TEMPORAL ASSESSMENT OF URBAN FOREST PATCH DYNAMICS USING MEDIUM SCALE AERIAL PHOTOGRAPHY AND GIS

By

ROSA MARIA ABBOTT

Bachelor of Science in Forest Resources
Oklahoma State University
Stillwater, Oklahoma
2000

Bachelor of Science in Nursing
Southern Illinois University
Edwardsville, Illinois
1986

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TEMPORAL ASSESSMENT OF URBAN FOREST PATCH

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AERIAL PHOTOGRAPHY AND GIS

Thesis Approved:

Dr. Thomas Hennessey
Thesis Advisor

Dr. Janet Cole

Dr. Mahesh Rao

Dr. A. Gordon Emslie
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Background. Among urban foresters, arboriculturists, and others interested in urban tree health, it is often assumed that urban forests suffer significantly from the effects of urban sprawl. The literature is replete with the negative effects of building construction on individual trees, as well as the stress experienced by urban trees in general, especially those located in areas of increased population density (American Forests, n.d.; Bryant, 2001; Harris, et.al., 1999). Changes in the urban forest are reflected by tree canopy loss, replacement of native by non-native species, replacement of established stands by pioneer species, or conversion of native stands to vegetation commonly found in populated areas. From the perspective of a medium-scale aerial photo image, natural forest stands become urban forest patches over time, with the size, shape or composition of these patches changing as urbanization proceeds.

Conversely, urban tree stands may appear in newly populated areas which were primarily non-forested in their natural state, as may be the case in ecosystems formerly consisting of prairie grasses. As such, it would seem that tree canopy additions in naturally non-forested areas may compensate for tree canopy loss in naturally forested areas if both are located within the boundaries of a developing metropolis. While

Stillwater, Oklahoma, may not yet qualify as a metropolis, it is nestled within the confines of a unique ecosystem known as the CrossTimbers, a natural transition zone between the forests of the eastern part of the country and the prairies to the west (The Nature Conservancy, 2001). As such, elements of both forest and prairie can be found within the study areas, albeit the original ecosystem has been adjusted by anthropocentric influence. The benefits of adding trees to areas that were originally meant to support grasses and forbes may be debatable, except when it is considered that the changes induced by urbanization, i.e., massive areas of impervious surfaces, are severe enough to warrant the establishment of an introduced canopy wherever possible.

The Problem. Loss of tree cover remains an overriding concern in any discussion about the increasing rate of urban sprawl. The concern is well-based: from 1982 to 1992, land in the United States was converted to development at the rate of 1.4 million acres per year; in the next five years, the rate had almost doubled to 2.2 million acres per year (Natural Resource Conservation Service, 2000). While rapid urbanization often translates into large-volume loss of tree canopy cover, reestablishing adequate tree canopy becomes problematic during and after urban spread, usually because defining what is adequate canopy is difficult. Opponents and proponents of urbanization have differing opinions about how much canopy is enough once an undeveloped landscape becomes a subdivision.

One simple remedy for correcting tree canopy loss due to urban encroachment is to replant as many trees as possible after development has occurred. Many grassroots groups throughout the country promote such a remedy and are quick to point out the benefits of replanting trees, including lessening of the heat island effect, control of soil erosion, and improvement of air and water quality (Maco and McPherson, 2002). In determining the appropriate amount of tree canopy cover for a given area, a number of studies have attempted to provide regional estimates of adequate tree cover in both urban and rural areas, with most studies focusing on reestablishing canopy in growing urban areas.

Like other urban areas around the country, the city of Stillwater, Oklahoma, is in the midst of a growth period (Stillwater Oklahoma Chamber of Commerce, 2004; Online Highways, 2004), with resultant removal of trees that are often replaced by impervious surfaces. The increase in development seems to follow an increase in population that has occurred in the city as well as within the general Stillwater area (Chart 1).

As building construction continues in Stillwater and the surrounding area, concern has escalated locally about what is perceived to be a serious loss in tree canopy (Stillwater Tree Board, 2000). Unfortunately, determination of an appropriate amount of tree canopy cover for Stillwater remains a vexing issue just as it does elsewhere in the United States, with tree advocates insisting on replanting or retaining as many trees as possible and developers just as stridently insisting that the current rate of tree removal or retention is acceptable. It may be useful to apply generalized tree cover standards as a compromise for both camps in the controversy. If national tree canopy standards for urban areas were applied to Stillwater, tree canopy coverage would need to be 60% in suburban areas such as the Deer Crossing [Section 32] subdivision, 25% in more urban residential areas like the CrossWinds [Section 19] or Hidden Oaks [Section 24] subdivisions, or 40% as an average throughout the whole community (American Forests, 2000a).

However, without knowing what the “normal”– or pre-settlement – tree canopy cover was for the city, it seems inappropriate to apply a generalized canopy standard that is based on attributes collected from a variety of urbanized settings around the country. Even the modest standard of 30% canopy recommended for urban residential areas in semi-arid climates (American Forests, 2000a) might be an incorrect standard for Stillwater if its lands were originally suited for lesser canopy, as is the case in regions where tall-grass prairie flourished centuries ago. By their nature, open prairie lands were subject to frequent fires, thus encouraging the growth of grasses and forbes in presettlement times (The Nature Conservancy, 2004b). Some soils commonly found in the Stillwater area (i.e., Stephenville-Darnelle and Masham Silty Clay Loam) are known to be more suited for little bluestem prairie grass or buffalograss than they are for the growth and development of trees (Natural Resources Conservation Service, 1982), as may be revealed by a soil map of one of the study areas (Figure 1). Conversely, much of the region has historically supported the growth of thick stands of post oak (*Quercus stellata)* and blackjack oak (*Quercus marilandica)*, with some stands reportedly forming closed tree canopies that were impassable in pre-settlement years (The Nature Conservancy, 2001). Known as the CrossTimbers, this area of oak savanna and tallgrass prairie forms a large region spreading throughout much of Oklahoma and extending north into Kansas and south into Texas (Figure 2).

In performing a historical assessment of the development of urban forest patches, a related variable that had to be considered was the possibility that the study areas were located within the boundaries of the Dust Bowl region of the 1930's and thus might have suffered severe setbacks in tree canopy cover prior to modern urbanization. Conversely, urbanization dampens the presettlement landscape changes incurred by the frequent fires of the open prairie, leading to growth of trees in areas that previously grew grasses and forbes. Because of the difficulty in determining the original tree canopy coverage of the study areas, therefore, the official state average tree canopy cover of 24% (Oklahoma Department of Tourism and Recreation, 2002) was used as the pre-development standard for the purpose of this research study.

The Hypothesis. It was hypothesized that urbanization had caused a decrease in tree canopy cover from 24% to approximately 15% in the three study areas located in CrossWinds, Hidden Oaks, and Deer Crossing subdivisions, resembling the low canopy cover of similar urban areas, i.e., the average canopy cover for the current metropolitan area of Garland, Texas, is 10% (American Forests, 2001). Because the focus of the study was on an assessment of temporal change in tree canopy area of the three study locations, no effort was made to determine change in tree species composition. To provide some perspective for the study, however, the time line of the tree canopy assessment intentionally included images dating back to the late 1930's, with assessment intervals that included images from every decade since then whenever possible. It was hoped that the breadth of scope of such a time line would offer more insight into urban forest patch dynamics coincident with urban sprawl patterns, particularly because pre-urbanization canopy coverage is unclear.

Objectives of the Study. The first objective of the study was to determine tree canopy cover changes in each study area over six decades, to include pre-development and post-development periods. The second objective was to determine whether an increase in population had any effect on the tree canopy change, since it was hypothesized that urbanization had a direct impact on the loss of tree cover. The third objective was to determine the maximum potential of canopy that could be grown in each study area so that a more realistic, area-specific canopy standard could be established. The fourth objective was to compare the change within each study area to any change in the other two.

Because measurement of tree cover is considered an important indicator of local ecology, measurement of temporal changes in tree cover allows tracking of ecological change in an urban area (City of Vancouver, 2003). More to the point, urban tree canopy measurement serves as a useful tool in assessing development of urban forest patches. Measurement of tree canopy can be done using any of several methods, including traditional field measurement of individual trees, dot density overlay or planimeter measurement of aerial photographs, or measurement of forested areas using a variety of geographic information systems (GIS) software. Geographic information systems can be used to manipulate, analyze, and store large volumes of geographically referenced data, making it a popular addition to the traditional methods used to analyze land cover, including tree canopy.

Further, while aerial photographs can be analyzed using GIS technology, more advanced remote sensing data can be obtained using airborne thermal scanning and satellite imagery techniques. Satellite imagery provided by the Landsat Multi Spectral Scanner (MSS) can provide false infrared color images that simplify identification of different land cover types. Modern SPOT and RADARSAT satellites provide images with better resolution, thus allowing for more accurate analysis of land use and land cover (Franklin, 2001). As useful as satellite imagery is, it remains a costly source of data and is limiting if an analysis of tree cover includes six decades of the 20th century, since early Landsat images do not pre-date the 1970's.

It should be stressed that some of the analysis of the aerial photographs may appear more qualitative than quantitative in nature, since assessment was difficult due to the poor resolution of some of the photos. For example, older photographs that contained changes in tonal quality required subjective discrimination of woodland areas. Analysis of such photos was enhanced by contrasting ground detail against data contained in Digital Elevation Models (DEMs) and Digital Raster Graphics (DRGs) produced by the United States Geological Survey (United States Geological Survey, 1994) and more recent Digital Ortho Quarter (DOQ) photographs that contained better detail. Geographic information systems techniques were then used to assist in the delineation of forest patches.

CHAPTER II

REVIEW OF THE LITERATURE

Overview of Study Area. Stillwater, Oklahoma is located in the midst of the Cross Timbers ecosystem, which still boasts tracts of centuries-old post oak (*Quercus stellata)*. Existing water sources (or lack thereof), soil types, topography, climate, and other natural variables shape this ecosystem. Population growth and density have also had an impact and combine with nature's variables to determine tree canopy cover. The three study areas being evaluated (Figure 5) are intended to represent the City of Stillwater, whose tree canopy has been shaped by such natural and human variables.

In presettlement times, the Cross Timbers are purported to have covered approximately 7,909,700 hectares (30,526 square miles) that extended from central Texas through Oklahoma and into southeastern Kansas (University of Arkansas, 2003). Even after settlement, the ecosystem remained a transitional area between eastern deciduous forests and the Great Plains grasslands and, as such, retained characteristics of both neighboring ecosystems. Ancient post oak forest fragments still exist throughout the Cross Timbers, with the oldest post oak dating back more than 400 years. Interestingly, such oaks adapted well to their drought-stressed woodland environment, as did thousands of red cedar (*Juniperus virginiana)* trees which can date back 500 years or more if located in the more rugged terrain (University of Arkansas, 2003). Existing before Oklahoma became a state and even before the United States became a country, the Cross Timbers woodlands greeted pioneer settlers who, in turn, gave the region its name. Many of these settlers considered the region a combination of grassland and woodland whose thickets of scrub oak presented a formidable crossing for any traveler. Those stout enough to travel through the area noted the prevalence of scrubby blackjack oaks and post oaks in the upland areas, while the valleys reportedly contained groves of taller oaks (red, white, and black) as well as pecan, hickory, and walnut trees (Stein and Hill, 1993). True to its nature as a transition area, the ecosystem was noted to have expanses of prairie grassland, often growing as an understory beneath the oaks. Unfortunately, long-term cattle grazing converted the prairie grass to shrubs in many localities (Costello, 1969). Yet, Payne County, of which Stillwater is the county seat, still reflected a complex landscape weave of oak-hickory forest, post-blackjack oak forest, and tallgrass prairie well into the 20th century (Figure 4).

Some of the terrain containing ancient oaks and cedars is scraggy enough to have resisted encroachment by farmers, wildfires, or developers (The Nature Conservancy, 2001). Surviving in areas considered too steep and rocky to farm or too difficult to develop, such terrain offers pockets of protection for the ancient trees. Conversely, North America's tallgrass prairie could offer no such resistance: once a major ecosystem spanning 14 states and covering more than 142 million acres, less than 10% of the original tallgrass prairie is in existence (The Nature Conservancy, 2004a). Though extinct as a true ecosystem, tallgrass prairie segments can still be found in Kansas, as well as north of Keystone Lake in Oklahoma (Figure 5).

Though not composed entirely of prairie, the city of Stillwater was built upon topography that generally lacked difficult rock cliffs and instead seemed to encourage farming and settlement with its mildly sloping terrain. Deer Crossing subdivision [Section 32, Range 2E, Township 19N), one of the three study areas, reflects such conservative topography (Figure 8).

Historically, the birth of the city was impeded not by terrain, but by a shortage of water. Stillwater had its beginnings during the first land run into Oklahoma in 1889 and, as such, was one of many "Boomer" settlements that got their start at that time (The Perkins Journal, 1895). The first permanent settlement in what is now known as Stillwater is believed to have been established in 1885 in what was Oklahoma Indian Territory, although the settlement was burned to the ground by federal troops not long after it began. An entire block of the town that grew in its place a few years later also burned to the ground (Stillwater Fire Department, 2002). Because of a shortage of water, fires remained a threat to the young community for years. Like the rest of Oklahoma, the city of Stillwater mobilized its resources and eventually established ready access to a constant water supply via regional man-made lakes. The Carl Blackwell, McMurtry, and Boomer Lakes are municipal water bodies located in or near Stillwater; Keystone Lake is located within easy driving distance of the city and is managed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 2004).

While limited water influenced the composition of the early tree canopy of

Stillwater, other factors played a role as well. One of these variables was soil type, which remains an unchangeable factor compared to water resources. The soils shown in Figure1 are representative [though not all-inclusive] of most of the soil types found in the city of Stillwater. In that northeast corner of Deer Crossing [Section 32] subdivision, the majority of the soils are nearly level or have less than a 5% slope (Table 1). Many are not suited or have a low suitability for crop cultivation. However, almost all can grow prairie grasses native to Oklahoma, such as Little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), indiangrass *(Sorghastrum nutans*), and switchgrass (*Panicum virgatum*) (Caddel, 2003). Erosion potential is high to severe in at least 30% of the soils in this location, which adds to the importance of retaining trees. In fact, the high erosion potential makes it preferable to retain native trees whenever possible, rather than remove them during building construction then replace them with non-native and/or immature trees with inadequate root spread. Most existing trees serve to stabilize the soil in highly erodible areas and their root systems have already adapted to local soil limitations.

Aside from water bodies, topography, and soil types, the climate of Stillwater should also be considered an important natural variable in regard to tree growth and tree canopy cover. Winters are temperate, with lows in the 20's and an average snowfall of less than 9 inches (National Weather Service, 2004). An average annual rainfall of 94 centimeters generally occurs from October through March and summers are usually hot and dry. Native trees must tolerate extended periods of heat and low rainfall, which explains the post oak's affinity for the Stillwater area. Post oak grows slowly, has a gnarled or twisted appearance, and may even appear shrubby in adverse conditions. It does well in this locality because of its tolerance to hot, dry weather and sandy to sandy-loam soils (Harlow, et.al, 1996). Other native trees that tend to grow in Stillwater areas preferred by post oak include blackjack oak, hickories, and eastern red cedar.

Though it is unclear how much tree canopy cover existed in presettlement times, the CrossTimbers contained not only savannah and glade, but large tracts of deciduous forest (University of Arkansas, 2003) when early settlers ventured through the area. By implication, then, some of Stillwater's current post oaks, blackjack oaks, hickories, and eastern redcedars might traced to the early "stunted oaks" (Irving, 1886) and "scrubby forests" (Spaulding, 1968) reported by settlers.

Loss of Tree Canopy due to Urban Encroachment. Though the precise proportion of native trees to non-native species is unknown in the Stillwater area, they both contribute to tree canopy cover, which has changed with increasing urbanization. An increase in population is accompanied by a loss of tree canopy in most localities, since existing trees must be removed to make way for agricultural uses, buildings, roads, or other human endeavors. Even in suburban locations that focus on developing wooded properties, some or all of the standing trees must be removed to allow for placement of homes, driveways, utilities and other structures (Miller, 1997).

In contrast to commercial timber harvests known as clearcuts, where tree loss is starkly visible, loss of tree cover in urban areas tends to be subtle (Friends of Trees, 2001). Those who notice the loss point out that urban canopy cover can decrease even in the midst of activist efforts to replace removed trees by replanting. In 2001, the Willamette

Basin of Oregon was reported to have lost almost 50 percent of its forest canopy over the previous 28 years in spite of active tree restoration programs (Friends of Trees, 2001). Vancouver-Clark, Washington, reported a decrease of 22 percent since 1972 (City of Vancouver-Clark, 2003). The city of Houston, Texas, had a net loss of 57 percent of its canopy between 1972 and 1999, while its light tree density (acreage with less than 20 percent tree cover) increased by 13 percent (American Forests, 2000b). San Antonio's canopy coverage is estimated to be only 7 to 20% overall, according to USDA Forest Service studies (Citizens Tree Coalition, 2002). Calls by the local citizenry for tree preservation have elicited criticism from authorities regarding cost and the unlikelihood of survival of transplanted trees. In the San Antonio case, authorities sought to reassure citizens by pointing out that several smaller, younger trees will eventually provide a larger canopy than an existing mature tree (Kaufman, 2001). Those preferring to keep mature, native species in place may find the latter statement is counter-intuitive, since smaller, younger trees take years to establish their canopy and offer no guarantee of adaptation to their new surroundings.

______Realistically, some tree loss in urban areas may not be subtle. One study referred to clearcutting associated with urban development as "catastrophic loss" and differentiated it from slow thinning, which was considered tree loss through attrition without replacement. In that study, the catastrophic loss tended to occur along major transportation corridors and in more urbanized areas (Watson, 1993).

Whether significant or subtle, urban tree loss continues to increase with the increase in development, even in states where urban sprawl appears less intense.

Nevertheless, at an average of less than 40,000 acres per year, Oklahoma's annual rate of land development is conservative compared to Florida and Georgia, each of which averages over 160,000 acres per year, or Texas, with 180,000 acres developed per year (Figure 7). While developers in Texas could point out that its rate of development simply matches its large area as a state, developers in Georgia cannot make such a claim. As a region, the fast-growing major cities of the sunbelt hold the worst record in urban deforestation, with Atlanta, Georgia, in the forefront as the urban area with the worst tree loss (Reuters, 2003).

Nevertheless, many large cities are making some progress at controlling tree loss in the midst of surging urban sprawl. Charlotte, North Carolina, and San Diego, California, are considered leaders in this nationwide movement (Reuters, 2003). In Oklahoma, the city of Tulsa developed a tree ordinance in 1993 (USDA Forest Service Southern Region, 2004a) to help preserve existing trees whenever possible or enhance the city's tree canopy with new plantings. The year before, Austin, Texas, developed its tree ordinance and specified that 1% of the construction cost of any roadway in the city must be devoted to tree plantings and to their maintenance for two years after being planted (USDA Forest Service Southern Region, 2004b).

<u>The Relationship between Tree Canopy and Population Density.</u> If urban sprawl is to be blamed for much of urban deforestation, then a review of the mechanics of urban sprawl may provide clues to the relationship between the change in tree canopy that accompanies the growth of cities and their population density. In areas of the world with a high population density, deforestation is only one part of severe ecological disturbance.

In India, for example, population density can be seven times higher than the world average at more than 300 persons per square kilometer, leaving little land unused by people. Alternatively, prairie regions of North America may have low population densities and yet still suffer from ecological degradation due to pollution, infrastructure development, and the building of highways or pipelines. Historically, forest systems are similar to other ecosystems in their response to an increase in human population: their potential for survival is lowest where population densities are highest (AAAS Atlas of Population and Environment, 2000).

In the United States, urban sprawl has been characterized by a change in pattern during the last several decades. High population density with its accompanying problems in city centers drove many to seek the open space beyond the edge of those cities in the 1950s and 1960s, resulting in the growth of suburbs. Because this type of phased development tended to move beyond city boundaries and encroach into farmlands or forests, some referred to this phenomenon as "leapfrog development" (Bryant, 2001). Such a pattern of development tended to fragment forests and farmlands around urban centers, though population densities were lower than that found in urban cores.

The growth of suburban America remained popular into the 1970's, but has now begun to decline due to increasing congestion and commuting costs. Fragmented properties with lower population densities eventually become defragmented and more densely populated as growing cities extend their urban footprint. As a result, those who choose to live in the suburbs expect to have a higher priority placed on the open, natural space around them. Even among citizens who choose to return to living in urban centers, a definite preference is shown for trees and similar, natural landscape features (Miller, 1997). Maintaining a satisfactory landscape in either urban centers or suburban public spaces remains a challenge, though maintaining tree canopy appears to be more of a challenge in urban centers due to their increased population density.

Urban sprawl can be evaluated on a different scale. If growth in land development is divided by growth in population for a region, a "sprawl index" can be calculated. California grew significantly in population between 1972 and 1996, but the leapfrog developments that appeared in that time period were smaller in size than their predecessors, resulting in a smaller footprint and a sprawl index of 0.92. Oklahoma, on the other hand, has a sprawl index of 2 (Bryant, 2001), presumably because new developments are leaving a larger footprint.

In Stillwater, Deer Crossing subdivision would reflect the latter index, since property sizes tend to be larger than those found in the central part of the city as well as larger than older subdivisions such as CrossWinds (Figure 8). In keeping with the traditional pattern discussed above, Stillwater's urban core has a higher population density than its suburbs with a resultant lower potential for urban forest canopy.

Assessment of Tree Canopy using Remote Sensing and GIS. Temporal canopy change can be assessed using pixel-by-pixel analysis in GIS software. Such change detection requires images with geometric accuracy on a subpixel scale, which necessitates use of high spatial resolution imagery, i.e., Compact Airborne Spectrographic Imager (CASI) data has a resolution to 25 cm (Franklin, 2001). Aerial photos are produced by sensors used in airborne camera systems and are usually considered medium resolution spatial imagery (medium scale images) or high spatial resolution imagery (large scale images). Low spatial resolution imagery (small scale) tends to be produced by satellite sensors that cover large regions measuring hundreds or thousand of meters (Franklin, 2001). Newer satellite platforms offering small scale imagery with a high degree of accuracy are useful in tree canopy analysis but tend to be expensive; as such, medium scale aerial photos are still useful in tree canopy studies and are available at little or no cost.

Older satellite imagery systems are also used in landcover analyses and their products have become less costly. Inexpensive Landsat MSS images for this study were obtained and evaluated but, at 79 m resolution, were too pixelated in enhanced views to be useful in this study (Figure 11). Medium scale aerial photos were appropriate because areas of tree canopy were analyzed, not individual tree crowns or tree species.

CHAPTER III

METHODOLOGY

Description of Study Area. The three sections chosen for the study were located in the south to southwest area of the city of Stillwater, Oklahoma. A noticeable change in development occurred in the south to southwest part of the city within the last 20 years or so (C. Tomlinson, Stillwater City Forester, personal communication, November 30, 2001), as reflected by the three study areas that each represent a city subdivision at a different stage of development. Each study area encompassed one square mile of its respective subdivision and age of development was determined according to plat filing date (Table 2). The three subdivisions studied were CrossWinds [older], Deer Crossing [younger], and Hidden Oaks [youngest].

Because the three study areas were within close proximity of each other (Figure 3), they shared similar climate and topography features that are characteristic of the city of Stillwater, Oklahoma. Located at 895 feet above mean sea level and nestled among rolling hills, the city of Stillwater has an average annual rainfall of 93.2 cm. Winters tend to be less severe than those in northern climes, with an average annual snowfall of 21.6 cm and a mean low temperature of -5.6^{0} C in January. Summers are hot and dry, with an annual July temperature of 34.2^0 C and little or no precipitation from May to September (National Weather Service, 2004).

The three Stillwater subdivisions chosen for study were presumed to possess the general soil, topography and climate characteristics of the Stillwater metropolitan region, and as such were also presumed to reflect Oklahoma Cross Timbers ecosystem characteristics, i.e., areas of prairie versus "scrub oak," as post and blackjack oaks are commonly referred to.

Data Collection and Preprocessing. The unique characteristics of the Cross Timbers were considered in determining the definition of adequate tree canopy cover for the three study areas. The determination of adequate tree canopy also included a retrospective evaluation of the change of Stillwater's tree cover from that found in undeveloped wildland or farm areas to what has become urban forest patches. Evaluating such a change required a historical assessment of aerial photographs of the study areas based on a timeline that spanned several decades.

Multi-decade vertical aerial photographs were obtained for each section from a variety of sources. In keeping with the original, cost-effective intent of the study, medium-scale aerial photographs were obtained at little to no cost from such sources as the library map room at Oklahoma State University; the USDA Farm Service Agency; and IntraSearch Corporation, a commercial vendor. Most photographs were black-and-white, with older photographs exhibiting mild to moderate tonal differences. Except for a photo created on mylar (Figure 15), a photo film product resembling a transparency plastic sheet, the Representative Fraction (RF) scale of the aerial photos were 1:20000, 1:40000, or

1:96000. While the mylar photo had an RF of 1:200 and was thus classified as a large-scale image, it was considered for use in the early collection of data because of the difficulty involved in obtaining sufficient aerial photos in appropriate time frames. For those photos without a scale imprint, a scale approximation was determined using the representative fraction (RF) formula (Avery and Burkhart, 1994):

$$RF = \frac{\text{photo distance between two points, ft}}{\text{ground distance between two points, ft}}$$

Determination of the RF scale was important in assuring use of images without large differences in pixel resolution, since aerial photos are viewed by ArcView, the GIS software, as raster images and small scale aerial photos tend to become more pixilated and difficult to analyze when digitized.

It should be emphasized that only vertical aerial photos were utilized, since oblique and other non-vertical aerial photos tend to distort geometric features of the earth's surface. Taken with a camera's optical axis at or less than 3^0 perpendicular to a level surface on the earth, vertical aerial photos qualify for use in the design of planimetric basemaps, topographic basemaps, raster digital elevation models (DEMs), and orthophotographs (Jensen, 2000).

