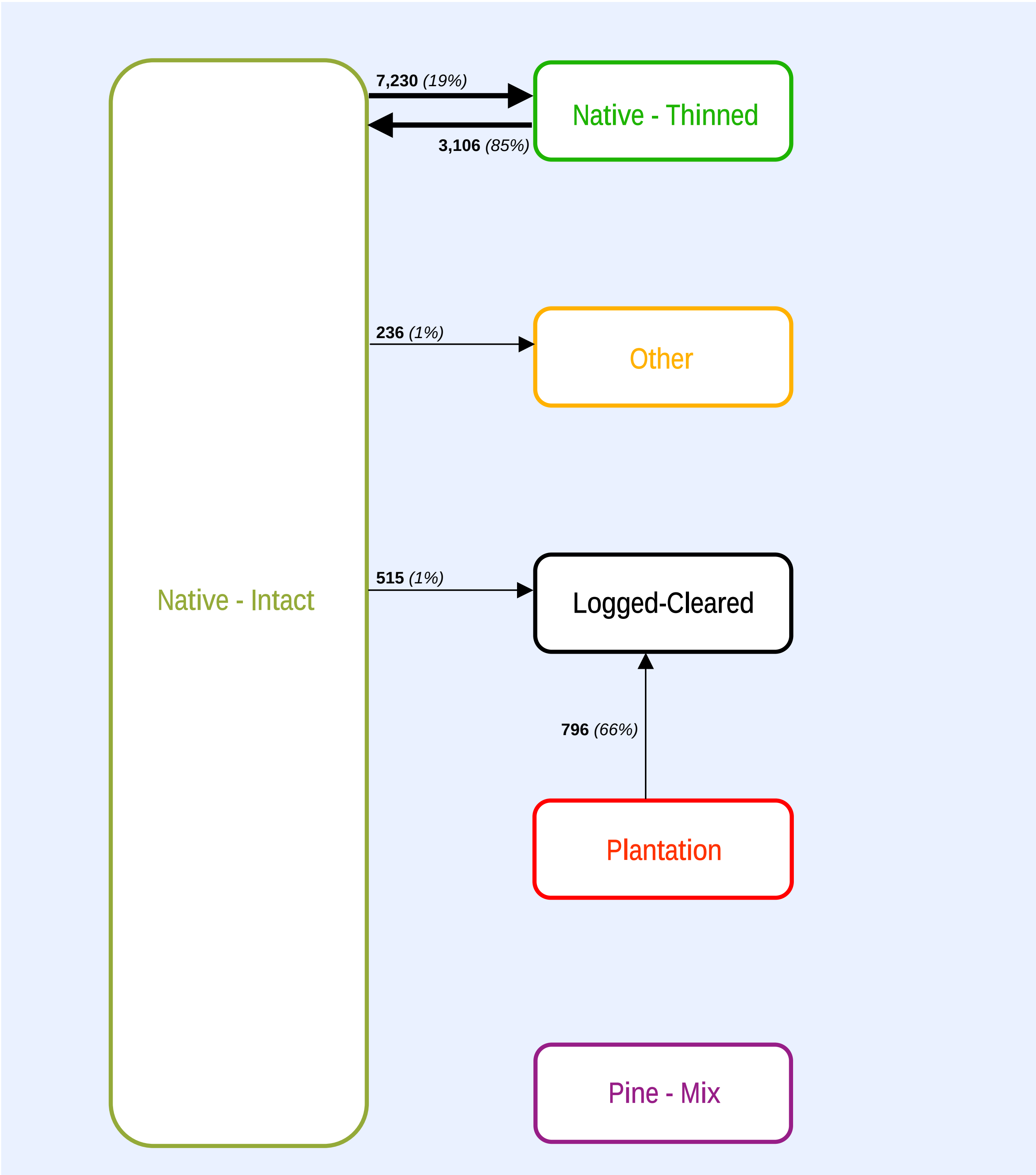
>1,000 acres

200 – 1,00 acres

Chart 2

Franklin County

(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

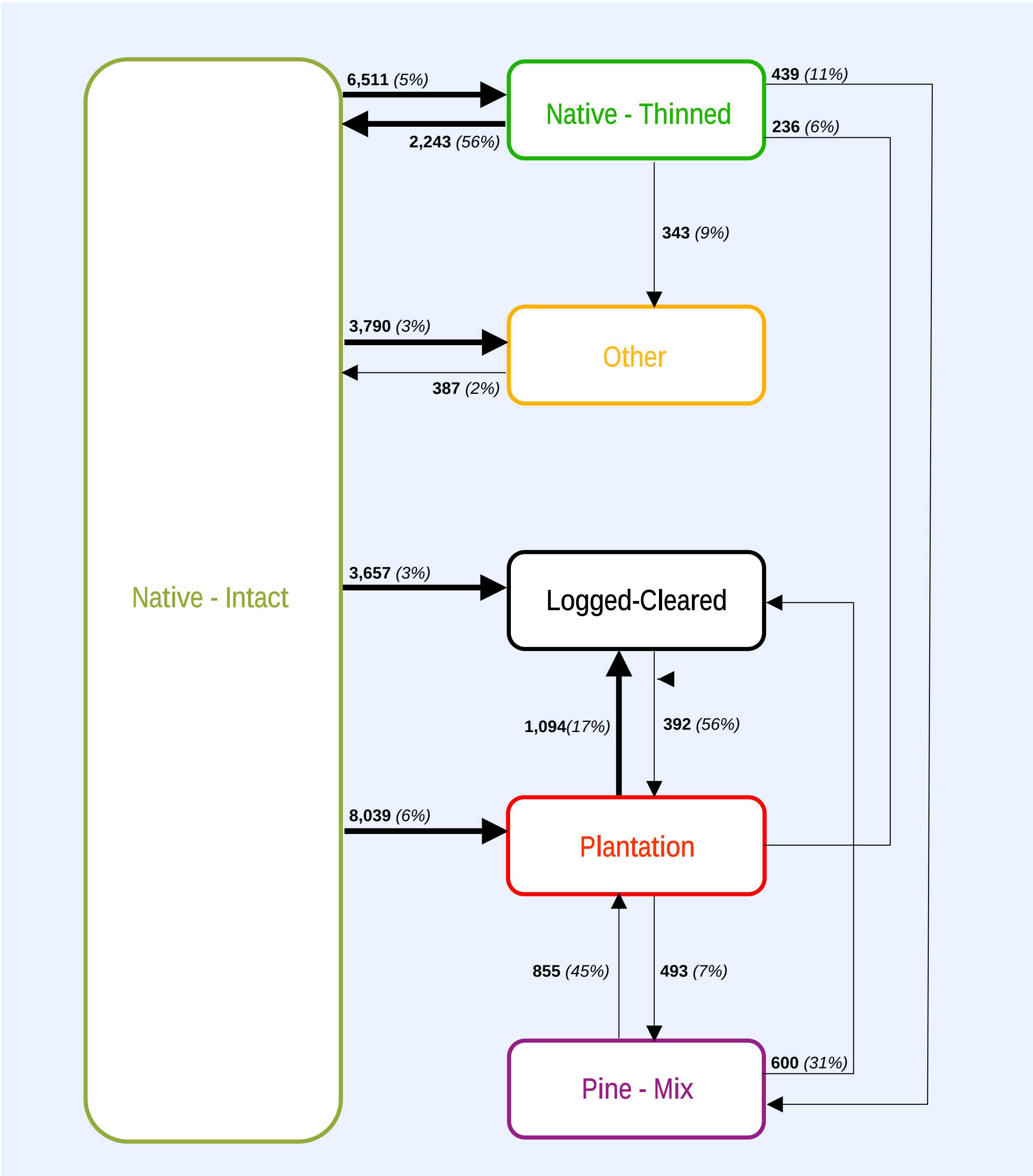
>1,000 acres

200 – 1,00 acres

Chart 3

