INTEGRATION OF FIELD-BASED ANALYSIS OF PLANT COMMUNITY DYNAMICS WITH QUANTITATIVE ANALYSIS OFLANDSCAPE CHANGE: RAY ROBERTS LAKE AREA, 1987-1997

Theresa J. McDonough, B.S

Thesis Prepared for the Degree of

MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

May 2000

APPROVED:

Samuel F. Atkinson, Major Professor and
Environmental Sciences Program
Coordinator
Earl Zimmerman, Committee Member and
Department of Biology Chair
Minhe Ji, Committee Member
C. Neal Tate, Dean of the Robert B. Toulouse
School of Graduate Studies

McDonough, Theresa J., Integration of field-based analysis of plant community dynamics with quantitative analysis of landscape change in the Ray Roberts Lake area, 1987—1997. Master of Science (Environmental Science), May 2000, 128 pp., 13 tables, 11 illustrations, references, 46 titles.

This study focused on the effectiveness of integrating traditional plant community analyses with landscape ecological analyses based on remotely sensed data. A temporal analysis of plant community diversity was conducted for major plant communities of the Ray Roberts Lake area using transect monitoring data collected between 1987 and 1997. Landscape analyses were performed with FRAGSTATS*ARC using classified SPOT satellite imagery for 1987 and 1997. Although the methodology developed in this work was exploratory, it was found that characterizing the dynamics of major plant communities in the study area produced a more effective and insightful analysis of Ray Roberts Lake area landscape dynamics.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Figure

CHAPTER I

INTRODUCTION

The continuing proliferation of remote sensing technologies has resulted in an increasingly broad spectrum of ways to collect information about the earth's surface features. This has become particularly important as concerns about loss of biodiversity and habitat have grown during the last decade. Dissemination of acquired data is becoming more cost-effective, and methodologies for applying the data to managing critical ecological and environmental issues are continually being advanced in the literature.

One of the key challenges ecologists face during the coming decades is integration of these technologies with traditional methods of investigation and analysis. Numerous studies have accomplished this goal effectively (Johnson, 1990) in broad scale or regional analysis of biodiversity and habitat for wildlife and landuse management applications. However, studies that examine the relationship between temporal variation in plant community composition and landscape change are lacking.

In fact, landscape ecological studies that deal with vegetation frequently do so from the perspective that vegetation provides habitat for wildlife. The effect of patch size, for example, on forest structure may be evaluated with respect to the effects on diversity of bird species (Bierregaard, et al., 1989). The effect of edge length along a forest edge is often analyzed with respect to the effect of edges on general habitat structure and availability of browse for ungulates.

Field assessment of plant community dynamics typically has not been a component of studies of landscape change because of the impracticality of assessing the innumerable patches comprising a landscape mosaic and the amount of time needed to compile the data (Dunn et al., 1991). Where collection of such data is practical, however, inclusion of a plant community diversity component in analysis of landscape change could yield valuable insight into observed variation across the mosaic. Conversely, processes underlying observed landscape dynamics over a given time period may yield insight into general trends observed in the landscape's major plant communities.

Within a single landscape, several types of patches may be experiencing changes at different temporal and spatial scales. For example, woodlots in a landscape dominated by agriculture may be undergoing secondary succession, even though the gross pattern of landuse is not changing at a noticeable rate (Dunn et al., 1991). Thus, landscape analysis may show that the landscape mosaic is relatively stable even though changes are in fact occurring, as manifested through dynamics in individual patches. Only a direct analysis of plant community dynamics, however, would verify this level of change on the landscape.

Objectives

The purpose of this research was to investigate the effectiveness of integrating traditional plant community analysis with landscape ecological analyses based on remotely sensed data. Analysis of plant community dynamics within the context of landscape ecological analysis may provide important insight into observed variation across the landscape mosaic, particularly for landscapes created and maintained by disturbance from human activity.

The study was carried out in the Ray Roberts Lake area, located in Denton, Cook, and Grayson counties in northcentral Texas. Digital satellite imagery and vegetation monitoring data for the major plant communities in the study area were available for 1987, 1992, 1995, and 1997. The following research questions were explored in this study:

- Can the landscape mosaic of the Ray Roberts Lake are be characterized as disturbance-maintained?
- Given the landuse history of the area, can rangeland, agricultural, shrubland, and forested plant communities of the Ray Roberts Lake area be characterized as disturbance-maintained communities?
- Can a qualitative relationship between disturbance-maintained landscapes and disturbance-maintained plant communities be elucidated?

The Ray Roberts Lake area has been settled for 150 years, during which it has remained largely rural and agricultural. As a result of the general stability of landuse trends in the study area, it is not expected that major change has occurred across the Ray Roberts landscape during the last ten years. More likely, the crop rotation system of agriculture that predominates has resulted in shifts from cropped to fallow to pasture landuses. Additionally, some transition from rangeland to transitional shrubland is expected to have occurred. Further, because both rangeland and agricultural use represent continual disturbance on the landscape, no clear directional change in the landscape is expected to have occurred.

The first research question was addressed through landscape analysis of remotely sensed data, including aerial photographs and satellite imagery. Integration of aerial photointerpretation with unsupervised classification of digital satellite imagery offers the ability to map accurately landuse and landcover characteristics that might otherwise be difficult to capture through spectral classification. Photointerpretation of aerial photos currently provides the most accurate classification of temporal landscape changes, although the process is admittedly time-consuming (Jensen, 1986).

As Quattrochi and Pelletier (1991) note remote sensing offers a wide array of opportunities for detection and observation of temporal changes in habitat conditions. Additionally, the use of spectral characteristics in classifying a landscape can yield valuable insight into variations in the physical character of the environment that would be difficult to detect in aerial photographs. Thus, the integration of photointerpretation with spectral classification methods was expected to provide a more accurate and, therefore, more informative analysis of landscape change during the 10-year study of the Ray Roberts Lake area.

The second research question was addressed through analysis of temporal variation in rangeland, shrubland, and forest community diversity across a 10-year period in the Ray Roberts Lake area. Additionally, abundance data for each community was fit to Fisher's log series model to determine whether communities could be characterized as undergoing continuing disturbance.

Finally, the results of these separate analyses were compared to determine whether change in community diversity for these habitats could be related to change in landscape structure between 1987 and 1997. The lack of quantitative methods to compare field-based measurements of community dynamics with measures of landscape dynamics necessitated a qualitative comparison. In that sense, the methodology developed through this research was exploratory. Nevertheless, it was found that characterizing the dynamics of the major plant communities in the study area would yield a more effective and insightful characterization of the dynamics of the Ray Roberts Lake area landscape.

About This Document

The information in this paper is presented in four chapters, including this introduction to the study's research objectives. The second chapter, Literature Review, focuses on two key issues related to the study: 1) the relationship between plant community processes and landscape dynamics, and 2) quantitative characterization of landscape structure and dynamics. The third chapter, Materials and Methods, describes the research design and analytical procedures. The fourth chapter, Results and Discussion, presents the results obtained from analysis of landscape and plant community dynamics and provides a synthesis of the two analyses.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the literature on the hypothesized relationship between plant community dynamics and landscape dynamics. The processes underlying the evolution of landscape pattern and the consequences of these processes on landscape patches are also reviewed. Finally, general types of quantitative measures of landscape change are reviewed.

Relationship Between Plant Community Processes and Landscape Dynamics

The common view of plant communities is that they pass through a series of successional stages to reach a stable endpoint, or climax, in equilibrium with the local environment. This view is based largely on the work of Clements and Gleason (Clements, 1936; Gleason and Cronquist, 1964) and has been pervasive in plant ecology and biogeography (Kershaw, 1964). Kershaw (1964) points out, however, that this view can be misleading, because the overall composition of a plant community results from the continuing interaction of external environmental factors with important internal characteristics of the plants themselves. The result of this interaction is that vegetation change is manifested as a cycle of events occurring at a given point in the community at a given point in time. The sum total of these cycles represents community composition (Kershaw, 1964).

As cited by Kershaw (1964), the work of Watt (1947) and others show that cyclic vegetational change is very often guided by some underlying factor, such as microtopography or local soil moisture variation. The consequence of a cyclic pattern of change is that at any one point in time, the plant community is actually a mosaic made up of patches undergoing various cyclic processes. The scale and number of the underlying factors (e.g. soil moisture variation or chronic grazing pressure) controlling the flow of these events, relative to the extent of the community, has important consequence in the spatial pattern of the overall community mosaic.

Watt's work has led to development in landscape ecology of the key concept of the shifting steady-state mosaic, in which a large area in equilibrium actually contains many patches in various successional stages (Forman, 1998; Turner, 1989). Observed spatial pattern, therefore, is a manifestation of different phases scattered across different patches of land. Patches appear and disappear across the mosaic over time as a result of various events or agents, usually anthropogenic in nature. The balance between appearance of patches and the subsequent rate of succession within individual patches determines both the rate and direction of change across the whole landscape mosaic (Forman, 1998).

There are many processes operating both on and within patches across the mosaic. Forman and Godron (1986) outline five basic causes or origins for vegetation patches. *Disturbance patches* are created in response to a local disturbance while *remnant patches*, conversely, are left behind when the surrounding area undergoes disturbance. *Environmental patches* are created by local variations in the environment, such as soil type, microtopography, or other edaphic factors. *Regenerated patches* are special forms of disturbance patches, wherein vegetation has re-established on a disturbed site. Finally, *introduced patches* are created as a result of human activities such as construction of buildings and establishment of gardens or other cultivated plots.

The implication is that the rate of change of the landscape varies according to the cause or origin of the patch. For example, according to Forman (1998) environmental patches change slowly, reflecting the stability of the underlying substrate. Remnant and disturbance patches can change quickly in response to disturbance-related colonization and succession events.

In terms of plant communities, these processes generally result in successional events. Although natural vegetative communities evolve as a result of the interaction of climatic, topographic, and edaphic factors, the arrival of human influence dramatically alters community dynamics. Once human influences are established on the landscape, natural vegetation may be altered permanently, reduced to small fragments, or a combination of both. In a landscape characterized by disturbance patches, repeated or chronic disturbance, such as grazing by cattle or mowing for hay, can maintain the patch in a static successionary state over time. Anthropogenic forces, therefore, frequently drive plant community dynamics in such landscapes (Figure 1).

