ASSESSMENT OF BLACK LOCUST ON THE BLACK KETTLE NATIONAL GRASSLANDS

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CHAPTER I

INTRODUCTION

The expansion of woody species in savannah and savannah-like ecosystems has greatly increased in the last several decades and has become a worldwide issue (Hudak and Wessman, 2001; Wu and Archer, 2005). These ecosystems are characterized by large areas of open grasslands with a few heterogeneously spaced patches of woody plants often existing in bottomlands, gullies, and along stream banks. The phenomenon of woody species proliferating into an area previously occupied by herbaceous plant species is known as woody encroachment. Woody refers to plants that contain hard lignified tissue mostly consisting of trees and shrubs. Herbaceous is a plant that does not contain woody tissue and will connote grasses and sedges. Woody encroachment occurs when conditions or resources become better suited for woody plants which then out compete and reduce the abundance of herbaceous plants; or a disturbance reduces herbaceous biomass allowing for woody plants to utilize resources previously used by grasses. Encroachment is often associated with alien or introduced plant species, but also may occur with plant species that are considered to be indigenous (Van Auken, 2000).

The transition to woody plants can potentially alter the function of a savanna or grassland ecosystem. Woody encroachment may lead to the displacement of wildlife species that depend on open grasslands, decrease species diversity, disrupt natural disturbance regimes, alter water/energy cycles, and reduce amount of grazing lands available for livestock (Laliberte, 2004). Woody encroachment within mixed grass prairie has led to a decline in grassland bird populations and increased bird species associated with shrub and woodlands (Chapman *et al,* 2004).

Shifts in vegetation types at a landscape scale are caused by several different factors, either natural or anthropogenic, but the causes and their effects may vary by region and species of concern. Climate change, application or suppression of disturbances, historic or current land use, or a combination of any of these can lead to shifts in vegetation. Causes of woody encroachment have been subject to considerable research in the last decade. Numerous studies have taken place in attempts to quantify the change from herbaceous to woody plant cover and determine causes for this change. Studies include invasions of *Juniperus virginianus* in tall grass ecotones in Nebraska, Kansas, Missouri, Oklahoma, and Texas (Chapman *et al,* 2004; Drake and Todd, 2002; Huggins, 2006); bush encroachment in African savannahs usually focused on species of Acacia (Hudak and Wessman, 2001; Knoop and Walker, 1985); mesquite encroachment in Texas, New Mexico, and Arizona (Jurena and Archer, 2003; Laliberte *et al*, 2004; Kepner *et al*, 2000). Each of these scenarios is somewhat different, but combinations of fire suppression and overgrazing by livestock are held responsible.

Remote sensing combined with GIS analysis has been established as one of the most effective ways to study shifts in land cover change such as the conversion of grasslands to forests and has been used in many parts of the world to analyze woody encroachment (Kepner *et al*, 2000; Hudak and Wessman, 2001; Laliberte *et al*, 2004). Remotely sensed data can be used to quantify land cover change by comparing sequential aerial photographs or satellite images. This information is also used to interpolate vegetation distribution patterns from one observation date to the next and project future distributions (Petit *et al*, 2001).

Study Area

The Black Kettle National Grasslands consists of 12,545 non-conterminous hectares (31,300 acres) mostly dispersed around western Roger Mills County in western Oklahoma. Each separate plot of land of varying area is referred to as a unit. This region is described as rolling hills of mixed grass prairie with an average rainfall of 63.5 cm/yr and an elevation above sea level ranging from 518 – 793 m. Average daily temperature ranges from 3º C in January to 28º C in July. The soils of the eastern portion of Black Kettle are characterized by loamy soils and the western portion as deep sand (Smith, 1998).

The National Grasslands were established in response to abandoned and eroded farmland in the 1930's due to Dust Bowl conditions and poor land management practices. The National Industrial Recovery Act of 1933 and the Emergency Relief Appropriations Act of 1935 enabled the U.S. government to purchase these lands and convert them back to permanent vegetative cover (Smith, 1998; USDA Forest Service, 2005). Black Kettle is currently managed by the U.S. Forest Service and primary management practices currently consist of prescribed fire applications and seasonal grazing of cattle. See Figure 14 for fire frequency on Black Kettle land units.

Rows of black locust trees, *Robinia psuedoacacia,* were planted along fence lines following the Dust Bowl period as an erosion preventative because of their ability to grow and reproduce rapidly in poor soils. Black locust is a legume which fixes atmospheric nitrogen for use as a soil nutrient and stimulates rapid juvenile growth. Black locust originally inhabited the eastern United States along the Appalachian mountain range and the Ozark Mountains to a lesser extent (USDA fact sheet, 2005). It now exists throughout the U.S., southern Canada, and parts of Europe and Asia (Huntley, 1990); and is classified as invasive or noxious in 19 states, including Texas and Missouri (PCA, 2006). Black locust reproduces by clones sprouting from the roots of existing black locust and is commonly used for land reclamation, wildlife cover and windbreaks. It is characterized by a widespread, shallow root system but has the ability to send out deeper roots to survive in drier soils (Huntley, 1990). An entire stand is likely all a part of one extensive root system and usually exists in very dense stands. Damage to roots and stems will actually increase sprouting making control very difficult (PCA, 2006). However, black locust can be greatly susceptible to insect and disease damage, especially to the locust borer (*Megcallene robiniae)* and heart rot fungi (*Phellinus rimosus*; Huntley, 1990).

Black locust trees now pose a threat to grassland vegetation at Black Kettle due to the same characteristics that made them a practical option for erosion control. Few grassland species are able to grow in the presence of black locust because they form a dense canopy preventing light penetration needed for survival of these grasses. This in turn reduces the amount of fuel load for prescribed fire and black locust is not highly susceptible to fire (PCA, 2005; Huntley, 1990).

In many locations, these trees are encroaching on areas of native and replanted prairie. However, there does appear to be a large variance in growth patterns for some of the stands. Some units on Black Kettle have a large portion covered by black locust while in other units it appears they have hardly moved beyond their original planting area. The reasons for this variation remain uncertain. It was found that black locust tended to be more invasive in lowlands than uplands and areas affected by human disturbance in South Korea where it was introduced in the 1960's for reforestation following the Korean War (Lee *et al*, 2003). It was also found to be the fastest growing woody species following a forest disturbance, such as a clear cutting, pasture abandonment, and road construction in southern Appalachian forests (Boring and Swank, 1984).

The purpose of this study is to analyze the distribution of black locust in the Black Kettle National Grasslands by comparing historical and current stand area and investigate the differences in encroachment rates focusing on the influence of potential soil moisture content. Woody encroachment has become an issue of global concern and has been extensively researched. There still remain many unanswered questions especially concerning the causes of encroachment for different species of woody plants. Black locust is identified as one of five invasive species of concern on the Black Kettle National Grasslands. Most research on black locust has focused on its role in eastern hardwood forest disturbances rather than in grasslands. Characteristics of black locust, such as principal means of reproduction and tolerance to fire, are significantly different than those of encroaching woody plants that have been more commonly researched. Therefore its reactions to the known drivers of encroachment may vary from other species. Its ability to reproduce at a rapid pace, its hardiness in harsh conditions, and its potential as an invasive species make it important to understand what is influencing the varying patterns of black locust cover on Black Kettle. Intact grassland ecosystems grow evermore scarce due to issues such as fragmentation and invasive species. Black locust is another threat to an already endangered ecosystem and it is critical to address this situation perhaps in its early stages.

Objectives and Hypothesis

I hypothesize that differences in area of black locust stands on Black Kettle are affected by variations in potential soil moisture content due to topographical features. Areas that have a greater potential for soil moisture based on topography will have experienced larger increases in stand size.

The objectives of this research were to:

- Quantify change in black locust cover from 1966 to 2005 using aerial photographs.
- Compare landscape metrics of black locust stands in 1966 to those in 2005.
- Apply topographic wetness index (TWI) using GIS to determine a relationship between potential soil moisture content and black locust encroachment.

Limitations

This research will only include populations of black locust on the Black Kettle National Grasslands and will not consider those on private lands in the same region. TWI can only predict the potential soil moisture content and does not guarantee to correlate with measurements of soil moisture taken from the actual sites. Also effects of interactions with other woody plants such as shinnery oak (*Quercus havardii*), sand plum (*Prunus gracilis*), and sumac (*Rhus*) will not be considered, which will likely be strong competitors with black locust. It will be assumed that all sites containing black locust experience identical climate conditions and similar effects of management practices (fire, grazing). Prescribed fire has only been implemented since 1993 and has occurred at least once on all units containing black locust which is not sensitive to fire. Seasonal grazing is also practiced on all units containing black locust (USDA Forest Service, 2005). Therefore, these factors will not be considered in causing the variations in growth patterns of black locust stands.

CHAPTER TWO

LITERATURE REVIEW

Introduction

The purpose of this literature review is to present the methods and findings of previous studies concerning woody encroachment in ecosystems similar to that of Black Kettle. To study encroachment of woody species in grasslands, it is important to understand the general relationship between trees and grasses and how they interact, but also to realize that these interactions will vary due to specific characteristics of tree species. It is also important to understand the major factors that lead to woody encroachment and their specific effects on woody and herbaceous plants. The various methods that have been utilized to analyze woody encroachment are also important due to the unique problems faced when dealing with an issue that occurs on such a large scale.

Relationship of Woody and Herbaceous Plants

There are many factors that influence the interactions of trees and grasses in grassland and savanna ecosystems. Woody plants can alter the composition, spatial distribution, and productivity of grasses. Effects of trees on grasses may be positive or negative and are dependent on physical characteristics of an individual tree, age and density of trees or tree stands, physiological traits of trees, and climate and soil properties in which interactions are taking place (Scholes and Archer, 1997). In some cases trees may improve growing conditions for neighboring grasses by increasing soil organic matter, nitrogen concentration, and soil water infiltration capabilities. Deciduous trees may increase soil nutrients by taking in nutrients beyond the reach of grass roots and depositing these nutrients back into the soil through the decomposition of leaf litter. Leguminous trees increase soil nitrogen concentrations by fixing nitrogen from the atmosphere and making the nutrients available in the soil (Scholes and Archer, 1997). Shrubs that often grow between a deciduous forest and prairie may also facilitate the encroachment of trees into grasslands. When shrubs encroach into the prairie they create an environment more suitable for hardwood forest establishment (Petranka and McPherson, 1979).

Competition for resources may take place belowground or aboveground. Belowground roots may compete for moisture, nutrients, and space (Jurena and Archer, 2003). A study to determine the effect of available space on neighboring roots using artificial roots, plastic wires that exert no effect other than occupying space for actual plant roots, resulted in an overall reduction of plant growth (McConnaughay and Bazzaz, 1992). Some tree roots will affect only grasses directly beneath their canopy, such as *Juniperus virginianus*, while others will prevent plant growth up to 9 m from its crown, such as *Acacia karroo* in African savannas.

Trees and grasses may not always compete directly for moisture. Grasses benefit more from moisture in the upper part of the soil profile, while trees may benefit more from moisture in deeper subsoils. This suggests that trees will be favored by wetter climates and soils with low water retention, which lead to accumulation of moisture in subsoils (Scholes and Archer, 1997). However, tree seedlings compete directly with grasses for moisture until their taproot reaches beyond the extent of neighboring grass roots. Trees then may take advantage of larger openings of space between clumps of grass, or in areas of lower grass biomass to become established (Jurena and Archer, 2003).