Grundy County

(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

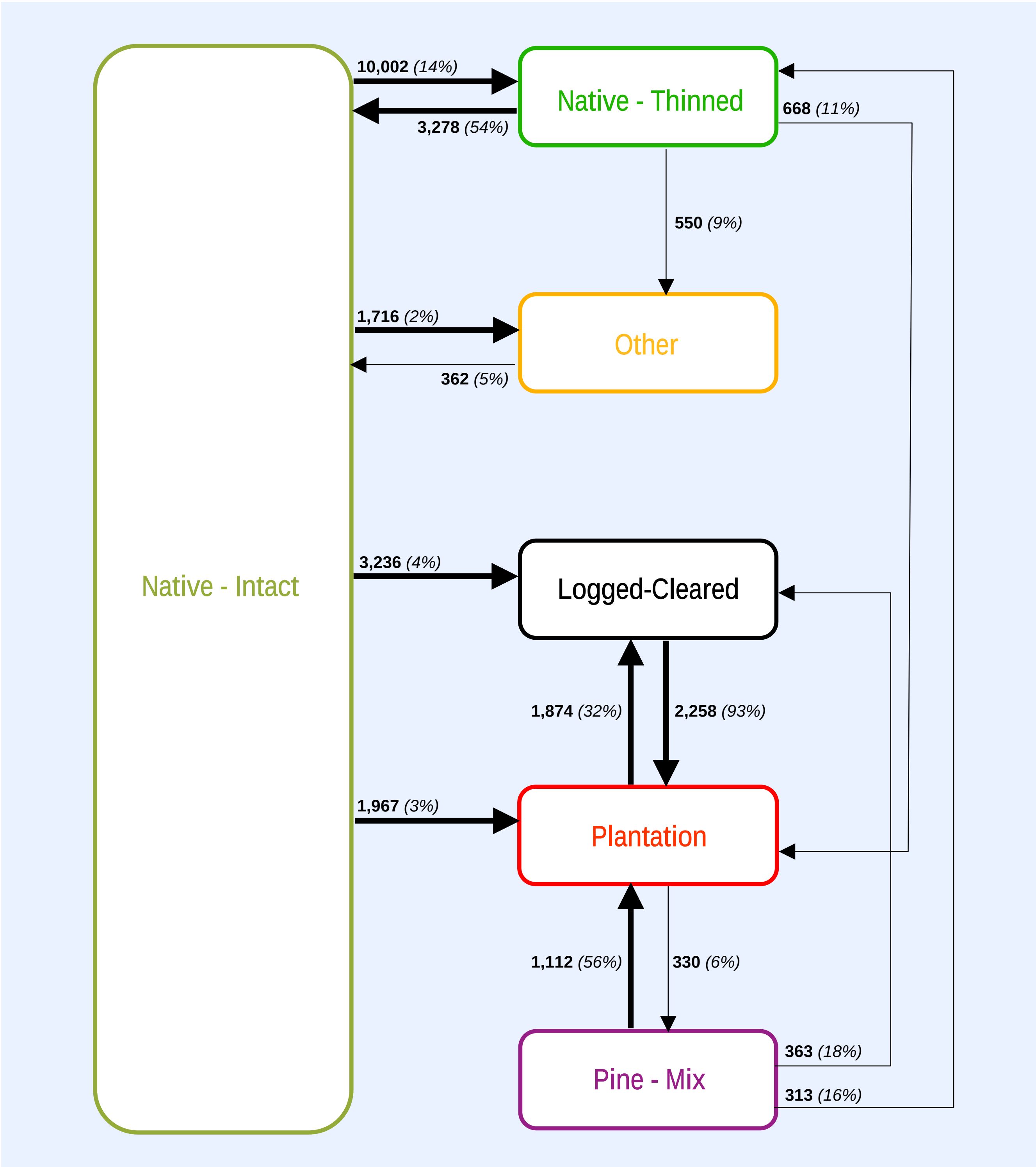
>1,000 acres

200 – 1,00 acres

Chart 4

Marion County

(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