In human-dominated landscapes, most patches in the mosaic can be characterized as disturbance or introduced patches, usually created during settlement and from

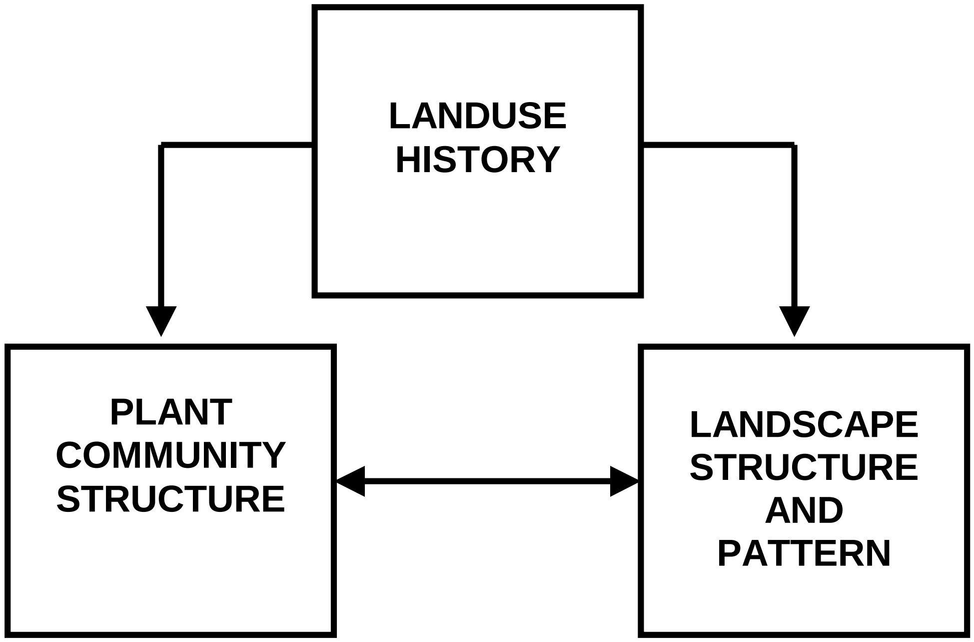


Figure 1. Conceptualization of the relationship between landuse history, existing landscape structure, and plant communities.

subsequent human activities such as farming, ranching, or urbanization. Examining the landuse history of a given area prior to landscape analyses, therefore, can be critical to effective landscape analyses, because landuse forms the basis for the general structure of the human-dominated landscape.

Landuse practices, such as crop rotation or management of rangelands for year-round grazing, determine the persistence of patches over time. In turn, landuse practice and landscape structure combine to determine the character, composition, and distribution of plant communities in the region. Thus, landscape change can be directly related to Watt's concept of cyclic vegetation change wherein the composition of the landscape is the sum total of processes operating within smaller patches over time (Watt, 1947).

Therefore, if a process (e.g. disturbance from grazing or farming) creates a patch and maintains its presence on the landscape over time, it follows that the same process may control the dynamics of the plant community within the patch. In other words, a landscape mosaic that has been created and maintained by disturbance from human activities like farming and grazing should be comprised of plant communities that also reflect the presence of chronic disturbance from these activities.

Characterization Of Landscape Structure And Dynamics

Before a connection between plant community dynamics and landscape dynamics can be explored, the evolution of the landscape pattern on which the vegetation patches exist must be understood. The first step, as mentioned previously, is to determine what landuse factors have influenced the current landscape pattern historically and what landuse practices are currently responsible for maintaining it. The second step in understanding landscape change is to quantify the spatial structure of the landscape.

Significant emphasis has been placed on the development of methods to quantify landscape composition and pattern (Turner and Gardner, 1991). Although a variety of metrics have been proposed, in general, they can be summarized as metrics that quantify 1) the number of landscape patches and the amount of edge between them, 2) patch shape and 3) indices of dominance, diversity, and contagion (Johnson, 1990; McGarigal and Marks, 1995; Turner, 1989).

The two main properties of landscape structure that landscape metrics attempt to address are composition and pattern (MacGarigal et al., 1995). Landscape composition is analogous to plant community composition in that it is an aspatial reference to the variety and abundance of different types of patches on the landscape mosaic. These metrics include the proportion of the landscape occupied by each kind of patch, the number of different types of patches (patch richness), patch evenness, and patch diversity.

Landscape pattern deals with the distribution of or spatial relationships between the patches. Because there are many interrelated factors operating across different scales to create the observed pattern, quantifying pattern can be much more complex than measuring landscape composition. As a result, there are numerous metrics that have been proposed for capturing various aspects of landscape pattern.

In general, landscape pattern can be quantified according to the properties of individual patches, classes of patches, or to the entire landscape. The three levels of analysis are hierarchical; in other words, patch metrics often have counterparts at the class and landscape level that are calculated by summing or averaging individual patch metrics. MacGarigal et al. (1995) point out that, while many of the indices overlap, interpretation varies from one level to the next and it is therefore important to interpret each metric according to the scale of the analysis. Metric selection and interpretation are complicated by the fact that some metrics that may not be spatially explicit at the patch or even class level become spatially explicit at the landscape level.

Eight general groups of composition and pattern metrics can be defined from the numerous metrics that have been proposed: 1) area, 2) diversity, 3) edge, 4) shape, 5) core area, 6) contagion and interspersion, 7) nearest-neighbor metrics, and 8) patch density, size, and variability metrics. Of the eight general groups of metrics, area, diversity, shape, and patch density, size and variability metrics are directly relevant to this study.

Area metrics describe landscape composition. They can be calculated at the patch, class, and landscape level of analysis. Patch level area metrics quantify the area of each individual patch while class level metrics quantify the area of a given class of patches. A landscape level area metric simply reflects the total area of the landscape.

The area of an individual patch is an important characteristic of the landscape mosaic because 1) it is the basis for many of the class and landscape level indices and 2) it is an important ecological property in own right (MacGarigal et al., 1995). The total area of a particular type of patch, or class, can also be important because it describes the extent of a particular community or habitat across the landscape.

Diversity indices are also measures of landscape composition. Like their counterparts in traditional ecology, landscape diversity measures are based on the number of different kinds of patches (patch richness) and the total number of patches in each patch class (abundance). As a result, diversity metrics are generally calculated only for the landscape level of investigation. Most landscape diversity measures have been borrowed directly from traditional ecology. The most popular are Shannon diversity and Simpson dominance, richness, and evenness.

Patch size, density, and variability metrics capture aspects of both composition and pattern, although they are not spatially explicit (MacGarigal, et al., 1995). Interpretation of these metrics varies according to the context in which the landscape analysis is taking place. For example, a large number of patches of highly variable size can be related to habitat fragmentation. Patch density can be an indicator of the isolation of different classes of patches on the landscape (Forman, 1995), and patch size variability can be an indicator of landscape heterogeneity (MacGarigal, et al., 1995). Ultimately, interpretation of these metrics will depend on the specific dynamics being observed in a given analysis (Forman, 1995; MacGarigal et al., 1995; Riiters, O'Neill, Hunsaker, Wickham, Yankee, Timmins, Jones, and Jackson, 1995).

Shape metrics measure landscape pattern in terms of the complexity of patch shape across multiple scales of inquiry. Shape indices are generally calculated from the ratio of patch perimeter (edge) to internal area. At the patch level, shape indices have many ecological applications, including studies of edge effect and the effect of shape on intra-patch dynamics. At the class level, shape indices describe the average patch shape for a specific type of patch. At the landscape level, shape can be a measure of the total shape complexity for all patches in the landscape.

One measure of shape complexity that has received considerable attention in landscape ecology is the fractal dimension. Mandelbrot (1983) introduced the concept of fractals, which are geometric forms that exhibit self-similar structure across multiple scales (MacGarigal, et al., 1995, Mandelbrot, 1983; Riiters, et al, 1995; Sugihara and May, 1990). Briefly, fractal dimension is calculated as a ratio of patch perimeter to patch area in the presence of a variable that is constant across multiple scales.

The perimeter-area method quantifies the degree of complexity in planar shapes as compared to simple geometric forms having known fractal complexity. Typically, this is carried out at the landscape level of analysis using the perimeter to area relationship:

$$A = k\,P^{2/D}$$

where area (A) is a function the perimeter (P), the scaling constant *k*, and the fractal dimension (D). The fractal dimension can be obtained by regressing the log of patch (or patch class) perimeter on the natural log of the patch (or patch class) area, finding the slope of the resulting line, and dividing it by 2 (MacGarigal et al., 1995). Thus, objects that are square or circular have simple geometric shapes and a fractal dimension approaching D = 1. Theoretically, as landscape patches become more complex, or plane filling, the fractal dimension approaches the maximum of D = 2.

Typically, fractal analysis is applied to the entire landscape mosaic, although some software, such as FRAGSTATS*ARC (ESRI), allows calculation of a fractal dimension for individual patches. Fractal dimension has been used to describe the diversity of a landscape by accounting for patch shape complexity and the distribution of the patches across the landscape (Olsen, Ramsey, and Winn, 1993). Fractal dimension has also been used to describe the relative complexity of the landscape in the presence of disturbance. For example, it has been suggested that human-influenced landscapes exhibit simpler patterns than do natural landscapes; accordingly, fractal dimensions will be lower for human-influenced or disturbed landscapes (Krummel et al., 1987; Turner et al., 1989).

All shape indices are subject to serious limitations resulting from scale, image resolution, and image format. With respect to these limitations, fractal analysis has received particular criticism (Frohn, 1998). Particularly, it has been noted that fractal dimension does not display scale-independence. In fact, the fractal dimension of natural landcovers has frequently been found to vary across spatial scales (Frohn, 1998; Leduc, Prairie, and Bergeron, 1994). Nevertheless, shape indices can provide useful insight, if applied with caution, into landscape level dynamics across time.

CHAPTER III

METHODS AND MATERIALS

Investigation of the relationship between plant community dynamics and landscape ecological dynamics in the Ray Roberts Lake area requires three primary components. First, compilation of the area's landuse history will allow identification of the origin and causes of the general landscape structure as well as providing a context for quantitative ecological analysis of vegetation and landscape change. Second, landscape structure in 1987 and 1997 were quantified using selected landscape ecological metrics. Finally, plant communities comprising the landscape were characterized and analysis of community diversity performed. This chapter will describe the study area and the materials and methods used in each of the three stages of investigation.

Study Area

The study area encompasses approximately 50,000 acres surrounding the Ray Roberts Lake reservoir in north Texas. Ray Roberts Lake is a 29,000 acre (conservation pool elevation) impoundment located on the Elm Fork of the Trinity River in Denton, Cooke, and Grayson counties (Figure 2).

The reservoir is located mainly in the Eastern Cross Timbers and Grand Prairie physiographic regions (Institute for Applied Sciences, 1999). The Grand Prairie is a relatively narrow region of rolling tallgrass prairie that overlies predominantly limestone soils. The Eastern Cross Timbers occupies the majority of the reservoir area, and is characterized by rolling post oak woodlands that follow the Woodbine sandstone