Since the areas of study measured one square mile each and were within close proximity, a medium-scale image approach was chosen during the early selection of aerial photos. Large-scale images represent features measured in centimeters to meters and provide excellent resolution; however, these images require high spatial resolution technologies such as that found in satellite imagery and were quite expensive. Small-scale images provide coverage of a large area (i.e., RF 1:1,000,000) but provide very little detail (Franklin, 2001). Since the goal of this study was to perform a cost-effective temporal analysis of urban forest patches, the primary type of data was limited to medium-scale aerial photographs that were readily obtained from various sources at little to no cost. Further, the historical limitations of satellite imagery, which tends to be unavailable before the 1970's, were not an issue when using aerial photography, since aerial photos of Stillwater were available with dates as far back as 1938. As such, the study's time line was drawn from the Dust Bowl era to the present and allowed for a more comprehensive assessment of changes in tree canopy cover. Geographic Information Systems technology was then used to analyze the data contained in the aerial photos.

Data Processing in GIS. The analysis of the images of all three study sections was based on the step-by-step procedure outlined in Figure 1. Whether black-and-white or color, most of the aerial photos were converted from their original format into digital form with the use of a Mustek MFC 6005 flatbed scanner (Mustek Systems, Inc., Hsin-Chu, Taiwan), although the 1979 mylar image of Section 19 was scanned with an ACTion Eagle 3640 large-format scanner (Colortrac Ltd, Golden, Colorado) . While the large image was saved as a Tagged Image File Format (tiff) image, all of the other digitized photos were saved as Joint Photographic Experts Group (jpeg) images, a compressed image form that is superior to other common formats when analyzing and manipulating large image files.

Figure 1. Flow Chart of Data Processing

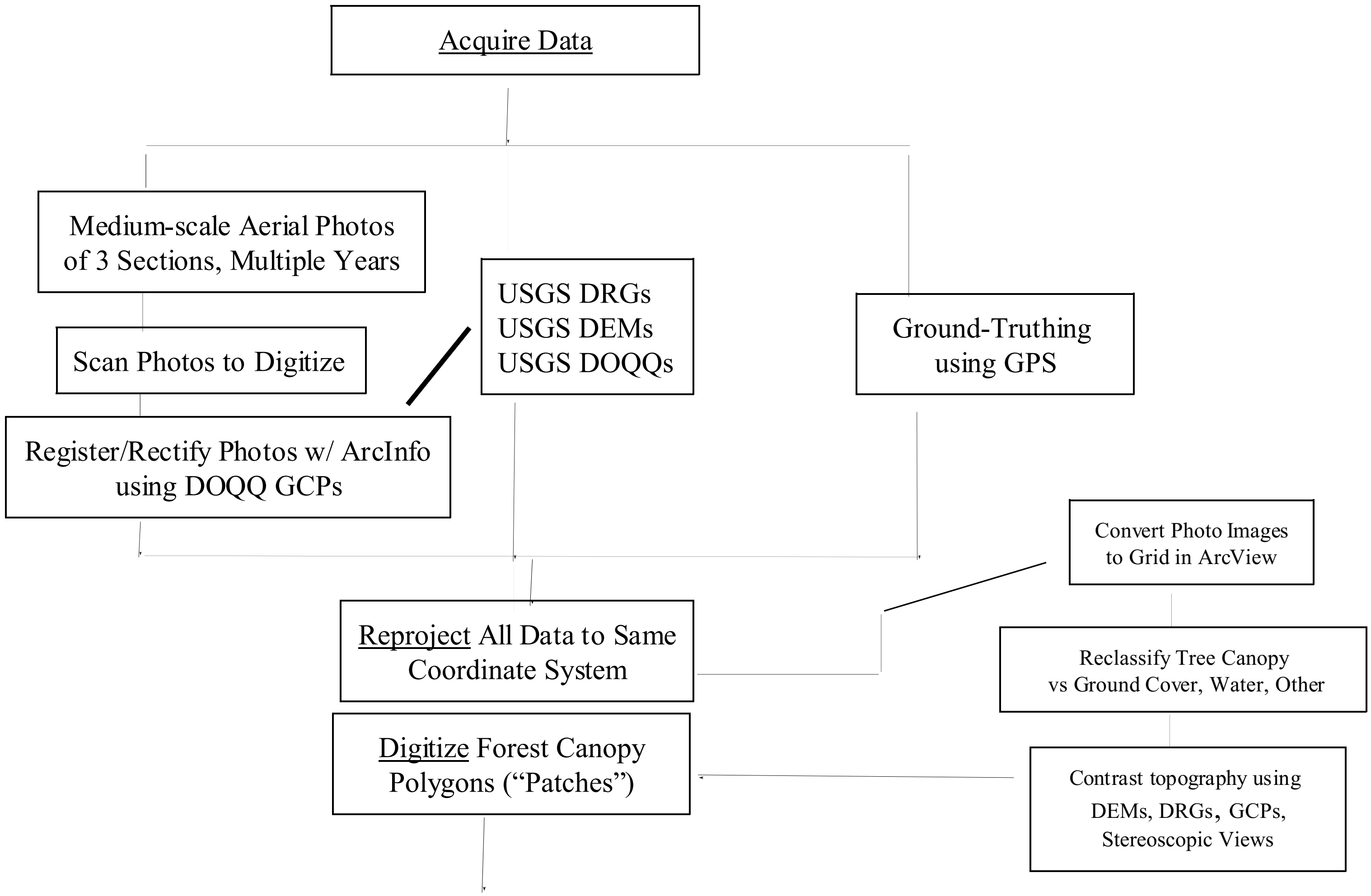
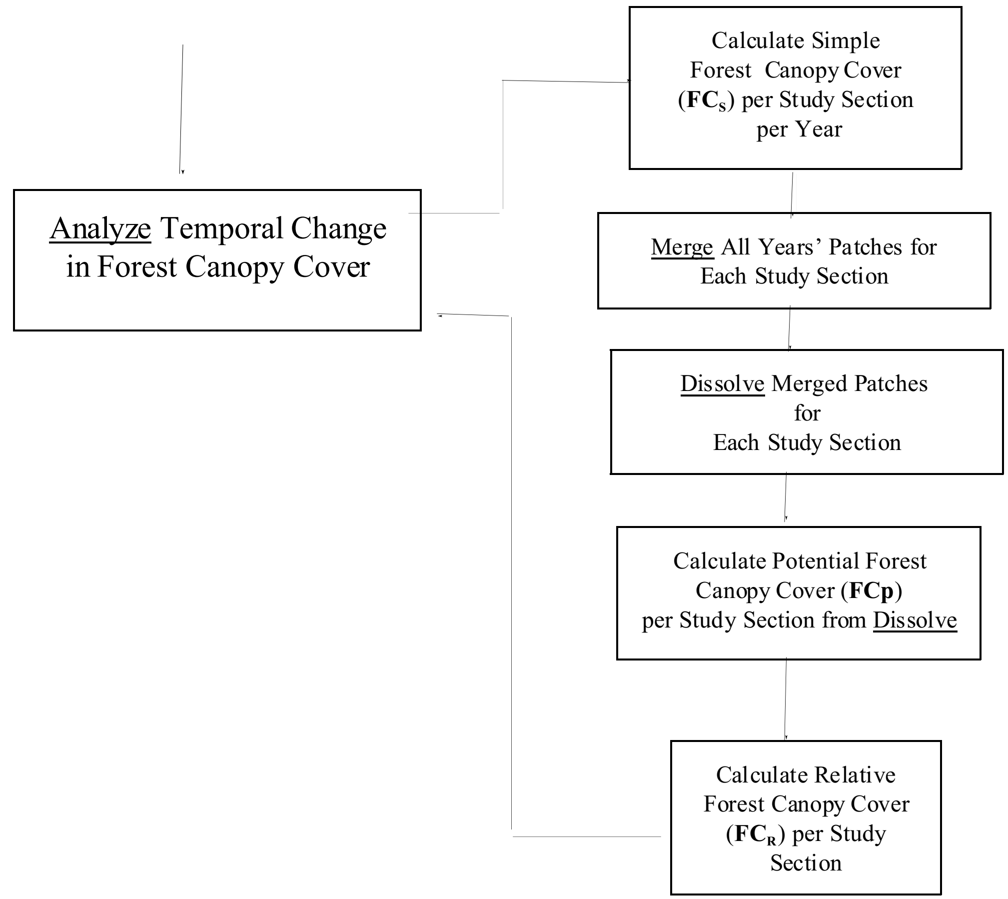


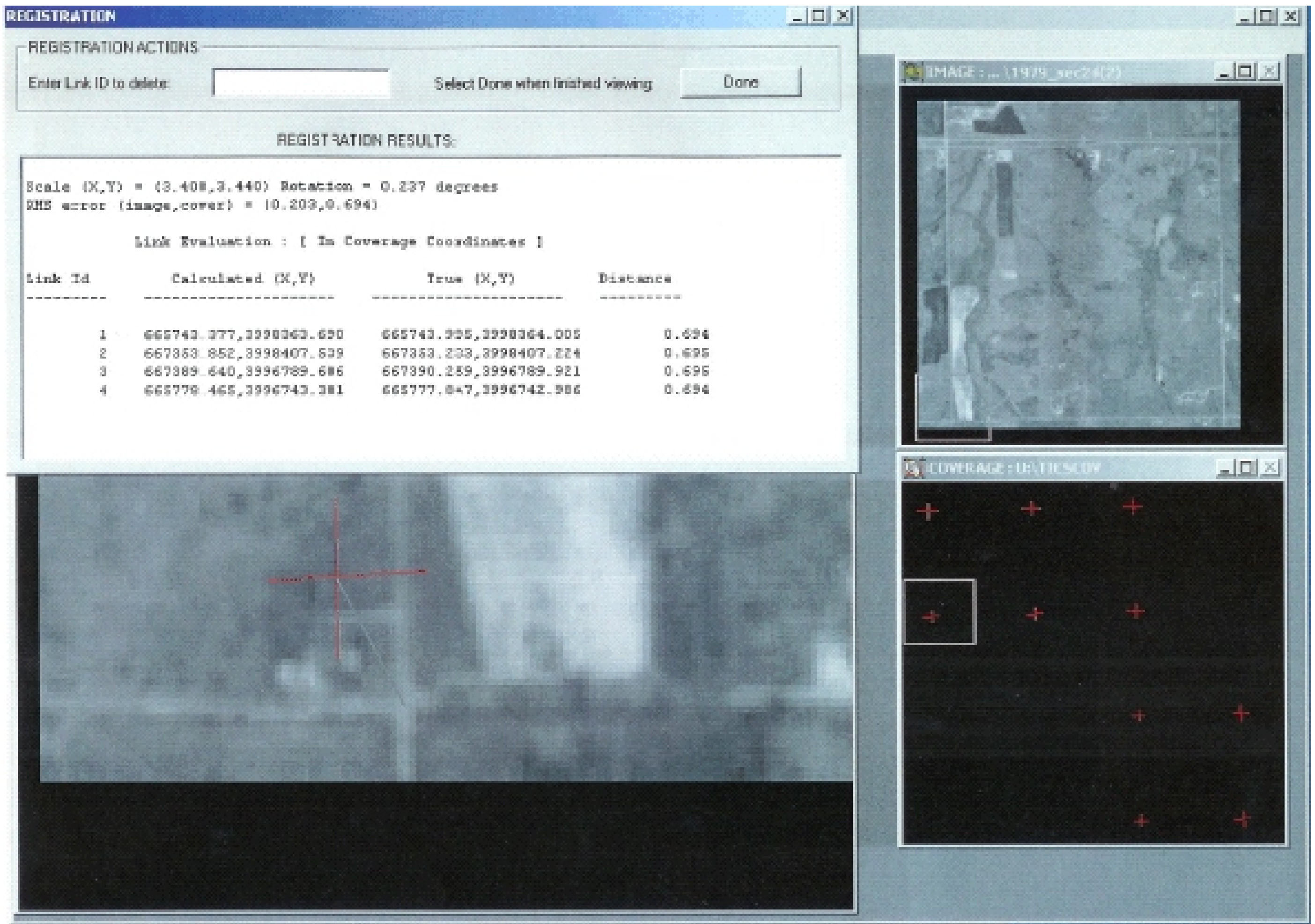
Figure 1(b). Flow Chart of Data Processing



Once in digital form, the photos underwent georectification via the registration feature in ArcInfo (Environmental Systems Research Institute, Redlands, California), as shown in Figure 2. Because of the different tonal qualities and scales of the various photos, however, georectification was preceded by conservative image adjustments in Micrografx Picture Publisher 8 (iGrafx, Tualatin, Oregon). From cropping an individual study section out of a regional aerial photo, to adjusting the contrast/brightness on either faded or underexposed photos, or rotating a photo to correctly orient north to south, the graphics program proved to be a useful tool for initial image preparation. Care was taken to make only conservative photo adjustments to avoid "stretching" or warping of images, since the latter could cause problems in areal calculations of urban forest polygons in the end stage of the study analysis.

Once initial image adjustments were completed, georectification proceeded in ArcInfo using ESRI's Avenue Macro Language (AML) in an on-screen register-and-rectify process. The "register" command in ArcInfo used an affine transformation approach [default setting of "Nearest Neighbor"] to unwarp an image and allow it to calibrate to a reference set of ground control points (GCPs) found on a digital orthophoto quarter quadrangle (DOQQ) photo with additional GCPs serving to enhance the accuracy of the transformation. The DOQQs' GCPs served to calibrate the new digital images, thus assigning them the correct location in geographic space, because DOQQs are preprocessed, orthorectified images (http://geo.ou.edu). To check validity of downloaded DOQQs, comparison GCPs were used from digital raster graphic (DRG) maps and digital elevation model (DEM) images, also downloaded from the University of Oklahoma.

Figure 2. View of Aerial Photo Undergoing Georectification via Registration in ESRI ArcInfo



In addition, field ground-truthing was performed to identify trees of different species that were beyond the seedling stage, i.e., greater than 4-inch diameter-at-breast-height (dbh), as GPS points for later digital canopy reference (Photo ThemeGPS_32, Appendix E). The ground-truthing points were obtained with the use of a GeoExplorer GPS (Trimble Navigation Limited, Sunnyvale, California) handheld unit and GPS data postprocessing was done using Pathfinder software (Trimble Navigation Limited, Sunnyvale, California). Pre-processing of data involved developing a data dictionary for import into the handheld GPS unit (Appendix C); the preinstalled data dictionary allowed for more efficient use of the GPS unit in the field. Post-processing involved differential correction using data from a 12-channel Trimble Pathfinder Community Basestation located on the top of a dormitory building at Oklahoma State University; basestation position is at 36.07.19.437940 North and 97.04.29.845180 West at an altitude of 316.29m and a datum of WGS 1984 (Department of Geography, 2002). Ephemereal data obtained from the basestation was downloaded from an Oklahoma State University website (www.geog.okstate.edu/labs/gps1.html).

Initial photo image processing was followed by georectification. In ESRI ArcInfo, effective registration of a generic aerial photo to the GCPs was indicated by a low root mean square error (RMSE) for each GCP used in registering, as shown in Figure 2. Although the RMSE for the photos processed in this study were 0.1 or less, high-value RMSE links should be discarded before completing the registration of an image to assure a quality affine transformation (Verbyla and Chang, 1997). After registration, the "rectify" command was used to finish the transformation of an aerial photo into an orthorectified digital image that no longer had the tilt and relief distortions of the original photograph.

Once georectification was complete, each digital photo was imported as a theme into an assigned ArcView 3.2 file location. Using both the Toolbox feature in ArcInfo and the Projection Utility Wizard extension in ArcView 3.2, all digital images were then reprojected to the same coordinate system, the universal transverse mercator (UTM) in Zone 14.

After reprojecting all data to the same coordinate system, the urban forest canopy patches, or polygons, were identified and digitized as separate themes using heads-up digitization. To aid in visualization of the forest canopy patches, each digitized photo was first converted into a Landcover grid using an iterative process as partly represented by Figures 16 and 17 to produce a high-quality grid; buildings and water bodies were then digitized to prevent them from being inadvertently outlined as forest canopy polygons. Further, to decrease examiner bias during the digitization of forest polygons, care was taken to avoid comparing pre-digitized photo images with post-digitized photo images of a different year in each section.

Many of the aerial photos presented a challenge during digitization, especially those reproduced from slide images (i.e., Photo 2002_32), those with age-induced tonal changes (i.e., Photo 1938_32), or those with poor resolution (i.e., Photo 1979_32). Before converting such photos to a Landcover grid, they were reproduced as pairs and viewed through a stereoscope to enhance viewing of heights and slopes (Aber, 2002), thus simplifying identification of forested areas.

Some variation was observed in the processing of the individual study sections. In Sections 32 and 19, the digitized, georectified aerial photo themes provided well-matched overlays on each respective image's DOQQ. Even after extensive review of the image preprocessing techniques that were used, however, a few of the Section 24 photo themes were imprecise overlays on that section's DOQQ. Fortunately, the problem was remedied with Shapefile Shifter (Raber, 1999, April 9), a custom extension downloaded from ESRI's website. Shapefile Shifter allows the user to move a shapefile easily from one location in space to another over reasonable distances.

Because of the complexity involved in processing almost two dozen aerial photos in different formats, variations were not unexpected. For comparison, a previously documented "woodlands" theme was digitized directly from Section 32's DRG, as were the DRG water bodies. It was thought that the DRG would be useful in assessing the accuracy of forest polygons that were digitized later as separate themes from each of the photos for the section. As a result, the 1964 woodlands and water graphics and the updated 1976 woodlands and water graphics of the Stillwater South DRG were digitized as separate themes and compared to the later-digitized forest and water polygons of the 1969 and 1979 aerial photos, respectively. Although most of the water bodies in the DRG appeared in the comparison photos and much of the woodlands appeared as well, the inconsistencies and generalizations of "woodlands" in the DRG themes were found lacking, i.e., many DRG woodland areas appeared to be ground vegetation on the aerial photos (Theme1979_sec32b). Because of this issue, the DRG woodland and water areas were deemed to be an unreliable reference for the purpose of this study.

In Section 24, digitization and georectification of the aerial photos from different sources and different scales resulted in a poor "stacking" of the photos over the respective DRG and the 1995 DOQQ (University of Oklahoma, 2003) that were used for ground control point (GCP) reference. After realigning the Stillwater Southwest Oklahoma-Payne County DRG from its native 1927 North American Datum (UTM 1927) to the project-specific UTM 1983, 4 GCPs were established, with one placed at each corner of Section 24 (Figure 12). The DOQQ photo image used for orthorectification of all Section 24 photos was then overlayed on the DRG. Using the Image Georeferencing Tools extension (Raber, 1999, November 15), the DRG's scale was then adjusted to match that of the DOQQ, with care taken to avoid warping either image. DRG scale adjustment was performed by a manual, iterative process of pixel size adjustment in the Image Information dialog box of the Image GeoReferencing extension in ArcView 3.2 (Figure 13).

Once the DOQQ and the DRG appeared to overlay well, the individual photos were overlaid as themes. Although each photo was "anchored" to a greater or lesser degree to the upper left corner GCP of the DRG because of its orthorectification previously done in ArcInfo, there were still significant differences in scale and resolution: the result of the incongruent overlays was less than satisfactory (Figure 14). To correct this deficiency, the Image Georeferencing Tools extension was once again utilized.

Section 19 was analyzed from black-and-white photos dated 1938, 1963, 1969, 1979, 1989; a black-and-white 1995 DOQQ image; a preprocessed color image dated 1998; and a scanned slide aerial photo from July, 2002. A mylar image was considered for use and was scanned into digital form but was found unsatisfactory due to incompatibility with the other images and poor resolution after scanning (Figure 15). Since this was the only mylar image discovered for any of the study areas, it was deemed unnecessary to pursue further processing of this type of image format.

To enhance visualization of groundcover differences, the aerial photos were converted into grids in triple bands using ArcView 3.2 GIS software (*Theme –> Convert to Grid*). [As an exception, the 1995 DOQQ black-and-white images for each of the study sections were preprocessed and orthorectified in a single band by an external source (University of Oklahoma, 2003) and were not amenable to conversion into grid form.] After reviewing a multitude of grids in each of the three bands for each of the photos of all of the study sections, it was determined that Band 2 provided the most useful Landcover representation, as shown by the graphic comparison in Figure 16. For consistency, then, only Band 2 was used when converting each of the aerial photos into a Grid. The Grid in default setting proved relatively useless and was therefore reclassed to produce the more acceptable image shown on the left in Figure 16. The preferred Band 2 grid conversion was obtained using the following process: open Legend Editor dialog box of individual grid >> Set classification settings at Equal Area with 50 classes >> set Color Ramps at Landcover #1 (leave default settings for Legend Type, Classification Field, and Normalize by) >> Invert new color ramp. The resulting grid image produced an enhanced version of pseudo-landcover that simplified the visual analysis of vegetation cover in each of the aerial photos, with only one caveat, however: the aerial photos of lesser quality produced grids of matching lesser quality (Figure 17). Nevertheless, the landcover grids greatly assisted in the heads-up digitization of urban forest polygon areas of each of the subject photos.

Analysis of Urban Forest of Study Areas. Previous studies involving measurement of tree canopy have utilized various data collection and processing methods, with varying degrees of success. Historically, aerial photographs have served as a primary data source; since the 1970's, satellite images have served to supplement then replace aerial photos as a primary source of data in tree canopy estimation. Assessment of tree canopy density from satellite imagery has been

Figure _____. Example of lesser-quality aerial photo producing a less ideal Landcover Grid

done using spectral mixture analysis (SMA), physically based models, or fuzzy logic, all of which are considered less than ideal for assessment of large areas. Because SMA and linear regression models depend on the relationship between spectral signature and tree canopy density, such models have difficulty dealing with the highly variable vegetation covers found on images of large land areas (Huang, et.al., 2001).

Medium scale aerial photographs were available long before satellite images and, as such, provide an important source of historical data that can be directly compared to modern aerial photos, thus simplifying a "before and after" comparison of tree cover in a particular area.

______The use of medium scale aerial photos of Stillwater, then, provided spatial and temporal data that allowed for an analysis of forest canopy cover in the three study areas and resulted in a determination of simple forest canopy Cover (FCs), potential forest canopy cover (FCp), and relative forest canopy cover (FCr). To calculate simple forest canopy Cover (FCs) for each photo year in each study section, forest polygon areas were summed. A calculation of the land area within the individual study section boundary was then made after a customized section boundary line in polygon form was created as a separate theme in each study section, as shown in ThemeDissolve_19 and ThemeDissolve_32 in Appendix F. Simple canopy cover (%) was obtained by dividing the sum of the forest polygon areas by the area of the section boundary and multiplying by 100 (Equation 1).

Equation 1. $$FCs = [\text{ Forest Polygon Total } / \text{ Boundary }] * 100$$

While the individual section boundary was a static number, the sum of the forest polygon areas changed with each photo year. Polygon areal calculations were performed with a customized ESRI ArcView extension known as *Area Tools* (Giarusso, 2002). FCs are useful in assessing the direct temporal and spatial change in tree canopy cover per each study section.

To obtain potential forest canopy cover % (FCp) in each study section, it was necessary to begin by creating a "Merge" theme: for each section, all of the photo year forest polygon themes were overlaid directly on each other as shown in ThemeMerge_19, Appendix F. A "Dissolve" theme was then created from the Merge theme, which essentially allowed all of the multi-year forest polygons to become one comprehensive polygon, as displayed in ThemeDissolve_19, Appendix E. Both Merge and Dissolve procedures were performed using the GeoProcessing Wizard feature in ESRI ArcView 3.2. The area of the polygon created by the Dissolve procedure was then calculated. Thereafter, potential forest canopy cover (%) was obtained by taking the area of the Dissolve polygon, dividing it by the area of the section Boundary polygon, and multiplying by 100 (Equation 2).

Equation 2. $FCp = [\text{Dissolved Polygon} / \text{Boundary Polygon}] * 100$

Potential forest canopy cover is a static number in each section and represents the most likely areas where forest canopy can be found per each study section, based on six decades of photo image information and without detailed evaluation of anthropogenic or natural variables. Chart 6 shows the FCp of each study site.

Relative forest canopy cover % (FCr) is obtained per photo year by dividing Simple forest canopy cover (FCs) by potential forest canopy cover (FCp) and multiplying by 100 (Equation 3).

Equation 3. $$FCr = [FCs / FCp] * 100$$

The resulting number represents the maximum area of ecologically sustainable forest canopy percentage in a given time period in a given location. Relative forest canopy reflects a comparison of simple forest canopy coverage to potential forest canopy coverage, thus yielding a realistic estimate of what canopy coverage should be at a given point in time based on a historical assessment. For each study section, an average FCr provides a realistic estimate of what canopy cover should be at any time, based on the previous six decades' canopy cover. The average FCr per study section may then be considered a realistic tree canopy coverage goal for that location. Further, a minimum FCr should be avoided and should represent serious deforestation, since it is based on a comparison of the lowest canopy coverage against potential canopy cover at any time in the previous six decades. Similarly, a maximum FCr should represent a most optimistic but realistic tree canopy coverage for the individual study section.

______An example of polygon area measurements and canopy cover calculations is provided in Table 3. Note that the unit of measure is in hectares.

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CHAPTER IV

FINDINGS

A simple visual assessment of the generic aerial photo images for each year in each study section provided clues regarding changes in landcover, specifically with regard to changes in tree canopy cover. Visual assessment was obviously enhanced by manipulation of data in GIS, since digitization of forest polygons to represent urban forest patches made it simpler to perform calculations involving canopy cover change.

A review of the images, charts, and tables used in this study confirmed that urbanization had an impact on tree canopy cover in the last six decades. However, the original hypothesis presumed that urbanization had caused a decrease in tree canopy cover from a state tree canopy standard of 24% to a local, post-development average of 15%. Using Charts 2 through 5 or Charts 7 through 10 would have confirmed the hypothesis as sound – if only data prior to 1970 were considered, since the graphs indicate growth in tree canopy above the state standard through the end of the last century.

Before affirming the original hypothesis as null and void, however, note must be made of the decrease in tree canopy evident just since the beginning of this century, during a period of increasing development in the study sections. In view of the fact that the first objective of this study was to determine tree canopy cover changes over six decades, note must be made of the fact that Section 19 (CrossWinds) exhibited a slight decrease in tree canopy, from 27% in 1995 to 23% in 2002. Section 32's (Deer Crossing) canopy is down slightly to 42% in 2002 from a high of 45% in 1995, though it was down to 11% in 1969. Section 24 (Hidden Oaks), on the other hand, has steadily increased in canopy cover from a serious low of 4% in 1949 to an average of 35% for the last several years.