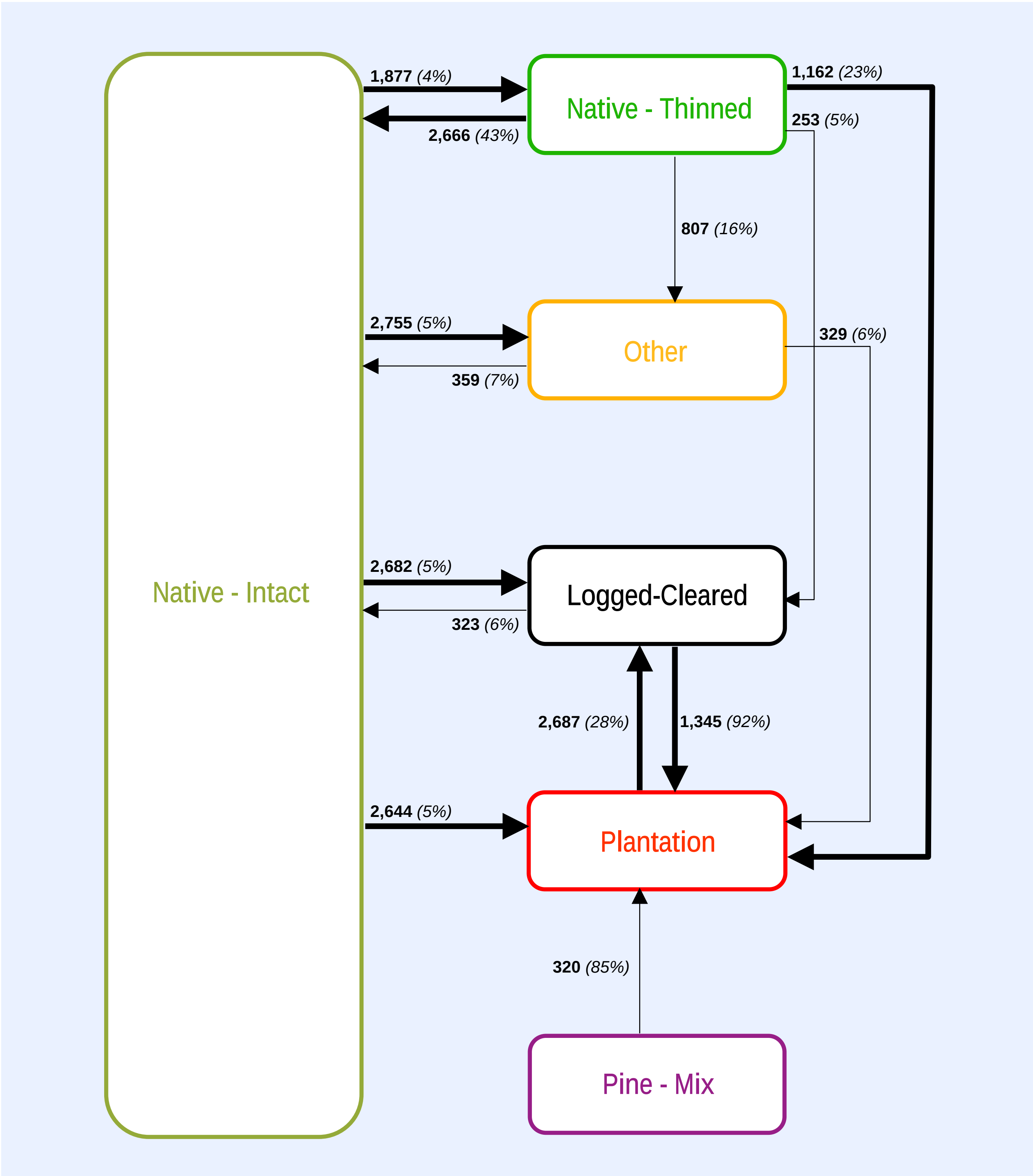
>1,000 acres

200 – 1,00 acres

Chart 5

Sequatchie County

(Canopy Cover Transitions 1981-2000)



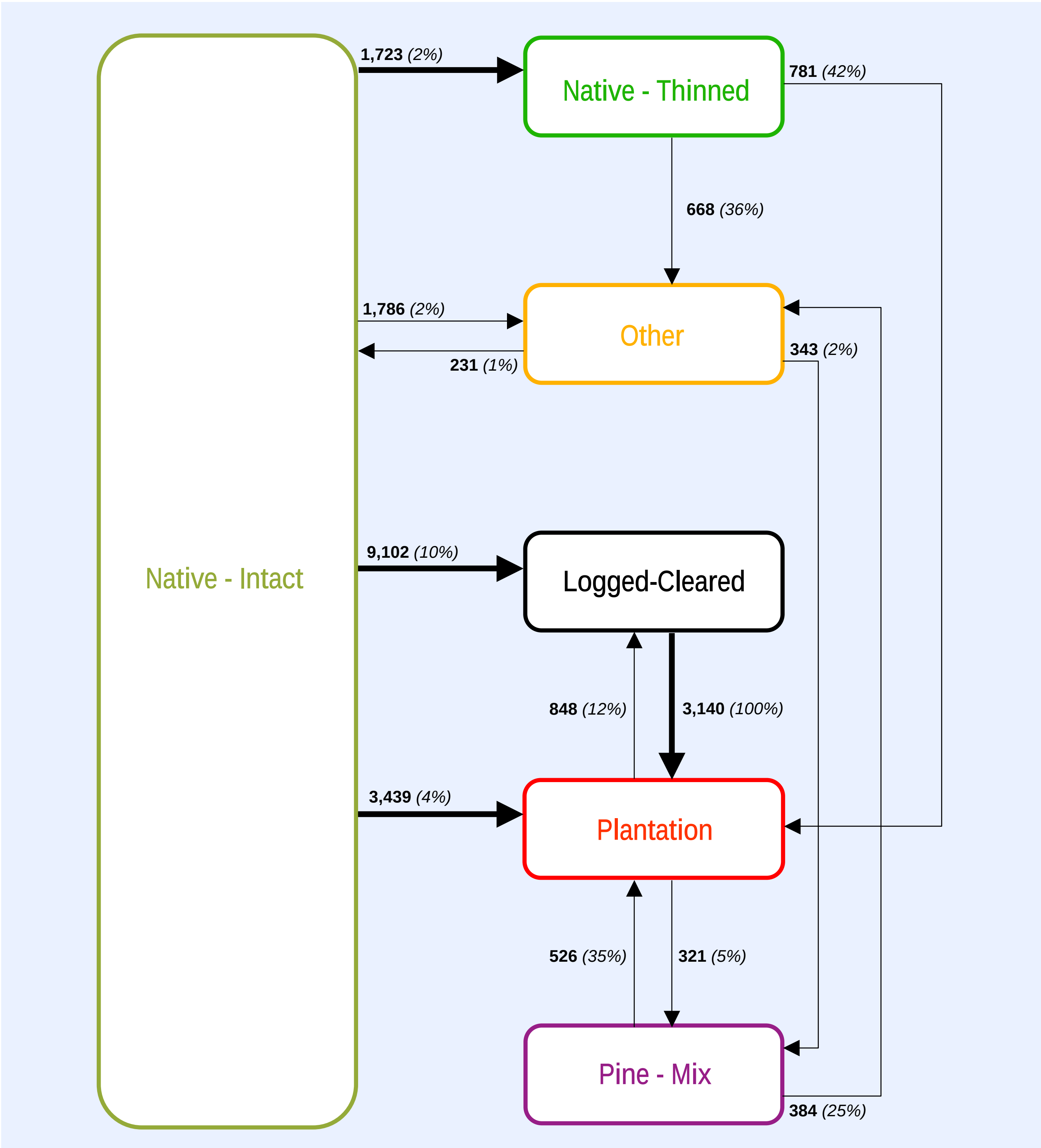
Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