Once trees are established they may also have many negative effects on grasses. Trees may intercept significant amounts of precipitation and sunlight needed for grasses to be productive. These effects will greatly increase with leaf surface area and canopy structure of a tree or groups of trees. Once a group of trees has matured to the point that a canopy is formed, very little light penetration is possible. Sparse herbaceous production beneath tree canopies may also lead to moisture losses by increasing surface flow due to loss of ground cover and soil infiltration capabilities (Scholes and Archer, 1997).

Drivers of Woody Encroachment

There are several factors that may lead to increases in woody species and these causes are widely debated. Climate, disturbances, soils and topographic features can influence vegetation shifts and most cases will be a combination of these factors. A given combination, however, will not always be responsible because these factors will have different effects as the dominant woody species change.

Climate variables affecting vegetation primarily include temperature and precipitation, but recent speculation also suggests that increased atmospheric CO_2 could be responsible for woody encroachment (Van Auken, 2000). Increases in temperature and precipitation could lead to the spread of woody species into normally drier upland areas or colder areas in higher elevations. However, elevated CO_2 could not account for differences in encroachment patterns of the same species in the same region that are influenced by identical climatic conditions (Van Auken, 2000).

The hypothesis that CO_2 is a main cause of woody encroachment is based on observations that most woody species are C_3 plants and most herbaceous plants have C_4 photosynthetic pathway (Van Auken, 2000). C_4 refers to the ability of certain types of plants to fix carbon outside of the Calvin cycle where carbon is fixed by C_3 plants. This means that C_4 plants use CO_2 more efficiently and require less available CO_2 for photosynthesis. C_3 plants benefit more from excess atmospheric carbon than C_4 plants. However, increased CO_2 levels do not explain why in some areas C_3 grasses are being replaced by C_3 woody plants. Also, production is similar for both types of plants, C_3 and C_4 pathways, at current atmospheric CO_2 levels. Increased atmospheric carbon may not be the initial cause of woody encroachment but could play a major role in further increases in woody species that utilize the C_3 pathway (Van Auken, 2000).

Fire and grazing of commercial livestock are disturbances that are major influences on vegetative structure in savanna and grassland ecosystems. Historically, fire played a major role limiting the distribution of woody plants in grasslands of the United States. Native Americans burned large tracts of land, which along with naturally occurring fires and native herbivores such as bison and deer, prevented many tree species from reaching maturity in predominantly grassland areas (Huggins, 2006). Frequency and intensity of fires were greatly reduced following Anglo-European settlement (Huggins, 2006). One species that has greatly benefited from reduced fire is *Juniperus virginianus*, eastern red cedar. The NRCS has estimated red cedar encroachment in Oklahoma at 300,000 acres per year (Drake and Todd, 2002). This species of juniper is highly flammable and very sensitive to fire, especially at early stages of maturity.

Prescribed fire is now being implemented in many areas to reduce and prevent further spread of red cedar (Brockway *et al*, 2001).

Healthy herbaceous vegetation can be sustained in the presence of domestic grazers with the proper amount of exposure, but chronic overgrazing can greatly diminish the ability of grasses to compete with woody species by damaging their leaves, stems, or roots (Van Auken, 2000). Over exposure to livestock may create windows for woody seedling establishment both spatially and temporally (Jurena and Archer, 2003). Livestock may also play a role in seed dispersal and facilitate seed germination in some species of *Acacia* and *Prosopis*. Fuhlendorf and Smeins (1997) found that shifts in distribution patterns and diversity in perennial grasses were driven primarily by grazing intensity at research sites near Sonora, Texas. They also concluded that the continued absence of fire would result in further increases of *Juniperus ashei* and other woody species (Fuhlendorf and Smeins, 1997).

The combination of fire suppression and extensive overgrazing seem to be the primary forces that have lead to widespread woody encroachment (Van Auken, 2000; Hudak and Wessman, 2001; Scholes and Archer, 1997; Kepner *et al*, 2000; Fuhlendorf and Smeins, 1997). Chronic grazing may substantially reduce the amount of fuel available for fire with sufficient intensity to eliminate or inhibit growth of woody species by removing herbaceous biomass (Fuhlendorf and Smeins, 1997; Van Auken, 2000). The increase in woody species in the semiarid southwestern grasslands over the last 150 years correlates with the introduction of large scale ranching and the reduction of fire (Van Auken, 2000). In this area an estimated 60 million acres of grasslands have been converted to shrublands. The dominant plant on 38 million acres in this area is *Prosopis* which is highly susceptible to fire (Van Auken, 2000). The most common species in African savannas prone to encroachment are *Acacia* species or closely related species. These trees are also susceptible to fire and encroachment regularly occurs on lands exposed to chronic overgrazing by domestic livestock (Hudak and Wessman, 2001).

Remote Sensing and GIS Applied to Woody Encroachment

Remote sensing is the collection of data on an object using a sensor that is not in intimate contact with the object based on its ability to reflect electromagnetic energy. Aerial photography and satellite imagery are the most common forms of remote sensing and are commonly combined with GIS for analyses. These images may be viewed electronically via GIS where the images are made of pixels with assigned values based on the spectral reflectance of the object represent by the pixel. Aerial photos and satellite imagery provide an efficient and cost effective method for viewing extensive areas of land compared to ground based research. It is important to use ground based measurements, known as groundtruthing, to reinforce the accuracy of research using remote sensing analysis.

Many of today's environmental concerns, such as conversion of grasslands to woodlands, occur on a large geographic scale making it difficult to form comprehensive management strategies. Remote sensing techniques allow environmental managers and decision makers to view issues at the scale in which management actions are required (Kepner *et al*, 2000). Remote sensing is one of the most effective ways to analyze changes in land cover at the landscape scale (Petit *et al*, 2001) and has been used in various regions of the world to study woody encroachment due to the ability to view extensive areas of land and efficiently delineate vegetation patterns (Laliberte *et al*, 2000). It is possible to view changes in land cover over time and estimate future distributions of land cover by viewing historical images of a specific area and comparing them to current images. Change in land cover can be quantified by percent of an area occupied by a certain cover type and finding the rate of change of cover types (Petit *et al*, 2001).

The most common approach is to create a land cover map through supervised and unsupervised classification of the area of study using aerial photos or satellite images of the area at multiple observation dates (Kepner *et al*, 2000; Petit *et al*, 2001; Wu and Archer, 2005; Huggins, 2006). Unsupervised classification is based on the spectral reflectance of pixels in which the user only specifies the number of desired classes and the software separates similar pixels into clusters. In supervised classification the user actually identifies desired cover types using some type of a reference. These identified areas are known as training sites and are used to drive supervised classification or manual classification. The latter is more labor intensive and requires extensive knowledge of the study area, but also gives the user more control over the initial classification.

Analysis of land cover maps often varies once they are created. Petit *et al* (2000) studied vegetation changes at a watershed scale in Sonora, Mexico and southern Arizona. They used satellite images at 3 different dates over a 20 year period and created land cover classifications for each observation date. They then used landscape statistical software to find the change in total extent of each land cover class based on size and shape of the landscape feature. Changes were displayed as gain, loss, or no change. Perhaps the most notable change was the increase of mesquite woodland from 20,812 ha in 1973 to 107,334 ha in 1986. Grasslands were the dominant cover type but declined steadily over the study period (Petit *et* al, 2000).

In one study, the land cover classification was the final product (Huggins, 2006). This was a baseline study focused on eastern red cedar encroachment in southern Missouri in which the goal was to accurately identify locations of the tree to use in future comparisons. Three different classification methods were used along with several methods for accuracy assessment. The decision tree classification was determined to be the best method for classifying eastern red cedar based on accuracy assessments. The decision tree method required that spectral data must meet user defined criteria to be classified as a certain cover type (Huggins, 2006).

Petit *et al* (2001) also looked at changes in land cover using satellite images in southeastern Zambia. The authors referred to this location as a "hot spot" due to the rapid rate of land cover change due to population increases and a series of droughts. Image differencing was performed to determine changes that occurred on land cover classifications on three separate observation dates. Image differencing involves taking the difference of reflectance values at a desired wavelength from two observation dates (2001). The near-infrared band (0.76-0.90 μm) is usually the most appropriate when viewing vegetation due to the high reflectance of vegetation at that range of wavelengths. They found an overall decrease in vegetation due to increased urbanization. These findings were then used to extrapolate future distributions of land cover types using the Markov chain process. This is based on the physics principle that the state of a system can be predicted based on what is known about the system through past observations. For this application, the "state" of the system is equal to the area occupied by each land cover class. It is important to realize that interpolation is really only viable as a potential look at future patterns to increase awareness of ecological implications if the process continues without restraint (Petit *et al*, 2001).

Wu and Archer (2005) used both manually digitized and unsupervised land classifications of aerial photography. Their main objective was to investigate the effect of topoedaphic characteristics on woody encroachment near Sonora, Texas. They hypothesized that differences in woody encroachment patterns were due to topography based hydrologic features. This means that areas of greater encroachment accumulate more soil moisture through surface runoff leading to moister subsoils that are more beneficial to trees than grass. The topographic wetness index (TWI), developed by Beven and Kirby (1979), was applied to test this hypothesis. The equation for TWI is $\ln(\acute{\alpha}/\tan\beta)$, where $\acute{\alpha}$ = flow accumulation per unit contour length and β = slope gradient. This index is used in TOPMODEL which is a topography based watershed hydrology model and has been applied to soil moisture fluxes, geochemical fluxes, evapotranspiration, erosion and sedimentation (Quinn *et al*, 1995). It was originally derived from contour maps, but now can be found using computer software and DEMs. Topography defines the influence of gravity on the movement of water in a watershed (Wolock and McCabe, 1995). Both flow accumulation and slope gradient can be found using a digital elevation model (DEM) in the ArcGIS Desktop spatial analyst extension. Average TWI values were found for larger woodland areas, smaller woodland areas, and herbaceous areas. They found no statistical difference in TWI values for these three classes in upland areas. There was a significant difference in TWI values for lowland woodlands and upland savannas suggesting that TWI is a significant method to determine woody plant distributions at the landscape scale, but not in primarily upland areas (Wu and Archer, 2005).

TWI can be used to quantify the effect of topography on saturation-excess surface flow, which occurs when surface flow occurs due to the soil being saturated and water is no longer able to infiltrate the soil. Saturation-excess is greatly influenced by topography and is more likely to occur in areas that receive larger quantities of surface flow and are in closer proximity to the water table where soils are likely to be more frequently saturated. Higher TWI values are more likely to contribute saturation-excess surface flow due to increased potential for soil moisture (Juracek, 1999). Juracek (1999) used this study to better recognize run-off contributing areas in Kansas to more accurately target implementation of best management practices (BMP's) to meet federal regulations of total maximum daily load (TMDL), an estimate of the maximum amount of pollutant load transported by point and nonpoint sources that a body of water can accept.