The second objective of the study was to determine whether an increase in population had any effect on tree canopy change. An evaluation of population density revealed that Section 19 (CrossWinds) had a high population density as evidenced by the smaller property lot sizes when compared to those of Section 32. Prior to significant development, Section 19 showed a canopy increase of 9.0% to 14.7% from 1938 to 1969, with the canopy decreasing sharply to 9.3% ten years later, with evidence of development seen even though the subdivision plat was not filed until 1980. Then an increase in canopy from 9.3% to 27.7% occurred between 1979 and 1995 as development progressed to cover most of the right lower quarter-section and part of the right upper quarter-section. By 2002, however, the canopy had decreased again to 23.3% as development also covered most of the left upper quarter-section. Thus, there is a recent downward trend in simple forest canopy cover, or FCs (Chart 3), with the decrease attributable to increasing population. The early canopy increase may be an effect of fire suppression, or proliferation of a rapid-growth species such as eastern red cedar, or both; further investigation and followup canopy assessments would be appropriate.

Like Section 19, Section 24 showed a significant canopy increase prior to development, with canopy coverage growing 4.3% to 31.3% from 1949 to 1989. During this time, minimal development was visible, i.e., a few roads and lots, mostly in the right lower quarter-section. Interestingly, canopy then dropped to 24.9% by 1995, then increased sharply again to 35.6% by 2000 and remained about the same at 35.7% by 2002. This section experienced minimal development after the subdivision plat permit was filed in 1997, so the impact of population density on canopy coverage is unclear.

Section 32 had a poor canopy coverage of only 7.7% in 1938 (Theme 1938_32, Appendix F). By 1969, canopy increased marginally to 11.7% and no development was yet apparent (Photo 1969_32, Appendix E). Canopy more than doubled to 26.6% by 1979, then almost doubled again to 44.7% by 1995. Of note, the subdivision plat filing occurred in 1997 and canopy decreased to 42.3% by 1998, then again to 40.1% by 2002 as development increased (Photo 2002_32, Appendix E). Like the other two study sites, Section 32 began with limited canopy cover at the beginning of the study timeline then improved canopy significantly for several decades until the beginning of development. While Section 19 showed only a 4% decrease in canopy in the last 7 years of the study timeline and Section 24 showed no impact, Section 32 showed a steady drop in canopy over the last 7 years of study, thus reflecting an impact from the increase in population density.

The third objective was to determine the maximum amount of canopy that could be grown in each study section so that a more realistic canopy standard could be developed. The "Potential Canopy Cover" equation helped to meet this objective. Calculating the potential canopy cover (Table 3) for each section showed where in the section trees tended to grow over the last six decades, as well as where they did not grow.

The fourth and final objective of this study was to compare any tree canopy change within an individual study section to the change in another section. As mentioned above, Section 32 incurred the most loss in tree canopy cover in the last 7 years of development up to 2002, followed by the more modest decrease in Section 19 and the lack of change in Section 24. However, the simple canopy cover calculation should be compared to the relative canopy cover calculation. Since Section 32 has an average relative canopy cover (FCr) of 48%, its current simple canopy cover of 40% needs monitoring to prevent further decrease. Section 24 has an average relative canopy cover of 31%, and its current simple canopy cover is appropriate at 35%. Unfortunately, Section 19 (CrossWinds) has a current simple canopy cover of 23% but its citizens should be striving toward an ideal of 29% as indicated by its relative canopy cover.

Scope and Limitations. While the intent of the research addressed in this paper was to evaluate temporal changes in the urban forest of Stillwater, the work was done with certain limitations in mind. Such limitations include the following:

(1) Single square mile sections of each of three subdivisions in different stages of urbanization were selected and were intended to be representative of the city as a whole. However, extrapolation of the data results beyond the area of Stillwater or Payne County was not intended.

(2) Not all years of photos were available as matched sets for all of the sections. For example, the photo time line for Study Sections 19 and 32 begins in 1938, but the earliest available aerial photo for Study Section 24 is dated 1949. Nevertheless, every attempt was made to obtain photos for each study section that would represent at least 6 different decades of tree canopy cover.

(3) Because the vast majority of the aerial photos are black-and-white images, specific

land cover class delineation or exacting vegetation class identification was not attempted, except as needed to differentiate trees from ground vegetation.

(4) While quantitative analyses are included in this research, some results may appear to be more qualitative than quantitative because of the questionable quality of some of the photos and the resultant difficulty involved in digitizing their canopy cover. A concerted effort was made to calibrate the examiner's eye by using GPS groundtruthing, iterative visual assessments of individual images, and other appropriate techniques used to obtain high quality data results.

(4) Caution must be used to avoid confusing "canopy coverage" with "number of trees" in the aerial photos. Assessment of tree canopy cover was done to determine the amount of tree canopy area per study section in each image without attempting to determine the number of trees in any given photo. Consequently, older trees with larger crowns may easily yield a high cover density in one image at one point in time, while the same image region shown in a different year may contain many younger trees with smaller crowns but with a similar amount of canopy cover.

(5) No species composition changes were intentionally identified nor was it a goal of this study to do so. The author acknowledges that some readers may feel as strongly about loss of native tree species as they do about loss of tree canopy caused by urban encroachment.

(6) Discussion regarding potential forest canopy cover or maximum potential canopy cover (FCp) refers to the maximum ecologically sustainable area of tree canopy cover based on a six-decade historical review. It does not imply that it is impossible to grow

trees in excluded areas within the FCp if an ideal amount of water, nutrients, and care are provided to the new growth.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

It was hypothesized that urbanization in the three study areas of CrossWinds, Hidden Oaks, and Deer Crossing had caused a decrease in tree canopy cover from the state average of 24% to approximately 15%. Analysis of aerial photographs spanning six decades revealed surprising results: prior to urbanization, tree canopy was as low as 4% from 1938 to 1949, then recovered nicely through four decades until peaking at up to 45% from 1989 to 1995. Initial urbanization seemed to have a positive impact on at least one study site, CrossWinds (Section 19), perhaps due to the suppression of the natural pattern of fire in the area which allowed for growth of woody species. During the last several years of the study, population density had a negative impact on tree canopy coverage in the Deer Crossing study site (Section 32), a negligible impact on the Hidden Oaks study site (Section 24), and a slightly negative impact on the CrossWinds study site (Section 19). However, none of the study areas showed as severe a loss of tree cover as initially hypothesized and analysis of multi-decade aerial photographs allowed for calculation of a more appropriate canopy standard for the study areas.

Calculation of a potential canopy cover and a relative canopy cover for a given area is based on extensive historical data pertinent to that area and, as such, should be much more relevant and useful in the development of an appropriate local tree canopy standard. While regional or state canopy standards can be used as a general guide, local standards based on local temporal studies of tree canopy change should be more accurate. It is appropriate to be concerned about tree canopy loss in the midst of urban sprawl, but it is perhaps more useful to know what the intangible limitations to increasing tree canopy are. Section 32, for example, has an average relative canopy cover (FCr) of 48%, while Section 24 has an FCr of 31% and Section 19's FCr is 29%. Based on historical data, these percentages would serve as excellent tree canopy standards. Further, the historical data was obtained at extremely low cost or was free.

Recommendations. For future reference, certain recommendations are offered based on the results of this study. First, it is important to note that analysis of the aerial photos utilized an iterative process involving more than one method. More detailed ground-truth using GPS technology should be performed, to include as many different types of ground features as practical, thus making it easier to select or de-select appropriate features during analysis of the aerial photos. Canopy cover assessments should continue to be done at intervals, such as every five years, to determine how urbanization continues to impact forest canopy. Ideally, photos used in the future should not only be selected for their "leaf-on" characteristics, but should be dated in the same month when possible for more consistent analysis of vegetative cover. A comparison of previous analyses with aerial photos should be made against an assessment using satellite imagery, which allows for more precise canopy identification and even species definition. With satellite imagery, it would also be useful to do an evaluation of tree species change in areas which have undergone urbanization.

CHAPTER VI

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APPENDIX A

ACRONYMS

ACRONYMS

DEM – digital elevation model

DOQQ – digital orthophoto quarter quadrangle

DRG – digital raster graphic

ESRI – Environmental Systems Research Institute

FCp – potential canopy cover or potential forest canopy cover

FCr – relative canopy cover or relative forest canopy cover

FCs – simple canopy cover or simple forest canopy cover

GCP – ground control point

GIS – geographic information system

GPS – global positioning system

MSS – multi-spectral scanner

USDA – United States Department of Agriculture

UTM – universal transverse mercator

APPENDIX B

FIGURES

Figure 3. Soil Types of Northeast Corner of Section 32, Deer Crossing Subdivision

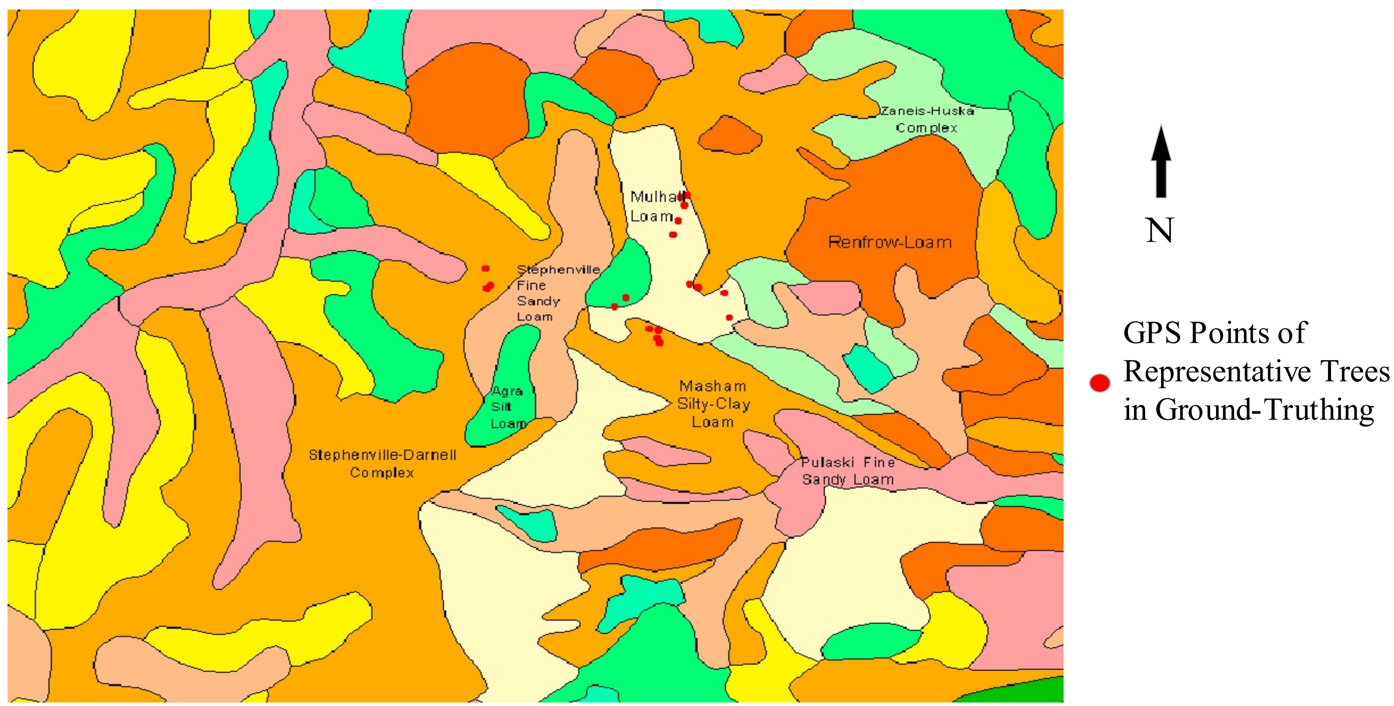


Figure 4. Extent of Cross Timbers region (shown in red), courtesy of *The Ancient Cross Timbers Consortium*

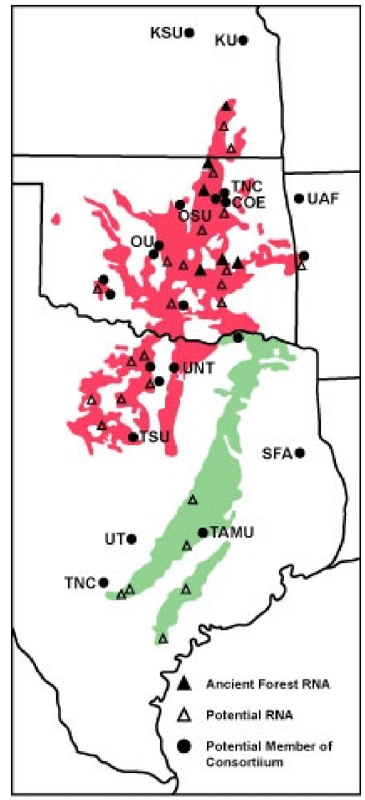


Figure 5. Location of Study Areas as Sections

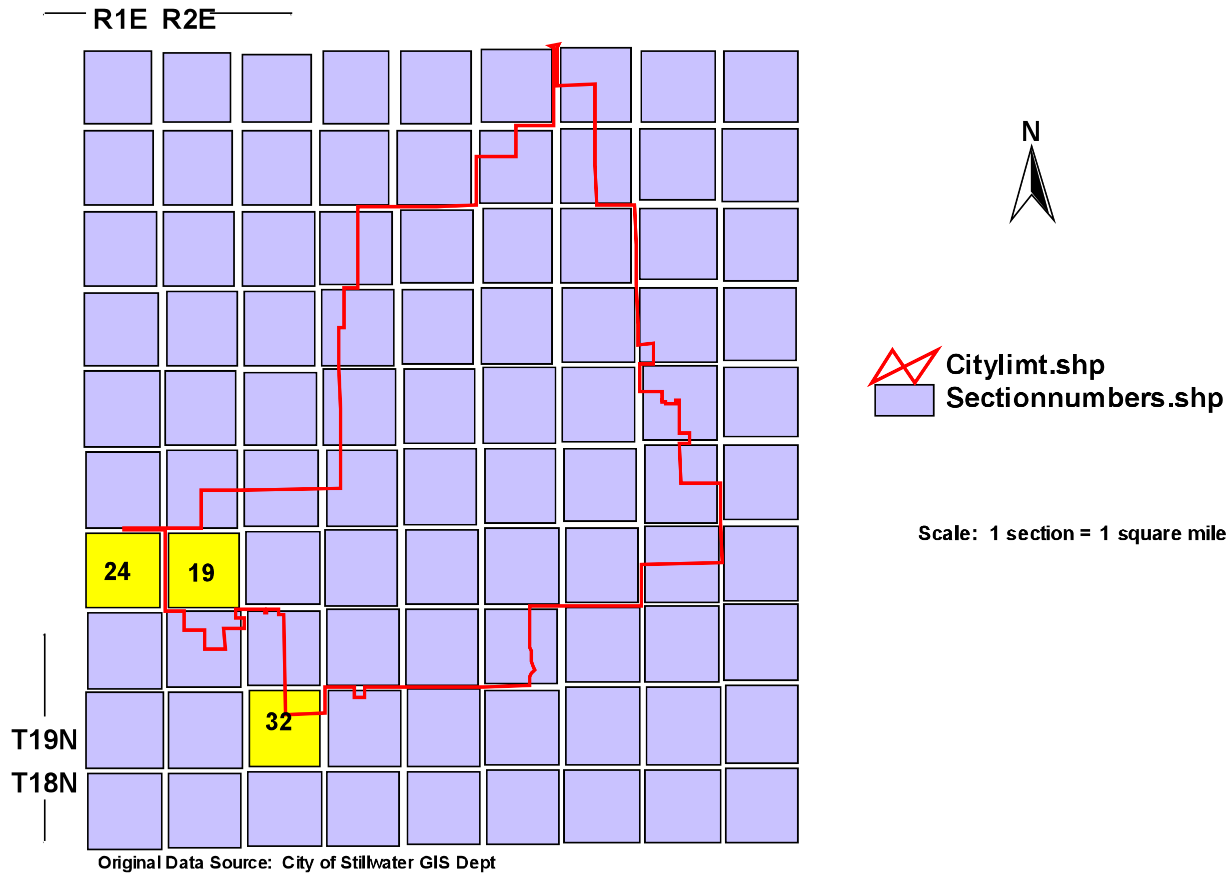


Figure 6.

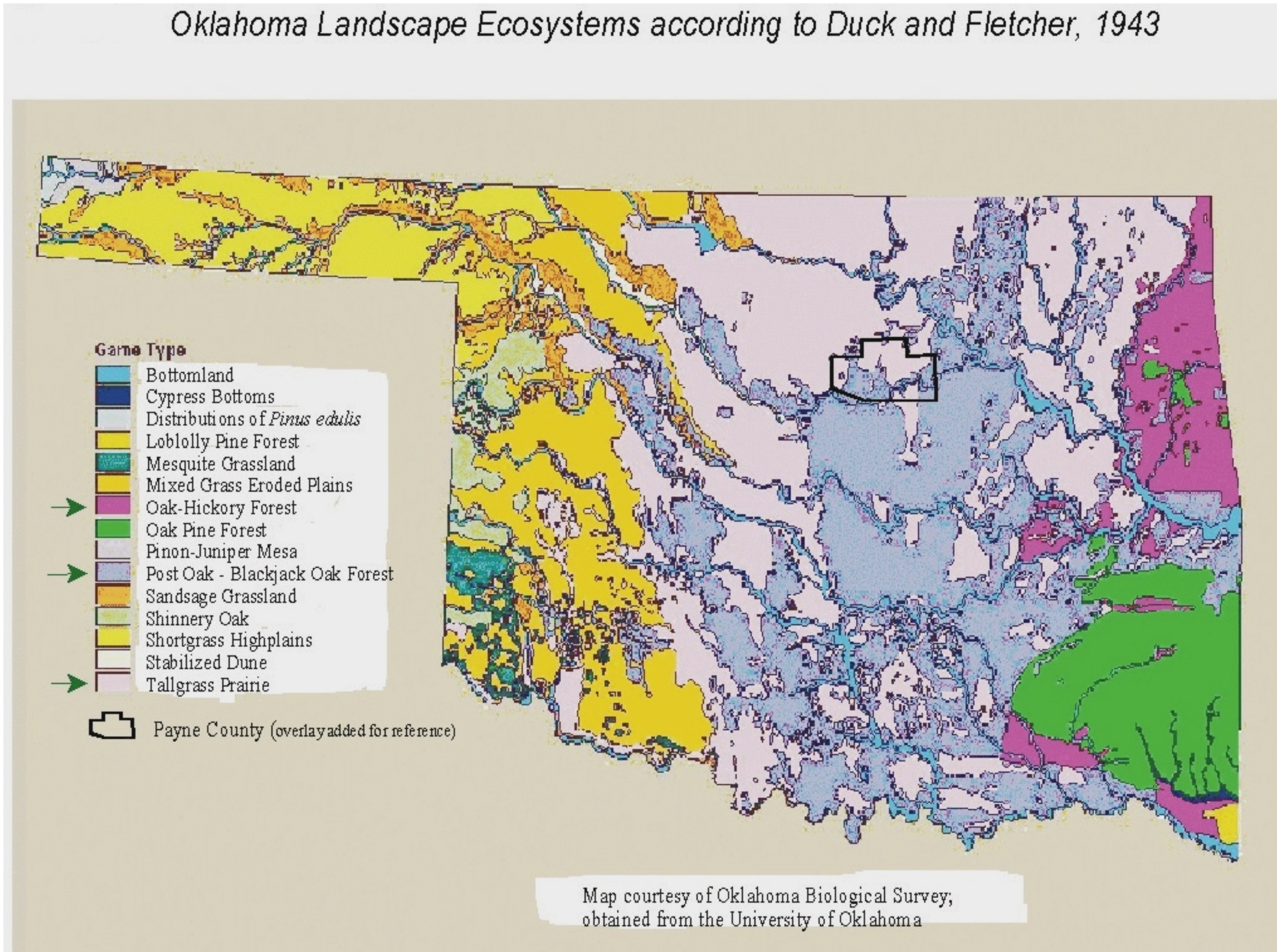

Oklahoma Landscape Ecosystems according to Duck and Fletcher, 1943
Game Type
Bottomland
Cypress Bottoms
Distributions of Pinus edulis
Loblolly Pine Forest
Mesquite Grassland
Mixed Grass Eroded Plains
Oak-Hickory Forest
Oak Pine Forest
Pinon-Juniper Mesa
Post Oak - Blackjack Oak Forest
Sandsage Grassland
Shinnery Oak
Shortgrass Highplains
Stabilized Dune
Tallgrass Prairie
Payne County (overlay added for reference)
Map courtesy of Oklahoma Biological Survey;
obtained from the University of Oklahoma

Figure 7. Cross Timbers Region and 3 Cross Timbers Sites in Oklahoma

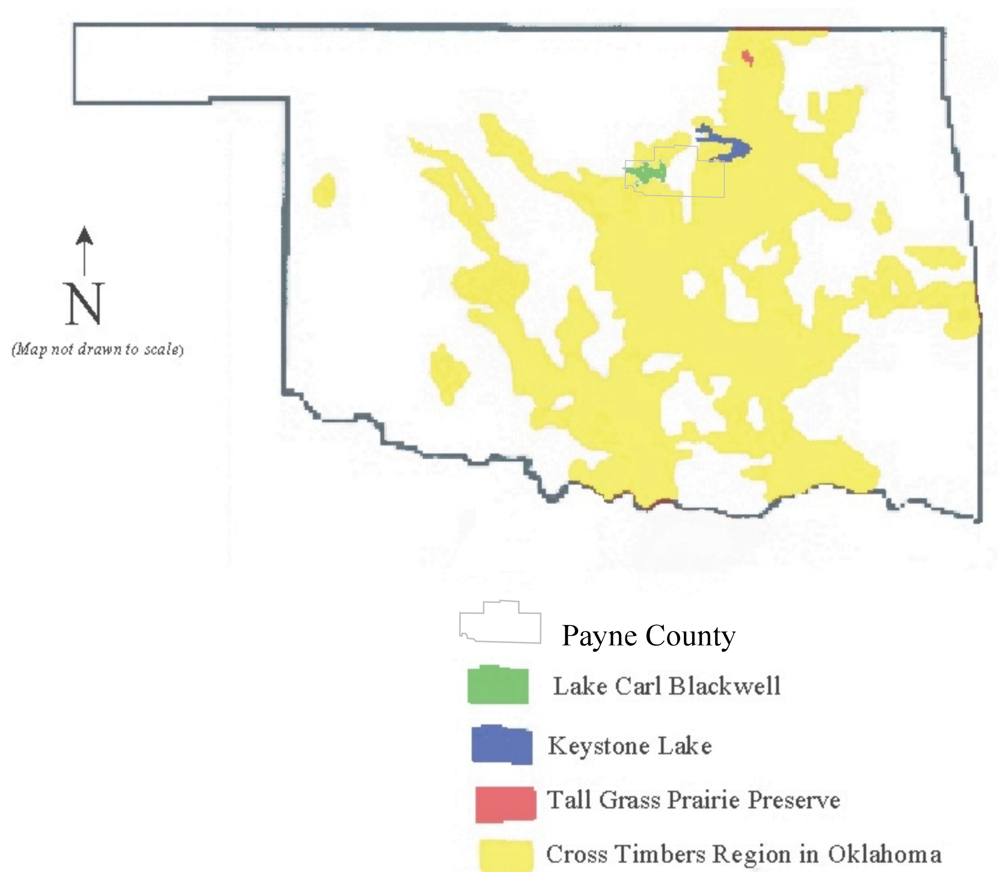
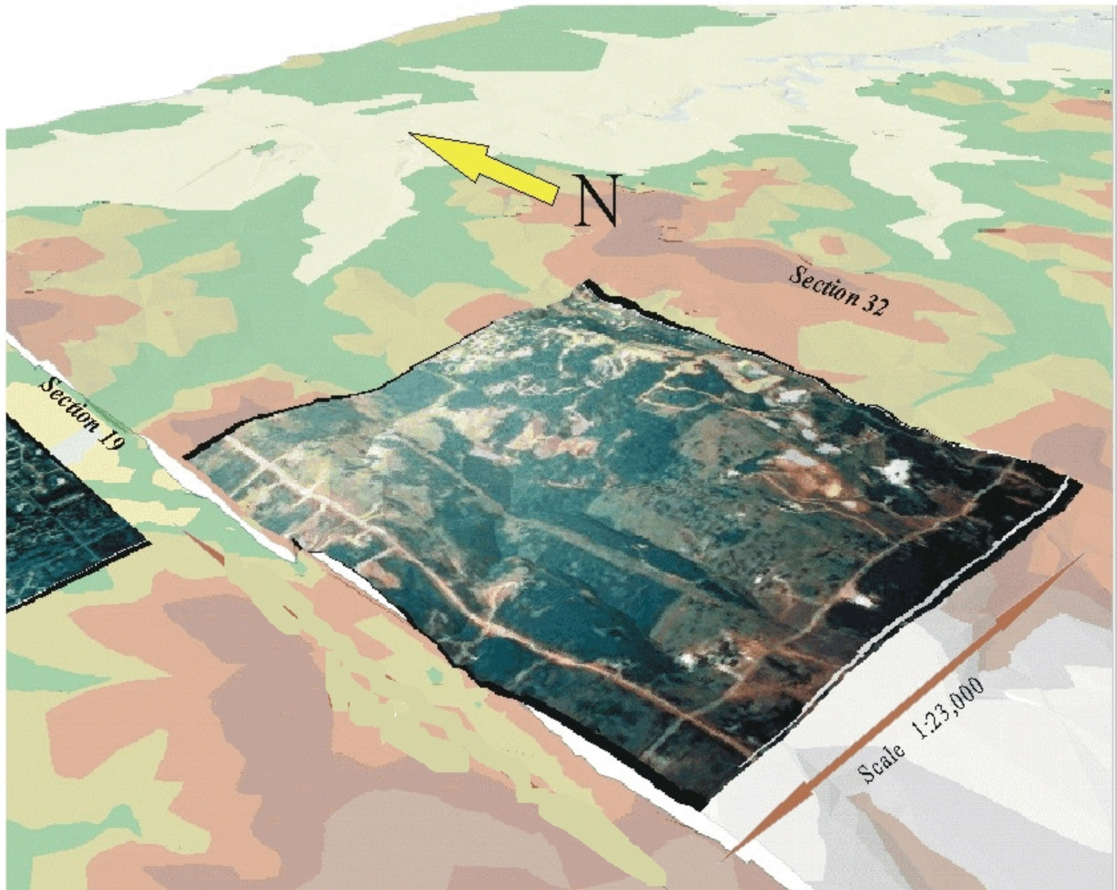