>1,000 acres

200 – 1,00 acres

Chart 6

Van Buren County
(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

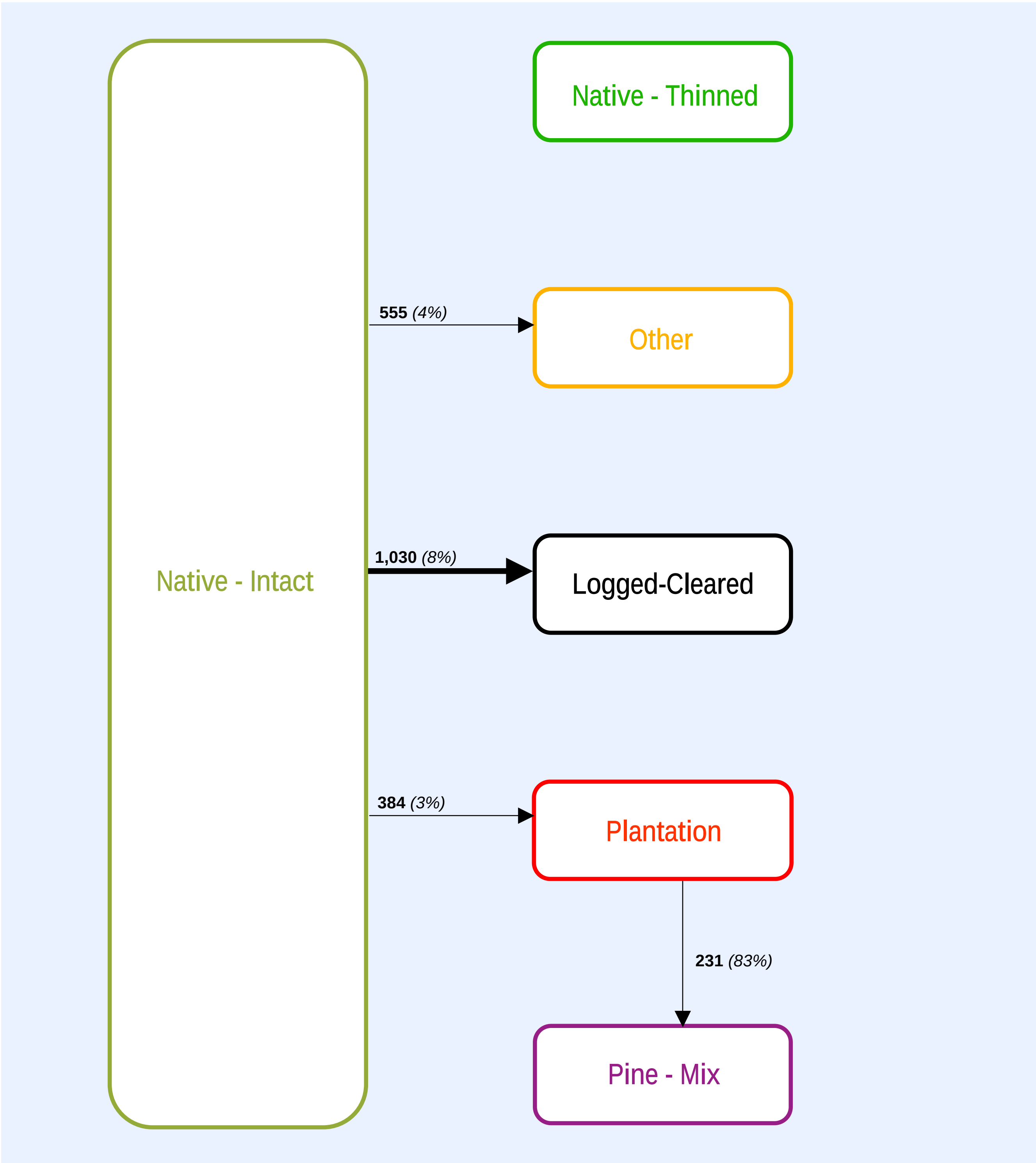
>1,000 acres

200 – 1,00 acres

Chart 7

Warren County

(Canopy Cover Transitions 1981-2000)



Arrows represent the net transition of acres (numbers in bold) between 1981 and 2000 from one cover category (beginning of arrow) to another category (end of arrow). The number in italics indicates the percentage of the total acres of a beginning cover category in 1981 that had transitioned to an end category by 2000.

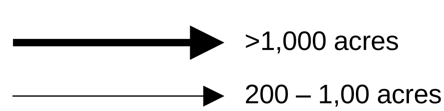


Chart 8

Appendix D

Glossary

accuracy assessment - The comparison of a land use classification call to geographical data that is assumed to be true. Usually, the assumed-true data are derived from visual ground verification.

aerial photography* - Photography from airborne platforms.

anaglyph stereo - The process by which blue, green and red are mixed and distorted to produce a digital stereo image on a computer monitor. Image may be viewed with red/green or red/cyan glasses but it is not possible to digitize over the image.

ArcView GIS - A computer mapping system created by ESRI Inc.

ArcView Spatial Analyst*** - An extension that gives ArcView the ability to create, query, analyze, and map cell-based raster data, and to perform integrated vector-raster analysis with feature-based and grid-based themes (layers).

attribute*** - The tabular information associated with a raster or vector layer

base map*** - A map portraying background reference information onto which other information is placed for comparison. Base maps usually show the location and extent of natural surface features and permanent man-made features

block - Term used to describe all of the information associated with a photogrammetric mapping project

block model - A layer in a GIS project which mathematically combines different types of information (i.e. elevation, geographical position) related to a specific mapping area.

buffer zone*** - A specific area around a feature that is isolated for or from further analysis. For example, buffer zones are often generated around streams in site assessment studies, so that further analyses will exclude these areas that are often unsuitable for development

calibration* - The process of comparing measurements, made by an instrument, with a standard.

calibration report*** - In aerial photography, the manufacturer of the camera specifies the interior orientation in the form of a certificate or report.

call - A land use classification of a particular parcel of land.

Cartesian***- A coordinate system in which data are organized on a grid and points on the grid are referenced by their X,Y coordinates.

classification*** - The process of assigning the pixels of a continuous raster image to discrete categories.

control point*** - A point with known coordinates in the ground coordinate system, expressed in the units of the specified map projection.

coverage** - 1. A digital version of a map forming the basic unit of vector data storage in a GIS program. A coverage stores geographic features as primary features (such as arcs, nodes, polygons, and label points) and secondary features (such as map extent, links, and annotation). Associated feature attribute tables describe and store attributes of the geographic features. 2. A set of thematically associated data considered as a unit. A coverage usually represents a single theme such as soils, streams, roads or land use.

datum** - A set of parameters and control points used to accurately define the three-dimensional shape of the Earth (e.g., as a spheroid). The datum is the basis for a planar coordinate system. For example, the North American Datum for 1983 (NAD83) is the datum for map projections and coordinates within the United States and throughout North America.

decimal degrees - Degrees of latitude and longitude expressed as decimal fractions of degrees rather than in degrees, minutes and seconds.

DEM (digital elevation model) - Continuous raster layers in which data file values represent elevation. DEMs are available from the USGS at 1:24,000 and 1:250,000 scale.

digital orthophoto - An aerial photo or satellite scene in which every point appears as if the observer were looking straight down at it. An image which has been digitally orthorectified.

DOQ (digital orthophoto quadrangle) - A computer-generated image of an aerial photo, which has been orthorectified to give it map coordinates. DOQs are produced by the United States Geological Survey (USGS).

DOQQ (digital orthophoto quarter quadrangle) - DOQ images covering 3.75 minutes of latitude by 3.75 minutes of longitude. In this format each pixel represents a square meter.

DRG (digitized raster graphic)*** - A digital replica of Defense Mapping Agency hardcopy graphic products

Digitize*** - A process that converts nondigital data into numeric data. Usually refers to the creation of vector data from hardcopy materials or raster images traced on a displayed image.

ETM (enhanced thematic mapper) - The image capture system carried by Landsat satellites. Early Landsat satellites used a system called **thematic mapper (TM)**.

enhancement* - The process of altering the appearance of an image so that the interpreter can extract more information. Enhancement may be done by digital or photographic methods.

ERDAS (Earth Resources Data Analysis System)*-. An image processing and GIS software package now called **ERDAS Imagine** and produced by ERDAS Inc.

extension**** - A program loaded inside ArcView to add new capabilities

exterior orientation - Defines the position and angular orientation associated with an image. For aerial photographs the position refers to the height of the camera above sea level. Angular orientation refers to the way the focal plane of the camera is oriented to the surface being photographed.

Feature**** - A map representation of a geographic object.

feature collection - The process of identifying, delineating, and labeling various types of natural and human-made phenomena from remotely sensed images.