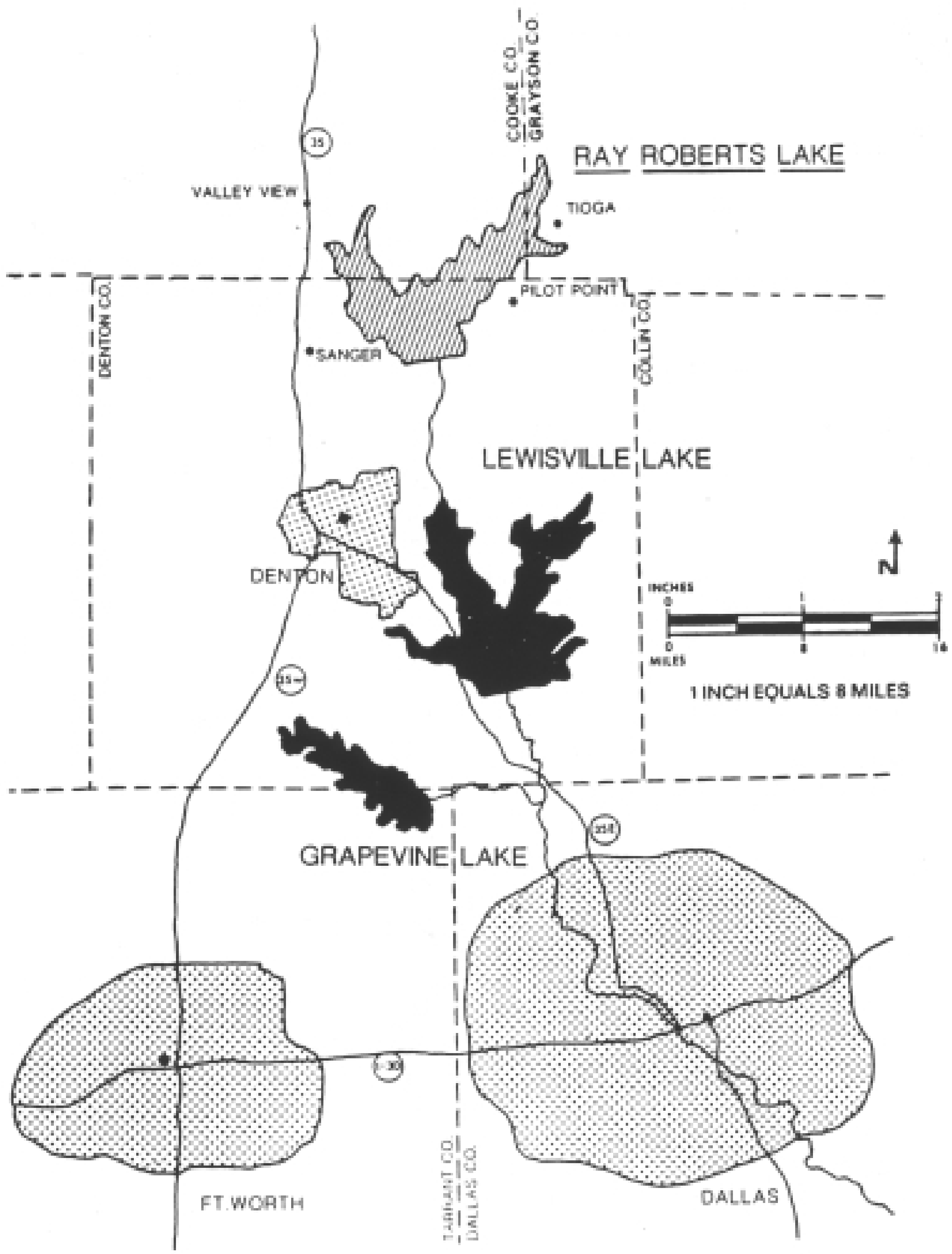


Figure 2. Location of Ray Roberts Lake in north central Texas (adapted from IAS, 1993).

formation (IAS, 1999). A small portion of the study area falls within the Blackland Prairie, a region characterized by tall and midgrasses. No vegetation data were available for the Blackland Prairie region of Ray Roberts Lake; consequently, this portion of the study area was eliminated from the vegetation and landscape analyses.

The area was chosen because it occupies three physiographic regions, each having distinctive characteristic vegetation and well-documented landuse histories. Plant species and abundance data are readily available for 1987 (IAS, 1988), 1992 (IAS, 1993), 1995 (IAS, 1995), and 1997 (IAS, 1999). Additionally, high-altitude false color-infrared aerial photographs (1:2000) and SPOT-1 digital satellite imagery were also available for all years. The study area boundaries were determined by the boundaries of the Ray Roberts Lake ten-year post-impoundment studies from which these data were taken.

Landuse History

Quantitative landuse data prior to and during the 19th century Anglo-settlement period do not exist. However, thorough historic accounts of pre-settlement conditions, settlement patterns, and landuse trends in Denton, Cook, and Grayson counties are readily available (Bates, 1918; Bridges, 1978; Dyksterhuis, 1946; Lebo, 1995). These were reviewed to identify landuse trends and to allow inference of associated landscape processes, such as fragmentation and dissection.

Landscape Analysis

Characterization of landscape structure and pattern was accomplished with remotely sensed digital imagery and Geographic Information System (GIS) analyses. Three steps were required for landscape analyses: 1) preparation and classification of input images, 2) conversion of images to vector format for FRAGSTATS analysis, and 3) selection and calculation of landscape metrics for each coverage.

Data preparation and image classification. SPOT images from 1987 and 1997 were classified according to landuse using IMAGINE (ERDAS, Version 8.3). The 1997 image was georectified to 0.3 pixel accuracy using 1:24,000 scale topographic map sheets (USGS). The 1987 image was georectified to 0.4 pixel accuracy with Texas Department of Transportation (TxDOT) road vector coverages using image-to-image rectification procedures in IMAGINE. The difference in methodologies is accounted for by the fact that the 1997 image was prepared a year earlier than the 1987 image; for the 1987 image, it was determined that rectification using road coverages would be more efficient while providing comparable rectification accuracy.

Image classification followed a four-step sequence: 1) subsetting according to east, central, and west geographic subregion, 2) unsupervised cluster analysis and initial class assignment, 3) development of “agricultural” and “developed” class templates for each section, and 4) developing a single mosaic from the three subregion images. The sequence was developed through “trial-and-error” with the objective of maximizing overall classification accuracy. The set of procedures is summarized in Figure 3.

Each image was subset initially into geographic regions for classification, resulting in three separate images for each year. The rationale for subsetting the images for each year was based on previous work with imagery in the Lake Ray Roberts area that indicated definite differences in soil conditions and overall landscape pattern from west to east. During unsupervised cluster analysis, frequently these differences resulted in a

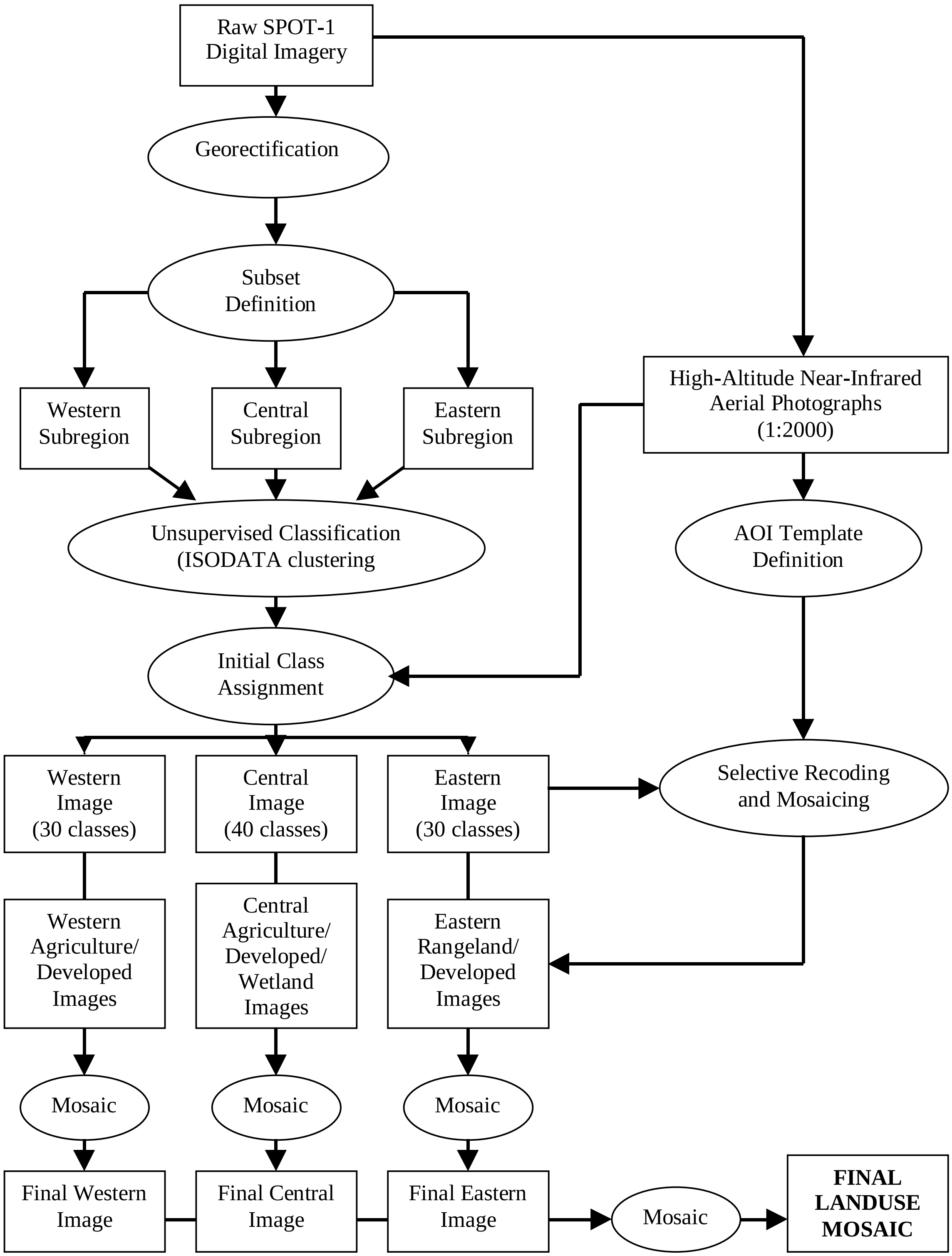


Figure 3. Summary of image classification procedures to produce the final mosaic for each year of the study period.

single spectral class containing two different landuse classes, depending on the geographic location of the area in the image (McDonough et al., manuscript in prep). It was expected therefore that segregation of the image into separate western, central, and eastern sections would result in less spectral confusion between classes and thereby improve classification.

Image classification was accomplished according to a combination of landuse and vegetative cover attributes. In the strictest sense, classification based solely on vegetative cover does not include explicit reference to the landuse or landuses responsible for creating and maintaining the cover. For example, two areas with a vegetative cover generally characterized as grasses with scattered trees may have been created and maintained by two very different landuses.

Examples of this are found in the Eastern Cross Timbers region of the study area, where rangeland and pasture on horse farms frequently contain the same vegetative cover, while being maintained by very different landuses. Conversely, stands of upland forest and shrubland riparian corridors in the Eastern Cross Timbers are more appropriately classified by vegetative cover than by landuse. Thus, classification of the study area was based on a combination of landuse and landcover features. Accordingly, the classification scheme for this study follows the landuse and landcover scheme developed by Anderson et al. (1976) and is summarized in Table 1.

Class definition was generally straightforward. Identification of shrublands, however, and transitional woodlands from aerial photographs and raw satellite was more complex. The Eastern Cross Timbers region of the study area is highly fragmented, and

Table 1. Description of landuse and landcover classification scheme for the Ray Roberts Lake Study area.

Class Value	Category	Description
1	Water	
2	Agriculture	Rotation-cropped agriculture and pastureland
3	Rangeland	Herbaceous rangeland with < 5% woody cover
4	Forested lands	Upland and bottomland forest lands
5	Shrubland	Rangeland with 5% - 10% woody cover
6	LDOW	Low density oak woodland
7	VLDOW	Intermediate phase between range/pasture with scattered trees and low-density woodlands.
8	Urban/Built-up Land	Roads, urban areas
9	Disturbed	1987 only: Area cleared for construction of Ray Roberts Lake Reservoir.
10	Residential	Urban and rural residential areas
11	Seasonal Wetland	Area of periodic indundation in Elm Fork flooplain at Lake Lewisville reservoir.
12	Gravel Pits	

there are numerous areas having low density tree cover that could not be characterized accurately as either shrubland or forest.

Two transitional woodland classes were developed to account for these cover types. The Low Density Oak Woodland (LDOW) category was generally characterized as being 1) a phase dominated by mixed shrubland and forest occurring as a successional stage in old forest gaps, 2) forest edges, or 3) a cover type occurring in pastures that are maintained by clearing and grazing.