Figure 8. 2002 3D-View of Section 32, R2E, T19N, in Stillwater, OK



3D-View Overlay of 2002 aerial photo built on raster TIN based on DEM of Stillwater South, using ArcScene

Figure 9. Rate of Land Development in Oklahoma vs Other States, 1992-1997

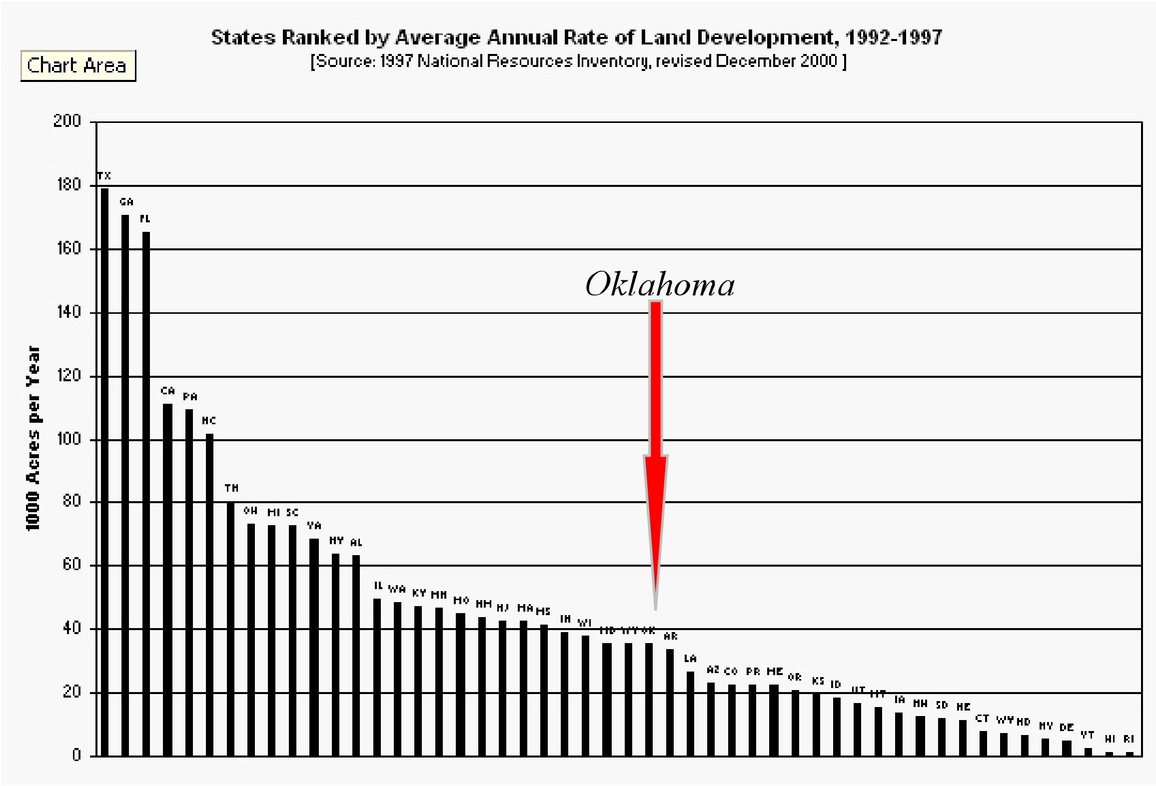


Figure 10. Contrasting Lot Sizes in Study Sections

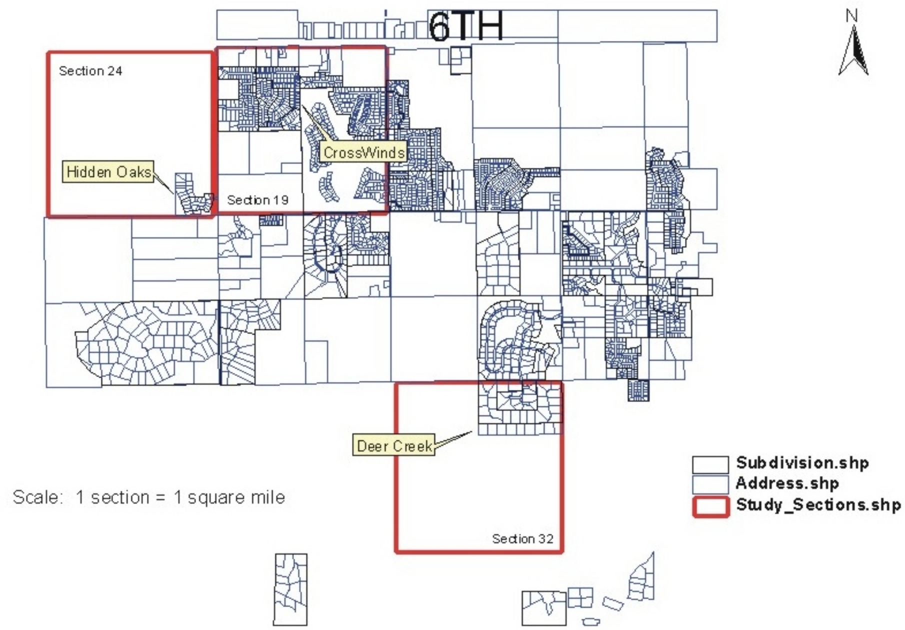


Figure 11. 1973 Landsat MSS Image of Study Areas

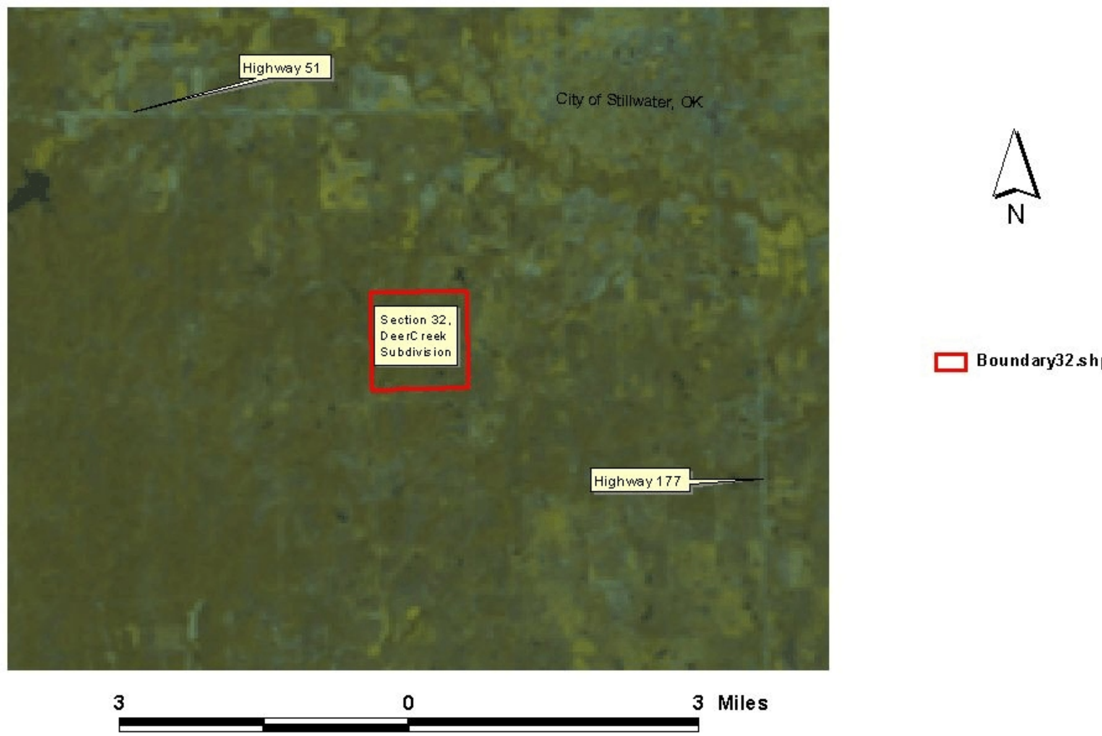
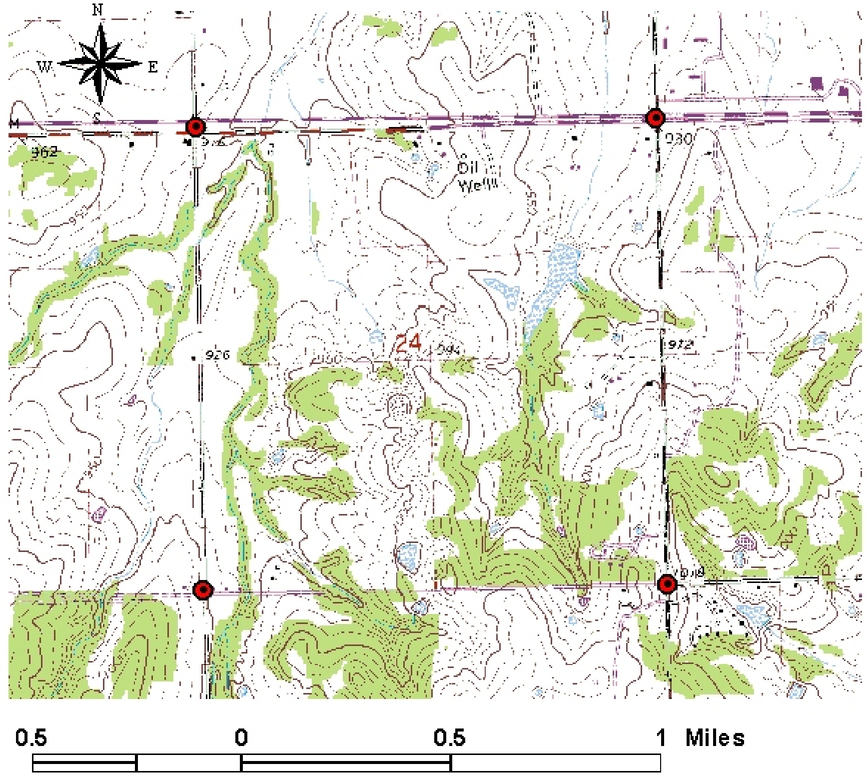


Figure 12. Ground Control Points Are Marked on Section 24, Hidden Oaks, on a Topographic Map



Ground Control Points are shown in red at each corner of Section 24

Figure 13. Image Information Dialog Box of the Image GeoReferencing Extension in ArcView 3.2

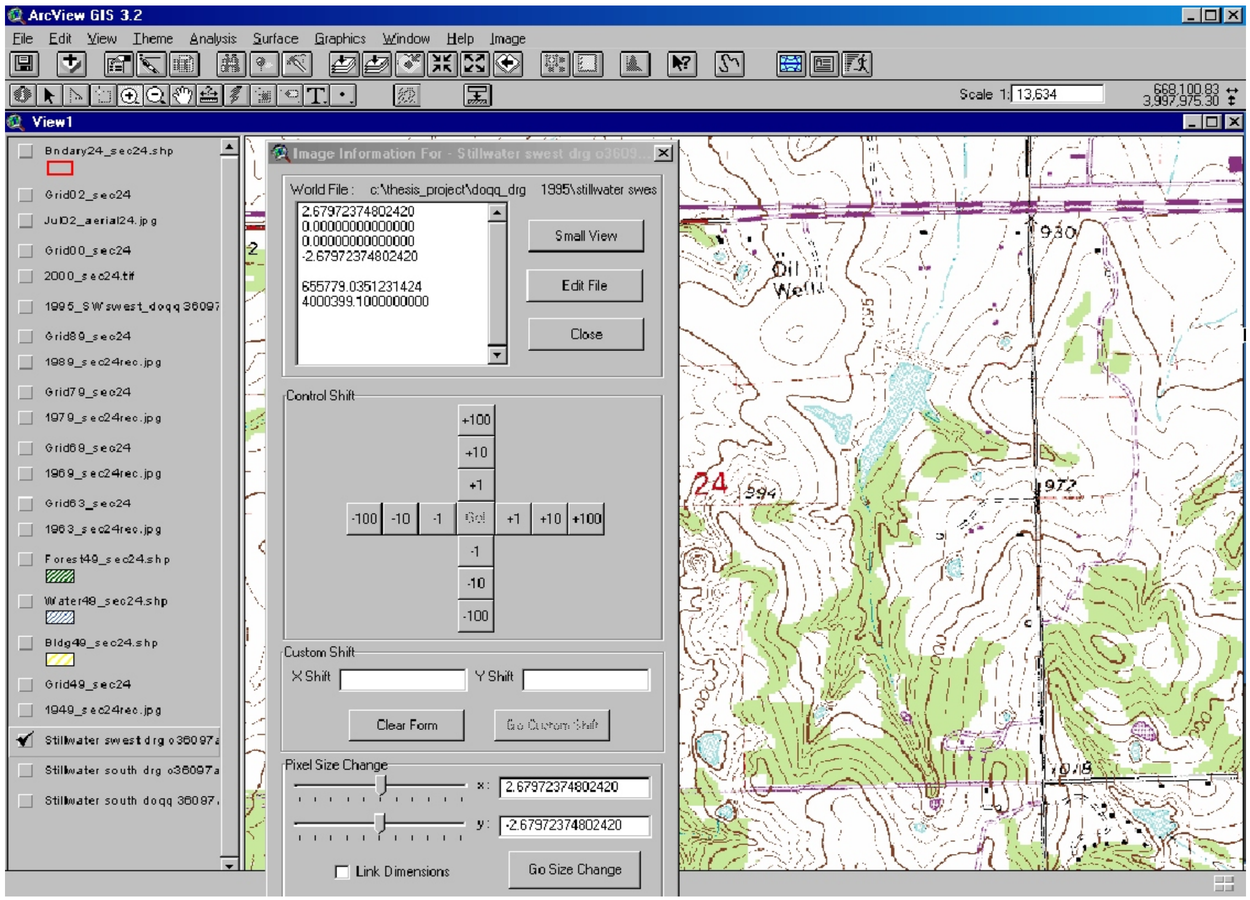


Figure 14. Unsatisfactory Overlays of Photo Image on DRG for Section 24, Hidden Oaks

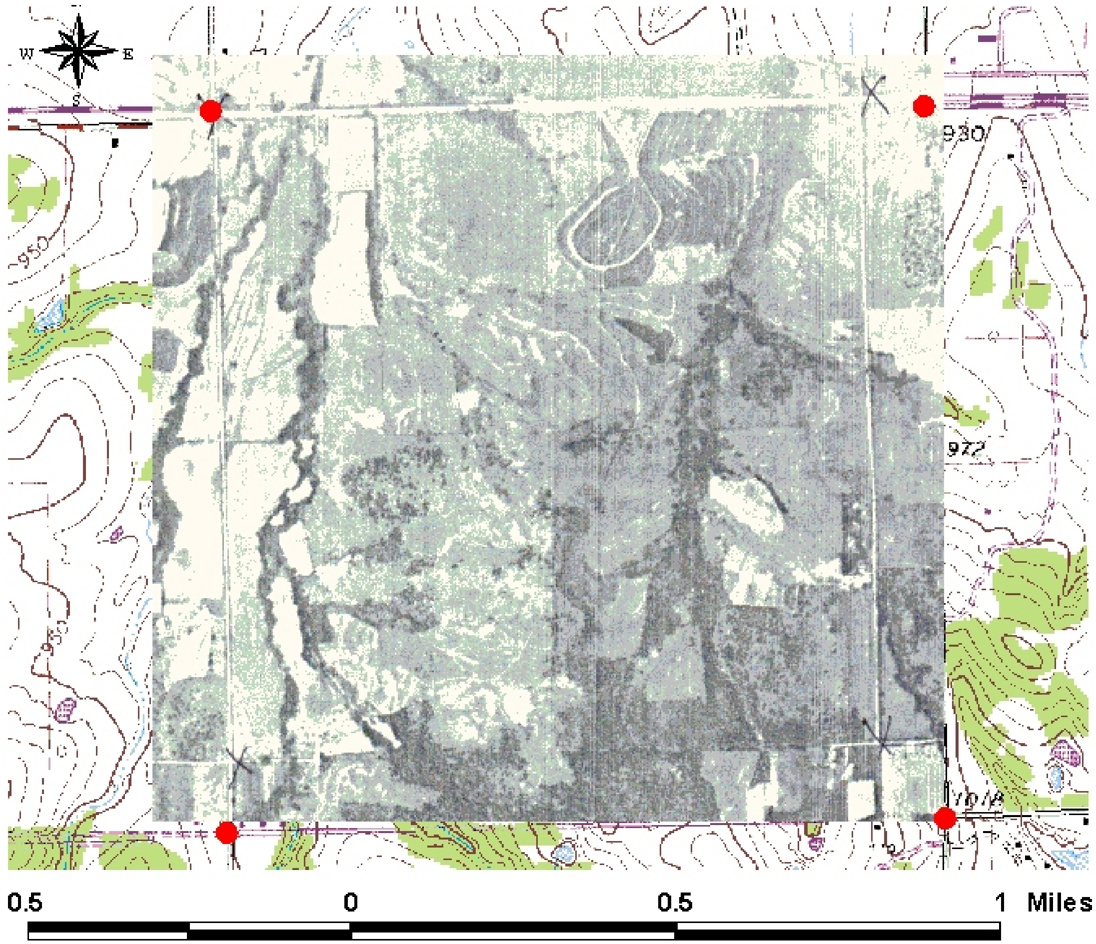
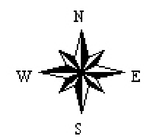


Figure 15. Mylar Image of Section 19, CrossWinds Subdivision, in 1979 in 1:200 scale



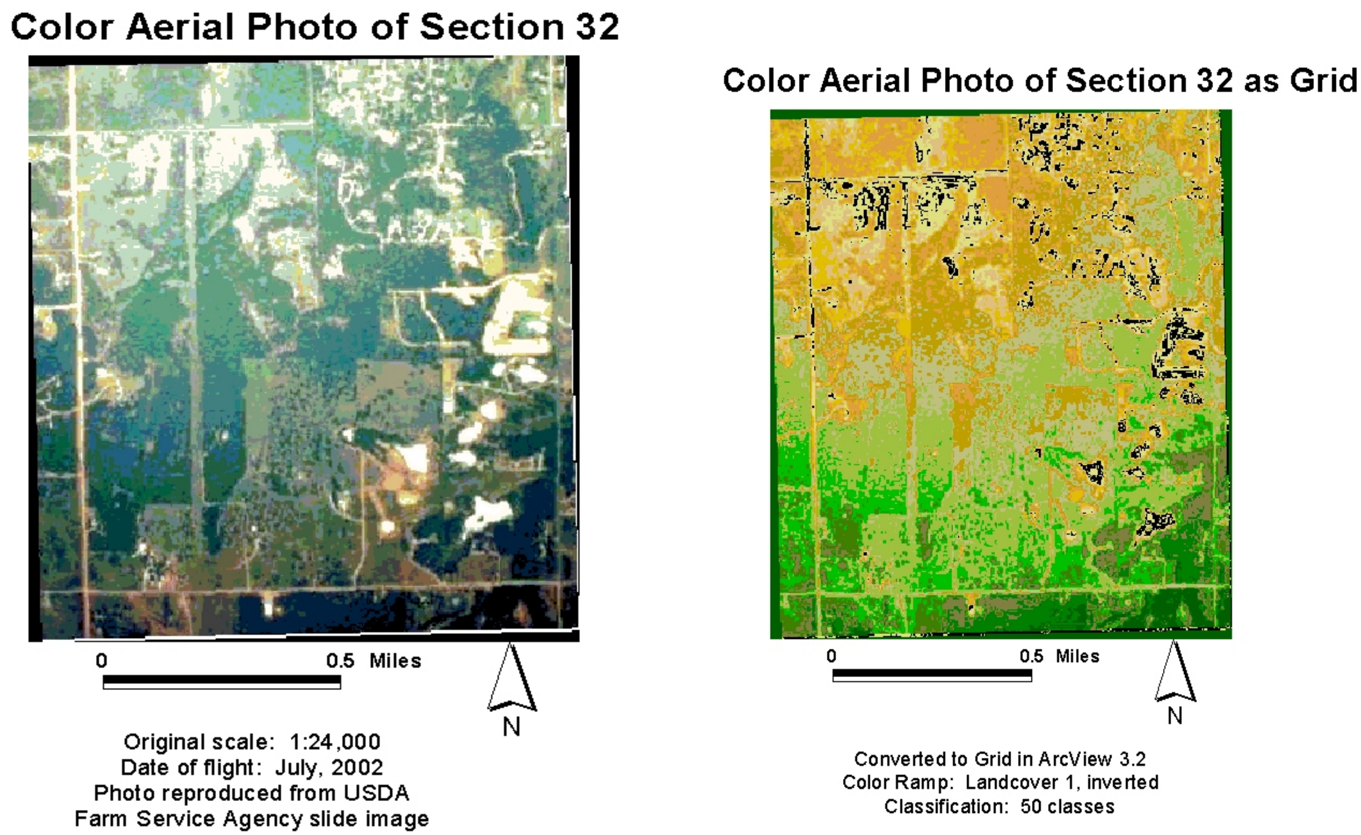
Section = 1 square mile

Flight Date = April 6, 1979

Image Courtesy of Mark Gregory, Oklahoma State University

Figure 16. Landcover view comparison of Bands 2 and 3 after grid conversion from a 1963 black-and-white aerial photo of Section 19, CrossWinds Subdivision

Figure 17. Lesser-quality digital photo image on left produces lesser-quality grid image on right



APPENDIX C

GPS DATA DICTIONARY

GPS DATA DICTIONARY

As part of the data preprocessing step in the study, the following data catalog was entered into a Trimble GeoExplorer handheld GPS unit to increase efficient data-gathering in the field. Collected as a .ddf file, the data was post-processed in the GIS Lab at Oklahoma State University using Pathfinder software and a desktop PC.

```
"Sec32_Field Data", Dictionary
"Road", line, "", 1, seconds, Code
  "Name", time, auto, 24, auto, normal, normal, Label1

"Tree", point, "", 5, seconds, 1, Code
  "Species", menu, normal, normal, Label1
    "Oak--Post"
    "Oak--Blackjack"
    "Oak--other"
    "Eastern Red Cedar"
    "Pine"
    "Elm"
    "Maple"
    "Cottonwood, eastern"
    "Baldcypress"
    "Other"
  "DBH", numeric, 0, 4, 50, 4, required, "inches", normal, Label2
  "Height", numeric, 0, 6, 200, 6, required, "inches", normal
```

APPENDIX D

TABLES

Table 1. Soil Types of Northeast Corner of Section 32 (Deer Crossing Subdivision) of Stillwater, OK

(Soil Conservation Service, 1982)

ID	Name	Slope (%)	Crop Cultivation Suitability	Erosion Potential	Natural Fertility	Organic Matter Content	Range Potential	Suitable Plants *
6	Pulaski fine sandy loam	nearly level	not suited		medium	low	high	LB, IG, BB, SG, Leg
10	Darnell-Rock	8 - 45	not suited	severe	low	low	low	LB, BB
11	Stephenville-Darnelle	1 - 8	not suited	severe	low to medium	medium	low	BM, WL, CB, PB, Leg
26	Grainola-Lucien complex	5 - 12	not suited	severe	medium	medium	medium	LB, IG, BB, SG, Leg
32	Harrah-Pulaski	0 - 8	not suited	severe	low to medium	medium	medium	BM, Leg, WL, CB, PB,
42	Ashport silty clay loam, occasionally flooded	nearly level	high		high	high	high	LB, IG, BB, SG, Leg wt, gs, al, veg, fts, nts
43	Pulaski fine sandy loam, occasionally flooded	nearly level	high		low to medium	low	high	LB, BB, IG, SG, al, veg, fts, nts
45	Renfrow silt loam	1 - 3	medium	medium	high	high	medium	LB, IG, BB, SG, Leg
46	Renfrow silt loam	3 - 5	low	medium	high	high	medium	LB, IG, BB, SG, Leg

Table 1, continued. Soil Types of Northeast Corner of Section 32 (Deer Crossing Subdivision) of Stillwater, OK

*** Suitable Plants Legend:**	LB	Little Bluestem	wt	Wheat
	IG	Indiangrass	gs	Grain Sorghum
	BB	Big Bluestem	al	Alfalfa
	SG	Switchgrass	veg	Vegetables
	Leg	Legumes	fts	Fruits
	BM	Bermudagrass	nts	Nuts
	WL	Weeping lovegrass		
	CB	Caucasian bluestem		
	PB	Plains bluestem		
	SOG	Sideoats grama		
	BGr	Blue grama		
	BF	Buffalograss		

Table 2. Plat Filing Dates of Study Sections

Subdivision ID	*Filing Date*
The CrossWinds 1st Section	19800603
The CrossWinds 2nd Section	19800603
The CrossWinds The Courts	19940320
The CrossWinds The Gardens	19950217
The CrossWinds the Highlands	19970820
The CrossWinds the UnNamed	19940320
The CrossWinds the Village	19910920
Hidden Oaks 1st Section	19971107
Deer Crossing Estates	19971009
Deer Crossing Estates 2nd Section	20001208

Source data courtesy of City Staff, City of Stillwater, Oklahoma

(Gao, J., 2004)

Table 3.
1938 Canopy Cover

Measurements
for Section 19, CrossWinds

(This table is representative of Calculations completed for each subdivision, all listed years, for Digitized Urban Forest Polygon Themes in Appendix F.)

ID	AREA (m^2)	HECTARES
1	163.474	0.0163474
2	219.014	0.0219014
3	248.355	0.0248355
4	277.697	0.0277697
5	279.793	0.0279793
6	293.416	0.0293416
7	330.093	0.0330093
8	333.236	0.0333236
9	367.817	0.0367817
10	381.440	0.038144
11	394.015	0.0394015
12	396.111	0.0396111
13	398.207	0.0398207
14	432.788	0.0432788
15	440.123	0.0440123
16	463.178	0.0463178
17	494.615	0.0494615
18	544.565	0.0544565
19	555.394	0.0555394
20	557.490	0.055749
21	620.365	0.0620365
22	657.041	0.0657041
23	674.856	0.0674856
24	702.102	0.0702102
25	702.102	0.0702102
26	745.066	0.0745066
27	811.085	0.0811085
28	856.145	0.0856145
29	873.959	0.0873959
30	1004.949	0.1004949
31	1057.344	0.1057344

Table 3, continued.