FGDC** - The United States Federal Geographic Data Committee. Composed of representatives of several federal agencies and GIS vendors, the FGDC has the lead role in defining spatial metadata standards, which it describes in the Content Standards for Spatial Metadata

fiducials*** - Four to eight reference markers fixed on the frame of an aerial metric camera and visible in each exposure. Fiducials are used to compute the transformation from data file to image coordinates.

focal length*** - The orthogonal distance from the perspective center to the image plane of a camera.

frame buffer stereo - A process of viewing stereo images on a computer monitor by using LCD glasses that are synchronized with the monitor display frequencies. A much more expensive process than anaglyph stereo but one which allows electronic digitizing over the image.

georeferencing - Refers to the process of assigning map coordinates to image data.

GIS (Geographic Information System) ** - An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display geographic information.

GPS (Global Positioning System) * - A network of 24 radio transmitting satellites (NAVSTAR) developed by the US Department of Defense to provide accurate geographical position fixing.

GCP (ground control point) - A point with known coordinates in the ground coordinate system, expressed in the units of specified map projection. Used in the process of rectifying imagery.

ground verification***- The acquisition of knowledge about the study area from direct observation. Ground verification data is considered to be the most accurate (true) data available about the area of the study.

hot link - In ArcView, a theme property that allows for the display of images linked to symbols on a map layer.

image file*** - A file containing raster image data. Image files in ERDAS IMAGINE have the extension .img. Image files from the ERDAS version 7X series software have the extension .LAN or .GIS.

Infra-red (IR) – A portion of the electromagnetic spectrum lying between the red end of the visible spectrum and microwave radiation (700 nm to 1000 □m).

Landsat* - A series (6 successfully launched since 1972) of unmanned earth-orbiting NASA satellites (formerly called Earth Resources Technology Satellite – ERTS).

map projection - A mathematical formula that converts spherical coordinates of latitude and longitude to planar coordinates on a map.

NAPP (National Aerial Photography Program) - Color, infrared positive aerial photographs on a 1:40,000 scale. One frame covers approximately 32 square miles. Average overlap between frames is 40%. May be leaf-on or leaf-off, depending on contracting season. Available for 1987 to present.

NHAP (National High Altitude Program) - Color, infrared positive aerial photographs on a 1:60,000 scale. One frame covers approximately 72 square miles. Available for 1980 – 1985, leaf-off and 1985 - 1987, leaf-on.

NDVI* - Normalized Difference Vegetation Index. An index of vegetation biomass.

NOAA - National Oceanic and Atmospheric Administration.

orthorectification***- The process of removing geometric errors inherent within photography and imagery. Geometric errors may result from such factors as camera orientation, topographic relief displacement and the curvature of the earth.

parcel**** - An area of land whose boundaries have been surveyed and recorded.

planimetric map - A map that presents the horizontal, but not the vertical, positions of the features represented. (See **topographic map**)

polygon** - A coverage feature class used to represent areas. A polygon is defined by the arcs that make up its boundary and a point inside its boundary for identification. Polygons have attributes that describe the geographic feature they represent.

pyramid layers*** - Image layers which are successively reduced by the power of 2 and resampled. Pyramid layers enable large images to be displayed faster.

quadrangle*** - 1. Any of the hardcopy maps distributed by USGS such as the 7.5-minute quadrangle or the 15-minute quadrangle. 2. one quarter of a full Landsat TM scene. Commonly called a "quad."

raster data** - A cellular data structure composed of rows and columns for storing images. Groups of cells with the same value represent features. Electronic images are often stored as raster data.

rectification*** - The process of making image data conform to a map projection system by **georeferencing** the data and removing geometric errors introduced by the imaging system and the curvature of the earth.

Orthorectification removes topographic relief (terrain) displacement errors.

registration - The process of making an image conform to another image.

remote sensing* - The collection of information about an object or event without being in physical contact with the object or event. Remote sensing is restricted to methods that record the electromagnetic radiation reflected or radiated from an object, which excludes magnetic and gravity surveys that record force fields.

softcopy stereo - Digital stereo imagery viewed using a computer. (see **anaglyph** and **frame buffer** stereo).

RGB* - Red, green blue. The primary additive colors which are used on most display hardware (computer monitors) to display images.

RMS error* - Root mean square error. The distance between the input (source) location of a known geographic feature and the rectified location for the same feature. A measure used to assess the accuracy of geometric correction.

screen digitizing*** - The process of drawing vector graphics on the display screen with a mouse. A displayed image can be used as a reference.

shapefile**** - ArcView's format for storing the location, shape, and attribute information of geographic features.

SMZ (streamside management zone) - Vegetation in a narrow buffer zone along both sides of a waterway.

stereographic*** - 1. The process of projecting onto a tangent plane from the opposite side of the earth. 2. the process of acquiring images at angles on either side of the vertical.

stereopair*** - A set of two remotely-sensed images that overlap, providing two views of the terrain in the overlap area

theme**** - In ArcView, a set of geographic features of the same type, along with attributes. A theme is stored as a unique set of files.

tie point*** - A point whose ground coordinates are not known, but can be recognized visually in the overlap or sidelap area between two images. Used in the process of rectifying imagery.

topographic map** - 1. A map containing contours indicating lines of equal surface elevation (relief). Often referred to as topo maps. 2. Often used to refer to a map sheet published by the U.S. Geological Survey in the 7.5-minute quadrangle series or the 15-minute quadrangle series. (See **planimetric map**).

triangulation*** - A process of establishing relationships among two or more images and the ground.

UTM (Universal Transverse Mercator) - A widely used geographic coordinate system

vector data***- Data that represents forms such as points, lines, and polygons. Only the vertices of the forms are stored. Images are usually stored as **raster data**.

* Environment and Development in Coastal Regions and in Small Islands (CSI)
** ESRI Library – The GIS Glossary
***ERDAS Support Center – Glossary of Terms
**** Getting to know ArcView – ESRI Press

Appendix E

Comparison of Forest Assessment Methods

Method I: Base Layer Determined from Photographs Using a Stereoscope

Summary:

This method differs from the others in using stereoscopic analysis of photographs to establish a base layer coverage for a single year. Polygons delimiting land use areas are originally drawn in ink on acetate overlays. These pen line polygons must then be digitized on a computer so land use in the base year can be compared to digital images of the same area in other years. Quantitative data can only be derived from the digital polygons.

This method requires less sophisticated computer equipment than the other methods but using a stereoscope requires considerable training and experience. Another disadvantage is that scanning, rectification and redigitizing of the acetate layers inevitably introduces errors in the final product.

This method is recommended for assessment of very small areas, which lack a wide diversity of landscape types. It is particularly useful if a trained stereoscope technician is available. For estimated costs involved in employing this methodology see Table 1.

Methodology:

1. **Data Acquisitions**
   a. Obtain a USGS quadrangle GIS map file from USGS or GIS data depot.
   b. Add both the names and the USGS codes—i.e. 035805232 is the same as The SMARTT MOUNTAIN QUAD (this will make it easier to find the files you need from USGS or data depot).
   c. Obtain 35 mm slides from Farm Service Agency.
   d. Obtain 1:24,000 scale digital topographic maps from USGS or data depot.

e. Obtain georeferenced digital reference map photography (called digital ortho quad—DOQ) from USGS or from datadepot.com. Note: each of the photographs covers about 12,000 acres.
f. Obtain Black and White aerial photographs for the area of interest from USGS ($9.00) Note: Each of these photos covers about 7000 acres.