Iverson *et al* (1997) also used a soil moisture index within a GIS to study decline in oak and hickory species in Ohio. Topography and soils are a major influence on the growth and distribution of trees in this region. They used an integrated moisture index (IMI) with some of the same features as TWI. This index involved GIS derived soil features as well as topographic features. Soil and topographic features included: hillshade (accounts for solar radiation affect on soil moisture due to evapotranspiration), flow accumulation, curvature (shape of the landscape), and soil water holding capacity. Water holding capacity was derived using attributes from a digitized soil survey map. Soil depth of A and B horizons was multiplied by available water-holding capacity to estimate water available to plants. These factors were used to assign a score between 0-

100 with a higher score meaning a greater potential for available water for plant use. They found that areas with low scores successfully predicted oak distributions. Oaks were more likely to out-compete other tree species in drier soils (Iverson *et al*, 1997).

Landscape metrics are another method of analyzing woody encroachment via GIS. Landscape metrics are used to analyze spatial attributes of vegetation patches and the spatial relationship of the patches within a landscape. A landscape can be defined as “mosaic of patches” that are relevant to a certain phenomenon, where patches refer to dynamic “environmental units” that make up a given landscape. Patches are usually discrete, homogenous areas that may be “distinguished by discontinuities in environmental character states from their surroundings” (McGarigal and Marks, 1994). McGarigal and Marks (1994) designed Fragstats, a software that can be implemented in GIS to quantify a variety of landscape metrics, as a tool to better understand and manage landscapes due to the growing realization of the role that landscape fragmentation plays in the widespread loss of biodiversity. Patch Analyst is another program that is used as an extension in the ArcView GIS system to analyze spatial patterns of patches. Patch Analyst has 2 versions, Patch Analyst (Grid) for raster data that uses Fragstats to calculate statistics and Patch Analyst for polygon themes which uses a modified version of Fragstats. Patch Analyst calculates statistics at the class level, all patches of a certain class which could be specific species or vegetation type, and the landscape level, all patches within a landscape regardless of scale.

Derner and Wu (2004) used landscape metrics to determine differences in light gap patches experiencing varying disturbance regimes in grasslands near Riesel, Texas. Disturbance regimes produce canopy gaps in vegetation that allow sunlight to penetrate to the soil surface which can create a window for plant invasions, in this case honey mesquite encroachment, and may provide a means for predicting future encroachment. Mesquite seedling survival greatly decreases when light quantity is below 25% at the soil surface (Scifres *et al*, 1973). Therefore 25% was used as a threshold to differentiate between areas of light gap (>25%) and non-light gap (<25%). Photosynthetically active radiation was measured at the soil surface of grasslands with three different intensities of haying which do not currently have substantial mesquite populations. Each location of measurement was given spatial coordinates as a point theme and then interpolated using the Inverse Distance Weighted interpolator in ArcView GIS Spatial Analyst to create plots or patches. The Patch Analyst extension was used in ArcView to calculate landscape metrics for each plot to quantify spatial characteristics of light gap and non-light gap patches and compared the metrics of three disturbance intensities on four different dates. Analyses showed there were significant differences in all but one landscape metric on all four dates for the areas with varying disturbances. Area of grasslands occupied by light gaps was much greater on locations with increased disturbance regimes. Grasslands with no disturbance had a greater number of light gap patches but mean individual plot size was much smaller than disturbed areas. Shape complexity was greater in disturbed grasslands and light gap patches were in closer proximity than non disturbed light gap patches. Collectively, this demonstrates that disturbances do influence spatial pattern and structure of light gaps in mesic grasslands and suggests that the potential ability of mesquite to invade grasslands differs for disturbed and non disturbed grasslands.

CHAPTER III

Methods

Introduction

The following section will explain the methods and instruments chosen to study the population of black locust trees on the Black Kettle National Grasslands. This research will represent only those trees located on Black Kettle lands. Not all of the sample stands will consist of only black locust trees, but it will be the dominant species in each stand. This was verified by Black Kettle management manually identifying locations of black locust on a unit map of the Black Kettle area. The researcher then located and mapped the stands by walking the outermost perimeter with a global positioning system (GPS).

Comparison of Current and Historical Populations of Black Locust

A NAIP 2005 color digital orthophoto quad (DOQ) downloaded from the University of Oklahoma geography website (http://geo.ou.edu) was used to quantify current populations of black locust. A DOQ is an aerial photograph that has been corrected for errors and given geographic coordinates. NAIP represents the National Agriculture Imagery Program which was created to make available DOQs taken during a region’s agricultural growing season available within a year of acquisition. NAIP DOQs are referenced to the UTM coordinate system, NAD 83 datum (USDA, 2006). ArcMap in ArcGIS Desktop 9.0 was used to delineate and digitize black locust land covers guided by polygons previously obtained with a GeoExplorer 3 Global Positioning System (GPS) by walking the outermost perimeter of black locust stands.

Aerial photos from 1966 obtained from the Oklahoma State University library were scanned and georeferenced in ArcMap to the same coordinate system as the 2005 DOQ. Six to eight control points were used for each 1966 aerial photograph to achieve a second order polynomial transformation. Control points were selected by finding the exact location on the 2005 DOQ and 1966 photos. Most control points were road intersections to ensure accuracy. Black locust stands from 1966 were again delineated and digitized to represent locust in their early stages. 1936 aerial photos were available but there were not enough images to cover all areas containing black locust. Also, it is likely that all plantings were not completed at this time and therefore it was decided that the 1966 photos were more appropriate to represent the historical stands. A Black Kettle geodatabase was created in ArcCatalog that will contain both current and early stands of black locust that were digitized in editing mode in ArcMap. ArcMap automatically calculated the area of the digitized polygons in an attribute table once the polygons are completed. There are two types of data models in GIS, raster and vector. Raster data is made up of pixels with x, y, and z values described earlier. Vector data can be stored simply as points with x and y values or with lines connecting the points. Polygon is a term referring to an enclosed area consisting of points and lines in a GIS vector data set. Once the area of all stands was found, the rate of encroachment was determined by finding the difference in black locust areas for both time periods and dividing by the number of years. This provided insight on the progression of the black locust existing on Black Kettle lands over a 39 year period as well as a total acreage.

Once both current and historical polygons were created, they were converted to shapefiles and then opened in ArcView 3.3 to quantify spatial attributes of the black locust polygons using the Patch Analyst extension downloaded from http://flash.lakeheadu.ca/~rrempel/patch/. Patch Analyst allows for a comprehensive comparison of spatial patterns for historical and current stands of black locust. Patch Analyst statistics calculated at the landscape level can be seen in Table 1 and include the following metrics: Class Area, Total Edge, Mean Patch Edge, Mean Perimeter-Area Ratio, Mean Shape Index, Number of Patches, Mean Patch Size, Median Patch Size, Patch Size Standard Deviation, Patch Size Coefficient of Variance, Edge Density, Mean Perimeter-Area Ratio, and Mean Patch Fractal Dimension.

Table 1. Definition of Patch Analyst metrics

Acronym	***Metric Name***	***Metric Description***
TLA	Landscape Area	Sum of Areas of all patches (ha)
NumP	Number of Patches	Total number of patches
MPS	Mean Patch Size	Average patch size in the landscape (ha)
MedPS	Median Patch Size	Median patch size in the landscape (ha)
PSCoV	Patch Size Coefficient of Variance	Coefficient of Variation of all patches: PSSD/MPS
PSSD	Patch Size Standard Deviation	Standard deviation of patch areas (ha)
TE	Total Edge	Sum of perimeter of all patches (m)
ED	Edge Density	Amount of patch size relative to landscape area (m/ha)
MPE	Mean Patch Edge	Average amount of edge per patch (m)
MSI	Mean Shape Index	Sum of each perimeter / the square root of patch area(MSI=1 when patch is circular)
MPAR	Mean Perimeter-Area Ratio	Average Perimeter to Area ratio for all patches
MPFD	Mean Fractal Dimension	Shape complexity: simple perimeters are close to 1 and more complex are close to 2

Relationship of Potential Soil Moisture and Black Locust Land Cover

Soil moisture indices are commonly used to understand ecological processes that are greatly affected by moisture at the landscape-level (Iverson *et al*, 1997) and predict the spatial distribution of soil moisture (Western *et al*, 1999). TWI, which has been used in hydrological and landscape studies, was used to determine if the potential soil moisture content influenced differences in area covered by black locust stands. A study on a forest in Ohio comparing TWI values to actual soil moisture measurements found there was a significant relationship and higher correlations with soil moisture than other indices used in the study although correlations were somewhat weak (Iverson *et al*, 2004). TWI assumes that topography is the key driver in runoff producing processes and does not consider affects of soil and vegetation. This will allow me to determine if topographic positioning alone is influencing the large variations in the expansion of black locust.

The equation for TWI is ln (ά/tan β), where ά = flow accumulation and β = slope percent. Flow accumulation and slope gradient can be found using spatial analyst tools in ArcMap. Flow accumulation is the amount of water due to gravity a given pixel would receive based on the number of pixels that "flow" into that pixel. For instance, a pixel found at the top of a slope would a have lower flow accumulation than a pixel found towards the bottom of a slope. Slope gradient refers to the angle of slope of each pixel. These features were found using a DEM of Roger Mills county at a scale of 1:24,000 and a cell resolution of 1 arc second (approximately 30m) downloaded from the National Elevation Dataset (NED; http://ned.usgs.gov/). A DEM is a raster dataset in which the z value of each pixel is elevation. Flow accumulation data were created from a flow direction layer by using the accumulation function in the hydrology tool box of spatial analyst. Flow direction is also a hydrological tool that gives the direction water would flow due to the steepness of neighboring pixels. The flow accumulation layer is characterized by the number of upslope pixels as the z value. The slope function in spatial analyst was then used to create a GIS layer with the percent of slope for each pixel as the z value. This resulted in two layers, one with flow accumulation data and one with slope gradient data. However, these two layers contained a considerable amount of “0” values which causes a problem when calculating TWI values. A “0” value entered in any part of the TWI equation will result in an output value of “0”. This then results in a large amount of null values, pixels assigned a value of “NoData” which will significantly affect mean TWI values for each black locust stand due to pixel values not considered in the calculation. To correct this, all “0” values in the flow accumulation and slope layers were changed to “1” and “0.1” respectively and all other values were left the same. The lowest values possible were chosen to replace “0” values so as to have minimal influence on the data. It was only possible to change the flow accumulation values to “1” because only integers are accepted for this layer because only whole cells can be used for flow accumulation. Since the range for this data was so large, 0-5600, this should not significantly affect the data. This was accomplished by performing a reclassification on both the flow accumulation and slope layers using raster calculator. All “0” values were changed to “1”, or “0.1” for slope, and all other values were classified as “0”. This gave a new output Boolean layer for both flow accumulation and slope, which were then added to the original layers using raster calculator. This resulted in two new layers for slope and flow accumulation in which only the “0” values were changed and the rest of the values were not modified.

Raster calculator, a spatial analyst tool in ArcMap that performs mathematical functions on raster layers in ArcGIS, was then used to create a layer representing the TWI values for each pixel using the equation for TWI with the flow accumulation layer as ά and the slope layer as β. Since slope was found as a percent slope instead of in degrees, the formula was adjusted. The following is the exact equation used in raster calculator:

ln ([flowacc_flow1] / ([slope_percent] / 100)). Next, I found the mean TWI values for all areas on the TWI layer encompassed by current black locust stands by using zonal statistics, another tool in spatial analyst. This created an attribute table with black locust identification, area of stand, and the average TWI value within each black locust stand. Higher TWI values will indicate a greater potential for soil moisture content.