32	1169.471	0.1169471
33	1234.442	0.1234442
34	1242.825	0.1242825
35	1343.425	0.1343425
36	1366.479	0.1366479
37	1406.299	0.1406299
38	1686.092	0.1686092
39	1714.386	0.1714386
40	2768.586	0.2768586
41	3247.483	0.3247483
42	3746.289	0.3746289
43	4318.450	0.431845
44	4476.685	0.4476685
45	4902.137	0.4902137
46	5065.612	0.5065612
47	5281.482	0.5281482
48	5559.179	0.5559179
49	6634.338	0.6634338
50	6829.249	0.6829249
51	7041.976	0.7041976
52	9356.816	0.9356816
53	9700.531	0.9700531
54	11359.378	1.1359378
55	20538.747	2.0538747
56	21167.844	2.1167844
57	22114.109	2.2114109
58	46404.734	4.6404734
Sum		22.7953
Mean		0.3930
Sec19 Boundary Area		250.6215
1938 Simple Canopy Cover % (FC_S) *(total tree polygon area / boundary area)*100*		9.0955
Dissolve Total for Sec19 *(total area of all forested areas, all years)*		128.3257
Sec19 Potential Canopy Cover % (FC_P) *(dissolve total / boundary area)*100*	51.2030	
Sec19, 1938 Relative Canopy Cover % (FCr) *(FCS / FCP)*100*	17.7636	

Table 4. Boundary Calculation for Section 19, CrossWinds

ID	AREA (m^2)	HECTARES
1	2506214.949	250.6214949

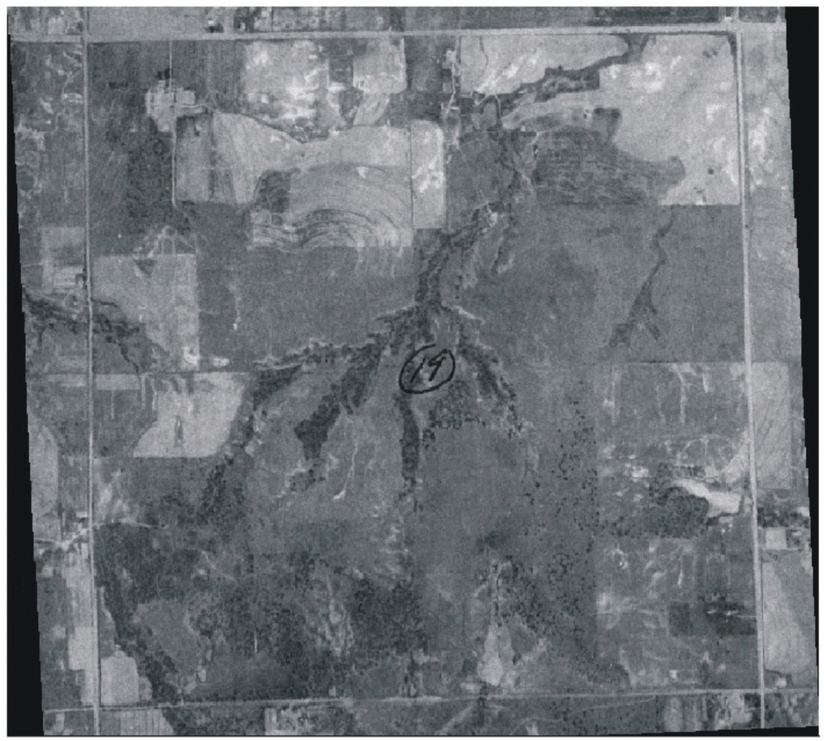
Table 5. "Dissolve" Theme Calculation for Section 19, CrossWinds

ID	AREA (m^2)	HECTARES
1	1283256.938	128.3256938

APPENDIX E

PHOTO IMAGES BY YEAR AND STUDY SECTION

_Photo 1938_19 . 1938 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK_



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1963_19. 1963 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1969_19 . 1969 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1979_19 .   1979 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1989_19.   1989 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1995_19. 1995 B&W Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

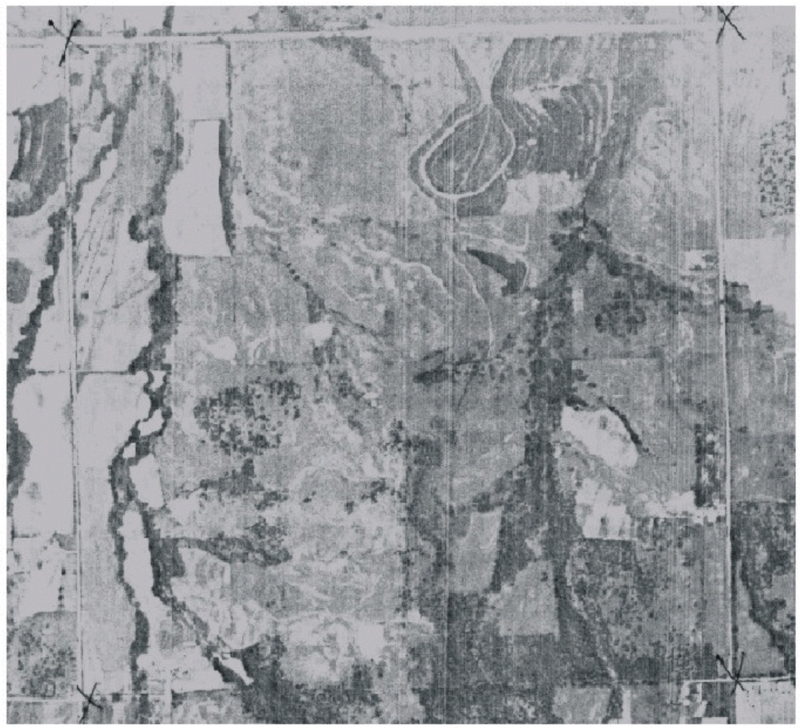
Photo 2002_19 .   2002 Color Aerial Photo of Section 19, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1949_24. 1949 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

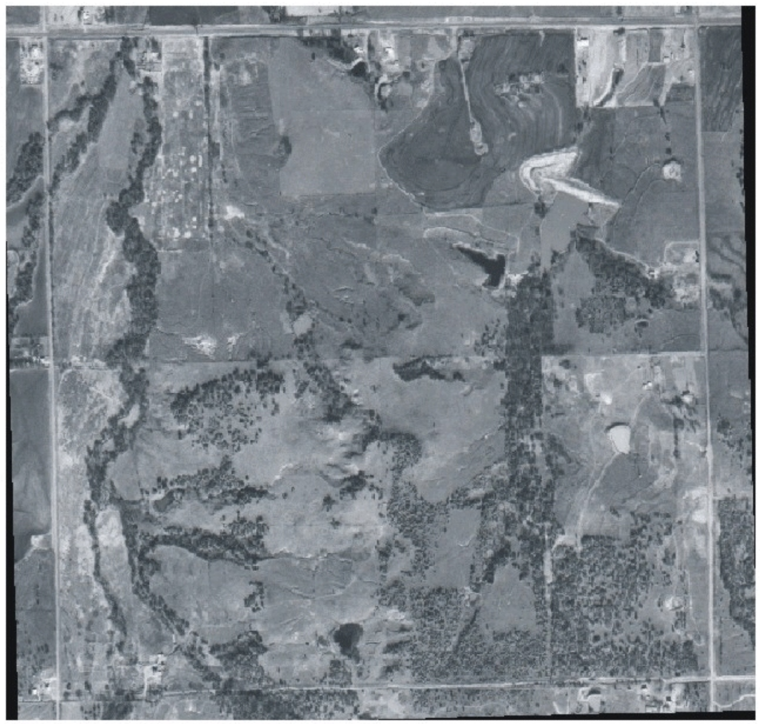
Photo 1963_24. 1963 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1969_24. 1969 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

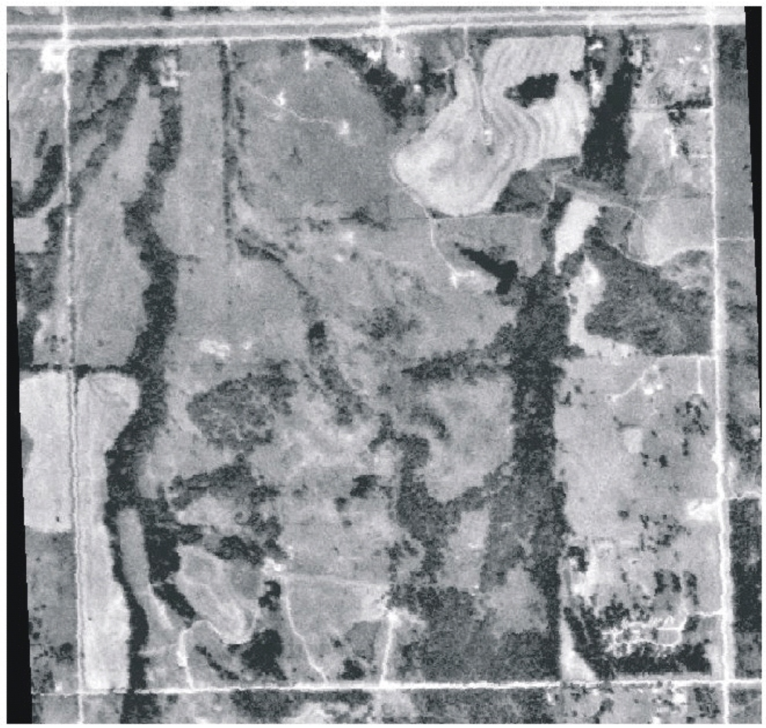
Photo 1979_24. 1979 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1989_24.   1989 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1995_24. 1995 B&W Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USGS; image cropped from
Digital Ortho Quarter Quadrangle

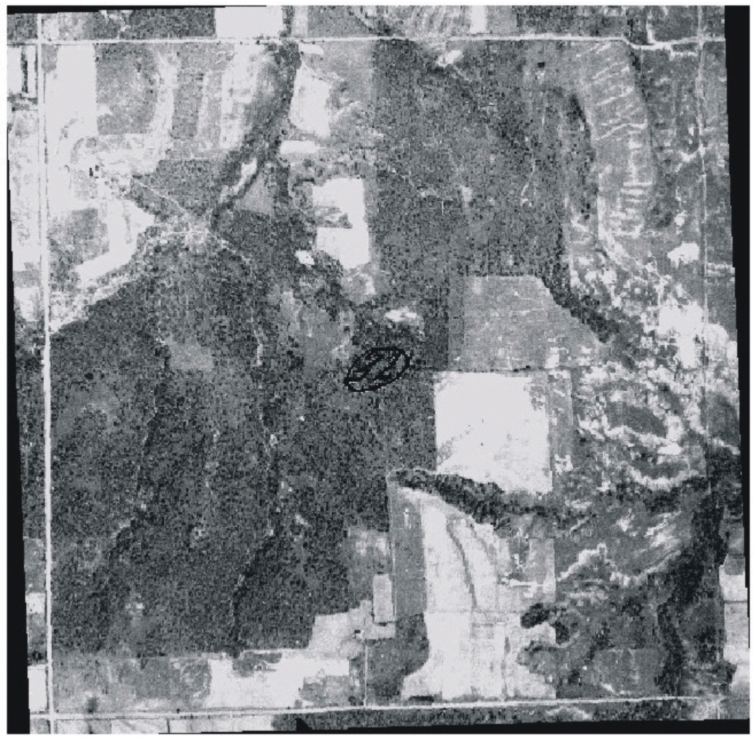
Photo 2002_24 .   2002 Color Aerial Photo of Section 24, R1E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1938_32. 1938 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

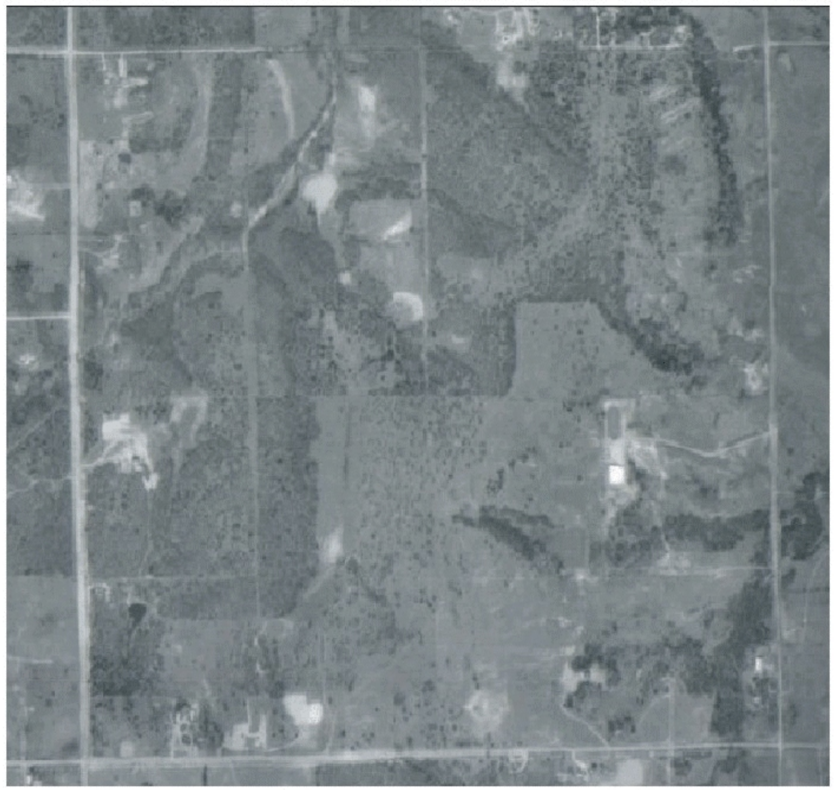
Photo 1969_32. 1969 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1979_32.   1979 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK

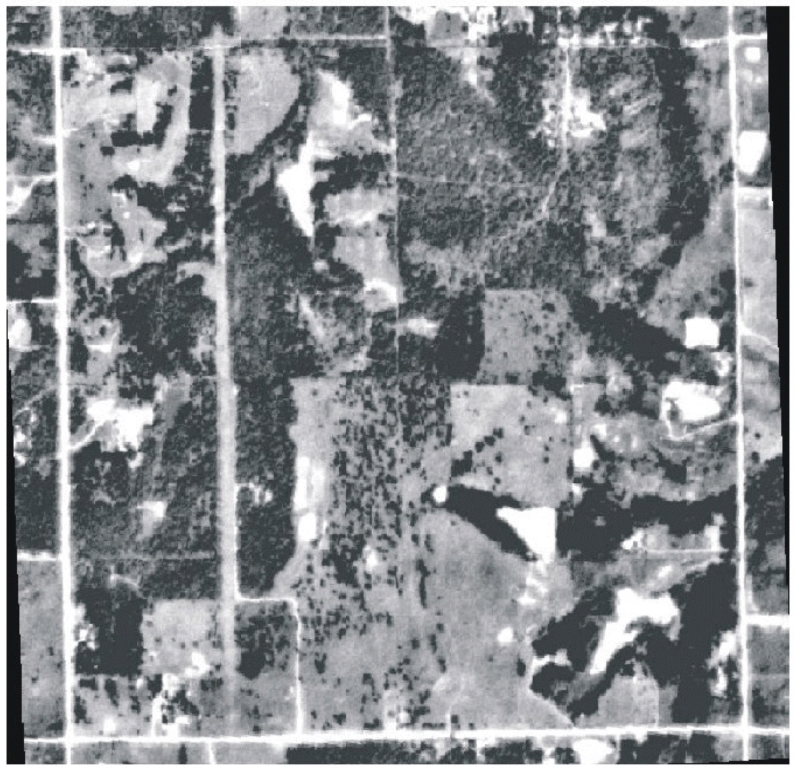


N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1989_32. 1989 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK



N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

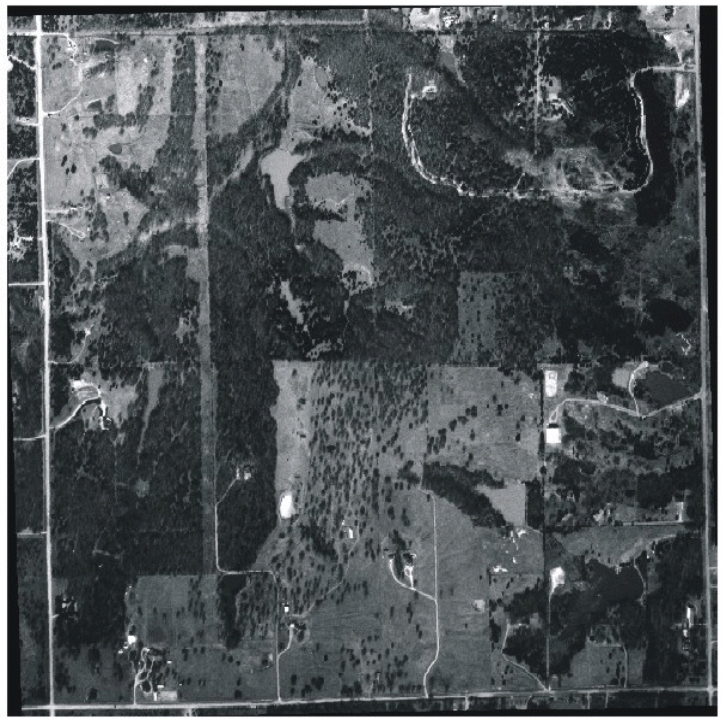
Photo 1995_32.   1995 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK

N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 1998_32. 1998 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK

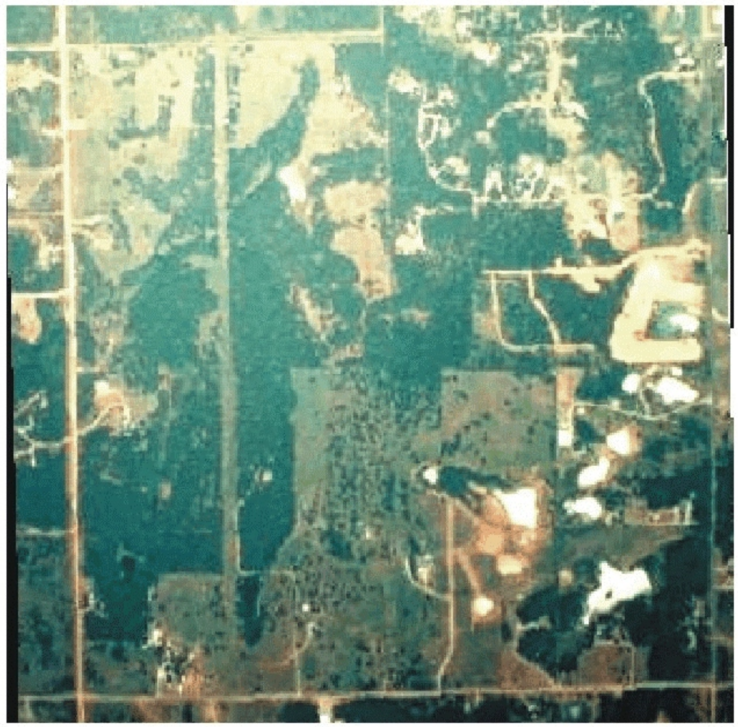


N

Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

Photo 2002_32. 2002 Color Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK



N

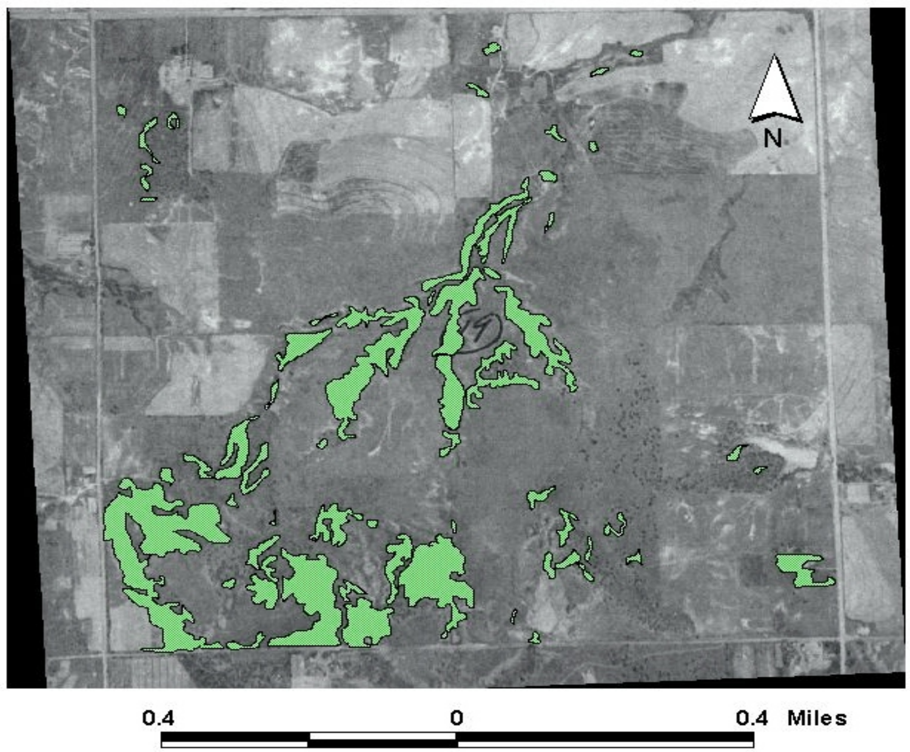
Scale: 1/12,000
Projection: UTM 83
Zone: 14

Source: USDA

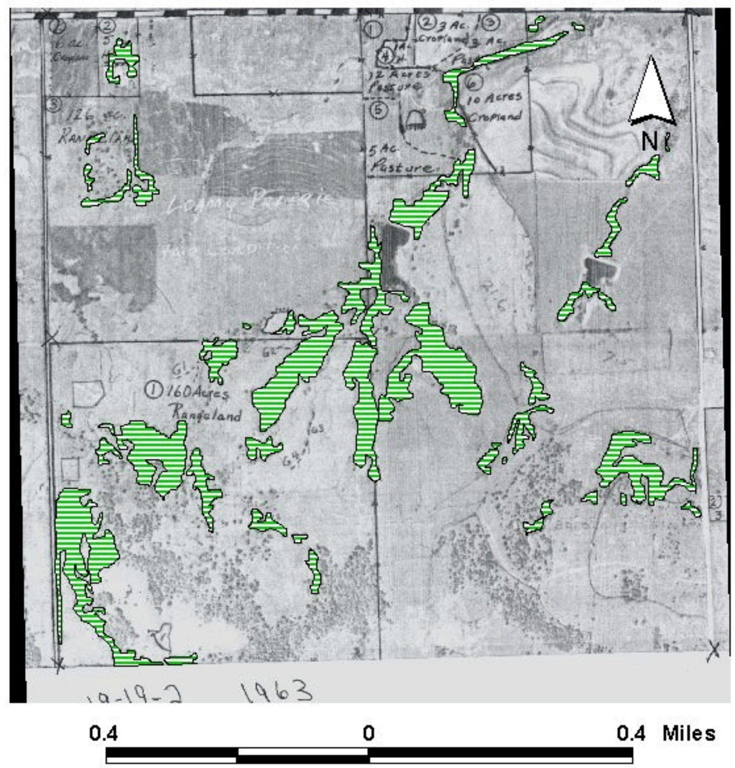
APPENDIX F

DIGITIZED URBAN FOREST POLYGON THEMES

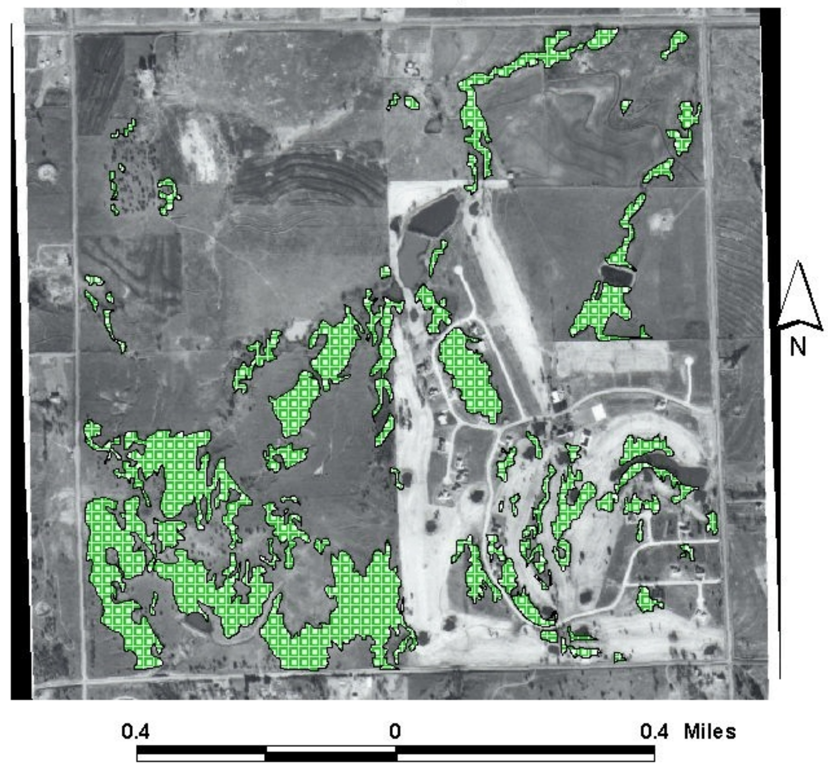
Theme 1938_19. Digitized Canopy Polygons for Section 19, 1938