2. **Data Prep**
   a. FSA slides must be arranged in a geographic order based on flight line and year.
   b. FSA slides must then be scanned at 300 dpi or higher (we used and recommend 1400 dpi which provides a nice tradeoff between image size and image quality—the image size is about 7-10 megabytes).
   c. GIS technician will fit the 35 mm slides to the reference map imagery (either the digital topographic maps or the digital base map photography). If a slide does not have similarly recognizable points on the base image layer, it can be rectified to other FSA slides that have already been fit to the reference map.
   d. Save rectified slides.
   e. Back-up rectified slides
   f. **Note:** each slide covers about 2000 acres of land (about 2.25 miles in longitude and 1.5 miles in latitude for north south flights), but it is often wise to have overlap between slides. Thus one should assume about 10-15 megabytes of disk space for every 2000 acres covered.

3. **Create a Photo vs. Land Use Key for Each Imagery Type**
   a. A section of the image (FSA slides, black and white Photography, or color infrared) representing the various land use types should be printed out as a key for identification.
   b. Print-outs should be taken to the ground location they represent to verify that the ground location and the photo are the same. It is best if a GPS is used to navigate to the locations.
   c. Once a reasonable number of FSA slides have been associated with their corresponding land uses the key can be formed. (Note: we recommend that all digitizers visit the ground locations of the key slides to provide a better “feel” for the photograph to land use associations).

4. **Creating the Base Map**
   a. Photogrammetrist will draw outlines of land use calls using acetate sheets overlaid on the black and white aerials.
   b. The acetate sheets will be scanned using the flatbed scanner at 300 dpi or higher.
   c. GIS digitizing tech will use the align tool in Arcview + Stereo Analyst to place the scanned map correctly over the Digital Topographic Sheet.
   d. GIS Digitizing tech will then "digitize" each of the polygons into an Arcview Polygon shape file assigning land use category determinations into the accompanying arcview table.

5. **Land Use Change in Other Years Covered by FSA Slides**
   a. The GIS tech will then open both the base layer and the georectified FSA 35mm slides in an Arcview view.
   b. The base layer should then be "saved as" a different file with some acronym for the year.
   c. Each polygon in the 1997 base map from the photogrammetrist will then be checked against the FSA slide for that year at that location.
   d. If there is no change the digitizer will record that in the table associated with that polygon.
   e. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
   f. Land use change in other years covered by Color Infrared if Digital Ortho Color Imagery from the 1981-1982 period is available.
   g. The GIS analyst will then open the ortho color imagery and the base layer in Arcview or another vector digitizing program.
   h. The base layer should then be "saved as" a different file with some acronym for the year.
   i. Each polygon in the 1997 base map from the two dimensional digitizing will then be checked against the FSA slide for that year at that location.
   j. If there is no change the digitizer will record that in the table associated with that polygon.
   k. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
   l. If a part of the polygon changes land use type only the change area will be digitized.

6. **Error Assessment—Spatial Accuracy**
    a. The spatial accuracy can be checked with either GPS unit or against a known reference such as a digital photo base map—the DOQ's in our case.
    b. Find a recognizable set of features in the digitizing—i.e. a road crossing in forest clearing, parking lot edge, bridge, reservoir, etc.
    c. GPS the actual ground locations for these positions.
    d. Calculate the absolute sum of the difference in X and Y or, even better, the average of the squared distances.

7. **Error Assessment—Land Use Call Accuracy**
    a. At least ten polygons from each land use category should be selected at random
    b. GPS coordinates for each site should be recorded.
    c. Design a driving plan to minimize travel between locations.
    d. Visit each point and take digital photo and make the call as to land use type.
    e. It is best if the land use call being visited is not known to the people making that call on the ground to avoid pressure to "err on the side of being correct."
    f. The ground data are then compared with the land use calls from the photography via a "cross-tabulation." This can be done in Excel or inexpensive statistical software such as NCSS.
    g. The percent correct for each category are then presented.
    h. Often a statistical summary called the Kappa statistics is reported. It is essentially the percent correct adjusted for the chances of being correct base on random chance alone—this statistic will always be lower than the percent correctly predicted.

Method II: Base Layer Determined from 2-Dimensional Digital Images and Checked Using Anaglyph Stereo

Summary:

In this method base layer land use calls are made from 2-dimensional digital images and checked using anaglyph stereo methods. Most procedures are the same as in the other methods. Digitized polygons from the base layer are overlain on digital images from other years and land use changes observed.

Digitizing from 2-dimensional digital images requires less training and experience than using a stereoscope. Problems involved in converting pen lines on acetate to digital polygons are avoided. However, using anaglyph stereo to check the results requires more sophisticated computer hardware and software than that used in method one.

This method results in greater spatial accuracy than method 1. It is recommended for assessment of small areas, especially if technicians are initially unfamiliar with GIS techniques. For estimated costs involved in employing this methodology see Table 1.

Methodology:

1. **Data Acquisitions**
   a. Obtain a USGS quadrangle GIS map file from USGS or GIS data depot.
   b. Add both the names and the USGS codes—i.e. 035805232 is the same as The SMARTT MOUNTAIN QUAD (this will make it easier to find the files you need from USGS or data depot).
   c. Obtain 35 mm slides from Farm Service Agency.
   d. Obtain 1:24,000 scale digital topographic maps from USGS or data depot.
   e. Obtain georeferenced digital reference map photography (called digital ortho quad—DOQ) from USGS (DOQ) or from datadepot.com. Note each of the photographs covers about 12,000 acres.
   f. Obtain Digital Ortho Color Infrared Imagery from USGS—if it is available for your region you will have to move to method III.
   g. Obtain 1:24,000 Digital Elevation Models (DEM’s) from USGS or other data provider—10 meter preferably, but 30 meter digital elevation models work as well.

h. Obtain black and white aerial imagery from USGS.
i. Obtain Landsat data for the locations and years of interest. ($600 per scene).

2. **Data Prep**
   a. FSA slides must be arranged in a geographic order based on flight line and year.
   b. FSA slides must then be scanned at 300 dpi or higher (we used and recommend 1400 dpi which provides a nice tradeoff between image size and image quality—the image size is about 7-10 megabytes).
   c. GIS technician will fit the 35 mm slides to the reference map imagery (either the digital topographic maps or the digital base map photography). If a slide does not have similarly recognizable points on the base image layer, it can be rectified to other FSA slides that have already been fit to the reference map
   d. Save rectified slides.
   e. Back up rectified slides.
   f. Note: each slide covers about 2000 acres of land (about 2.25 miles in longitude and 1.5 miles in latitude for north south flights), but it is often wise to have overlap between slides. Thus one should assume about 10-15 megabytes of disk space for every 2000 acres covered.
   g. Scan black and white image pairs necessary for areas with land use cover confusion.