For each year, unsupervised cluster analysis was performed on each subregion image using the ISODATA clustering algorithm in IMAGINE. The western image corresponds with the Grand Prairie while the eastern image approximates the Blackland Prairie region. Visually, the sections were characterized by large areas of rangeland, rotation cropped fields, and pastures bounded by linear features such as fence lines and roads. The initial classification, therefore, began with only 30 classes for both the western and eastern images. The central section of the study area follows the Eastern Cross Timbers; visual inspection of the image showed much smaller and more numerous patches with more complex boundaries resulting from upland forest stands, riparian corridors, and rangeland and pasture with varying densities of trees. To account for this complexity, initial classification of the central region for each year was based on 40 classes.

Initial class assignments for the each subregion were made according to water, upland forest, shrubland, and rangeland classes. All cropped areas, roads, urban, and residential areas were assigned initially to rangeland. Roads and other urban areas were added by first selecting the spectral classes that detected these landuses from the initial unsupervised classification and then using them as the basis for building a separate template for the new class.

For example, in the western subregion three of the initial 30 classes detected roads and urban areas with high fidelity. These three classes were combined into a separate image that was then overlaid on the raw rectified image to define a “developed/built-up land” class template. The raw image was enhanced using contrast-manipulation of display breakpoints to emphasize roads and developed features. Using aerial photographs for each year as a guide, areas overlapping cropped fields or rangelands were eliminated from the “developed/built-up land” image and missing sections of road were added.

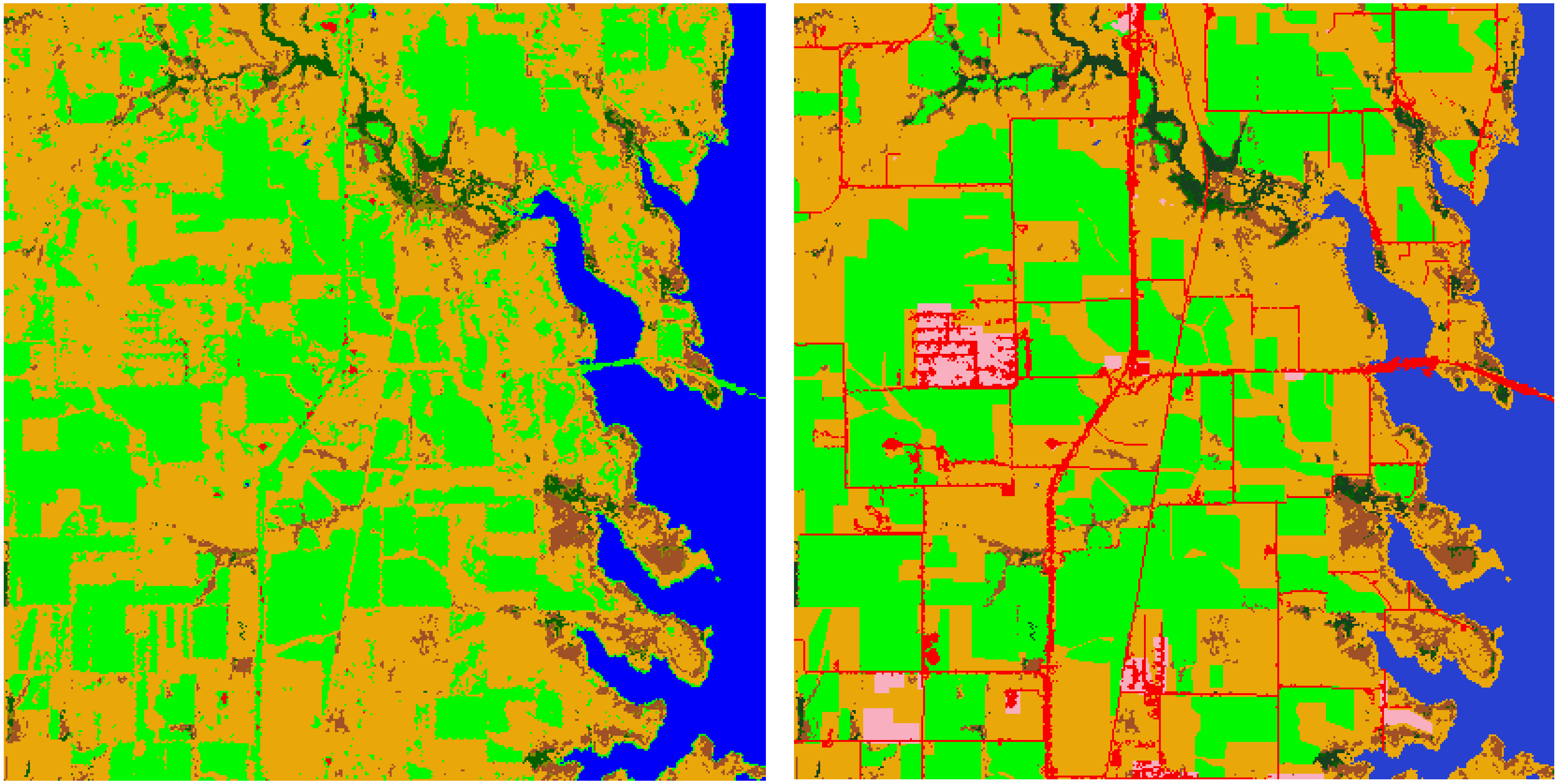
The elimination and addition procedures were accomplished through the use of selective recoding and overlay methods in IMAGINE. Selective recoding was accomplished by first defining two separate series of areas-of-interest on the raw image. An area-of-interest (AOI) is a user-defined point, line, or polygon. The first AOI template was delineated to remove all areas classified initially as “rangeland” from the image containing the roads and urban areas. All pixels having a rangeland class value that fell within the template were recoded to the value of the image background (0). A second AOI template was delineated to fill in missing sections of road; all of those areas in the “developed/built-up land” image that fell within the template were recoded to the class value of the “developed” class.

The two images were then overlaid using mosaic procedures in IMAGINE. Mosaicing lays one image on top of the next, allowing those areas that overlap to take on the class value of the input image that the user specifies. The resulting output image contained only the roads and urban areas for the western section of the study area.

An AOI template for residential and urban areas was also generated, following the same procedures, to eliminate erroneous rangeland classes from within city boundaries and to include rural neighborhoods. Similarly, there are several gravel pits located to the east and southeast of Ray Roberts Lake; these were also defined from aerial photos in a separate AOI template.

Agriculture templates were produced for the western and central regions following the methods described above. The decision to define this class by creating a template rather than using unsupervised methods was based on the fact that in the initial unsupervised images apparent variation in factors such as soil moisture and amount of crop residue created extensive spectral confusion between rangeland and agriculture classes. Calculation of accurate landscape metrics requires not only accurate classification, but also accurate definition of individual patch boundaries. Thus, defining the agricultural class based on spectral classes did not result in a reliable classification for the category.

Agriculture in the western region of the study area is comprised almost exclusively of sorghum-wheat-fallow rotation cropping. In the central region, agriculture is a mixture of rotation cropping (south of the lake) and pastureland (north of the lake). Preliminary inspection of aerial photographs for each year showed that, in general, these activities are carried out on large, regularly shaped sections of property bounded by linear stretches of fenceline and roads. The regularity of shape and the linearity of the boundaries for these properties made them generally easy to identify from aerial photographs and simple to distinguish in the raw imagery. Thus, hand-digitizing agricultural templates rather than attempting to classify the class through unsupervised cluster analysis resulted in improved classification for the western and central regions (Figure 4).



a. b.

Figure 4. Sample of results obtained in classification of agricultural class (shown in bright green) using a) unsupervised classification procedures and b) aerial photointerpretation-aided delineation of an AOI template.

In the eastern region, agriculture was observed to be a far more widespread landuse than ranching on rangelands. Similar to the central part of the study area, agriculture is comprised of both row cropping and pastureland associated with extensive horse farm operations. Therefore, in the initial classification for each year, all classes that were not assigned to upland forest or shrublands were assigned to the agricultural class. Rangeland and developed class templates were defined, as described previously, from the aerial photos and overlaid on the unsupervised classification image.

One significant assumption was made regarding classification of the lake reservoir. In 1987, construction of the reservoir was underway and there had been extensive clearing of agricultural, rangeland, and forested areas across the site. Thus, a "disturbed" class was added to the classification scheme for the 1987 image. However, distinguishing rangelands and agricultural lands that had been cleared for construction from rangelands and agricultural lands that had been left undisturbed was frequently problematic in both the aerial photographs and the raw satellite imagery. Therefore, determining the precise boundaries of the disturbed area around the reservoir site was not possible. Therefore, the assumption was made that the reservoir boundary in the 1997 image could serve as an adequate proxy for the boundary of the disturbed class in the 1987 image. Thus, the boundary of the disturbed class in 1987 are identical to the boundary of the lake in 1997.

To obtain the final classification for each image section, the individual rangeland, agriculture, and developed class images were overlaid on the unsupervised classification image through mosaic operations. For each year, the results were three fully classified images representing the western, central, and eastern portions of the study area. These were mosaiced to create the final landuse mosaic for each year (Figures 5 and 6).

Classification accuracy

To determine overall accuracy of the classification, 250 points were generated in IMAGINE through an automated stratified random sampling procedure. Using aerial photographs, the landuse class of each point was compared to the landuse class value in the classified image. Random points that fell outside the area covered by the aerial photographs were eliminated from the accuracy assessment. Overall image classification accuracy was calculated as a simple proportion of true land cover types, as determined from ancillary data, to the classified imagery.

Landscape analysis software installation

Landscape analysis was accomplished using FRAGSTATS*ARC (Environmental Systems Research Institute [ESRI], Version 2.0.3). The software is a fully functional evaluation copy of the program that was downloaded from the ESRI Internet site. FRAGSTATS*ARC is vector-based, rather than raster-based, requires approximately 6 MB of hard disk space, and launches directly from ARC/INFO in UNIX.

Image conversion and FRAGSTATS pre-processing.

Image conversion and pre-processing required three steps: 1) subsetting the landuse mosaic, 2) conversion of raster image subsets to vector format, and 3) final preparation of each coverage in FRAGSTATS*ARC. A summary of the image conversion and pre-processing procedures is shown in Figure 7.