The following (Fig 1) is a flow chart created using ArcCatolog in ArcGIS Desktop describing the steps taken to find TWI values for black locust stands.

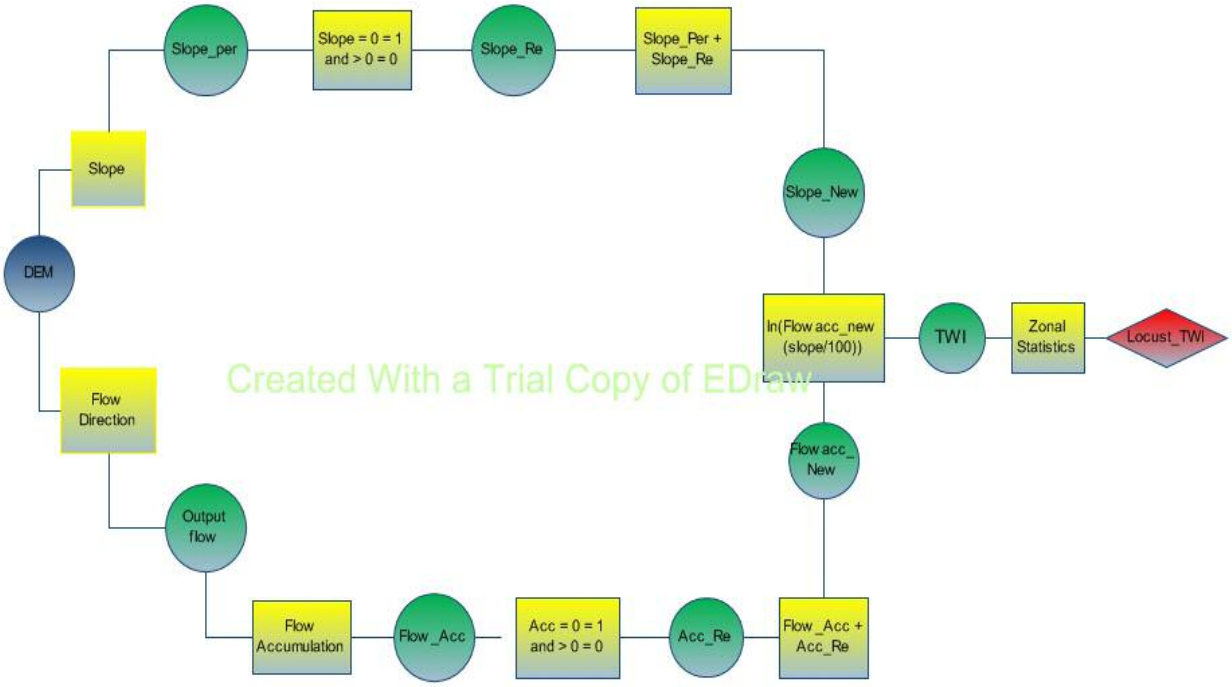

FIG. 1. Work flow chart to find TWI values for black locust stands. Circles represent GIS layers and squares represent tools or functions used in GIS.

The median value of black locust areas was used to distinguish small stands of black locust from large stands. Everything below the median is considered small and everything above the median is considered large. Small stands will be referred to as clusters and large stands as groves following the terminology used by Wu and Archer

(2005). I used a student t-test at a 95% confidence interval (p = .05) for a statistical comparison of mean TWI values for black locust clusters and groves to determine if there was a difference between acreage of black locust cover and potential soil moisture based on topographic positioning.

CHAPTER IV

RESULTS

Comparison of Current and Historical Populations of Black Locust

There were 46 stands of black locust delineated in 1966 totaling 188.96 ha (467 acres) with a mean of 4.11 ha (10.15 acres) and a range from 0.41 to 23.45 ha. Not all black locust stands could be distinguished on the 1966 aerial photographs and therefore could not be used for historical stand calculations. There were 52 current stands delineated from the 2005 NAIP image. Total current area was 580.07 ha (1433.86 acres) with a mean of 11.18 ha (27.64 acres) and a range of 1.32 to 40.94 ha. Total increase of delineated black locust stands from 1966 to 2005 considering only stands that were visible at both observation dates was 365.01 ha (901.96 acres) and a mean increase of 7.95 ha (19.61 acres) per stand. This yields an average encroachment rate of 9.36 ha (23.13 acres) per year and 91.25 ha (225.49 acres) per decade over the 39 year period. Average percent increase for black locust stands from 1966 to 2005 was 267%.

Patch Analyst statistics confirmed the difference in black locust stands in 1966 and 2005. The total mean and median of black locust areas was much greater for 2005 than 1966 (Table 2). Standard deviation was higher for current stands, but the coefficient of variance was high. Total edge and mean patch edge was also much greater for 2005 stands; however edge density, mean perimeter to area ratio, mean fractal dimension and mean shape index values were higher for 1966 stands (Table 2).

Table 2. Patch Analyst statistics for 1966 and 2005 Black Locust Stands at the landscape level

Metric	*1966 Locust Patches*	*2005 Locust Patches*
TLA	188.96	582.56
NumP	46	52
MPS	4.11	10.59
MedPS	3.28	9.67
PSCoV	99.15	86.48
PSSD	4.07	9.16
TE	64,138.94	83,184.04
ED	339.43	142.79
MPE	1394.33	1512.44
MSI	2.07	1.42
MPAR	2.15	1.45
MFPD	1.38	1.29

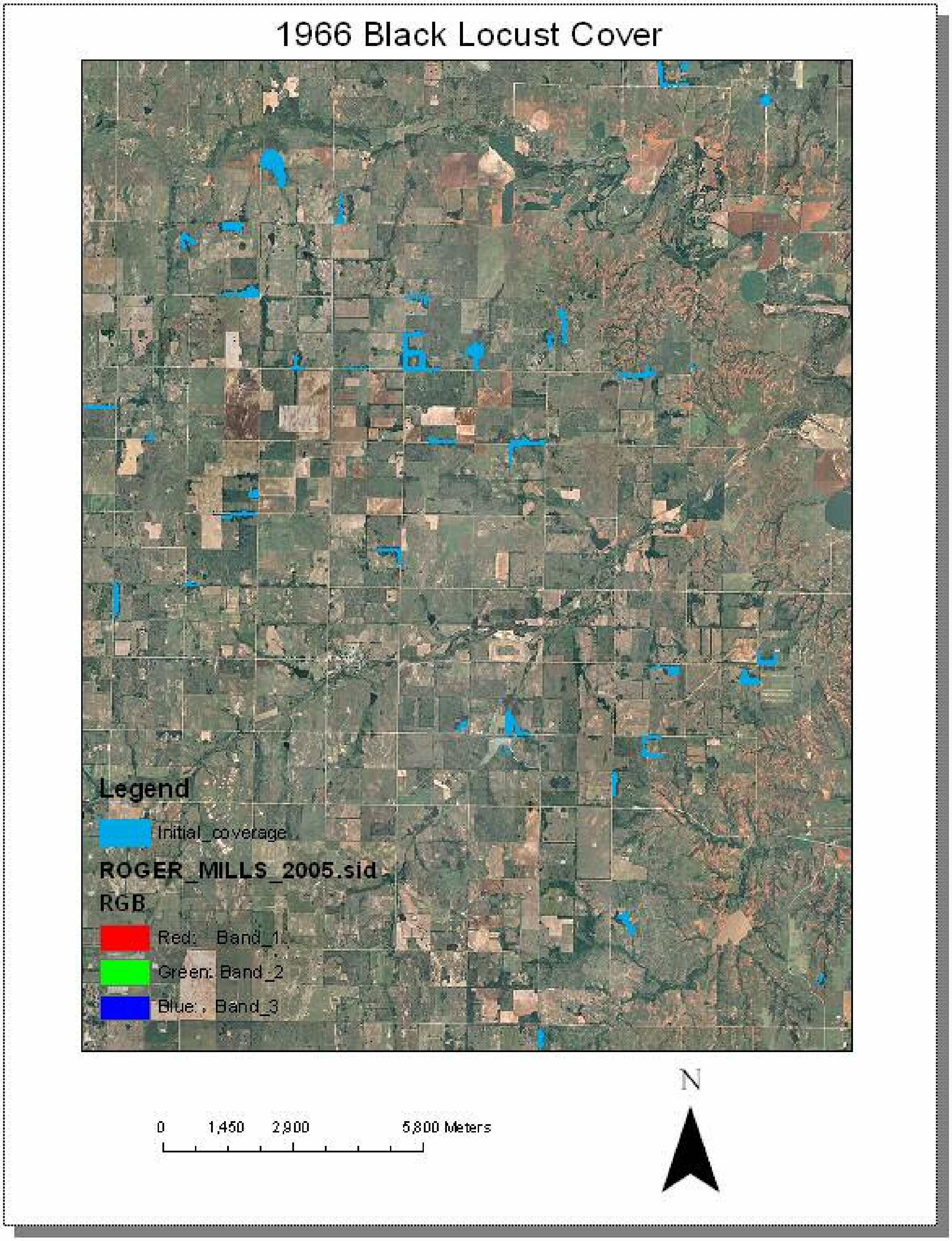

FIG. 2. Historical black locust polygons on a NAIP 2005 DOQ of Roger Mills County.