3. **Create a Photo vs. Land Use Key for Each Imagery Type**
   a. Section of the image (FSA slides, Black and White Photography, or Color Infrared) that represents the various land use types should be printed out as a key for identification
   b. Print-outs should be taken to the ground location they represent to verify that the ground location and the photo are the same. It is best if a GPS is used to navigate to the locations.
   c. Once a reasonable number of FSA slides have been associated with their corresponding land uses the key can be formed. (Note: we recommend that all digitizers visit the ground locations of the key slides to provide a better "feel" for the photograph to land use associations).

4. Creating the Base Map

a. Digitize base layer.
   - The base layer is then created from the orthophotos by digitizing all recognizable shapes above a certain size threshold. Non Land use calls are made in the first run through the data.
   - The layer should then be error checked for accuracy and corrected where necessary.

b. Make land use calls.
   - The base layer is overlaid on all available imagery in an area including orthophotos, FSA slides, and satellite imagery.
   - Additional layers such as roads and houses are added to assist in the land use call.
   - Each polygon will then be checked and a land use call made consistent with the key.
   - If there are difficulties in making land use call from the orthophotos, then use the scanned black and white aerial photos in Stereo Analyst to improve the cover calls.

5. Land Use Change in Other Years Covered by FSA Slides

a. The GIS analyst will then open the satellite imagery and the base layer. The satellite imagery will be used to identify areas that are different from the base layer.

b. The base layer should then be “saved as” a different file with some acronym for the year.

c. The area of changes will be ‘tagged” with rough polygons in the location of the changes.

d. The GIS tech will then open the georectified FSA 35mm slides for that location.

e. Each polygon in the 1997 base map from the photogrammetrist will then be checked against the FSA slide for that year at that location.

f. If there is no change the digitizer will record that in the table associated with that polygon.

g. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.

h. If a part of the polygon changes land use type, only the change area will be digitized.

6. **Land Use Change in Other Years Covered by Color Infrared if Digital Ortho Color Imagery from the 1981-1982 Period is Available**
   a. The GIS analyst will then open the Ortho Color Imagery and the base layer in Arcview or another vector digitizing program.
   b. The base layer should then be “saved as” a different file with some acronym for the year.
   c. Each polygon in the 1997 base map from the two dimensional digitizing will then be checked against the FSA slide for that year at that location.
   d. If there is no change the digitizer will record that in the table associated with that polygon.
   e. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
   f. If a part of the polygon changes land use type only the change area will be digitized.

7. **Error assessment—Spatial Accuracy**
   a. The spatial accuracy can be checked with either GPS unit or against a known reference such as a digital photo base map—the DOQ’s in our case.
   b. Find a recognizable set of features in the digitizing—i.e. a road crossing in forest clearing, parking lot edge, bridge, reservoir, etc..
   c. GPS the actual ground locations for these positions.
   d. Calculate the absolute sum of the difference in X and Y or, even better, the average of the squared distances.

8. **Error Assessment—Land Use Call Accuracy**
   a. At least ten polygons from each land use category should be selected at random.
   b. GPS coordinates for each site should be recorded.
   c. Design a driving plan to minimize travel between locations.
   d. Visit each point and take digital photo and make the call as to land use type.
   e. It is best if the land use call being visited is not known to the people making that call on the ground to avoid pressure to “err on the side of being correct.”

f. The ground data are then compared with the land use calls from the photography via a "cross-tabulation." This can be done in Excel or inexpensive statistical software such as NCSS.
g. The percent correct for each category are then presented
h. Often a statistical summary called the Kappa statistics is reported. It is essentially the percent correct adjusted for the chances of being correct base on random chance alone—this statistic will always be lower than the percent correctly predicted.

Method III: Base Layer Determined from Frame Buffer Stereo Digital Images

Summary:

In this method base layer land use calls are made from 3-dimensional digital images. In order to digitize in stereo sophisticated frame buffer techniques must be used. The technician utilizes electronic glasses, which can be synchronized to the frequencies of the computer monitor display. (Anaglyph stereo, used to check results in the previous method, can be viewed using cardboard glasses with different colored plastic lenses).

This method is much more costly than the other two because it requires an expensive stereo video card and much more expensive software. In addition more time is required to prepare digital images for frame buffer stereo viewing. The resulting analysis is much more accurate than the other two methods.

This method is recommended for larger, more complex landscapes and where greater accuracy is required. Unfortunately, the expense may limit the use of this technique to large institutions such as universities or state agencies. For estimated costs involved in employing this methodology see Table 1.

Methodology:

1. **Data Acquisitions**
   a. Obtain a USGS quadrangle GIS map file from USGS or GIS data depot.
   b. Add both the names and the USGS codes—i.e. 035805232 is the same as The SMARTT MOUNTAIN QUAD (this will make it easier to find the files you need from USGS or data depot).
   c. Obtain 35 mm slides from Farm Service Agency.
   d. Obtain 1:24,000 scale digital topographic maps from USGS or data depot.
   e. Obtain georeferenced digital reference map photography (called digital ortho quad—DOQ) from USGS (DOQ) or from datadepot.com. Note: each of the photographs covers about 12,000 acres.
   f. Obtain Digital Ortho Color Infrared Imagery from USGS—if available for your region.
   g. Obtain black and white aerial photograph for the area of interest from USDA ($ 9.00). Note: each of these photos covers about 7000 acres.

h. Obtain Color Infrared Photographs from USGS for study location ($15 per image).
i. Obtain 1:24,000 Digital Elevation Models (DEM's) from USGS or other data provider—10 meter preferably, but 30 meter digital elevation models work as well.
j. Obtain camera information for the aerial black and white or color infrared photography from USGS.
k. Obtain Landsat Data for the locations and years of interest.

2. Data Prep

a. FSA slides must be arranged in a geographic order based on flight line and year.
b. FSA slides must then be scanned at 300 dpi or higher (we used and recommend 1400 dpi which provides a nice tradeoff between image size and image quality—the image size is about 7-10 megabytes).
c. GIS technician will fit the 35 mm slides to the reference map imagery (either the digital topographic maps or the digital base map photography). If a slide does not have similarly recognizable points on the base image layer, it can be rectified to other FSA slides that have already been fit to the reference map.
d. Save rectified slides.
e. Back–up rectified slides.
f. Note each slide covers about 2000 acres of land (about 2.25 miles in longitude and 1.5 miles in latitude for north south flights), but it is often wise to have overlap between slides. Thus one should assume about 10-15 megabytes of disk space for every 2000 acres covered.
g. Scan each of the aerial photos on the large format scanner at 1600 dpi or higher –lower resolutions make it difficult to digitizing in three dimensions. Higher resolutions require excessive hard disk storage space.

3. Create a Photo vs. Land Use Key for Each Imagery Type

a. A section of the image (FSA slides, Black and White Photography, or Color Infrared) representing the various land use types should be printed out as a key for identification.
b. Print-outs should be taken to the ground location they represent to verify that the ground location and the photo are the same. t is best if a GPS unit is used to aid navigation.

c. Once a reasonable number of FSA slides have been associated with their corresponding land uses the key can be formed. (Note: we recommend that all digitizers visit the ground locations of the key slides to provide a better “feel” for the photograph to land use associations).