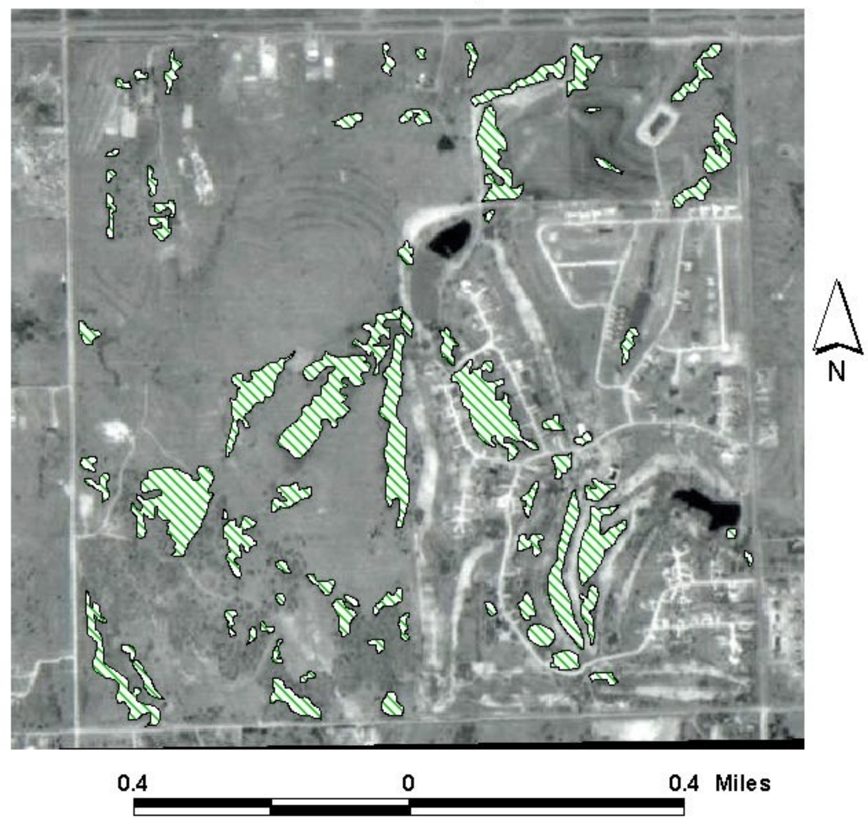
Theme 1963_19. Digitized Canopy Polygons for Section 19, 1963



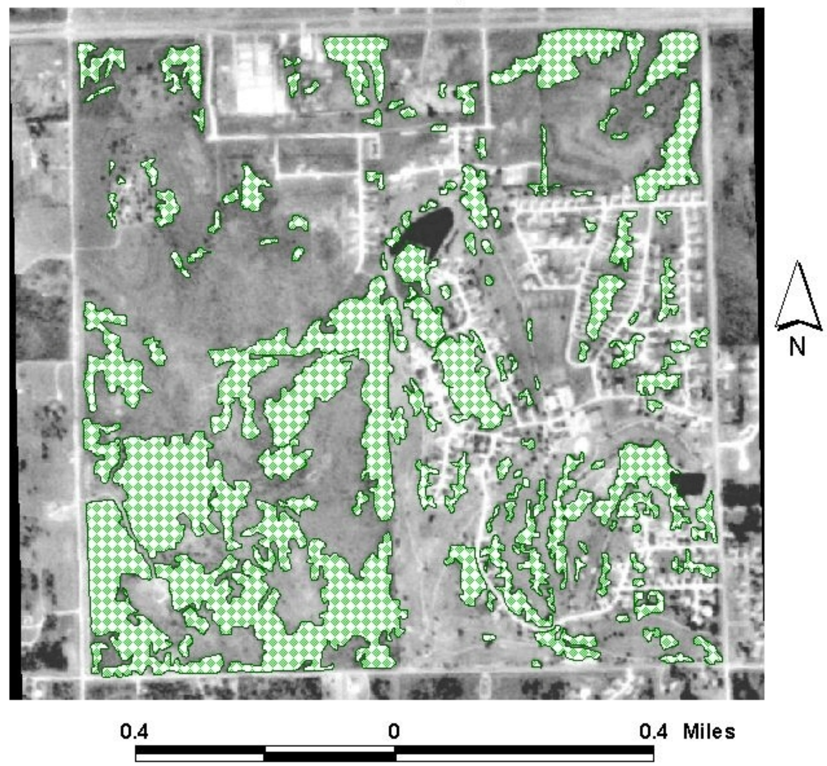
Theme 1969_19. Digitized Canopy Polygons for Section 19, 1969



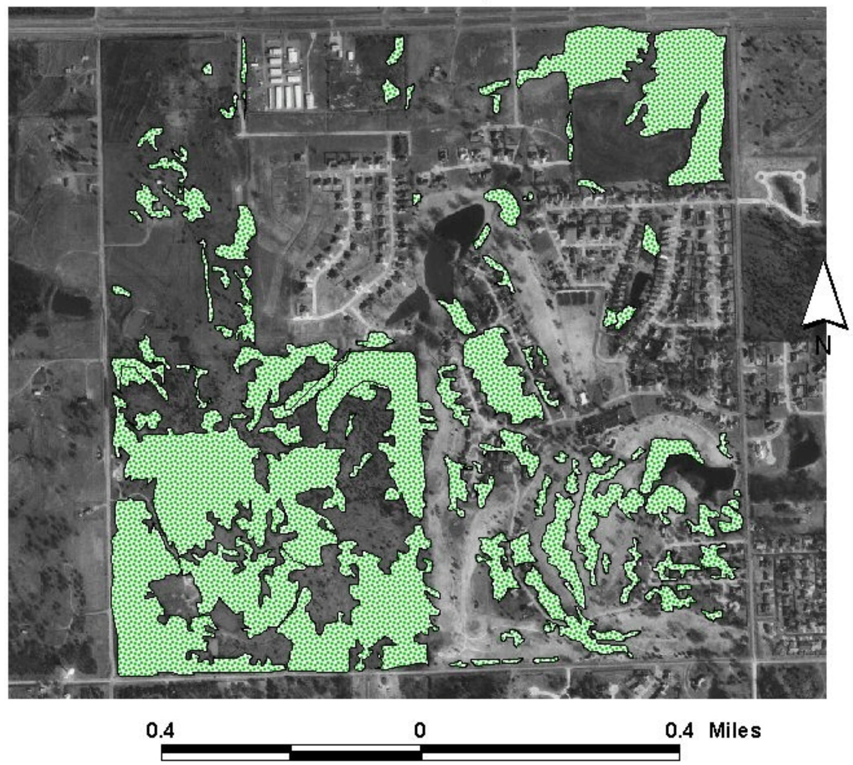
Theme 1979_19. Digitized Canopy Polygons for Section 19, 1979



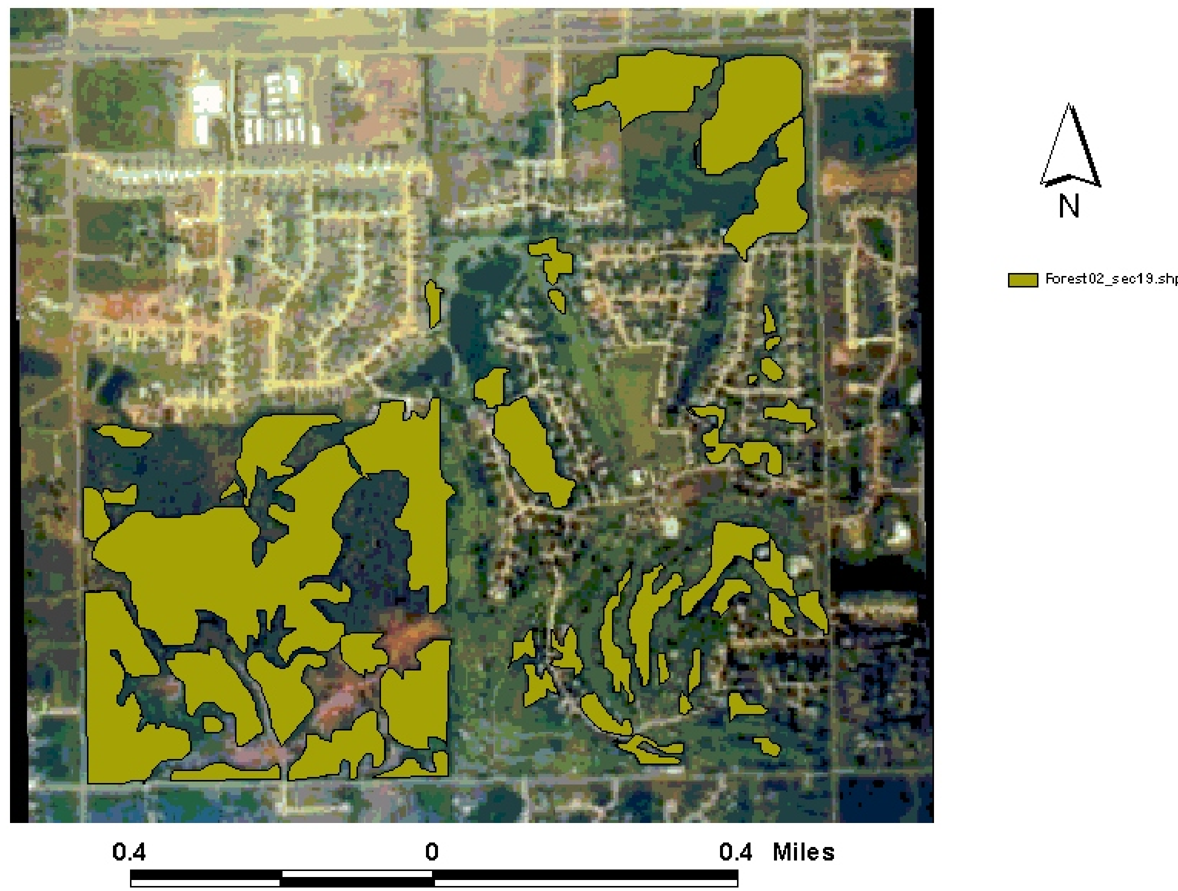
Theme 1989_19. Digitized Canopy Polygons for Section 19, 1989



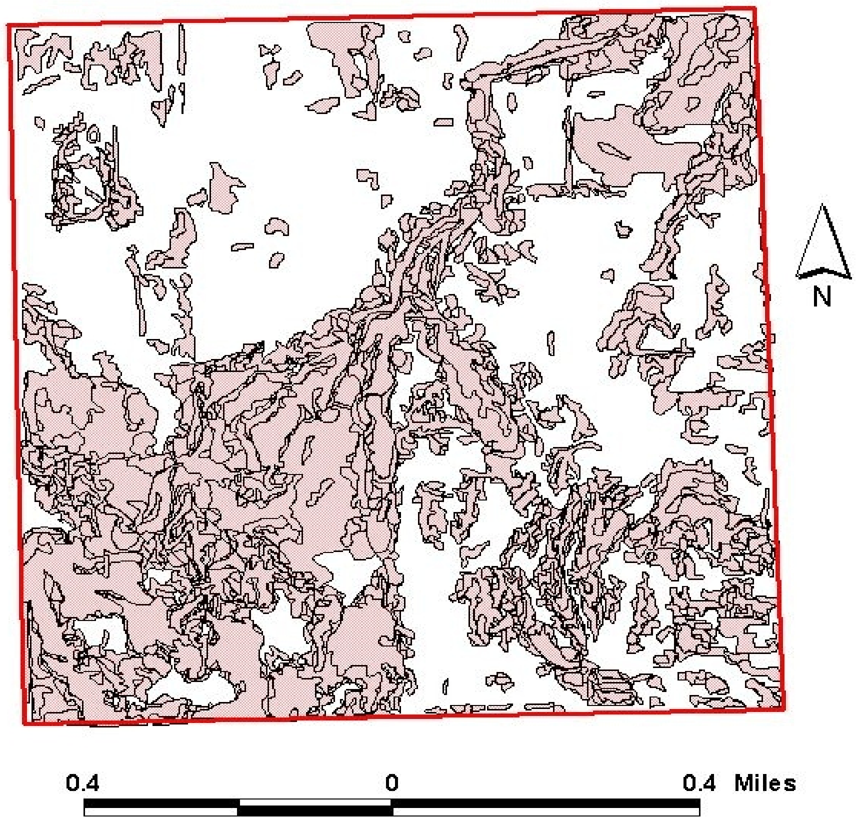
Theme 1995_19. Digitized Canopy Polygons for Section 19, 1995



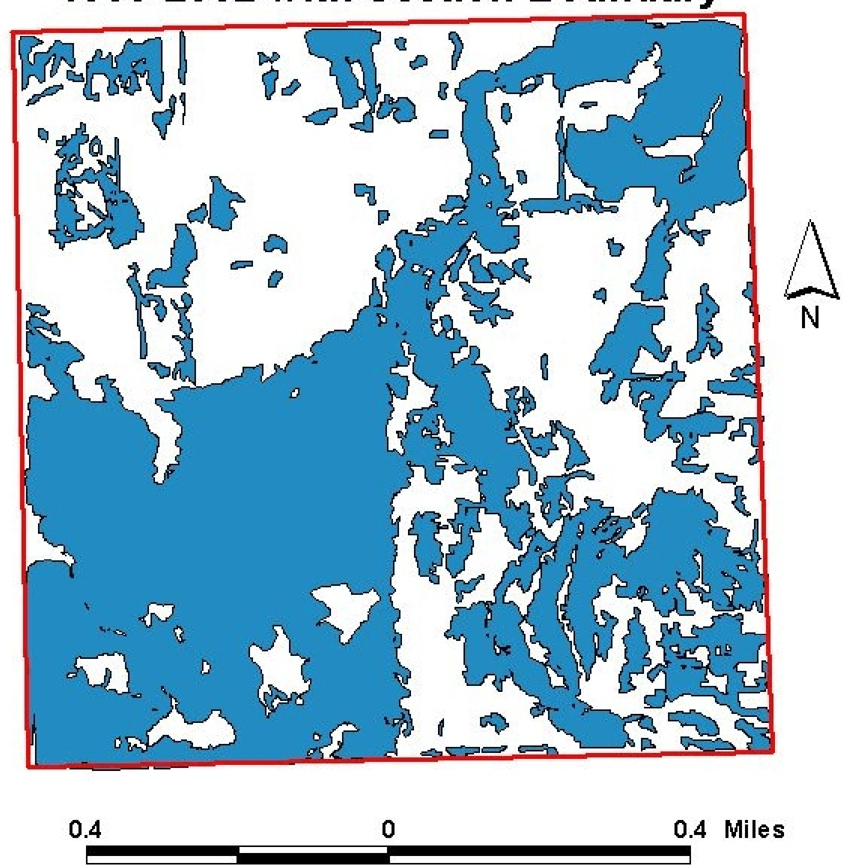
Theme 2002_19. Digitized Canopy Polygons
for Section 19, 2002



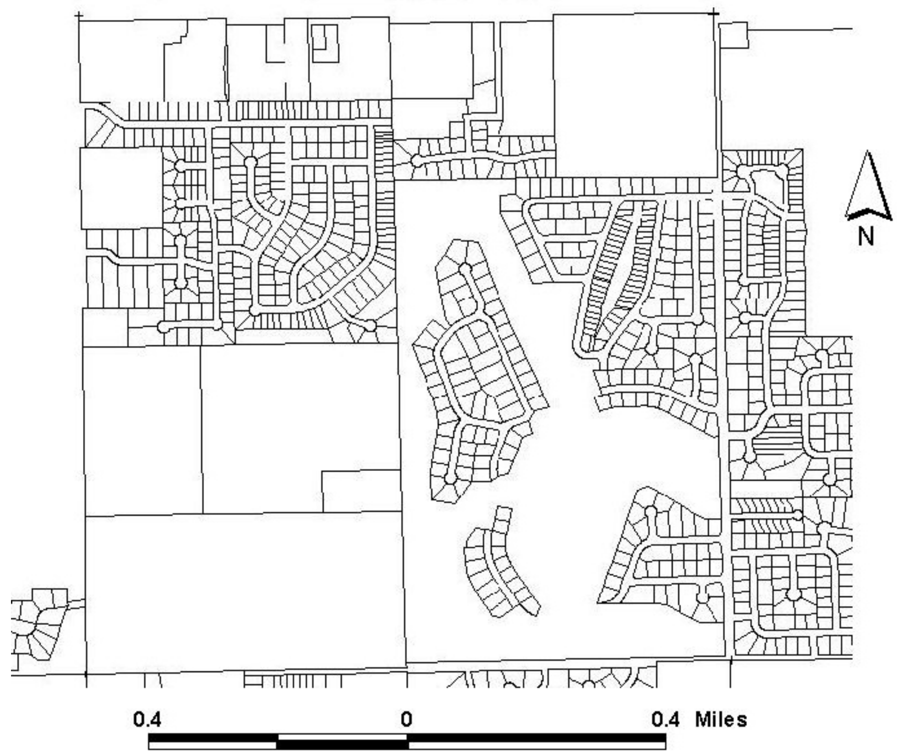
ThemeMerge_19. Merged Forest Polygons for Section 19 from Photo Years 1938-2002 with Section Boundary



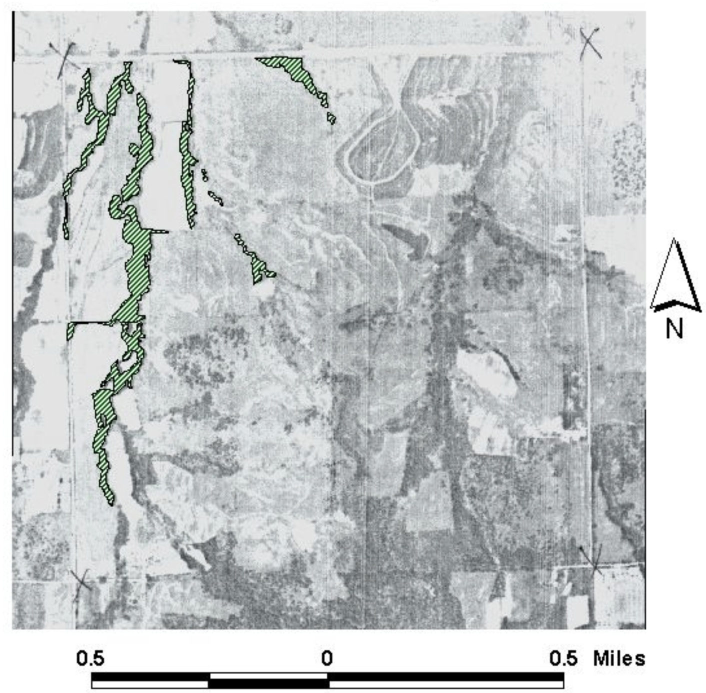
ThemeDissolve_19. Dissolve of Merged Forest Polygons for Section 19 from Photo Years 1938-2002 with Section Boundary



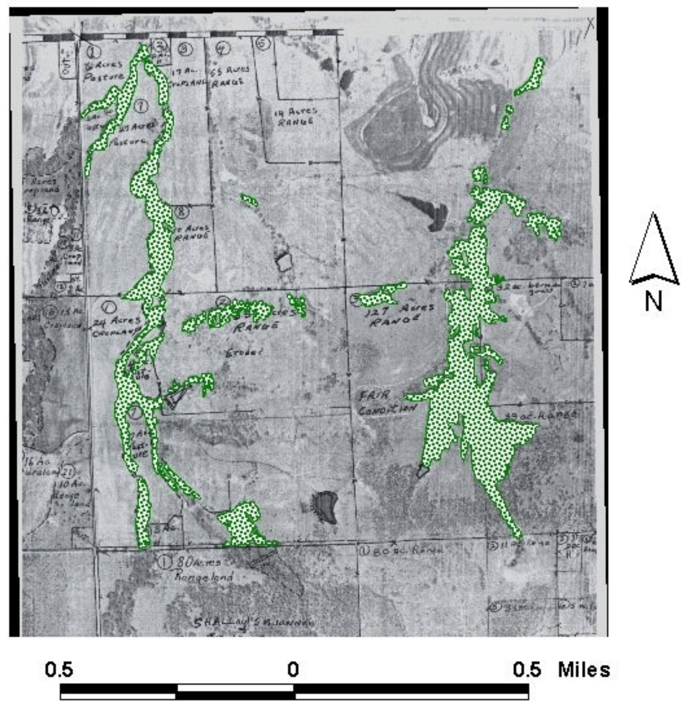
ThemeDensity_19. Digitized Property Lots for Section 19 in 2000



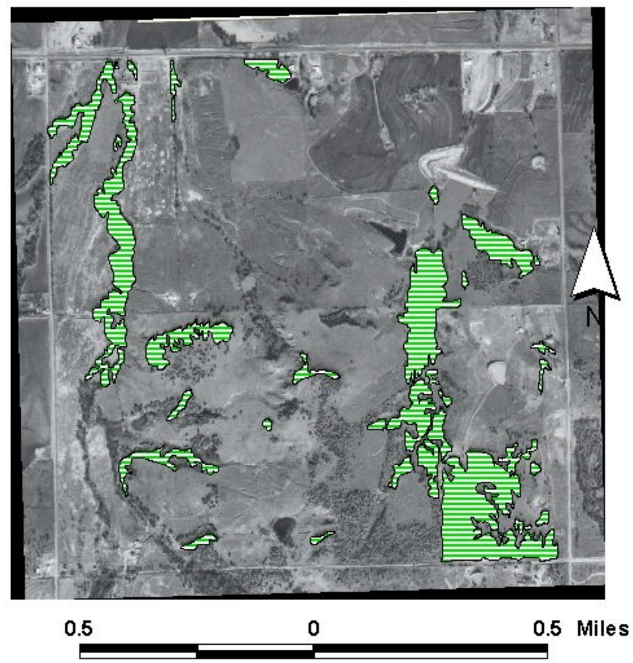
Theme 1949_24. Digitized Canopy Polygons for Section 24, 1949



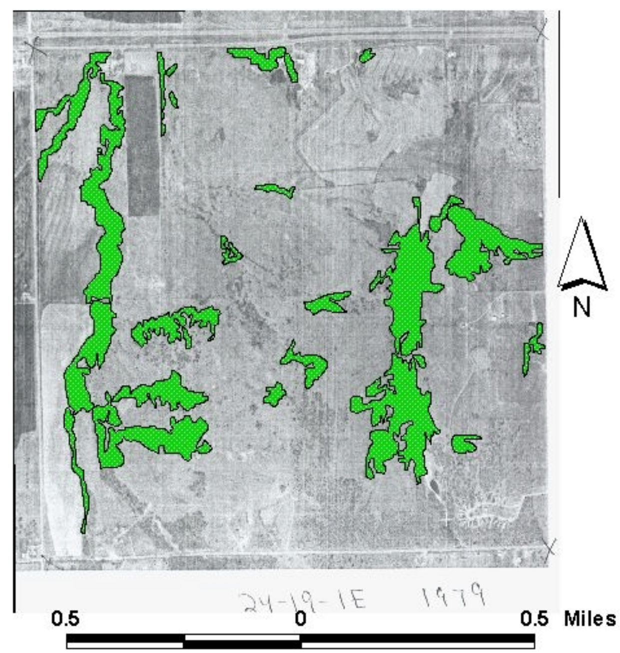
Theme 1963_24. Digitized Canopy Polygons for Section 24, 1963



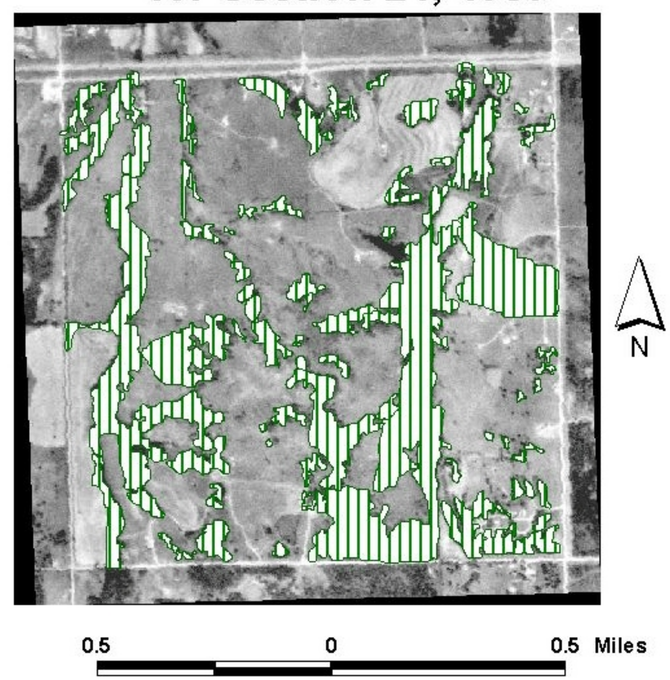
Theme 1969_24. Digitized Canopy Polygons for Section 24, 1969



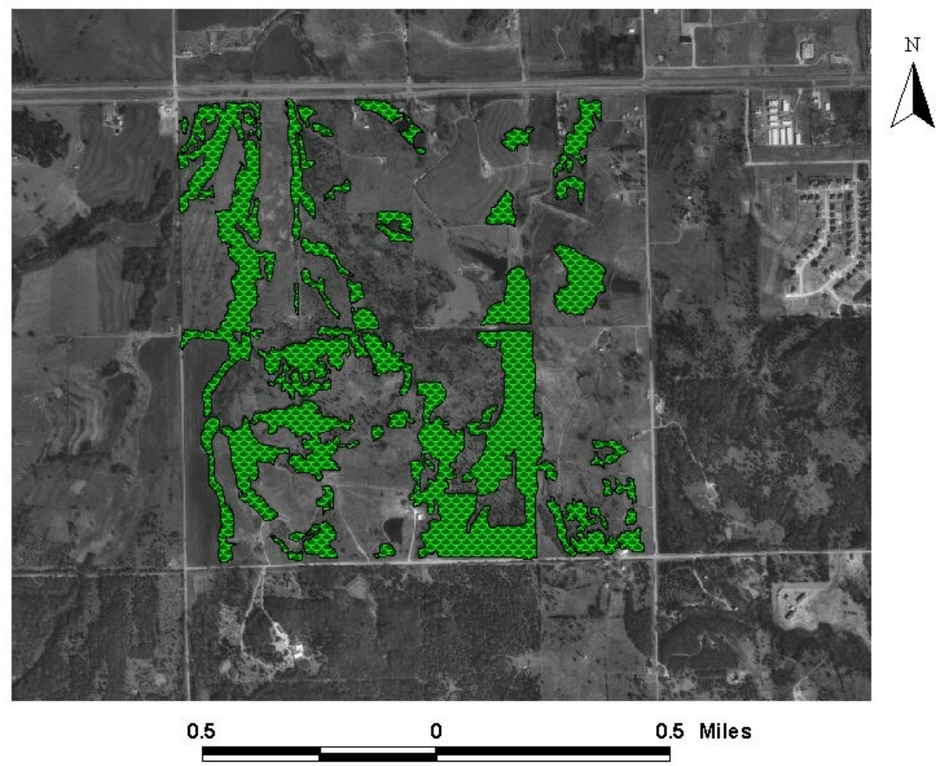
Theme 1979_24. Digitized Canopy Polygons for Section 24, 1979