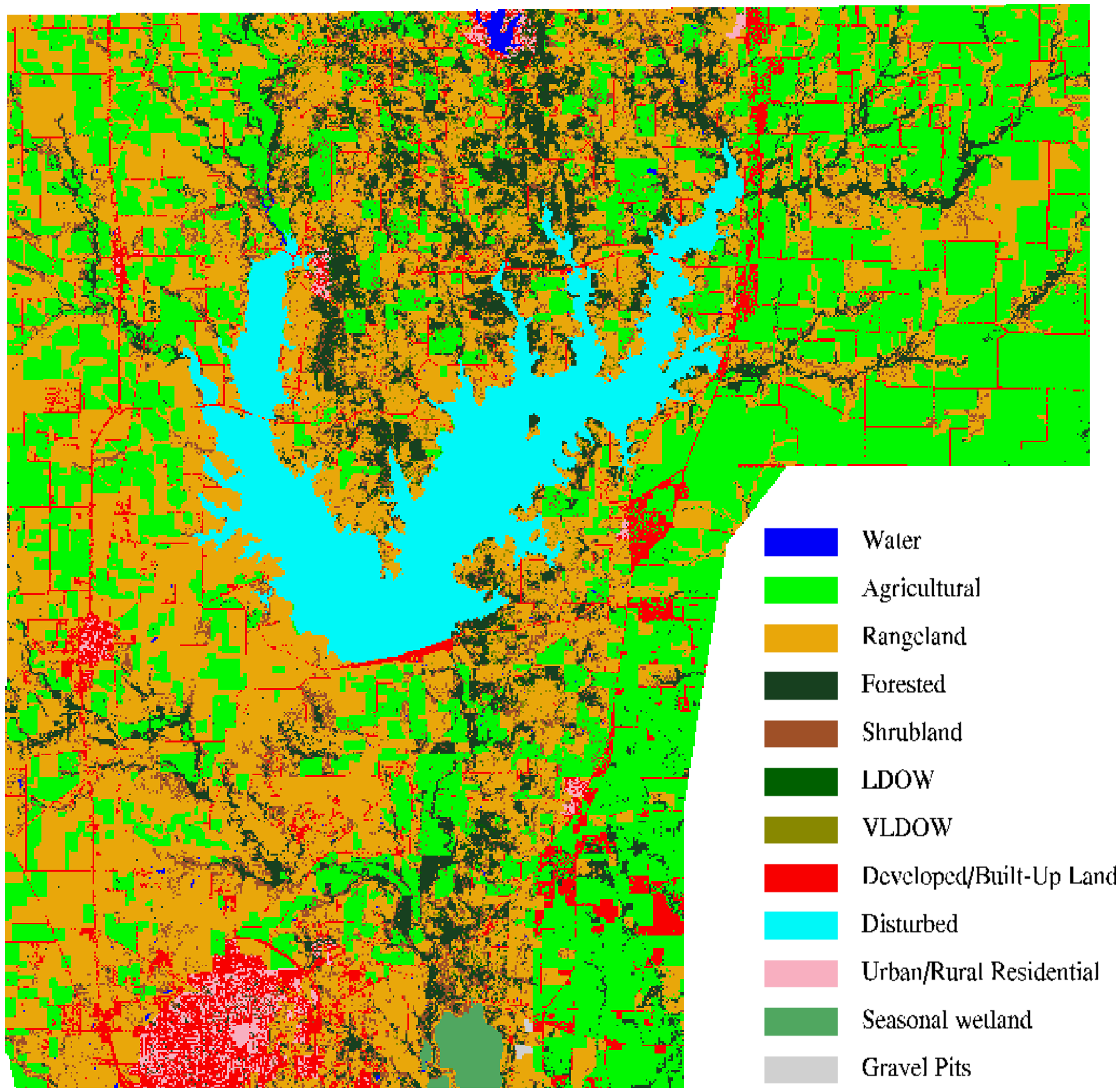


Figure 5. Classified landuse mosaic of the Ray Roberts Lake study area,1987.

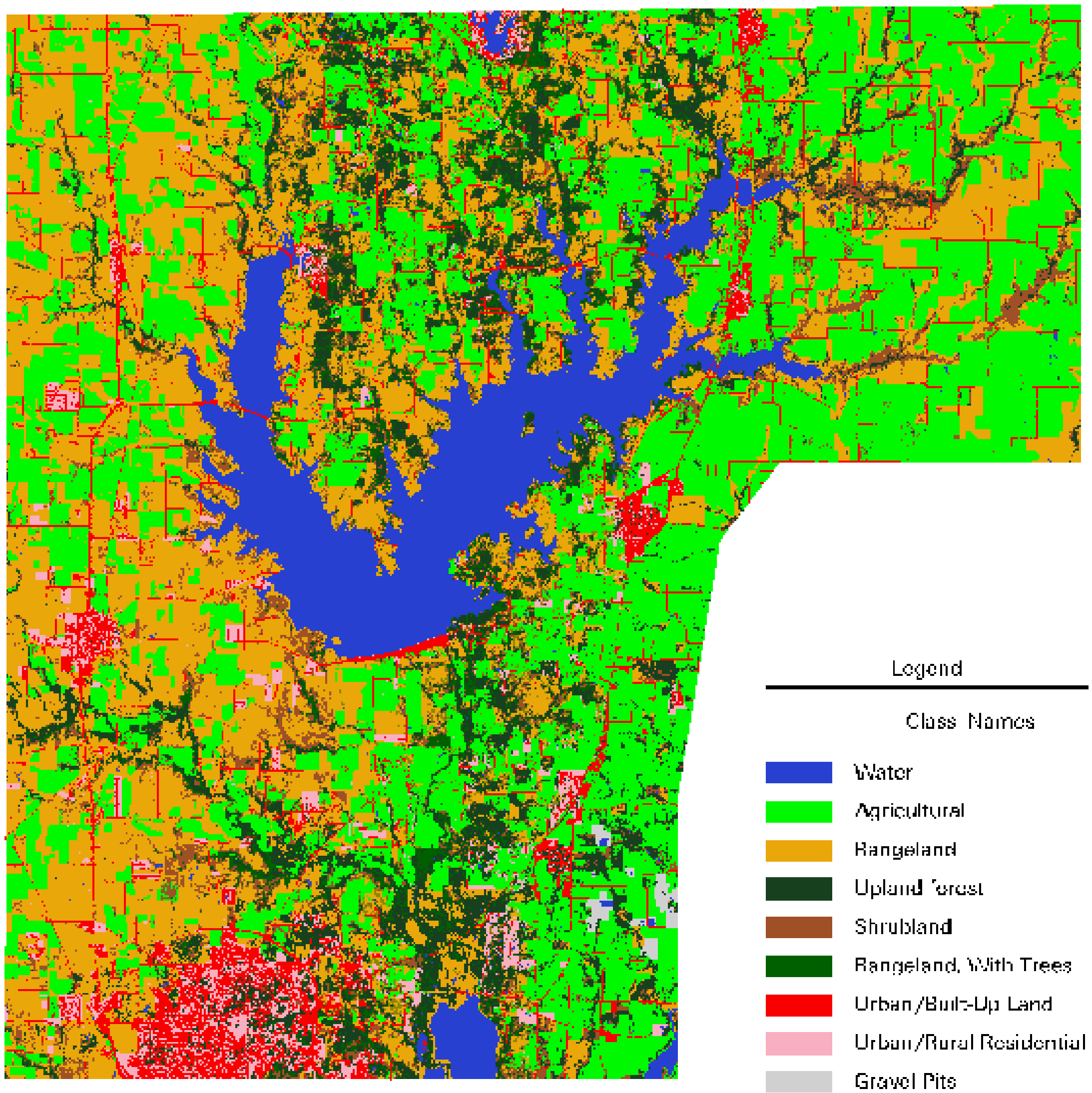


Figure 6. Classified landuse mosaic for the Ray Roberts Lake study area, 1997.

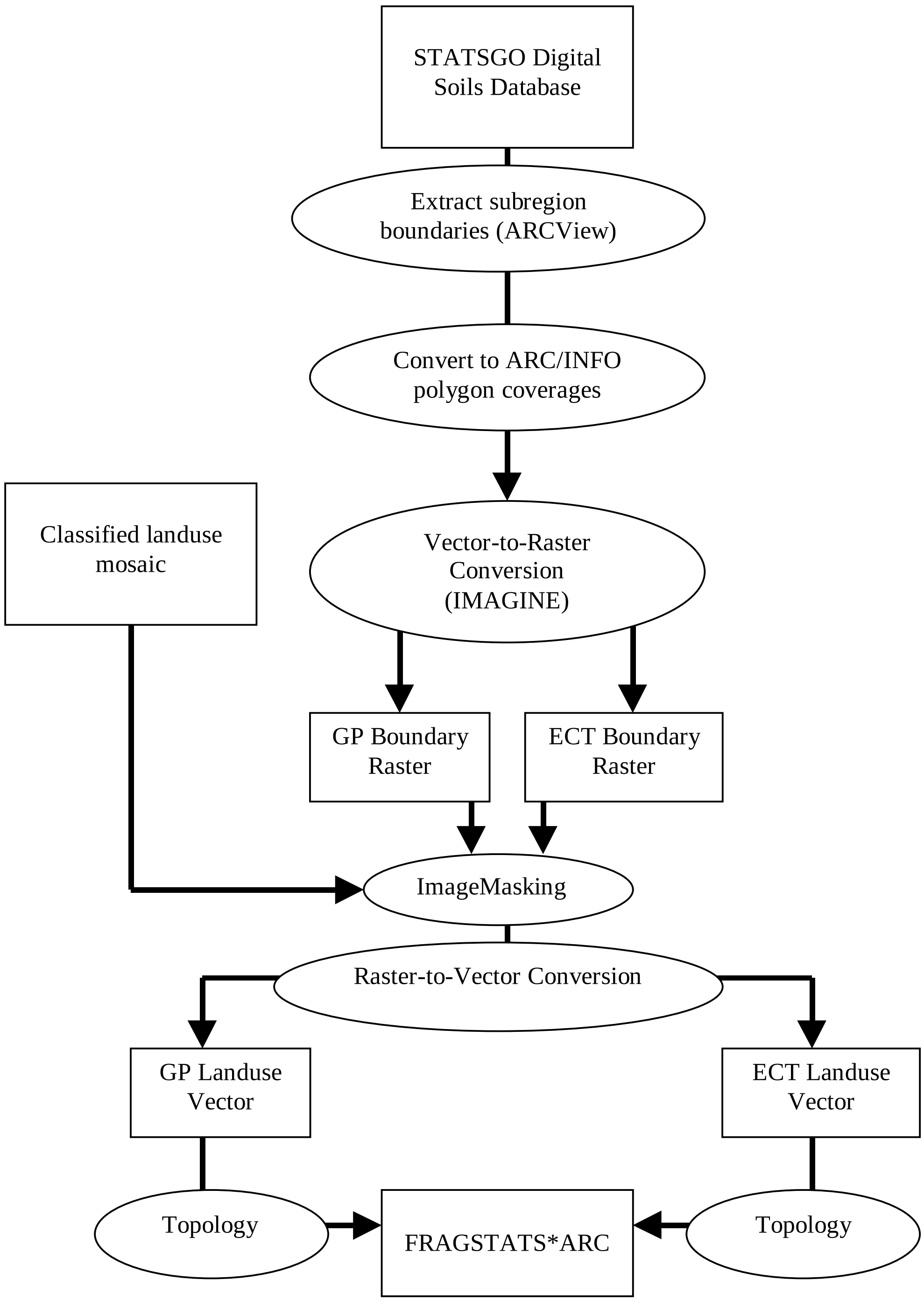


Figure 7. Flowchart summary of image conversion and FRAGSTATS*ARC preprocessing procedures.

The classified landuse mosaic for each year was subset according to the boundaries of the Grand Prairie and Eastern Cross Timbers physiographic regions. This was done because landuse in the study area has historically been based along physiographic lines. The Grand Prairie, for example, was settled primarily by cattle ranchers, while early farmers favored the Eastern Cross Timbers because of the region's richer soils (Lebo, 1995). In general, these patterns have persisted across time.