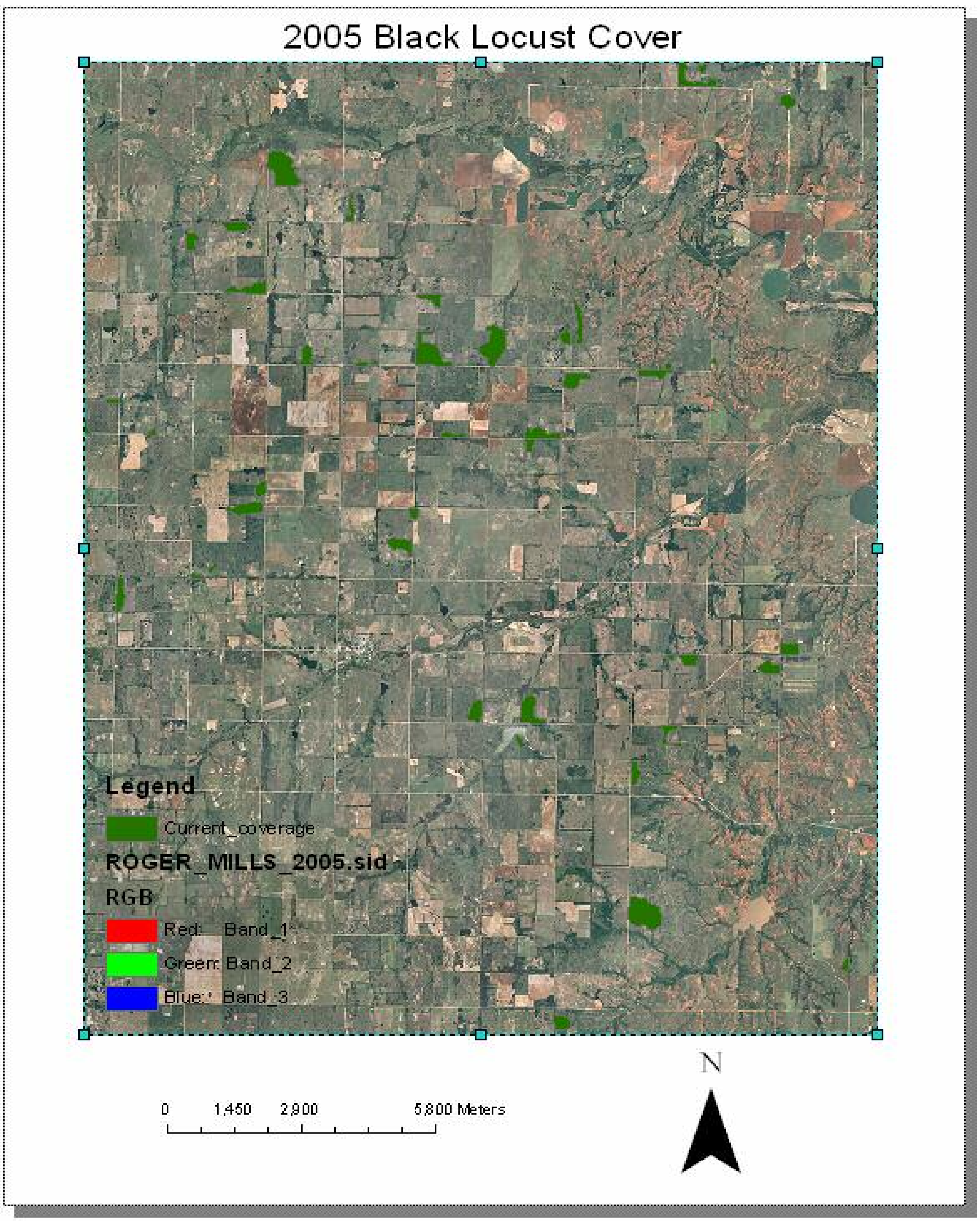

FIG. 3. Current black locust polygons on NAIP 2005 DOQ of Roger Mills County.

Relationship of Potential Soil Moisture and Black Locust Land Cover

The F-test for equal variances of TWI values for black locust stands showed that the variances are not equal with an F value of 2.64 ($p < .05$). The t-test for the comparison of mean TWI values with unequal variances showed that there is not a significant difference between TWI values for black locust clusters and black locust groves (Table 4). The mean TWI value for clusters was 5.25 compared to 5.47 for groves. The range of TWI values for the entire area containing Black Kettle units was 1.95 to 14.85 so both mean values are relatively low. In the flow accumulation layer, lighter colored areas represent high accumulation values and likely correspond to actual drainage pathways for surface flow while darker areas have low accumulation values and correlate to upland areas (Fig 6). Figure 7 shows the slope layer where the lighter areas represent steeper slopes and darker areas represent leveler surfaces. Figure 8 shows the TWI values where lighter areas represent higher values that correspond to potentially high soil moisture content and darker areas represent potentially more arid soils.

Table 3. F-Test Two-Sample for equal variances for clusters and groves

	Mean TWI Values for Locust Stands < Median Area	*Mean TWI Values for Locust Stands > Median Area*
Mean	5.25	5.47
Variance	1.19	0.45
Observations	26	26
df	25	25
F	2.644	
P(F<=f) one-tail	0.009	ά = .05
F Critical one-tail	1.96	

Table 4. t-Test: Two-Sample Assuming Unequal Variances for Black Locust Clusters and Groves

	Mean TWI Values for Locust Stands < Median Area	*Mean TWI Vales for Locust Stands > Median Area*
Mean	5.244615	5.467692
Variance	1.189738	0.449938
Observations	26	26
Hypothesized Mean Difference	0	
df	37	
t Stat	-0.88831	
P(T<=t) one-tail	0.189718	ά = .05
t Critical one-tail	1.681952	
P(T<=t) two-tail	0.379436	ά = .025
t Critical two-tail	2.018082	

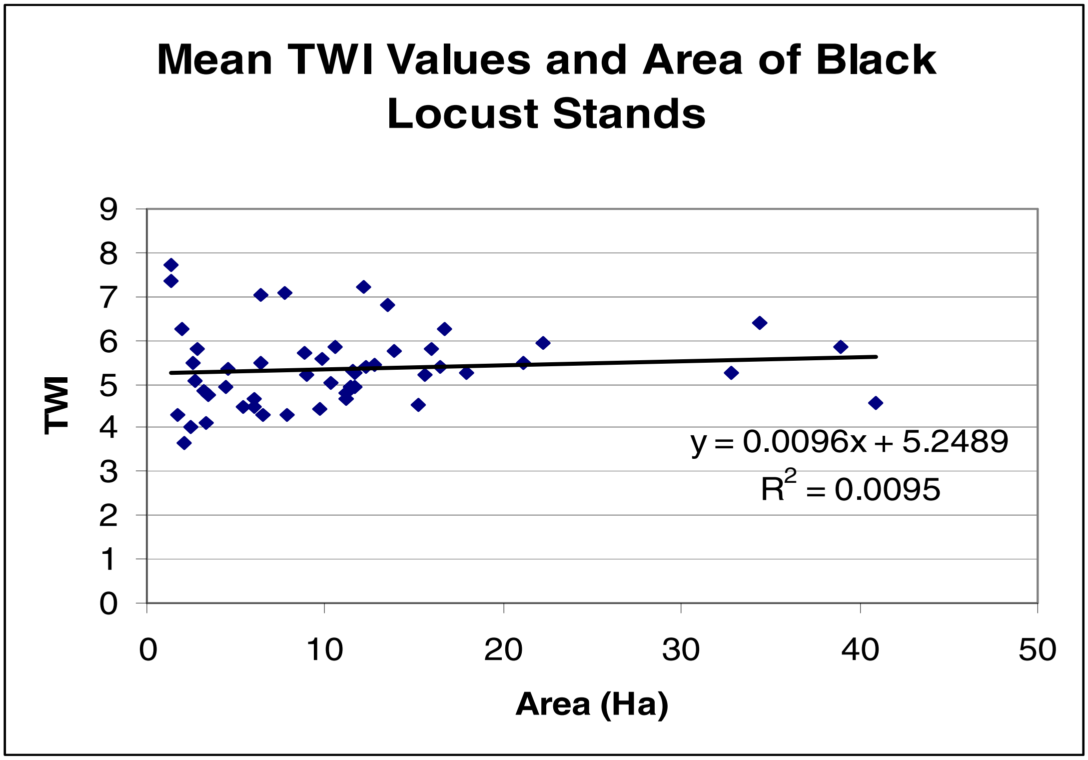

Fig. 4. Scatter plot of black locust stand areas and mean TWI values of black locust stands.

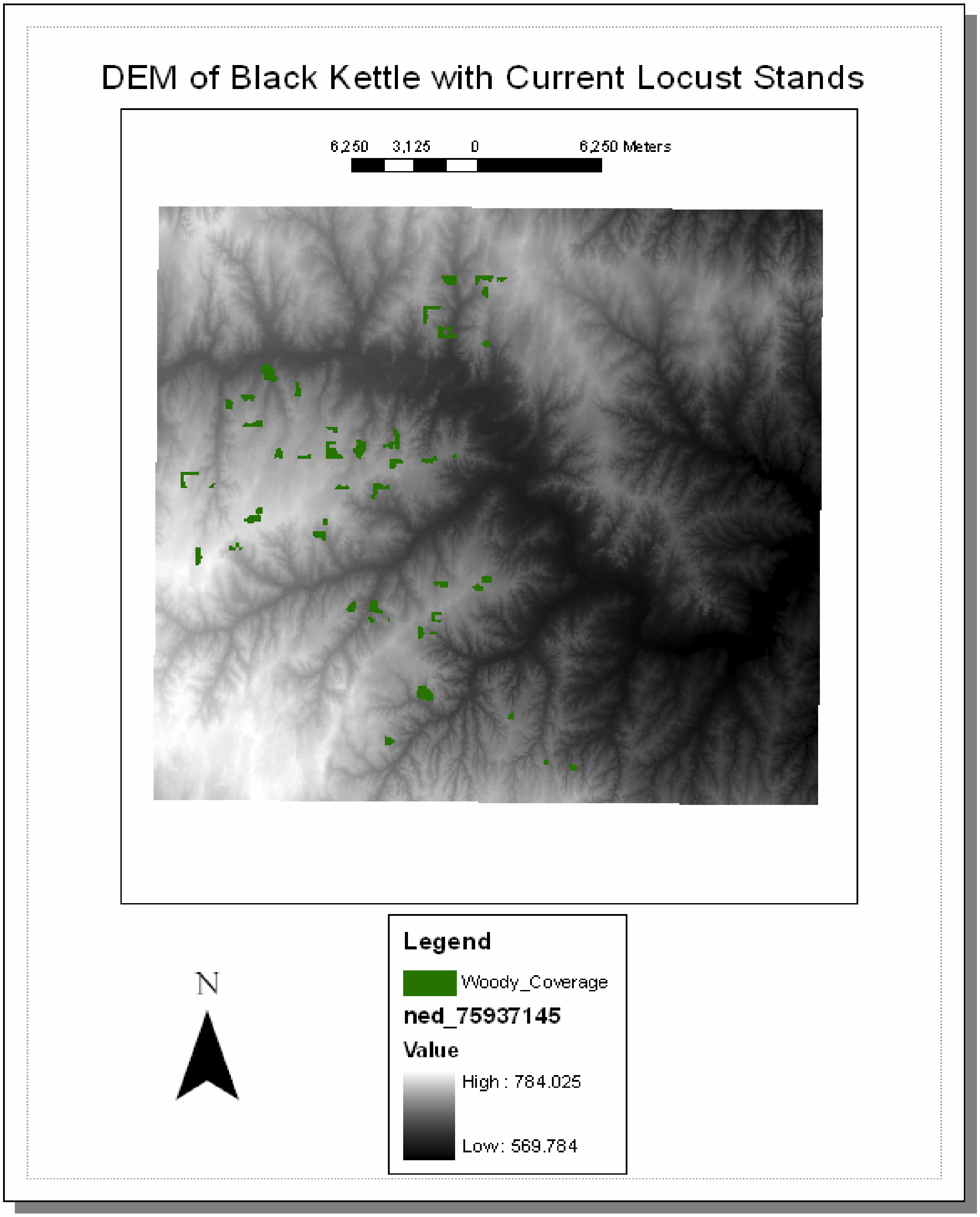

FIG. 5. DEM used to find slope and flow accumulation to calculate TWI layer.