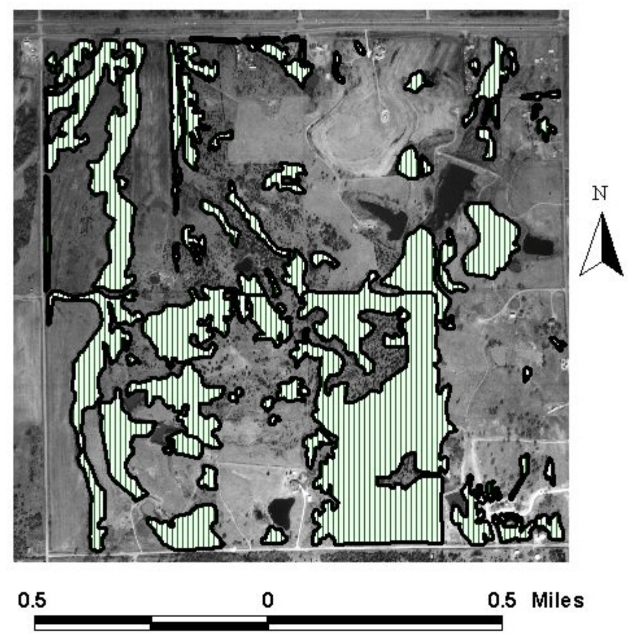
Theme 1989_24. Digitized Canopy Polygons for Section 24, 1989



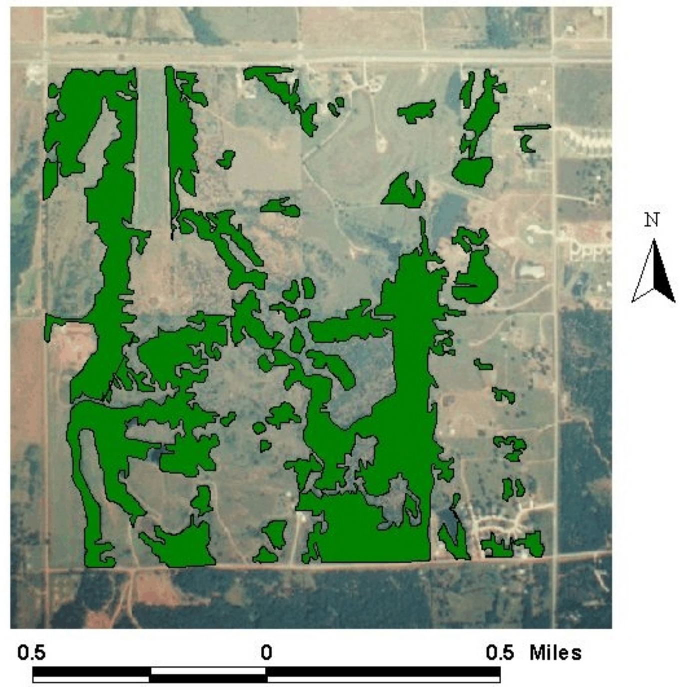
Theme 1995_24. Digitized Canopy Polygons for Section 24, 1995



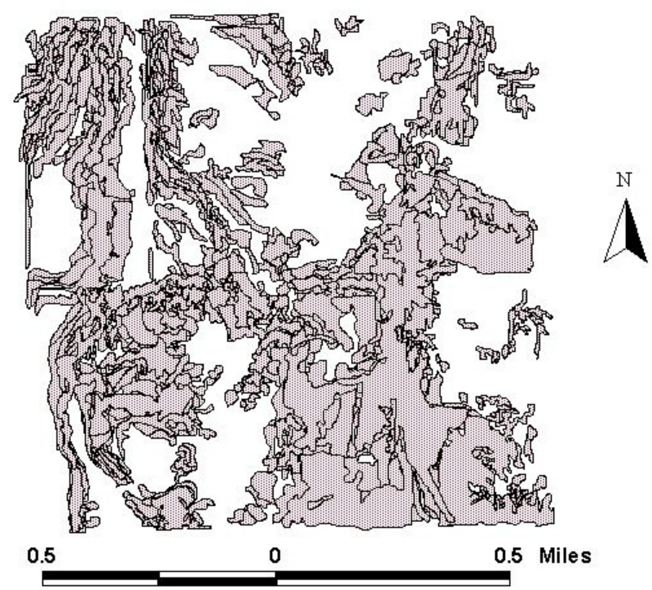
Theme 2000_24. Digitized Canopy Polygons for Section 24, 2000



Theme 2002_24. Digitized Canopy Polygons for Section 24, 2002



ThemeMerge24 Merge of Digitized Canopy Polygons for Section 24, Photo Years 1949-2002



ThemeDissolve24 Dissolve of Merged Canopy Polygons for Section 24, Photo Years 1949-2002

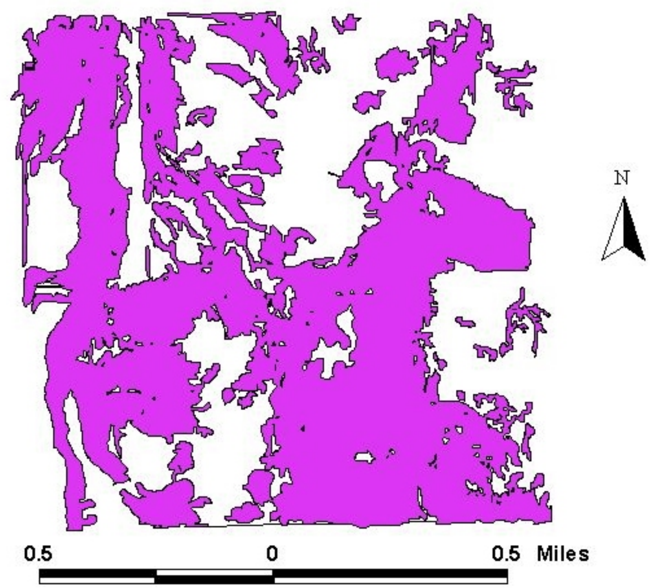
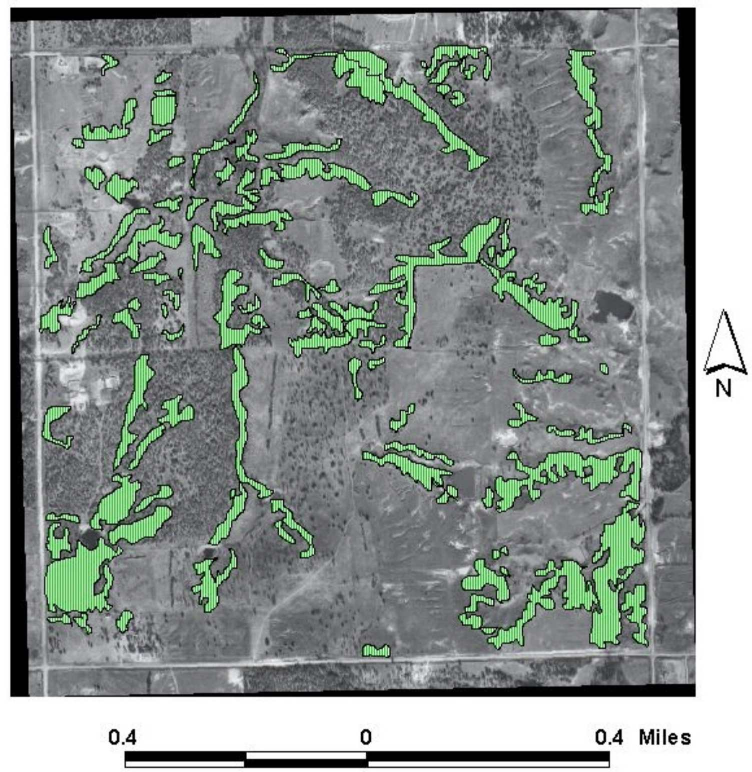
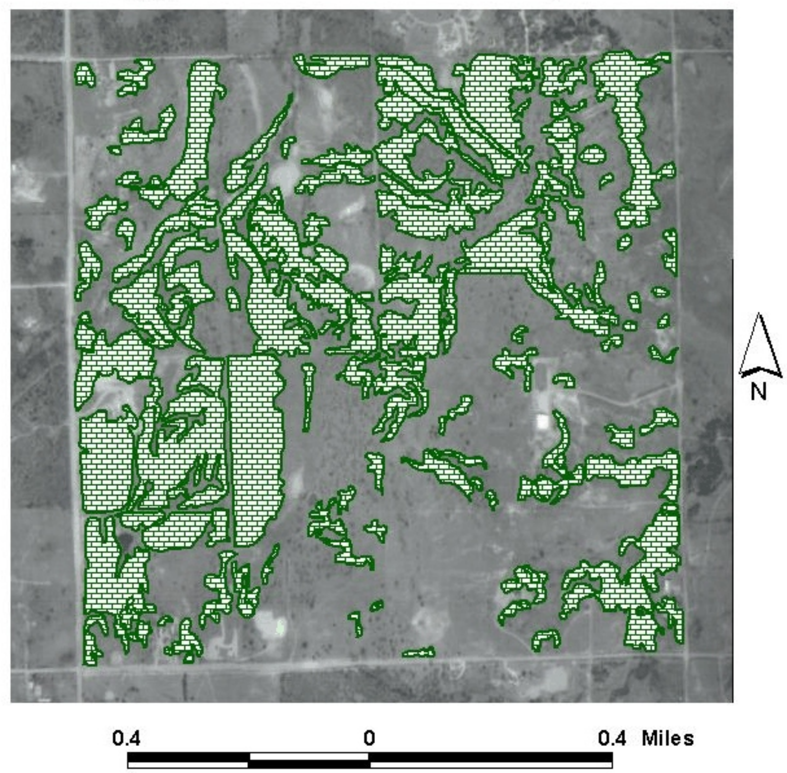


Photo 1938_32. 1938 B&W Aerial Photo of Section 32, R2E, T19N, in Stillwater, OK

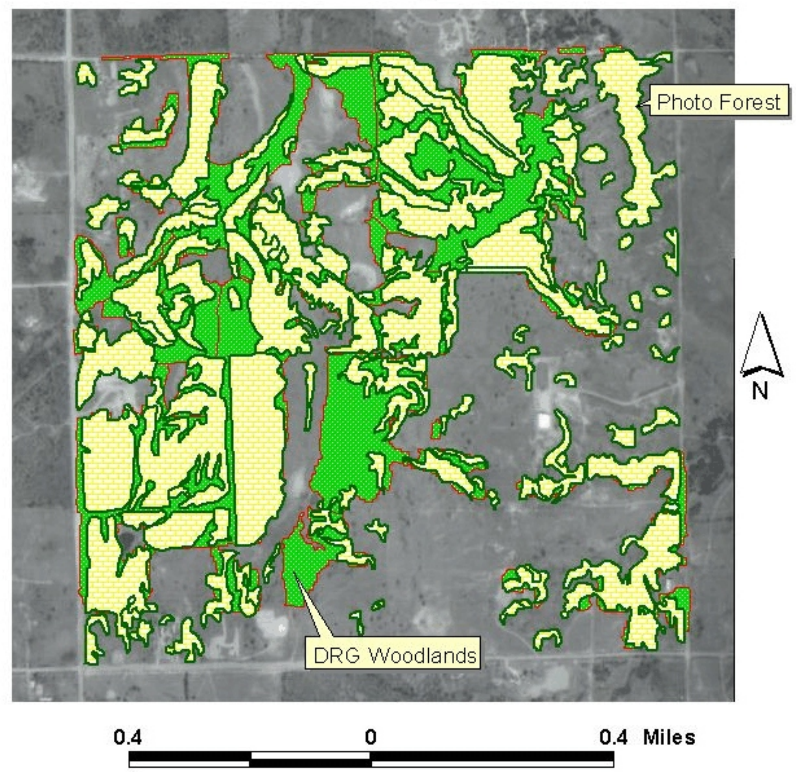
Theme 1969_32. Digitized Canopy Polygons for Section 32, 1969



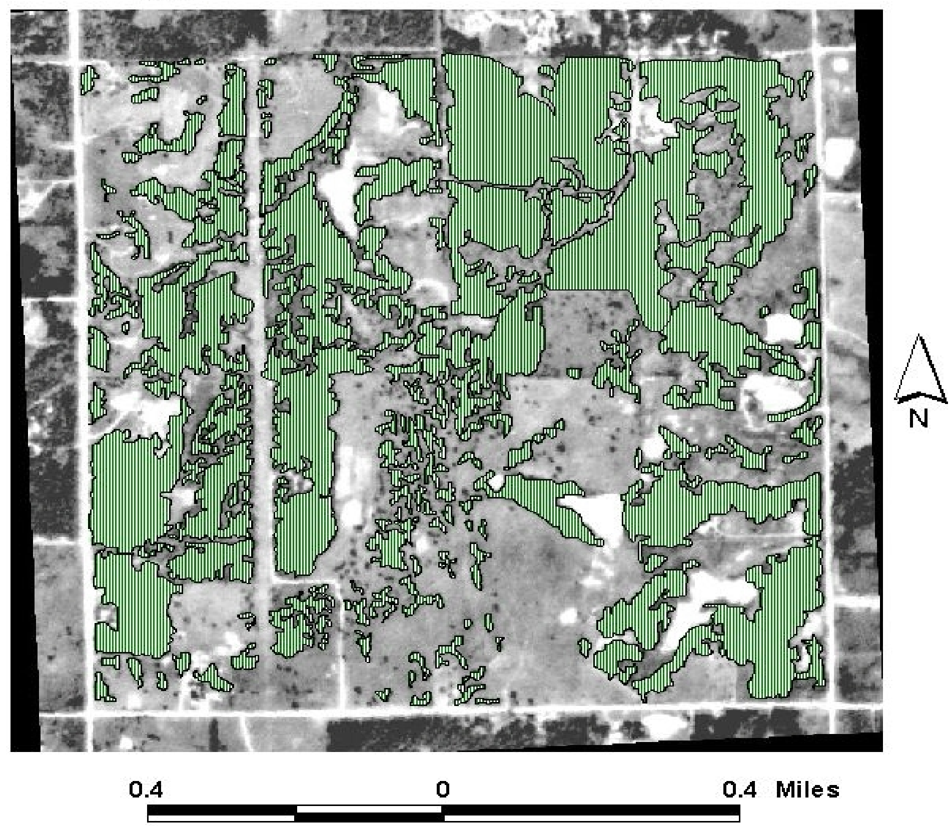
Theme 1979_32a. Digitized Canopy Polygons for Section 32, 1979



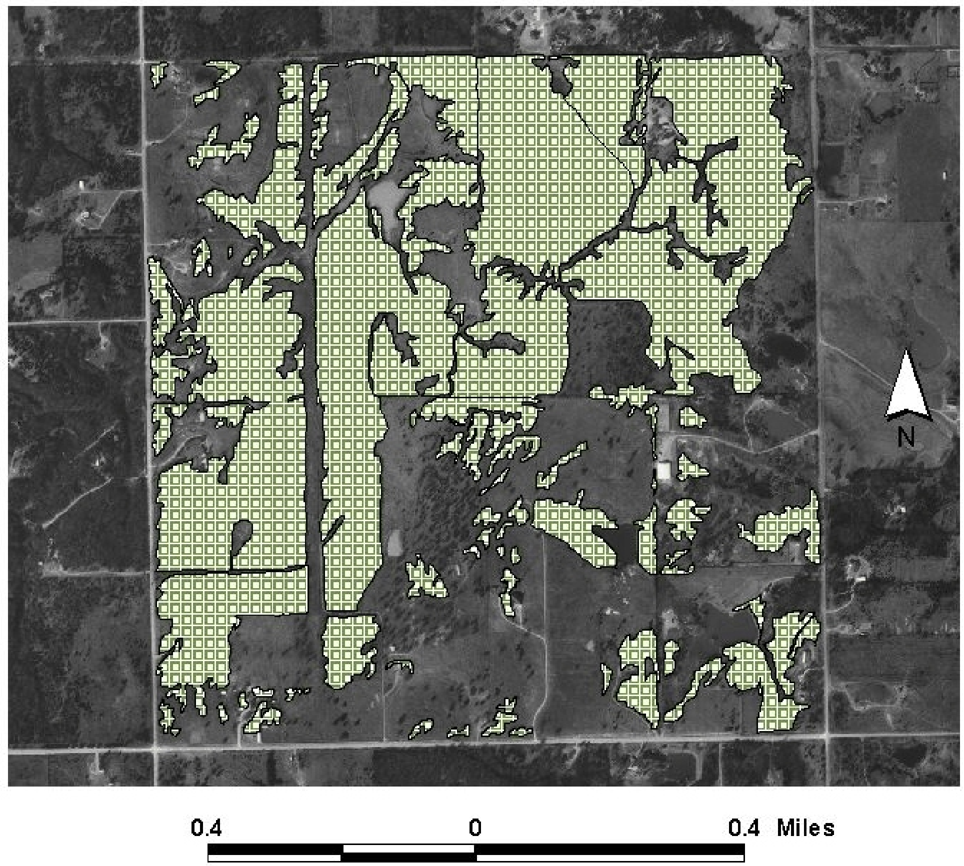
Theme 1979_32b. "DRG vs Photo" DigitizedCanopy Polygons for Section 32, 1979



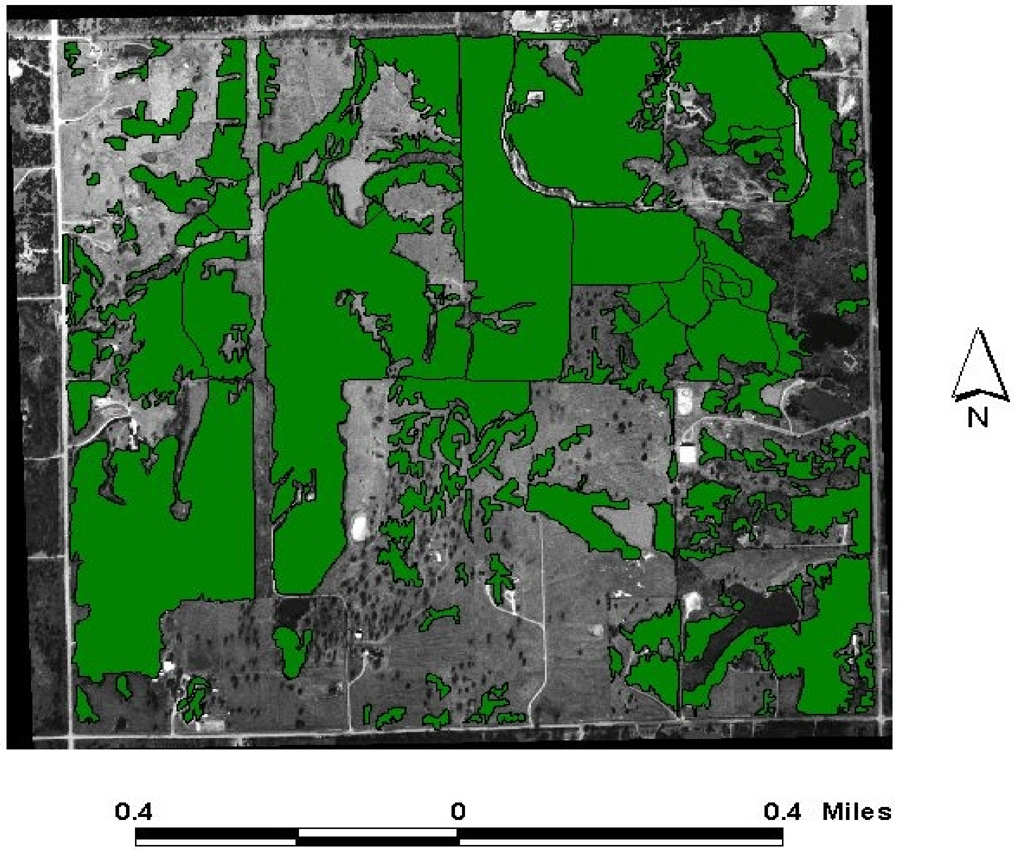
Theme 1989_32. Digitized Canopy Polygons for Section 32, 1989



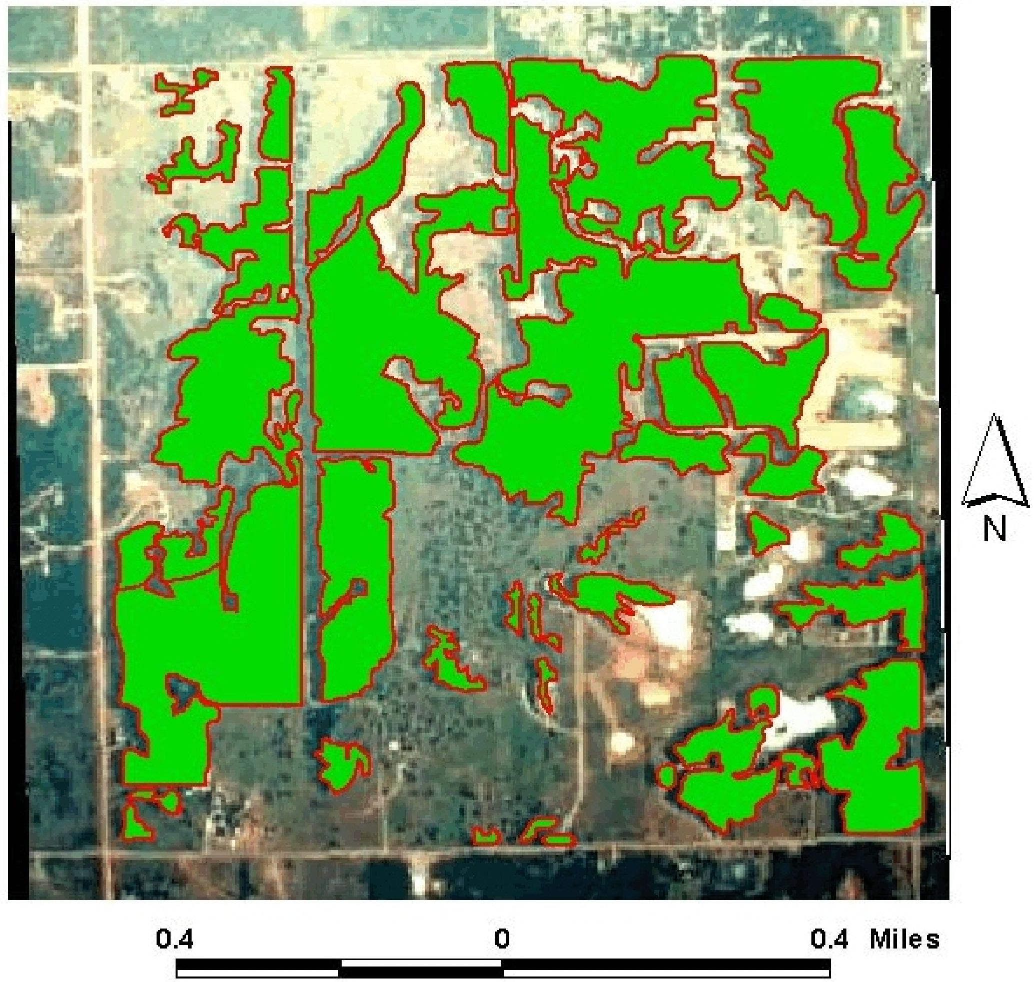
Theme 1995_32. Digitized Canopy Polygons for Section 32, 1995



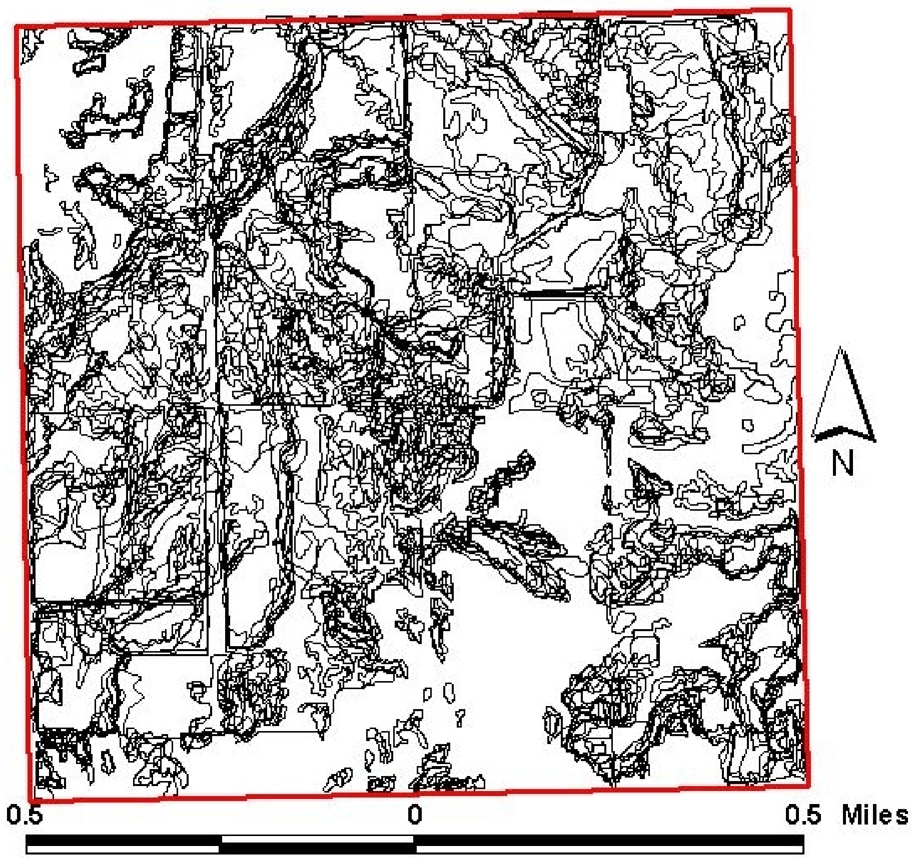
Theme 1998_32. Digitized Canopy Polygons for Section 32, 1998