The boundaries of each physiographic region were extrapolated from soil type boundaries in the STATSGO Digital Soils Database using ARCView (ESRI, Version 3.1). In general, the Grand Prairie region is comprised of limestone and clay soils; the Eastern Cross Timbers is made up predominantly of deep sandy soils. Soil types in the study area were identified from the STATSGO database; clay soils west of the lake were selected for the Grand Prairie boundary and combined into a single vector coverage. Similarly, a vector coverage of the Eastern Cross Timbers boundary was defined by selecting sandy soils occupying the central portion of the study area.

The vector coverages were converted to raster images in IMAGINE. To create the Grand Prairie (GP) and Eastern Cross Timbers (ECT) subsets, the boundary images were then applied as masks to the landuse mosaic for each year. Masking creates a new image in which the user can specify that all areas falling outside of the mask are to be part of the background. The resulting GP and ECT images for each year (Figures 8 and 9) were converted to vector format in IMAGINE.

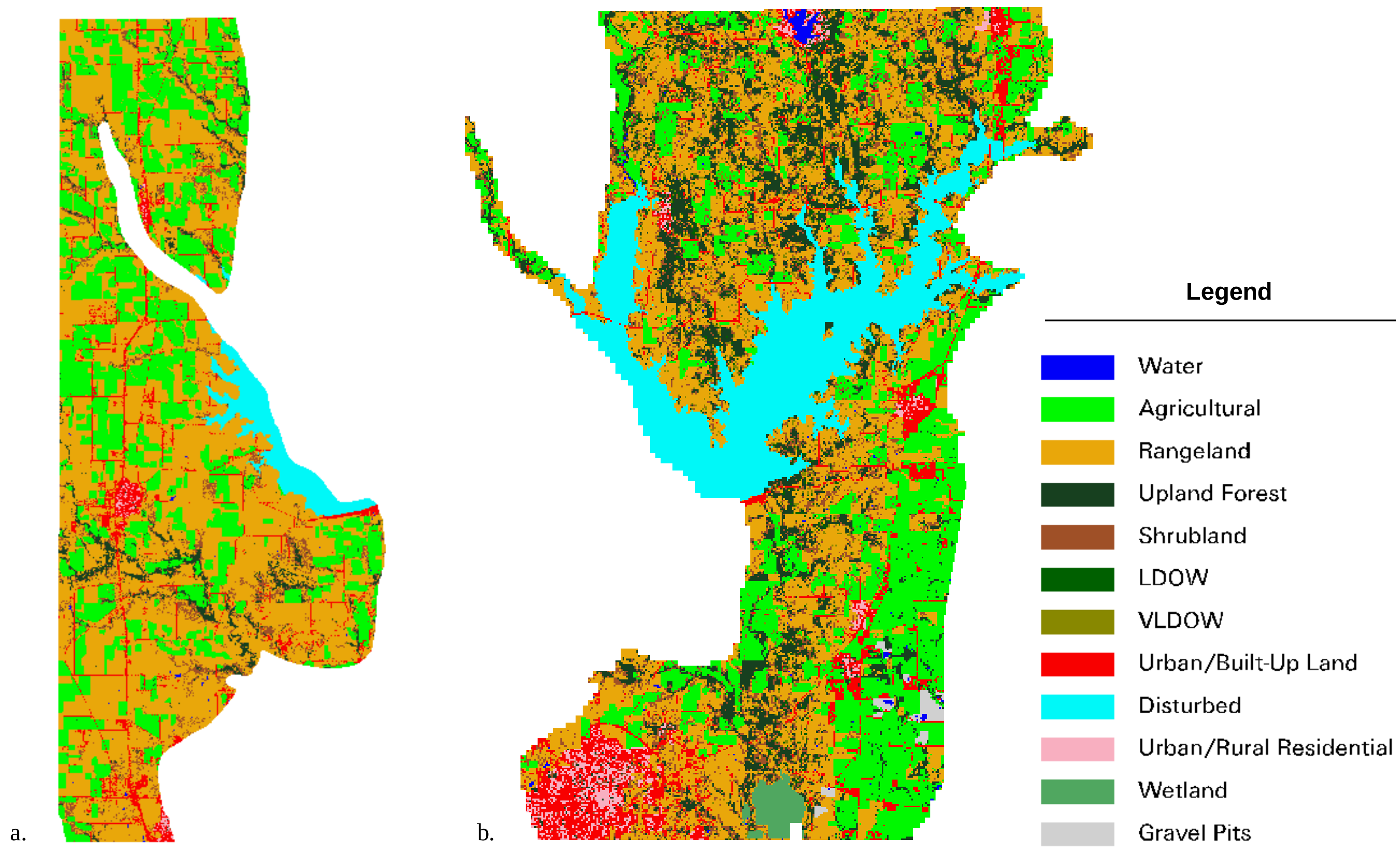


Figure 8. Subsets of the 1987 landuse mosaic according to (a) Grand Prairie and (b) Eastern Cross Timbers physiographic regions.

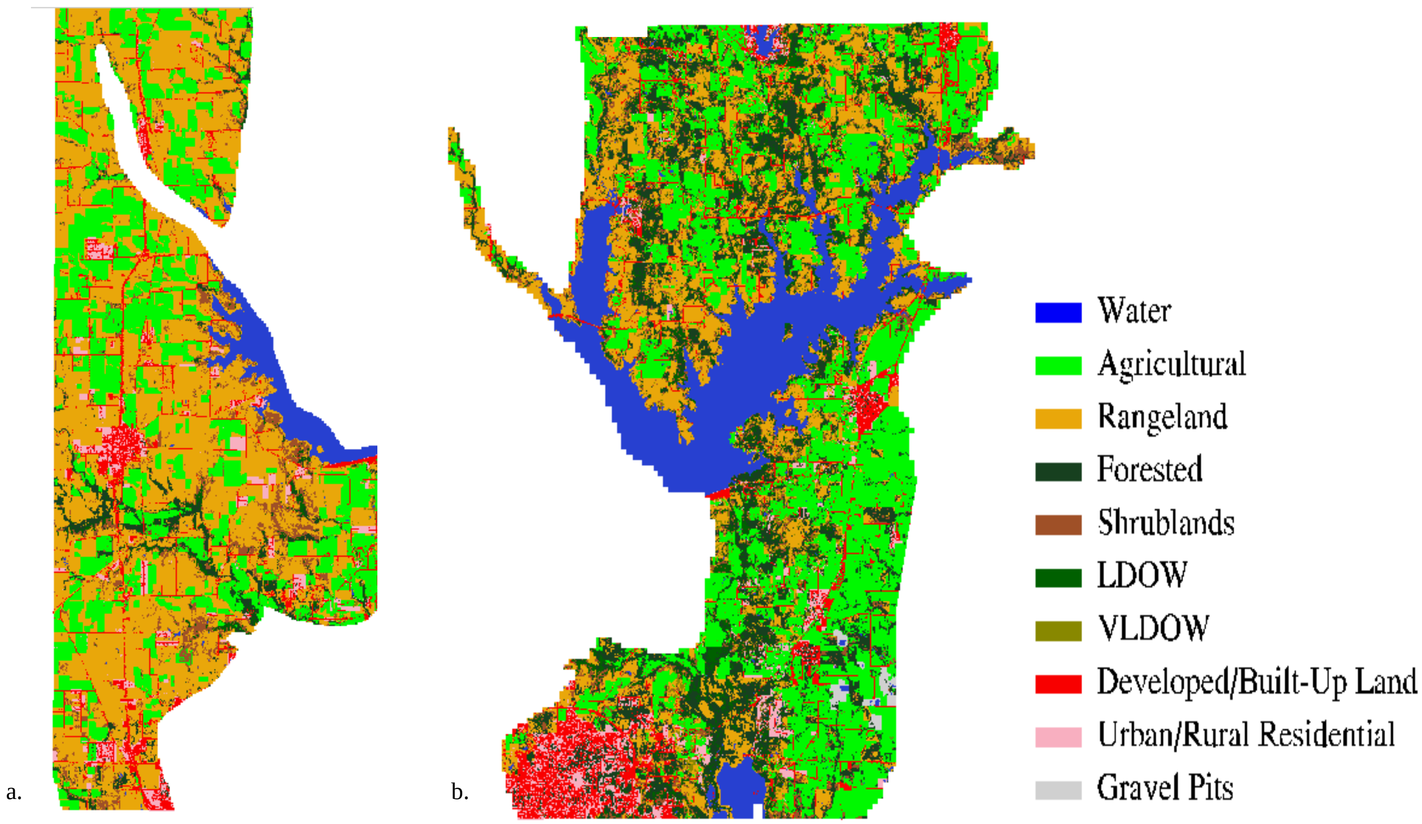


Figure 9. Raster subsets of the 1997 landuse mosaic according to (a) Grand Prairie and (b) Eastern Cross Timbers physiographic

Final preparation of the coverages was performed in FRAGSTATS*ARC. There are three requirements for coverages to be processed by FRAGSTATS*ARC: 1) the coverage must have polygon topology, 2) the coverage must have line topology, and 3) the coverage must contain a suitable patch attribute on which to base the analysis (Innovative GIS Solutions, Inc. [IGIS], 1998). Polygon and line topologies were established in FRAGSTATS*ARC after the images were converted from raster to vector format. The attribute item "GRID-CODE", contained in the INFO table for each vector coverage, was selected for use as the patch attribute for each analysis; the value of this item represented the numeric class value for each landuse class.

Selection Of Metrics And Landscape Analysis.

Initialization of a FRAGSTATS*ARC analysis follows an interactive automated four-step sequence: 1) selection of the coverage and verification of topology and patch attributes, 2) identification of background features, if any, to be excluded from the analysis, 3) selection of metrics, and 4) verification of analysis parameters. For all coverages, only the background (class value 0) was excluded from the analysis.

FRAGSTATS*ARC generates a spectrum of metrics, with the results of each analysis grouped according to patch, class, and landscape levels of analysis in separate output INFO files (MacGarigal et al., 1995). An additional output INFO file contains the edge metric values. There is no overall agreement on which metrics are most relevant to landscape analyses, and selection of which metrics to interpret for the landuse analysis is ultimately based on the goals of the analyst (MacGarigal et al., 1995).

Selection of metrics for this study was based on the ability of an individual metric to quantify information needed to support the objectives of the landuse analysis. Additionally, reliable quantitative and statistical methods to compare metrics are still being developed; thus, comparison of metric values from one year to the next was necessarily qualitative. Accordingly, metrics for this study were also chosen for their ability to complement and support other metrics in the analysis. Thus, the two primary criteria for selection of landscape metrics in the study were 1) sensitivity of the metric to changes in landscape heterogeneity and 2) the ability of the metric to quantify changes in individual patch types. Landscape metrics selected for this study are summarized in Table 3.

Three area metrics, calculated at the class level, were used in the landscape analysis. The first, class area (CA), was chosen to quantify the area of each patch type, or landuse/landcover category, in each of the subregions during the study period. The CA metric quantified changes in the proportion of these communities on the landscape between 1987 and 1997.

%LAND was selected to quantify the percentage of the landscape that is similar to a given class in each subregion for each study year. The %Land metric provides a summary of the landscape composition during each year. It is calculated as follows:

$$\%\text{LAND} = \frac{\sum_{j=1}^{n} a_{ij}}{\text{A}} (100)$$

where the total area (*a*) for all patches (*j*) in each class type (*i*) is divided by the total area (A) of the landscape, expressed as a percentage.

Table 2. List of metrics used in analysis of landscape structure in the Grand Prairie and Eastern Cross Timbers subregions of the Ray Roberts Lake study area.