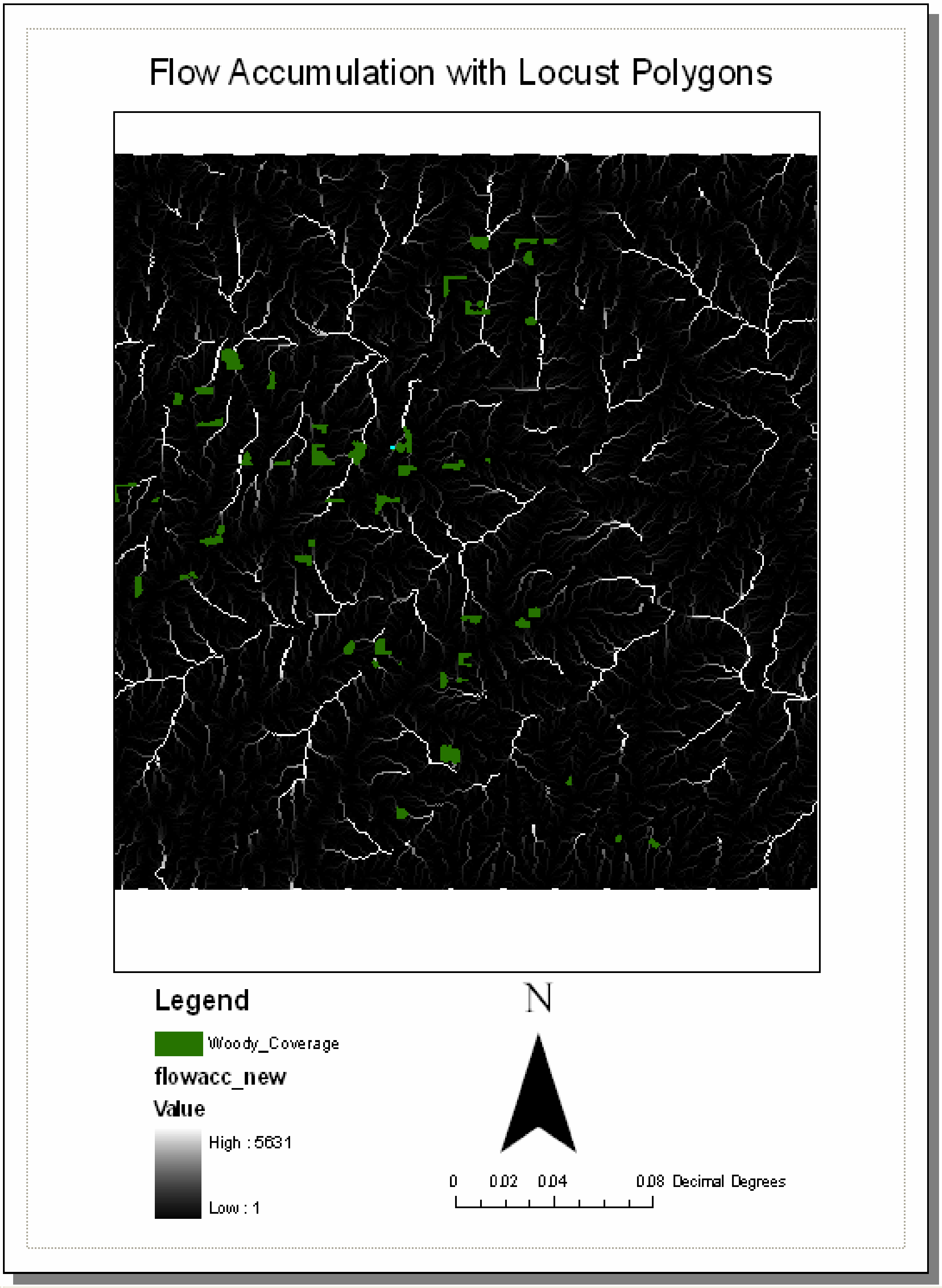

FIG. 6. Layout map for flow accumulation with current black locust polygons.

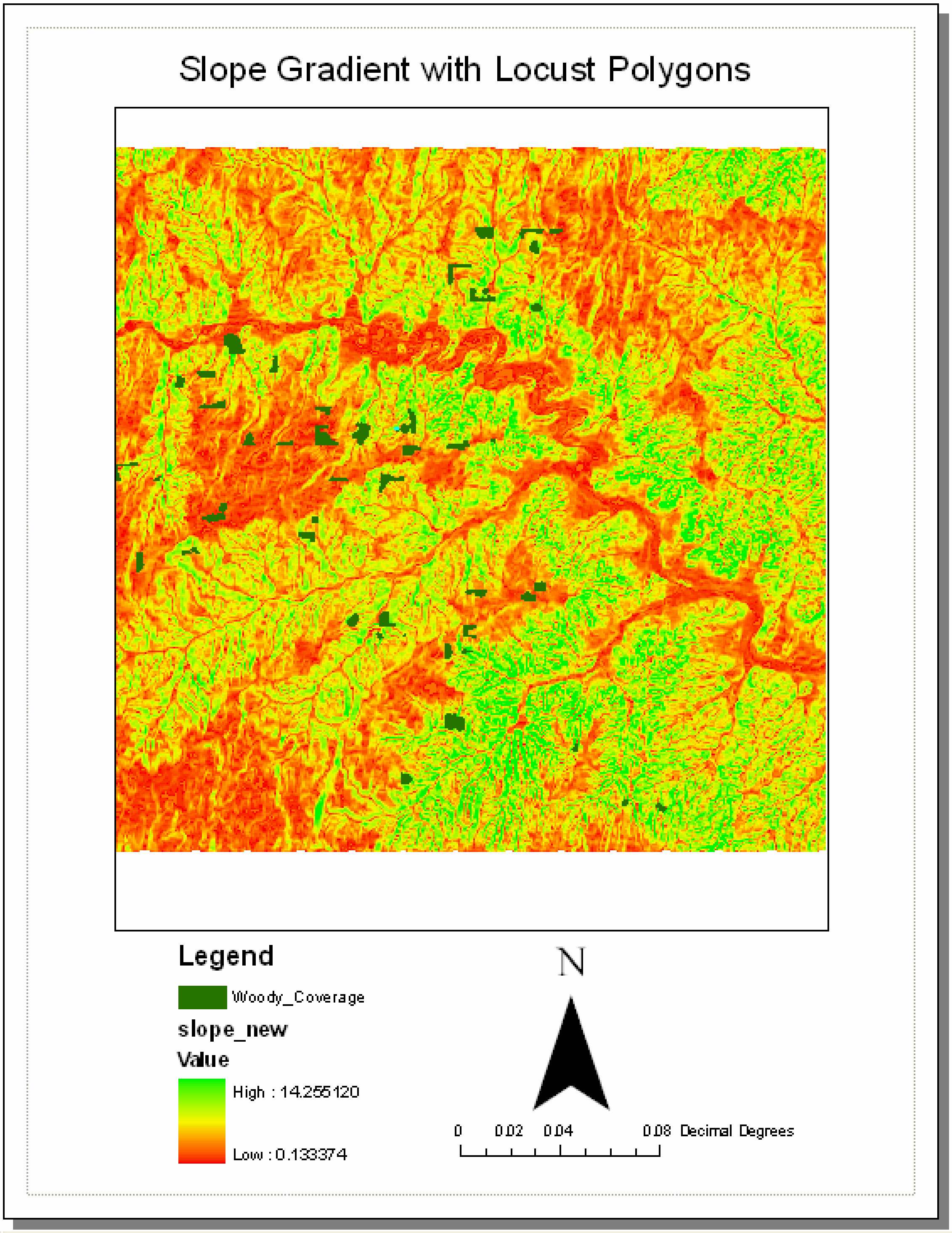

FIG. 7. Layout map for percent slope with current black locust polygons.

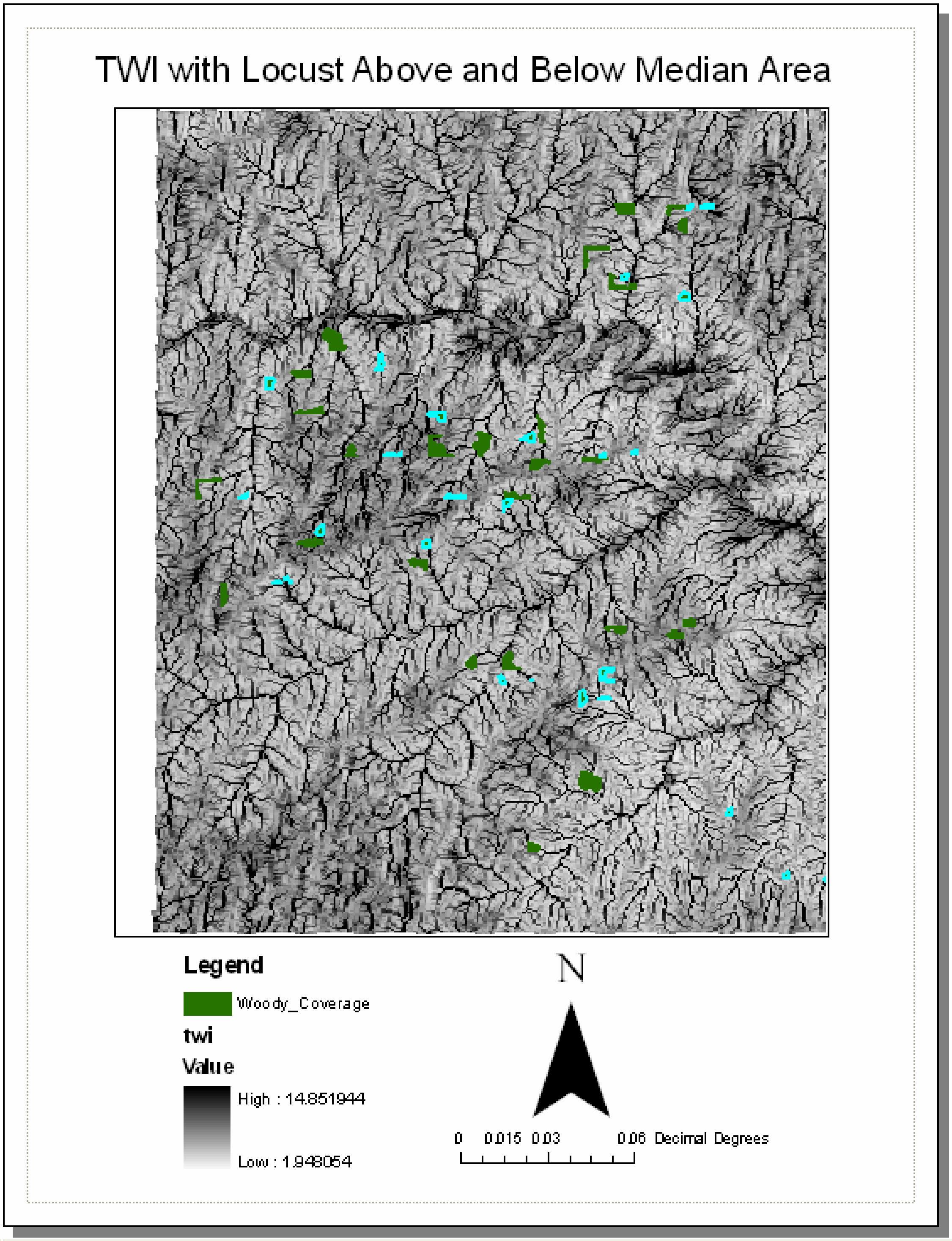

FIG. 8. Layout map with TWI values for each pixel and current black locust polygons above and below (highlighted in blue) the median area.