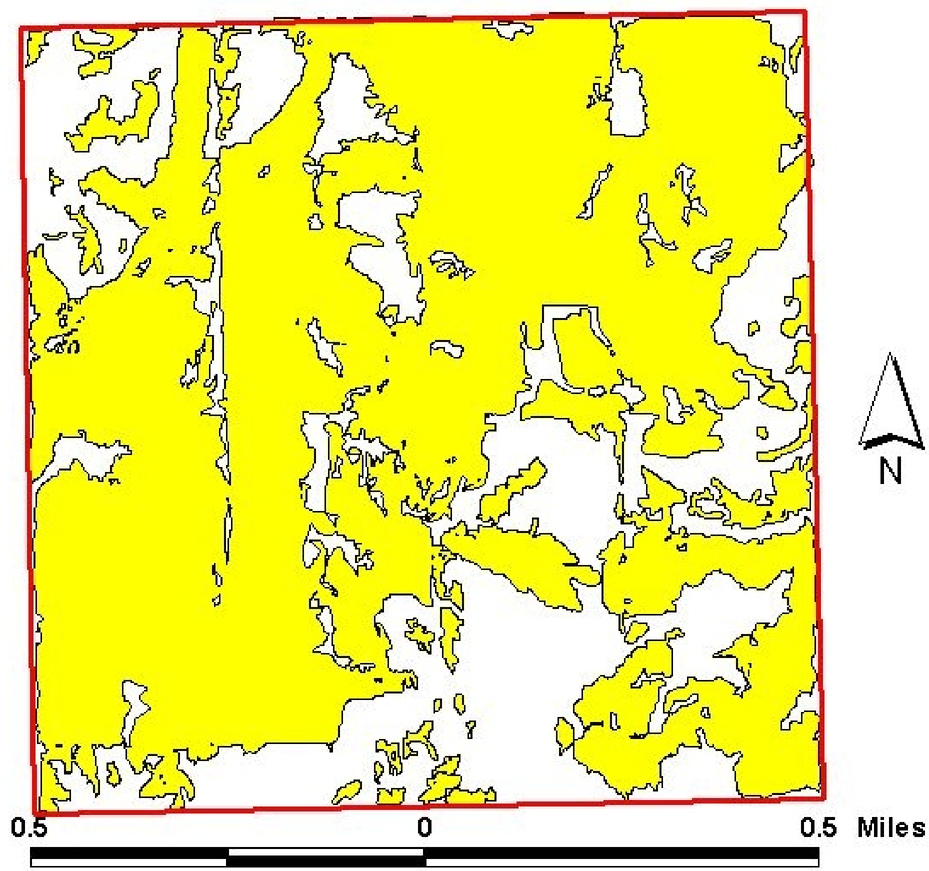
Theme 2002_32. Digitized Canopy Polygons for Section 32, 2002



ThemeMerge_32. Merge of Digitized Canopy Polygons for Section 32, Photo Years 1938-2002



ThemeDissolve_32. Dissolve of Merged Canopy Polygons for Section 32, Photo Years 1938-2002

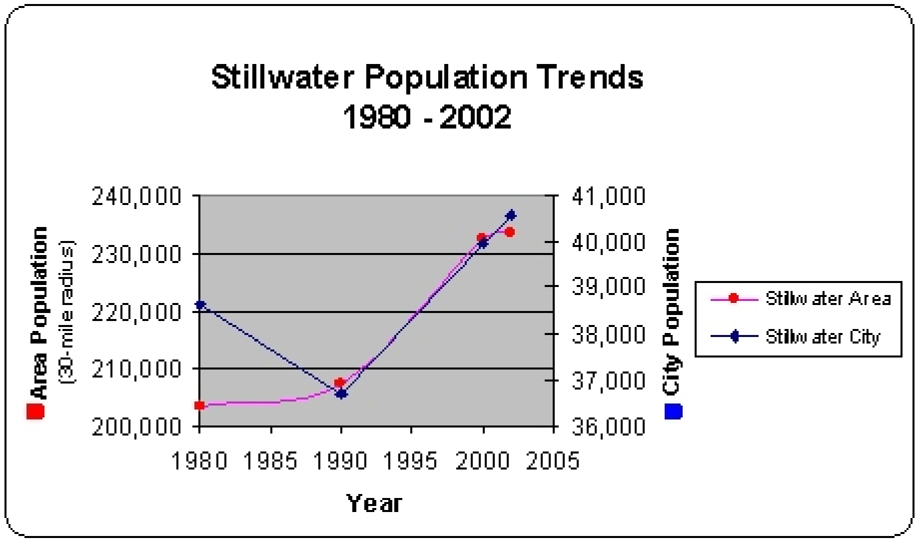


Theme GPS_32. Ground-Truthing with Trees as GCPs for NE of Section 32, 2002

APPENDIX G

CHARTS

Chart 1.



Source data from Stillwater, Oklahoma, Chamber of Commerce, 2004

Chart 2.

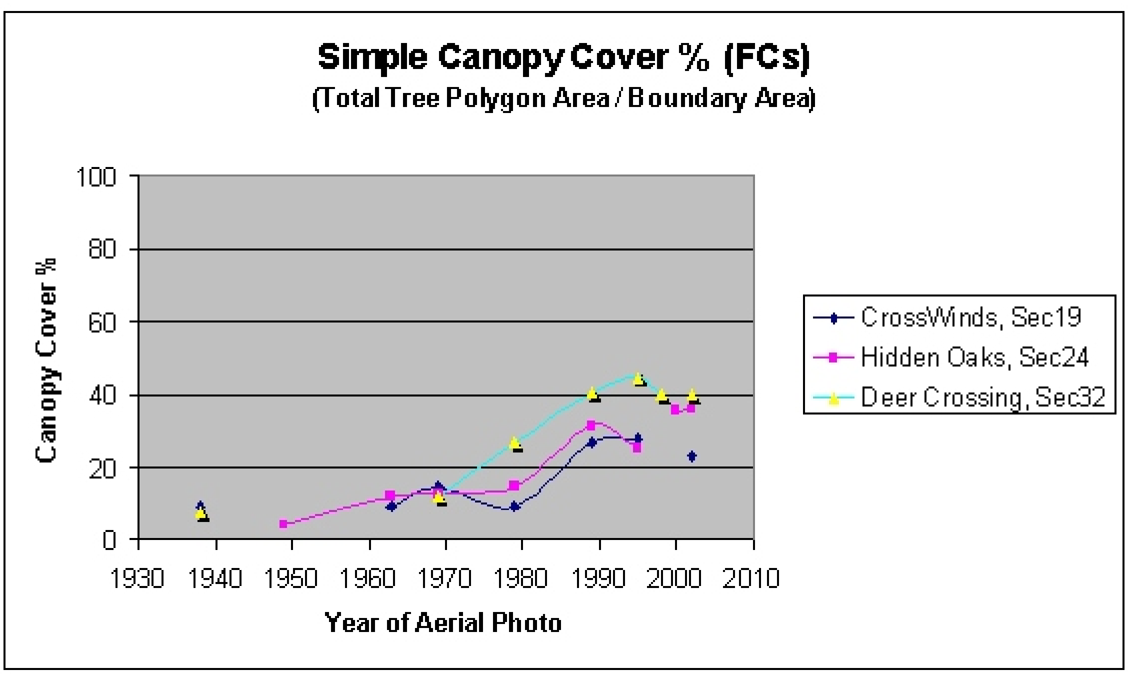


Chart 3.

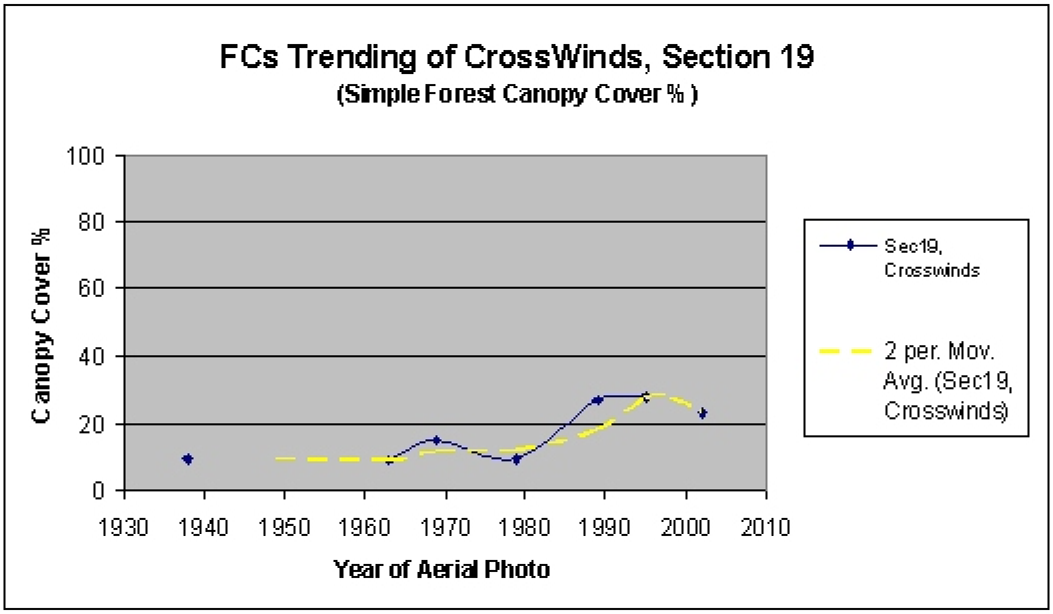


Chart 4.

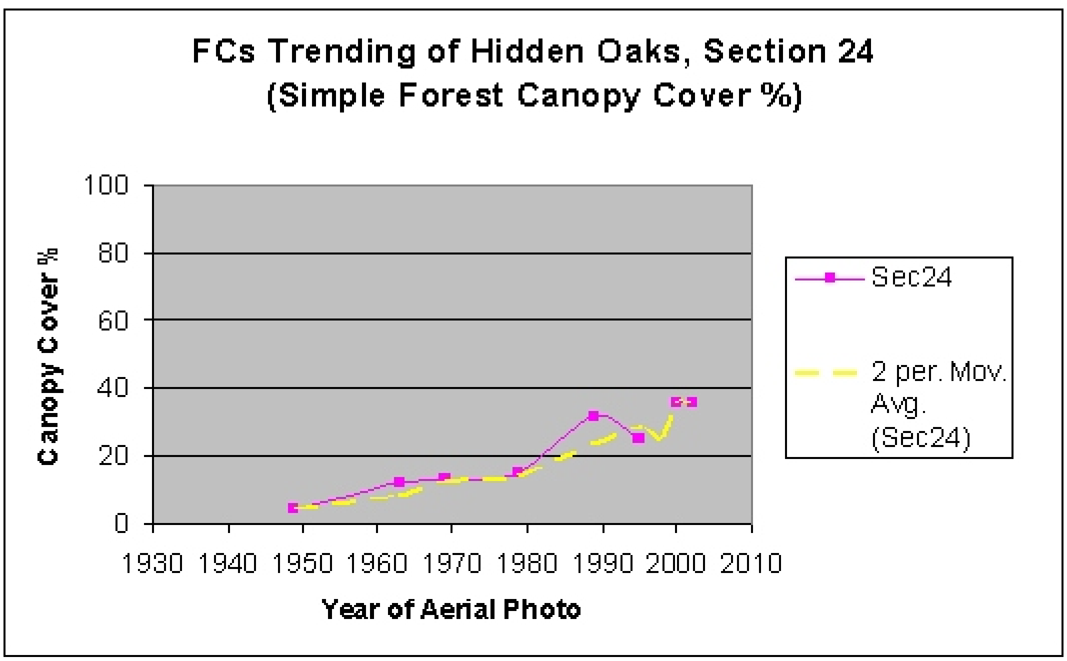


Chart 5.

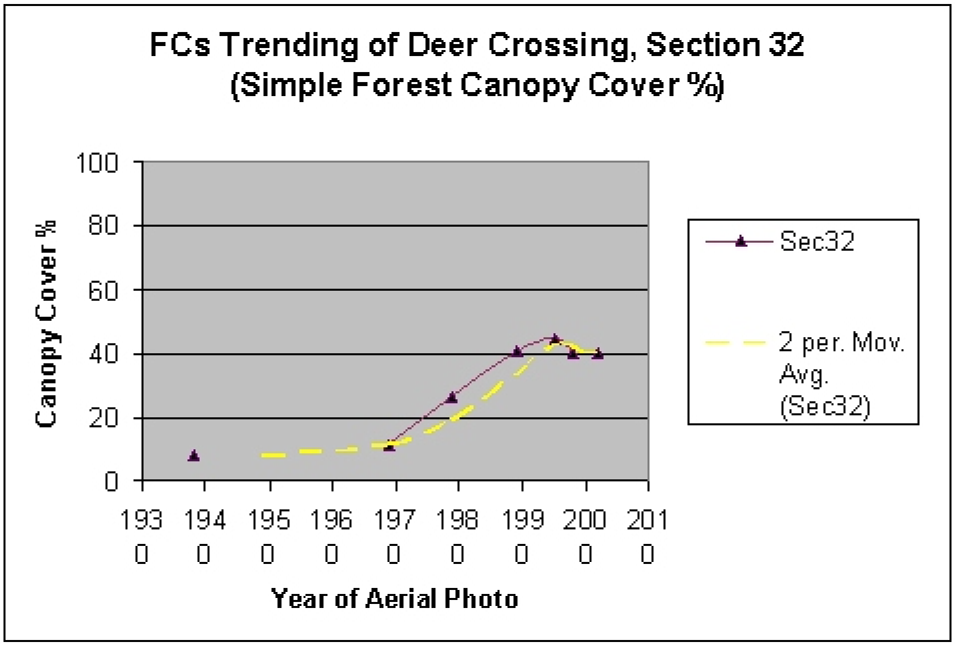
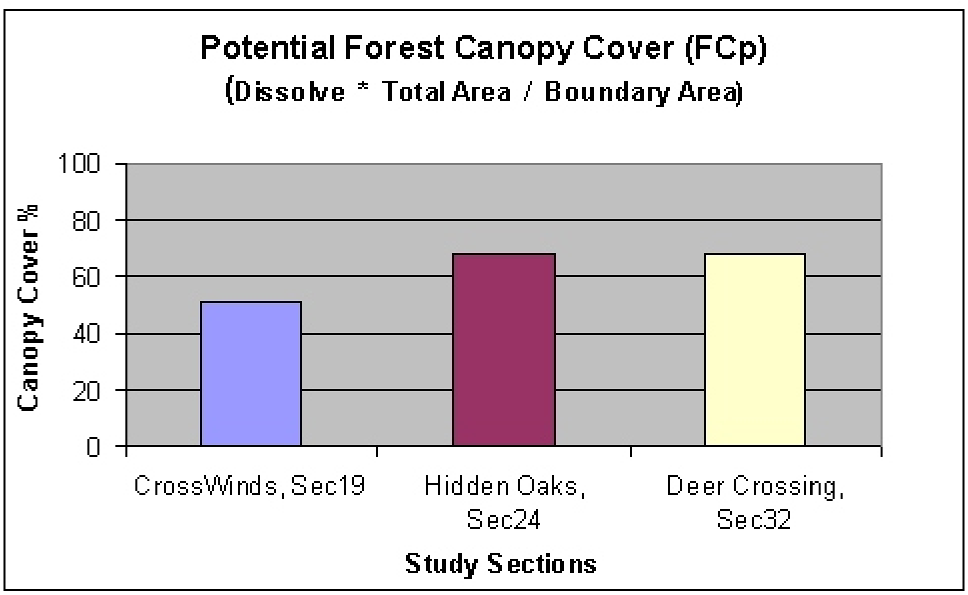


Chart 6.



*** dissolve** - - > in each section, multi-year forest polygons are stacked to yield a combined, single polygon theme with a measured area

Chart 7.

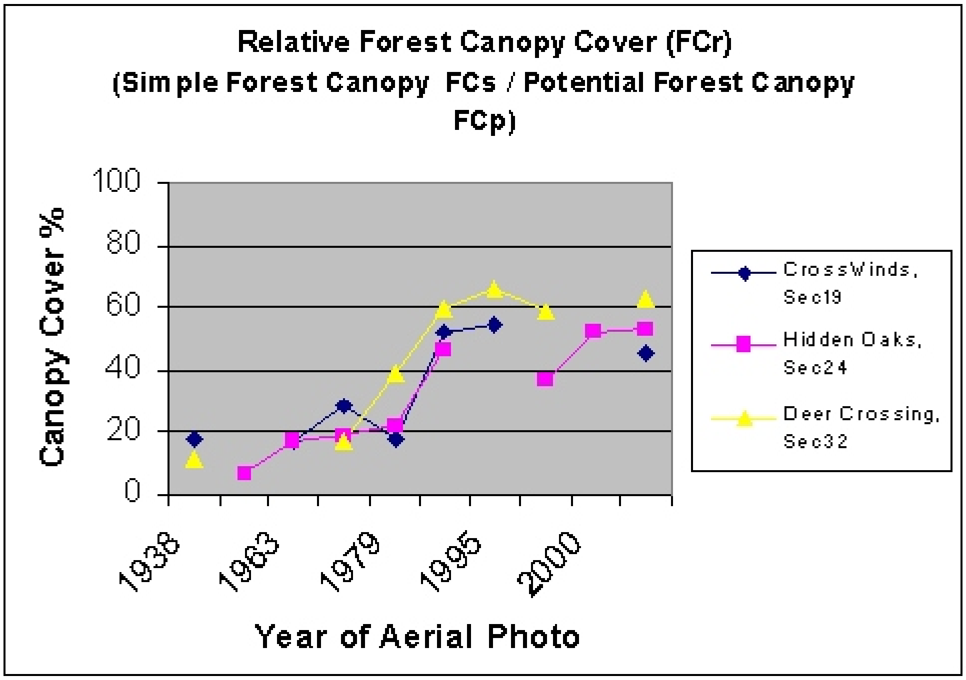


Chart 8.

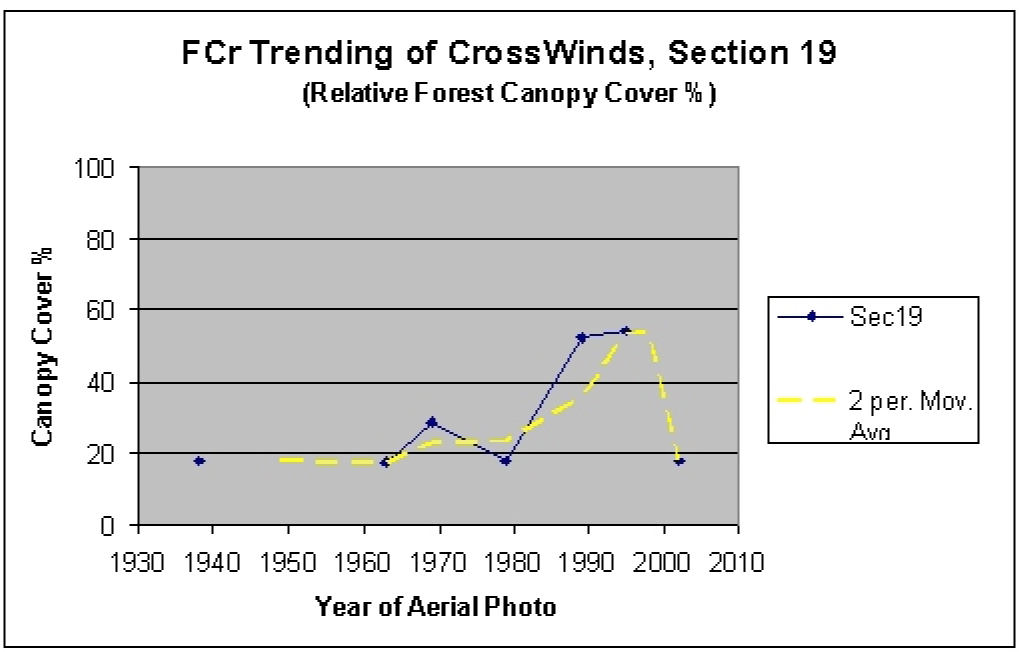


Chart 9.

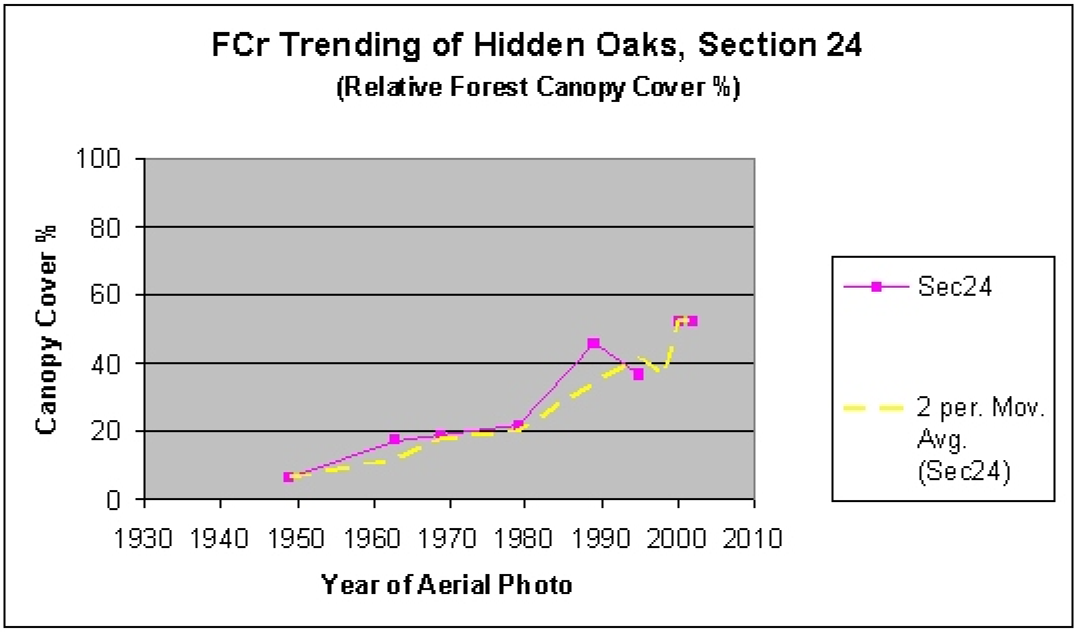
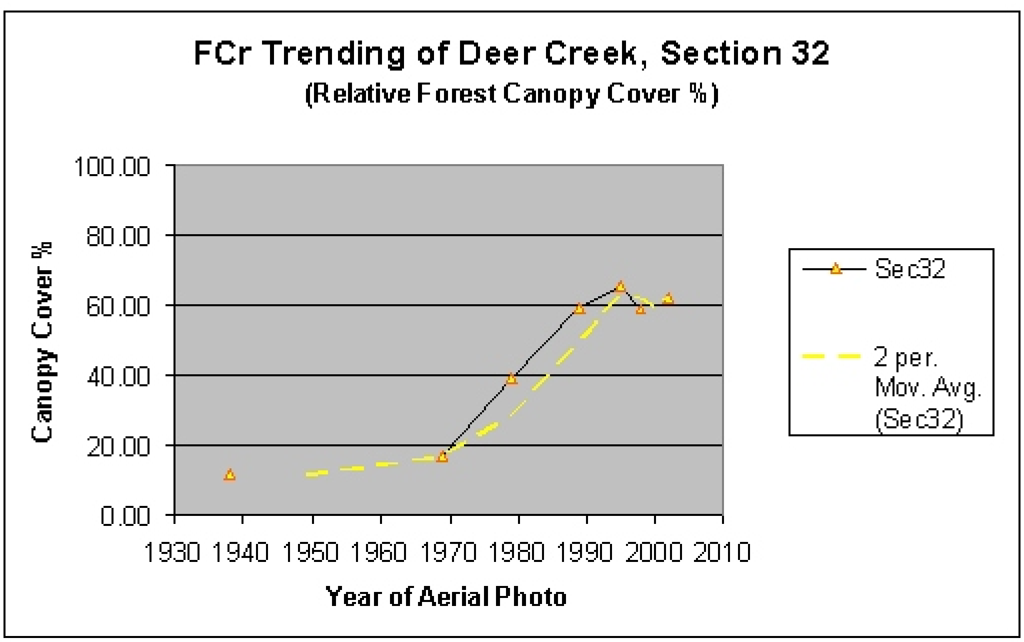


Chart 10.



VITA

Rosa Maria Abbott

Candidate for the Degree of

Master of Science

Thesis: TEMPORAL ASSESSMENT OF URBAN FOREST PATCH DYNAMICS USING MEDIUM SCALE AERIAL Photography AND GIS

Major Field: Forest Resources

Biographical:

Education: Graduated from Brownsville High School, Brownsville, Texas, in 1972; attended Laredo Junior College, Laredo, Texas, 1974 to 1976 and received an Associate Degree in Nursing; attended Southern Illinois University at Edwardsville, Edwardsville, Illinois, 1982 to 1986, and received a Bachelor of Science in Nursing; attended Oklahoma State University, Stillwater, Oklahoma, 1996 to 2000 and received a Bachelor of Science in Forest Resources; completed the requirements for the Master of Science degree with a major in Forest Resources at Oklahoma State University in December 2004.

Experience: Employed as a registered nurse at hospitals in Texas, Missouri, Hawaii, Oklahoma, and Arkansas, primarily in Critical Care Nursing. Served in the United States Air Force on active duty from 1977 to 1986, then in the United States Air Force Reserve from 1986 to 1988, and was stationed in Texas, Illinois, and the Azores, Portugal. Employed by Oklahoma State University, Department of Forestry, as a graduate research assistant; by the Department of Zoology, as a graduate and teaching assistant; and by the Distance Learning Center as a Spanish teaching assistant. Currently serving in the United States Naval Reserve, stationed at Naval Reserve Naval Hospital Pensacola Detachment J in Little Rock, Arkansas; working as a civilian Critical Care Nurse at a hospital in Little Rock, Arkansas; and enrolled in studies as a Doctoral Student at the University of Arkansas Medical Sciences College of Nursing.

Professional Memberships: American Association of Critical Care Nurses (AACN), Society of American Foresters (SAF), Society for the Advancement of Chicanos and Native Americans in Science (SACNAS).