Measurement Type	Scale	Metric	Description (units)
Composition:			
Area	Class	CA	Class area (hectares)
Area	Class	%LAND	Percent of landscape (%)
Area	Class	LPI	Largest patch index (%)
Diversity	Landscape	SHDI	Shannon's diversity index
Diversity	Landscape	SIDI	Simpson's diversity index
Diversity	Landscape	PR	Patch richness (#)
Diversity	Landscape	SHEI	Shannon's evenness index
Landscape pattern:			
Patch density	Class/Landscape	NP	Number of patches (#)
Patch size	Class/Landscape	MPS	Mean patch size (hectares)
Patch density	Class/Landscape	PD	Patch density (#/100 ha)
Patch size	Class/Landscape	PSSD	Patch size standard deviation (hectares)
Patch size	Class/Landscape	PSCV	Patch size coefficient of variation (%)
Shape	Class/Landscape	MSI	Mean shape index
Shape	Class/Landscape	AWMSI	Area-weighted mean shape index
Shape	Class/Landscape	DLFD	Fractal dimension

Landscape composition was quantified through calculation of four diversity indices: Shannon diversity (SHDI), Simpson's diversity (SIDI), Shannon's evenness (SHEI), and patch richness (PR). Calculation of the metrics is similar to the calculations described for plant community diversity, with the exception that the diversity metric reflects the abundance of different classes of patches rather than the abundance of different species of plants. FRAGSTATS*ARC calculates diversity indices only at the landscape level of analysis.

The patch density, size, and variability metrics were selected to quantify both landscape composition and temporal variation in landscape pattern, aiding in identification of trends in landscape heterogeneity. Patch density (PD) expresses the number of patches on a per unit area basis. As MacGarigal et al. (1995) suggest, patch density across the landscape mosaic could serve as a good heterogeneity index because a landscape with greater patch density would have more spatial heterogeneity.

The mean patch size (MPS) metric is also based on the number of patches in a given class. MPS can serve as a fragmentation index, although the metric does suffer from some limitations. Especially important is the minimum patch size, which in turn is determined by the resolution of the satellite image. Below this threshold, relationships between patches and classes cannot be determined. Additionally, MPS conveys the mean patch size without conveying any information about the number of patches being represented by the mean. Finally, because MPS is an average, valuable information about the variability of the patches within each class is not considered.

Accordingly, FRAGSTATS*ARC calculates two measures of variability: patch size standard deviation (PSSD) and patch size coefficient of variation (PSCV). PSSD reflects variability in absolute terms, while PSCV reflects variability in patch sizes about the mean patch size. The shape complexity metrics were chosen to quantify variation in class or landscape level complexity, which is also an indication of landscape heterogeneity.

Landscape composition was also quantified through four diversity metrics: patch richness (PR), Shannon evenness (SHEI), Shannon diversity (SHDI), and Simpson diversity (SHDI). All diversity metrics were calculated at the landscape level of analysis. Of these, patch richness (PR) and the evenness with which the patches are distributed among the class types (SHEI) received emphasis.

Plant Community Analysis

Plant community analysis consisted of two phases: 1) vegetation analysis and 2) temporal analysis of community diversity. Species abundance data from monitoring associated with the Lake Ray Roberts Post-Impoundment Study conducted by the Institute for Applied Sciences were available for 1987 (IAS, 1988), 1992 (IAS, 1992), 1995, (IAS, 1995) and 1997 (manuscript in preparation).

Vegetation analysis was conducted along four permanent transects that were established during the 1987 pre-impoundment environmental study, following consultation with the Fort Worth District of the U. S. Army Corps of Engineers. Adequate representation of the Project Area was the primary consideration in designation of transects. Transect locations are shown in Figure 10, descriptions of the length and habitat types of the transects are provided in Table 4. Each transect was divided into sections according to the habitat types present when the transects were established in 1986.

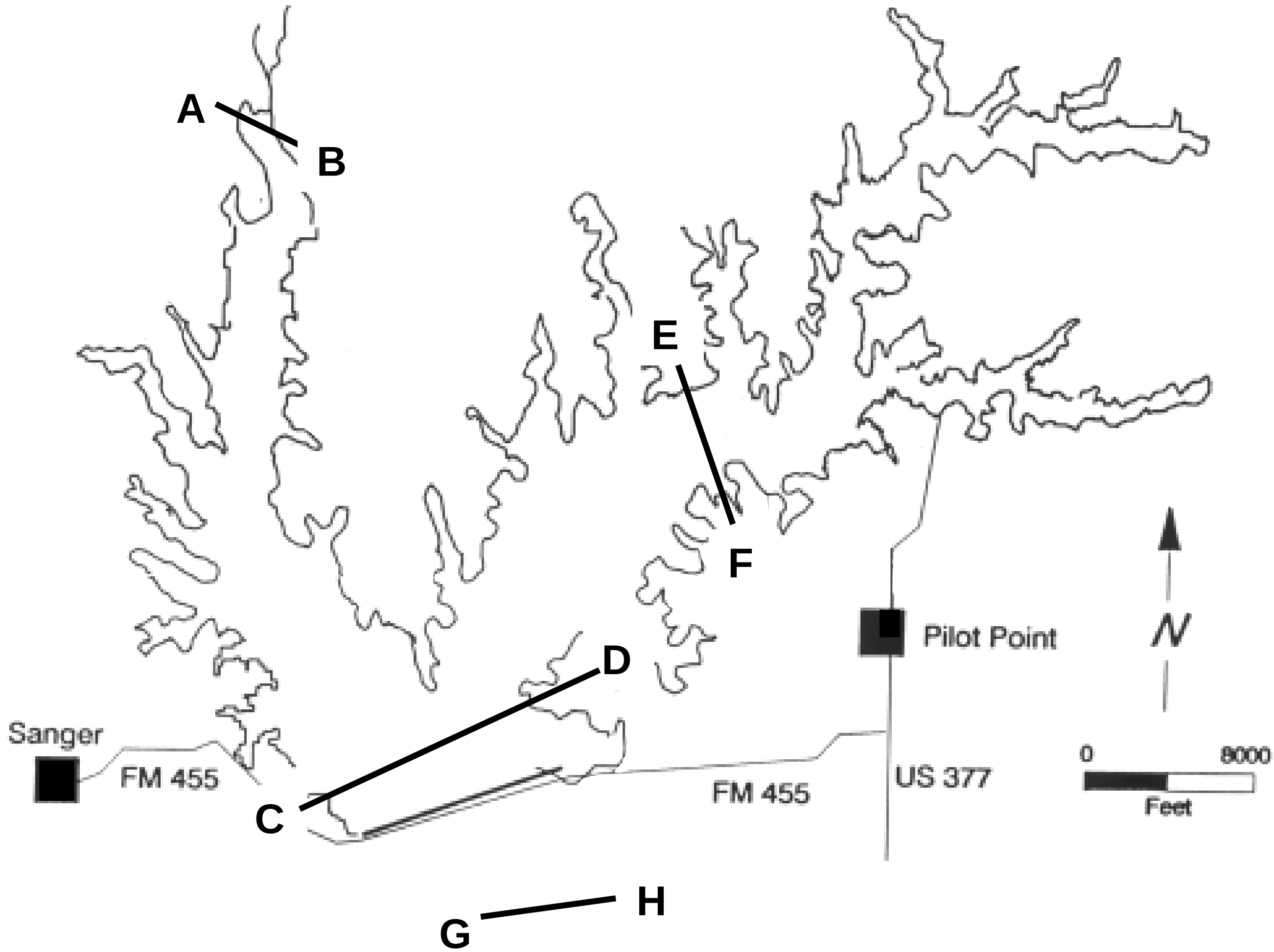


Figure 10. Location of vegetation monitoring transects in the Ray Roberts Lake study area.

Table 3. Description of vegetation monitoring transects in the Ray Roberts Lake study area.

Transect Section	Length (m)	Plant Community
AB1	160	Mesquite Shrubland
AB6	70	Mixed Shrubland
CD1	720	Oldfield/Rangeland
CD2	770	Oldfield/Rangeland
CD7	490	Upland Forest
CD8	720	Mixed Shrubland
CD9	460	Upland Forest
CD10	1010	Oldfield
EF1	965	Oldfield/Rangeland
EF9	575	Oldfield/Rangeland
EF10	450	Oldfield/Rangeland
GH3	125	Bottomland Forest

Three transects are located within the reservoir acquisition boundaries, extending across both the Elm Fork River (transect AB) and Isle du Bois River (transect EF) arms of the lake and across the main body of the lake (transect CD). The fourth transect (transect GH) is located across the Elm Fork, downstream from the reservoir's dam.

Floral inventories and community structure were monitored during the spring and fall of each study year according to the following divisions:

- Trees = woody plants greater than 6.5 ft (2 m) in height and 1 in (2.5 cm) DBH (diameter at breast height)
- Shrubs = woody plants less than 6.5 ft (2 m) in height or 1 in (2.5 cm) DBH.
- Herbs = non-woody annual or perennial grasses and forbs.

For the year-two, year-six, and year-ten post-impoundment studies, herbs were surveyed with a rectangular quadrat (0.1 m^2) according to the point-centered quarter method, in which five equidistant sampling sites were located along each transect section.

At each sampling site the quadrat was randomly placed five times, giving a total of 25 sampling points for each transect section. Within each of the 25 quadrats, the species present were noted and the following field measurements were recorded: percent herbaceous ground cover, average height, and total number. Vegetative community structure within each transect section was described through calculation of density, dominance, frequency, and importance values as described in the Ray Roberts Lake year-six post-impoundment study (IAS, 1995).

It is noted that the survey methodology used for the year-two, year-six, and year-ten post-impoundment studies differs from that of the 1986 pre-impoundment survey, in which circular quadrats were used. The change in 1989 from circular quadrats to smaller rectangular quadrats resulted in improved ground coverage estimation and more comprehensive site sampling during all subsequent studies. A detailed description of the circular quadrat method used in the pre-impoundment study may be found in the pre-impoundment report (IAS, 1988).

Temporal Analysis Of Community Diversity

Analysis of changes in community diversity between 1987 and 1997 required two stages: 1) delineation of the study area into Grand Prairie and Eastern Cross Timbers physiographic regions, and 2) selection and calculation of appropriate diversity indices. As with the landscape analysis, temporal analysis of vegetative communities was accomplished according to physiographic region. The vegetation monitoring transects were visually compared with the Grand Prairie and Eastern Cross Timbers boundaries to assign them to a physiographic region for the community analysis.

In terms of plant community analysis, the simplest measure of biodiversity is species diversity, which considers both the number of species and the evenness with which individuals are distributed across those species. Although numerous measures of diversity have been proposed, none has received unanimous support. MacGurran (1988) provides a detailed and useful review of many of these indices and their drawbacks.

Four traditional and commonly accepted measures of plant community diversity were calculated: Shannon-Wiener diversity index, Simpson’s dominance index, species richness, and Shannon evenness. Species richness is simply the number of species (S) observed at each transect during a given monitoring year.