CHAPTER V

DISCUSSION

Comparison of Current and Historical Populations of Black Locust

Black locust populations on Black Kettle National Grasslands have shown a substantial amount of growth beyond their original plantings beginning in the late 1930's. The large range value of current area exhibits the variation in growth rate of black locust stands, but each stand area has increased since the 1966 observation period. However, it is not possible to determine if the growth has been linear through time or if encroachment has been concentrated into certain time periods of ideal growing conditions for black locust. Many of the black locust stands observed in the 1966 aerial photographs had not expanded much beyond what appeared to be their original planting, which suggests that a great extent of the growth occurred after 1966. The high percentage increase in growth of black locust stands from 1966 to 2005 is also indicates this. One factor that could have led to a high quantity of growth after 1966 could be an increased amount of rainfall from an annual mean of 23.87 cm from 1936 to 1966 to 27.75 cm from 1967 to 2004. This could also be the cause of inaccuracies in the delineation of the 1966 stands due to the lower quality of the historical photographs compared to the 2005 NAIP photographs. It is possible that newer growth could not be deciphered in the 1966 images as well as the core of the stands. This could also be due to the date on which the stands were planted. Since the exact date that each stand was planted is unknown, some stands simply may have not had sufficient time to experience considerable growth. Since black locust reproduce through root suckering, it is likely that stands will increase in growth rate as their root systems gain maturity.

The Patch Analyst extension in ArcView 3.3 confirmed the accuracy of calculated values for total, mean, median, and perimeter of black locust stands. The fact that historical stands had higher values for measurements of shape shows that they are more complex in shape. This is due to the pattern in which they were planted. They were planted as shelterbelts often along fence lines or roads resulting in a rectangular shape or two rectangles meeting at a corner to form a right angle. As black locust stands began to expand outward from their core plantings, rectangular shapes became more circular. This also caused the perimeter to area ratio and edge density, which is the total amount of edge divided by the total area of black locust, to decrease. A larger perimeter to area ratio for a black locust stand would increase its potential for growth due to the greater amount of edge exposed to grassland. However this may be misleading, because a majority of stands exist on fragmented lands that are encompassed by roads or fences inhibiting their ability to expand. For these stands, much of their perimeter is adjacent to these restrictions which limit the area black locust may expand. So in reality, the black locust stands may not be able to move beyond the Black Kettle units in which they exist due to barriers provided by roads or varying land use practices that may take place on adjacent lands. These barriers will then limit the potential invasive ability of black locust in western Oklahoma. However, black locust encroachment will compound the effects of fragmentation by further reducing grassland cover in a landscape already fragmented by roads and agriculture.

A higher standard deviation for current stands is expected because of the higher total area and mean for current stands. The coefficient of variance shows that there is actually a greater variance of mean patch size for historical stands in relation to stand area which is likely a result of the differences in original planting areas. As the original plantings have grown over time they have developed a more even distribution, 44% of current stands fall in a range of 9 to 18 ha and the standard deviation for these stands is only 2.29 ha. This suggests a range in which expansion for many of the stands began to stabilize.

Relationship of Potential Soil Moisture and Black Locust Land Cover

The hypothesis that differences in area of black locust stands on Black Kettle are affected by variations in potential soil moisture content due to topographical features was not supported. Black locust stands with an area larger than the median area of 10.04 ha did not have a significantly higher mean TWI value which indicates that soil moisture is not the primary driver for larger increases in stand area. Also, smaller stands had some of the highest TWI values. For example, the two smallest stands had an area of 1.75 and 2.13 ha and the two highest mean TWI values of 7.35 and 7.71 respectively. Increased competition with other woody species common to lower elevations and larger quantities of available soil moisture could account for the lack of expansion of these stands. These findings contrast with those of black locust invasion in South Korea where black locust was more prevalent in lowlands than uplands areas. Although in that study, this prevalence in lowlands was credited to increased artificial disturbance opposed to increased soil moisture (Lee *et al*, 2004).

The area of original planting size may also influence the current area of black locust stands. Figure 9 shows that there is a positive correlation between stand area in 1966 and 2005; current areas tend to increase as historical areas increase, and the R^2 value is high at 0.65. This data alone can not conclude that the size of original planting area is the primary cause of the variation in current black locust stand area. The historical stands can only give an idea of the plantation area because some of the 1966 stands already began to expand. It does suggest that original planting size may be one factor causing the observed variation.

Black locust stands classified as groves did have a considerably higher mean maximum TWI value compared to clusters. It is likely then that some locations within grove land covers do receive more surface flow and therefore have a higher potential for soil moisture. A way to test this would be to create a buffer zone within each black locust stand in ArcMap and find the mean TWI values for only the pixels inside the buffer. This would give the potential soil moisture for just the core area of each black locust stand. Another option would be to compare TWI values for clusters and groves by the area each stand increased from 1966 to 2005 instead of only current stand size.

It is possible that the algorithm used for calculating TWI had an effect on the results. The algorithm used for this experiment followed that used by Wu and Archer (2003) and developed by Bevin and Kirby (1979) then adjusted to eliminate “0” values. Quinn *et al* (1995) suggested that it is almost inevitable that some modification of the model structure may be necessary for each different application. Flow accumulation (ά) for this application was only the number of upslope cells contributing runoff where Juracek (1999) found flow accumulation by the following: (ά + 0.5) x (grid cell length).

However, this should not affect the outcome of the data for this application because the grid cell length is the same for each pixel.

TWI values may also be influenced by cell resolution of the DEM (Quinn *et al*, 2006). Quinn *et al* (1995) recommended that cell resolution be between the ranges of 1m to 50m with 100m resolution being too coarse for TWI application. They also found that cell resolution of 50m was more appropriate for finding moisture distributions on a macro-scale opposed to point data values or defining accurate catchment areas and does not well mimic local fluctuations. The DEM cell size for this application was approximately 30m and should be appropriate for accurate mean TWI values at the scale of this research.

The mean TWI values for all black locust stands was relatively low compared to the maximum values for TWI within the extent of the DEM in which TWI was found and suggests that black locust exists primarily in upland areas with low flow accumulation or significant slopes. This is also consistent with the type of areas in which black locust would have been planted for the purpose of an erosion preventative and abandoned farmland restoration.

Conclusions

The fact that black locust is resistant to drought conditions and reproduces clonally through a shallow root system means that it may not require a high amount of soil moisture from deeper soils compared to other woody species, even though it does have the ability to tap into moisture in deeper subsoil (Huntley, 1990). Since soil moisture is not the primary driver of black locust encroachment, like other woody species that have been researched for encroachment, it is likely that black locust encroachment is a result of a combination of factors (Van Auken, 2000). Black locust expansion is also likely influenced by disturbance regimes, competition, soil characteristics, and land use history.

The impact of prescribed and naturally occurring fire on black locust suckers should be thoroughly understood. Lee *et al* (2004) referred to black locust as a large gap species (LGS) in their study of introduced black locust in South Korean forests. LGS are usually characterized as shade intolerant, fast growing, and responding well to disturbances. Black locust stands were more prominent in forests where tree removal by humans was widespread. In areas of forests where black locust was free from human disturbance were more likely to be recolonized by native species. Black locust is sensitive to competition as well as intolerant to shade. It only exists in closed canopy forest as a dominant tree and does not grow well in open areas with dense herbaceous growth (Huntley, 1990). Prescribed fire is one of the primary disturbances occurring on Black Kettle lands and could possibly promote gaps in herbaceous cover that allow for black locust colonization. These gaps allow sunlight to penetrate to the soil surface and could stimulate new black locust sprouts. These light gaps often indicate less subsurface biomass and reduced competition for root space (Derner and Wu, 2004).

Shinnery oak, which is a common woody shrub in western Oklahoma, is also a deciduous clonal species that reproduces through rhizomes (Smith, 1990; Boyd and Bidwell, 2002). Although shinnery oak cover was decreased following fire, stem density (stems/m^2) was nearly doubled due to vigorous resprouting of shinnery oak in response to fire on plots on and near by Black Kettle lands (Boyd and Bidwell, 2002). Petranka and McPherson (1979) found an increase of 232% in growth height of dwarf sumac (*Rhus* *copallina)*, a shrub species that reproduces through rhizomes, that was recently burned compared to unburned dwarf sumac in a tallgrass prairie-forest ecotone near Stillwater, OK. They did report only a slight increase in horizontal spread of rhizomes following fire. Due to similar means of reproduction and response to fire of black locust to dwarf sumac and shinnery oak, these same effects may occur with black locust suckers that are exposed to fire. Most fires probably only affect the outer perimeter of black locust stands due to the lack of fuel beneath closed canopies of black locust (Sullivan, 1993; Anderson and Brown, 1980; Fig 10). Fire may top-kill smaller black locust, but a high frequency of fire would be required to keep new suckers from reaching fire tolerant sizes (Sullivan, 1993). A study in Illinois showed a complete mortality in aboveground locust stems, but the number of stems returning doubled shortly following the burn (Anderson and Brown, 1980).

Livestock grazing is closely monitored at Black Kettle and likely has little effect on reduction of above ground biomass and therefore does not significantly reduce competition of grasses for black locust. However, it was suggested that cattle stocking rates do have an affect on plant community composition (Smith, 1998) and will likely have some influence on black locust encroachment. Young black locust sprouts are a known target for browsing by white-tail deer and cattle (Sullivan, 1993) which may temporarily reduce new sprouts as well as stimulate new growth.

Smith (1998) found that soil type and cultivation history both played an important role in determining plant community composition on Black Kettle. Shrub species such as shinnery oak and Oklahoma plum (*Prunus gracilis*) have not revegetated on areas that were previously cultivated due to severe degradation of soil quality caused by wind erosion. It is unclear how this relates to black locust encroachment. Most plantings were on previously cultivated soils because these were the sites that required windbreaks; still some stands have encroached into adjacent areas of native prairie. Black locust can withstand poorer soils, but since they do excel in richer soils (Huntley, 1990), encroachment rates may increase when they spread into non-cultivated soils. Most of the black locust in this study exists on the western portion of Black Kettle which is characterized by deep sandy soils (Smith, 1998).

The interaction of black locust and shrub species, such as shinnery oak and *Rhus* species, is also of particular interest. Not all black locust stands interface with shrub species but it was observed that these shrub types do form a barrier between black locust and grasses in some locations which most likely were not previously cultivated. It has been shown that dwarf sumac can invade grasslands and create a more ideal environment for hardwood seedling establishment (Petranka and McPherson, 1979). However, *Rhus* species are clonal with the same mechanism for their primary means of reproduction and would likely compete with black locust for resources as opposed to facilitate black locust encroachment. Petranka and McPherson (1979) also cited the ability of *Rhus* species to produce a toxin that can inhibit the nitrification of legumes. There is no research found on this effect on black locust specifically. Shinnery oak is a dominant woody species in many upland areas at Black Kettle and will also act as a direct competitor for resources due to similar mechanisms for expansion (Boyd and Bidwell, 2002).

Future Research

It is imperative to determine management practices that will slow or halt further encroachment of black locust on Black Kettle lands. It is important to relate the influence of prescribed fire and grazing practices to black locust encroachment and determine the fire frequency and grazing intensities that are most appropriate to limit new growth of black locust suckers as these are the two most prominent management practices. Future studies should focus on fire and grazing impacts on the density of young black locust shoots on the outer edges of black locust stands. This research should provide insight for managers at Black Kettle for determining management priorities. Prescribed fire does have many benefits on vegetation communities that can not be overlooked, but its effects on invasive species should also be well understood and considered when determining strategies for its application.

Additional research should also look at the impact of black locust stands on grassland wildlife, such as breeding bird populations associated with grassland ecosystems focusing on the displacement of grassland species with those more commonly associated with eastern deciduous forest. The relationship of black locust with shinnery oak, sumac, and sand plum is also a topic for future research. It should be better understood if black locust is in direct competition with these native shrubs or if they may benefit by prior encroachment on grasses by these species.