4. Creating the Base Map

a. Create mathematical geometric models for each quad in study area.
   - Collect control point from recognizable ground locations using a GPS or by ‘picking’ them off the digital photographic reference source (DOQ).
   - Enter the camera information and control point into the “block model” in ERDAS ORTHOBASE.
   - Provide elevation reference source—digital elevation model.
   - Calibrate models and test for accuracy.
   - If accuracies are acceptable, move on, otherwise add more control points and recalibrate.

b. Digitize base layer.
   - The base layer is then digitized from these three dimensional geometric models using the Imagine Stereo Analyst for each land use type.
   - **Note:** it is important to create regular back-ups of data as the stereo digitizing process can ‘crash’ and loose data. It is also important to have sufficient memory on the computer—the software manuals say that 256mb is adequate, but that lower amounts of memory increase the digitizing time dramatically.

c. Merge base layer in ArcView or ERDAS
   - The individual coverage layer need to be combined using vector editing software package such as ARCView 3.2, ARCEdit or ERDAS.
   - The digitizing slivers and overlaps need to be cleaned-up.

5. Land Use Change in Other Years Covered by FSA Slides

a. The GIS analyst will then open that satellite imagery and the base layer. The satellite imagery will be used to identify areas that are different from the base layer.

b. The base layer should then be “saved as” a different file with some acronym for the year.

c. The area of changes will be ‘tagged” with rough polygons in the location of the changes.

d. The GIS tech will then open the georectified FSA 35mm slides for that location.
e. Each polygon in the 1997 base map from the photogrammetrist will then be checked against the FSA slide for that year at that location.
f. If there is no change the digitizer will record that in the table associated with that polygon.
g. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
h. If a part of the polygon changes land use type only the change area will be digitized.

6. Land Use Change in Other Years Covered by Color Infrared if Digital Ortho Color Imagery from the 1981-1982 Period is Available

a. The GIS analyst will open the Ortho Color Imagery and the base layer in Arcview or another vector digitizing program.
b. The base layer should then be "saved as" a different file with some acronym for the year.
c. Each polygon in the 1997 base map from the three dimensional digitizing will then be checked against the FSA slide for that year at that location.
d. If there is no change the digitizer will record that in the table associated with that polygon.
e. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
f. If a part of the polygon changes land use type, only the change area will be digitized.

7. Land Use Change in Other Years Covered by Color Infrared if Digital Ortho Color Imagery from the 1981-1982 Period is Not Available and Changes in Topographic Features Such as Stream Banks or Landslides DO NOT Need Digitizing.

a. Create mathematical geometric models for each quad in study area.
   - Collect control point from recognizable ground locations using a GPS or by 'picking' them off the digital photographic reference source (DOQ).
   - Enter the camera information and control point into the "block model" in ERDAS ORTHOBASE.

- Provide elevation reference source—digital elevation model.
- Calibrate models and test for accuracy.
- If accuracies are acceptable move on, otherwise add more control points and recalibrate.

b. Generate Color Orthophotos from ERDAS Orthobase.

c. Follow the procedure in #6 above.

8. **Land Use Change in Other Years Covered by Color Infrared if Digital Ortho Color Imagery from the 1981-1982 Period is Not Available and Changes in Topographic Features Such as Stream Banks or Landslides Need Digitizing.**

   a. The base layer from the black and white imagery will be opened in stereo analyst over the "block models" created for the color infrared photography.
   b. Each quad will be carefully scanned for changes in polygon types.
   c. Each polygon in the 1997 base map from the 3-D base layer will then be checked against the color infrared in three dimensions.
   d. If there is no change the digitizer will record that in the table associated with that polygon.
   e. If the entire polygon changes land uses then the digitizer will digitize the change portion of the polygon and enter the change in the associated table.
   f. If a part of the polygon changes land use type only the change area will be digitized.

9. **Error assessment—Spatial Accuracy**

   1. The spatial accuracy can be checked with either GPS unit or against a known reference such as a digital photo base map—the DOQ's in our case.
   2. Find a recognizable set of features in the digitizing—i.e. a road crossing in forest clearing, parking lot edge, bridge, reservoir, etc.
   3. GPS the actual ground locations for these positions.
   4. Calculate the absolute sum of the difference in X and Y or even better the average of the squared distances.

10. **Error Assessment—Land Use Call Accuracy**

   a. At least ten polygons from each land use category should be selected at random.
   b. GPS coordinates for each site should be recorded.

c. Design a driving plan to minimize travel between locations.
d. Visit each point and take digital photo and make the call as to land use type.
e. It is best if the land use call being visited is not known to the people making that call on the ground to avoid pressure to “err on the side of being correct.”
f. The ground data are then compared with the land use calls from the photography via a “cross-tabulation”. This can be done in excel or inexpensive statistical software such as NCSS.
g. The percent correct for each category are then presented.
h. Often a statistical summary called the Kappa statistics is reported. It is essentially the percent correct adjusted for the chances of being correct base on random chance alone—this statistic will always be lower than the percent correctly predicted.

Table 1: Cost comparison of methodologies tested.

	METHOD 1	METHOD 2	METHOD 3
IMAGERY			
AERIAL IMAGERY	NHAP, NAPP, DOQ, FSA slides	NHAP, NAPP, DOQ, FSA slides	NHAP, NAPP, DOQ, FSA slides
SATELLITE IMAGERY	None	Thematic Mapper and Enhanced Thematic Mapper	Thematic Mapper and Enhanced Thematic Mapper
Imagery Expenses	**$2,000.00**	**$3,000.00**	**$5,000.00**
HARDWARE			
	Pentium III class Workstation	Pentium III class Workstation	Pentium III class Workstation
	256 Megabytes of RAM	256 Megabytes of RAM	512 Megabytes of RAM
	80 Gigabyte Hard Disk Drive	80 Gigabyte Hard Disk Drive	80 Gigabyte Hard Disk Drive
	CD-RW	CD-RW	CD-RW
	17" Monitor	19" Monitor 100Hz Capable	19" Monitor 100Hz Capable
	Slide Scanner	Slide Scanner	Slide Scanner
	Flatbed Desktop Scanner	Large Format Scanner	Large Format Scanner
	Stereoscope	Anaglyph Glasses	NuVision 60GX LCD Glasses
			NuVision Stereo Converter Box
			3DLabs Oxygen VX1 Video Card
	GPS and Digital Camera	GPS and Digital Camera	GPS and Digital Camera
			Large Storage and Backup Solution
Hardware Expenses	**$5,000.00**	**$6,000.00**	**$15,000.00**
SOFTWARE			
	ESRI ArcView 3.2a	ESRI ArcView 3.2a	ESRI ArcView 3.2a
	ERDAS Image Analysis Extension	ERDAS Image Analysis Extension	ERDAS Image Analysis Extension
		ERDAS Stereo Analyst	ERDAS Imagine
			ERDAS OrthoBASE
			ERDAS Stereo Analyst
Software Expenses	**$5,000.00**	**$6,000.00**	**$10,000.00**
TOTAL	**$12,000.00**	**$15,000.00**	**$30,000.00**