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APPENDIX

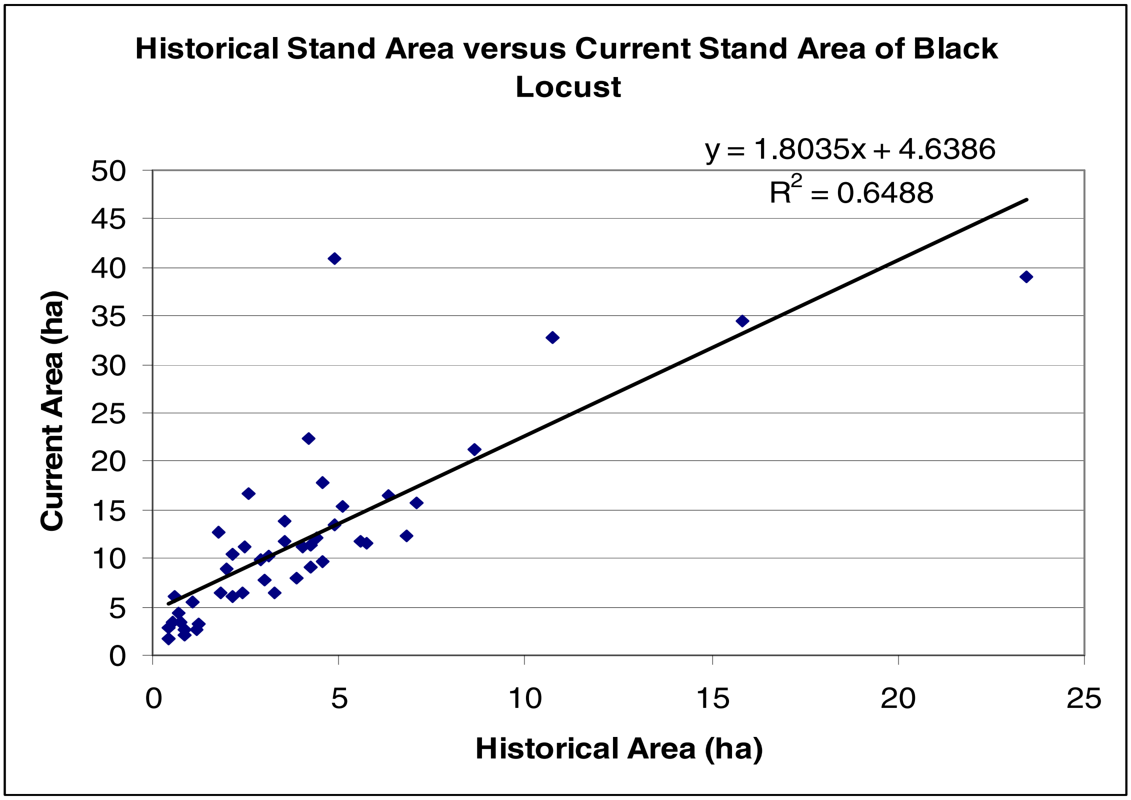

FIG. 9. Scatter plot showing the relationship of historical and current black locust stand Size.

Fig. 10. Black locust stand following fire. The fire only affected the outer most portion of the black locust and was not able to penetrate into the more mature black locust.

FIG. 11. Black locust stand showing new growth of trees at the outer perimeter of the stand.

FIG. 12. Dense thicket of black locust.

FIG. 13. Interface of black locust stand and mixed grass prairie.

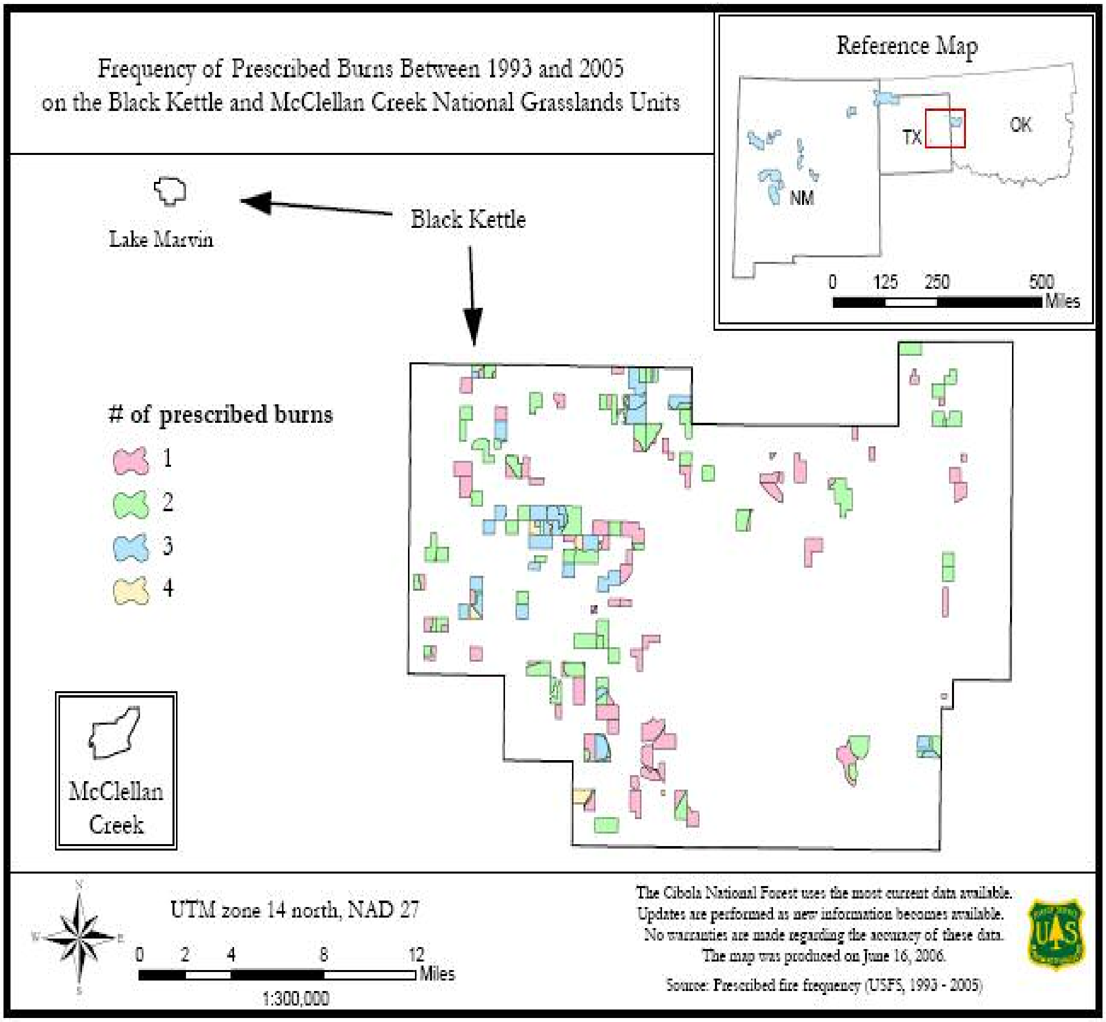

FIG.14. Layout map of Black Kettle units coded for the number of prescribed burns between 1993 and 2005. The majority of units experienced a frequency of 4 to 6 years per burn (USDA Forest Service, 2006).

Table 5. Black locust historical and current stand size with TWI values.

Locust_ID	Initial_Hectares	Current_Hectares	Diff_Hectares	%_Increase	Mean_TWI
34b	0.41	1.75	1.34	326.83	7.35
34a	0.88	2.13	1.25	142.05	7.71
44b	0.84	2.61	1.77	210.71	4.29
54c	1.17	2.68	1.51	129.06	6.26
61a	0.45	2.78	2.33	517.78	3.64
11c	1.25	3.16	1.91	152.80	4.02
107b	0.54	3.35	2.81	520.37	5.5
66a	0.74	3.45	2.71	366.22	5.09
28a	0.71	4.37	3.66	515.49	5.82
107a	1.09	5.4	4.31	395.41	4.85
3a	0.57	5.97	5.4	947.37	4.11
47a	2.13	5.97	3.84	180.28	4.76
43a	3.27	6.4	3.13	95.72	4.93
46b	2.4	6.44	4.04	168.33	5.36
31c	1.85	6.47	4.62	249.73	4.49
22a	3.03	7.68	4.65	153.46	4.65
17a	3.86	7.89	4.03	104.40	4.46
29a	2	8.85	6.85	342.50	5.48
26b	4.26	9.01	4.75	111.50	7.05
65a	4.58	9.67	5.09	111.14	4.29
65b	2.89	9.79	6.9	238.75	7.08
2a	3.1	10.29	7.19	231.94	4.3
27a	2.17	10.51	8.34	384.33	5.69
2b	2.46	11.19	8.73	354.89	5.2
35a	4.01	11.19	7.18	179.05	4.42
57a	4.23	11.38	7.15	169.03	5.56
59a	4.22	11.41	7.19	170.38	5.02
44a	5.73	11.58	5.85	102.09	5.84
58a	5.6	11.65	6.05	108.04	4.78
74a	3.55	11.67	8.12	228.73	4.65
111a	4.42	12.18	7.76	175.57	4.92
26c	6.8	12.23	5.43	79.85	4.93
62a	1.76	12.75	10.99	624.43	5.31
31a	4.87	13.51	8.64	177.41	5.27
53a	3.52	13.89	10.37	294.60	4.93
42a	5.11	15.25	10.14	198.43	7.2
26a	7.06	15.64	8.58	121.53	5.37
11a	6.31	16.47	10.16	161.01	5.43
46a	2.57	16.69	14.12	549.42	6.81
11b	4.58	17.88	13.3	290.39	5.77
110a	8.64	21.16	12.52	144.91	4.51
1a	4.18	22.27	18.09	432.78	5.19
29b	10.74	32.85	22.11	205.87	5.81
30a	15.84	34.39	18.55	117.11	5.4
20a	23.45	38.94	15.49	66.06	6.27
71a	4.88	40.94	36.06	738.93	5.25

VITA

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The expansion of woody species in savannah and savannah-like ecosystems has greatly increased in the last several decades and has become a worldwide issue. Woody encroachment may lead to the displacement of wildlife species that depend on open grasslands, decrease species diversity, disrupt natural disturbance regimes, alter water/energy cycles, and reduce amount of grazing lands available for livestock. Rows of black locust trees were planted along fence lines of what is now the Black Kettle National Grasslands following the Dust Bowl period as an erosion preventative and now these trees are encroaching on areas of native and replanted prairie. Remote sensing combined with GIS analysis has been established as one of the most effective ways to study the conversion of grasslands to forests and has been used in many parts of the world to analyze woody encroachment. The purpose of this study is to analyze the distribution of black locust in the Black Kettle National Grasslands by comparing historical and current stand area using aerial photography and investigate the differences in encroachment rates focusing on the influence of potential soil moisture content using the topographic wetness index. Total area of black locust in 1966 was 188.96 ha and the total current area was 580.07 ha. Black locust populations on Black Kettle National Grasslands have shown a substantial amount of growth beyond their original plantings beginning in the late 1930's. Increased soil moisture due to topography is not the primary driver of black locust encroachment and is also likely influenced by a combination of disturbance regimes, competition, soil characteristics, and land use history.

Advisor's Approval: Lowell Caneday