Calculation of Shannon diversity for each year at each transect section follows Brower, Zar, and von Ende (1989) and MacGurran (1988):

$$H = -\sum_{i=1}^{s}(p_i)(\log_2 p_i)$$

where

H = information content of sample = index of species diversity

s = number of species

p_i = proportion of total sample belonging to the *i*th species

Two components of diversity are combined in the Shannon-Wiener function: 1) number of species and 2) equitability or evenness of allotment of individuals among the species (Greig-Smith, 1983). The Shannon index is abundance driven, meaning that it is weighted towards those species that are represented by the greatest number of individuals. As a result, a greater number of species increases species diversity, and a more even, or equitable, distribution of individuals among species will also increase species diversity measured by the Shannon-Wiener function. As Tivy (1993) notes, abundance driven models are particularly appropriate to analysis of grassland communities (e.g. Grand Prairie grasslands), because the dominance of grasses in the community is based on abundance and biomass.

Statistical analysis of the significance of differences between Shannon diversity from one year to the next was accomplished using a Student's-t test, as described by Brower et al. (1989). To compare Shannon diversity indices from two collections of data (H_1' and H_2'), the variance (s^2) of the index for each dataset was calculated:

$$s^2 = \frac{\sum f_i \log^2 f_i - (\sum f_i \log f_I)^2 / n}{n^2}$$

where *fi* is the number of individuals in each species and *n* represents the total number of individuals sampled. Then, a value of *t* was determined from:

$$t = \frac{H_1' - H_2'}{(s_1^2 + s_2^2)^{1/2}}$$

and compared to the critical value of Student's *t* ($\alpha = 0.05$) with the following degrees of freedom (DF):

$$DF = \frac{(s^2_{H1'} + s^2_{H2'})^2}{\frac{(s^2_{H1'})^2}{n_1} + \frac{(s^2_{H2'})^2}{n_2}}$$

Simpson's dominance index was also calculated. The Simpson metric was selected because it is weighted toward the abundance of the most common species and is commonly accepted. Weighting the metric to the abundance of the most common species is based on the concept that, in general, in most communities a few species are very common and dominate the community while the remainder are considered rare.

Calculation of Simpson's dominance index follows Brower et al. (1989):

$$D = \frac{\Sigma n_i(n_i - 1)}{N(N - 1)}$$

where n_i is the number of individuals in a given species and N is the total number of individuals in the dataset. A large value of D is interpreted to mean that a large number of individuals are distributed in only a few species, indicating that the community is relatively homogenous. Conversely, a small value of D means that the individuals are distributed across species more evenly and the community is, therefore, more heterogeneous.

In addition to Shannon diversity and Simpson's dominance indices, the evenness with which individuals are distributed across species in the community was also determined. Measurement of evenness, or equitability, of distribution first requires determining the maximum diversity of a community possible if all species were assumed equally abundant:

$$H_{\max} = \ln S$$

where:

$H_{\max}$ = species diversity when all species are equally abundant

S = number of species in the community

Equitability or evenness is then defined as the ratio between observed species diversity and maximum species diversity:

$$E = \frac{H}{H_{\max}}$$

The final community analysis that was performed was log series modeling through calculation of Fisher's α. As described by MacGurran (1988), Fisher's logarithmic series model describes the relationship between the number of species and the number of individuals representing the species in the community. The model predicts a small number of abundant species and a large proportion of "rare" species; as such, it generally fits communities where one or a few factors dominate the ecology of the community.

This is important in light of Watt's work, which shows that community composition is the sum total of processes occurring across a series of smaller patches in the community. The number of patches is in turn controlled by the scale and number of the factors underlying the flow of these processes.

The composition of grasslands on the Grand Prairie and the oak woodlands of the Eastern Cross Timbers are generally controlled by a small number of natural and anthropogenic factors, the most important of which are soil type and disturbance intensity. With soil type held constant across the study period, therefore, disturbance (e.g grazing, mowing, and rotation cropping) is predicted to be the controlling factor. The log series model was chosen to verify this hypothesis.

The log series takes the form:

$$\alpha x,\ \frac{\alpha x^2}{2}, \frac{\alpha x^3}{3}, \ldots \frac{\alpha x^n}{n}$$

where αx is the number of species predicted to have one individual, $\alpha x^2 / 2$ those with two individuals, and so on. Fitting the series requires estimation of the x and α parameters. The parameter x is estimated from iteration of the following term:

$$S/N = [(1 - x)/x][-\ln(1 - x)]$$

where S is the total number of species and N is the total number of individuals. According to MacGurran, x is usually greater than 0.9 and always less than 1.0, providing useful guidance for a starting point in estimating the parameter.

After x was determined, α was calculated from:

$$\alpha = \frac{N(1-x)}{x}$$

where α is an index of diversity. Estimation of both x and α was accomplished using EXCEL (Microsoft, Version 7.0) and S-PLUS (Mathsoft, Version 4.0). For each transect section, the ratio of S to N was calculated in EXCEL. A table of values for x was compiled in EXCEL and transformed into a vector in S-PLUS to estimate the value of x for each transect section.

Once the model parameters were calculated, the number of species expected to have 1, 2, 3, … n individuals were calculated and a table giving the number of expected and observed species in each abundance class was compiled. Abundance intervals were defined on a base 2 logarithmic scale. Statistical comparison of the two distributions was accomplished using a chi-square goodness of fit (GOF) test, where:

$$\Sigma\chi^2 = \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}}$$

was calculated for each abundance class and compared to the χ^2 distribution with degrees of freedom equal to the number of classes – 1.

CHAPTER IV

RESULTS AND DISCUSSION

Overview Of General Landuse Trends, 1840 – 1990

A review of the history of the Lake Ray Roberts area indicates that there were probably three main periods of landscape change in the region. First, the primary settlement period, which ranged from 1840 to approximately 1900. This was followed by a relatively static period of agriculture and ranching from the early 1900s to around 1960. The final period has been characterized by post-impoundment related shifts in landuse and development occurring between 1987 and 1997.

The period from approximately 1840 to 1900 was the primary settlement period, during which the present-day predominance of agriculture and ranching was established across the study area. Initial settlement began in the 1840s in the Eastern Cross Timbers, as early colonists followed major waterways such as the Elm Fork of the Trinity River. At the time, the area was described as being densely wooded by post oak and blackjack oak, with a thick understory of greenbriar (Kendall, 1845).

Although the Eastern Cross Timbers were described as an impenetrable thicket (Bates, 1918), early settlers discovered that, once cleared, the deep sandy soils in the area provided excellent farmland. Consequently, the woodlands of the Eastern Cross Timbers were cleared extensively during the 19th century as direct consequence of several human activities, including construction of buildings on rural farmsteads, firewood, and clearing acreage for farming (Lebo, 1995). Typically, farms were initially granted as 160-acre or 320-acre claims.

The Grand Prairie was found to be suitable for cattle ranching. As the western edge of settlement, farming, and ranching spread west of Cooke and Denton counties in the 1860s, a higher percentage of cattlemen settled and established ranches in these two counties (Lebo, 1995). During this period of rapid growth, the number of cattle in Denton County grew from just over 15,000 head in 1857 to nearly 50,000 in 1861 (Bridges, 1978). In fact, with the elimination of natural prairie fires, the most significant influence on Grand Prairie vegetation in the 1860s was cattle grazing (Dyksterhuis, 1946).

The Ray Roberts Lake area was characterized by subsistence farming during the post-Civil War period. By 1870, most of the area's arable farmland had been claimed (Lebo, 1996) and the median farm size ranged between 50 and 99 acres, with the primary crops being corn, wheat, oats, and sorghum (U. S. Bureau of Census, 1870). Cotton tenant farming and sharecropping occurred in both the Grand Prairie and the Eastern Cross Timbers regions, and grew in economic importance throughout the remainder of the 19th century.

Lebo (1995) notes two major changes in agricultural practices that would have had significant impact on the late 19th century Ray Roberts Lake landscape. First, the introduction of barbed wire in 1874 meant that, for the first time, farmers could fence cattle in rather than fencing their crops to keep the cattle out. The consequence of this was that the amount of open range decreased dramatically between 1874 and 1900.

The second major change was the arrival of the railroad. In terms of landscape change, the immediate impact of improved railway access was that more land was put into cash crop production between 1875 and 1900. In fact, the period from the post-Civil war to the turn-of-the-century was characterized by steady increases in both the number of farms and in average farm size throughout the study area. The total number of farms in Denton county increased from 566 in 1870 to over 5,000 in 1900 while the median farm size rose to between 100 and 500 acres (Lebo, 1995).

Between 1900 and approximately 1960, farming and cattle ranching remained the most significant landuses in the area. The landscape seems to have been characterized by a shifting mosaic of these landuses as farms grew smaller and more numerous and cattle ranching began to diminish in economic importance.

Although no direct analysis of the stability of the landscape during this period can be made due to lack of supporting quantitative data, there is some indication that the agricultural and ranching pattern did remain relatively constant. For example, a 1972 assessment of the impacts of the then-proposed reservoir on local families showed that several families living in the reservoir site had occupied their property for more than 50 years and that some farms had been in the same family since the mid- to late-1800's (IAS, 1972).

Around 1960, it was determined that production of grains was more sound economically than growing previously important crops like peanuts and cotton. Growing grains was less work and required less labor than growing corn or cotton (Lebo, 1995). Accordingly, around 1964 a shift from cotton-wheat-corn farming to a sorghum-wheat-fallow agricultural system began to occur throughout both the Grand Prairie and Eastern Cross Timbers regions of the study area. Associated with this shift, large parcels of land previously devoted to cattle grazing were plowed, likely resulting in additional landscape fragmentation and associated loss of rangelands.

Although cattle grazing had declined in economic importance from its peak in the 19th century, ranching remained an extremely important component on the landscape in the period preceding impoundment of the reservoir. In fact, by the early 1970's there were no completely natural areas that remained and much of the reservoir site was being grazed to capacity (IAS, 1972).

The final period of landscape change occurred with the impoundment of Lake Ray Roberts in 1988. According to landuse monitoring studies conducted by the Institute of Applied Sciences at the University of North Texas, during the period following impoundment of Ray Roberts Lake no major change in the general landuse character of the surrounding landscape occurred. Between 1987 (IAS, 1988) and 1997 (manuscript in preparation) the predominant landuse was agricultural, followed by cattle ranching on native rangelands.

The implication from these trends in landuse and landscape change is that the major fragmentation processes that created the basic landscape pattern that exists in the region today occurred approximately 150 years ago. Particularly, in the Eastern Cross Timbers region of the study area clearing during the 19th century resulted in heavy fragmentation of upland oak woodlands; review of the area's history indicates that this pattern has persisted into present-day time. The Lake Ray Roberts area, therefore, has been human-dominated and, from an ecological perspective, heavily disturbed for over a century. Consequently, it can be concluded that all of the non-forested lands in the study area can be characterized as either disturbance, regenerative, or introduced patches. In the presence of continuing disturbance across the landscape, it is expected that the plant communities have generally remained in a static successionary state as a result of sustained disturbance from grazing and crop rotation.

Landscape characterization

The objective of characterizing temporal variation in landscape composition and pattern was to determine 1) whether the Ray Roberts Lake landscape can be characterized as disturbed and 2) whether the mosaic has been maintained at a steady state equilibrium during the 1987-1997 study period. Key to interpreting landscape metrics is the fact that the landscape in the baseline year, 1987, is assumed to be human-dominated. This assumption is based upon both inference from the area's landuse history as well as a high percentage of human-related landuse, as opposed to natural landcover such as upland forests or native grasslands, across the region.

Landuse classification accuracy

The results of the classification accuracy assessment are summarized in Table 2. Overall classification accuracy is the average of individual class accuracies. Several classes show 100% accuracy; this is explained by the fact that heavy reliance was placed on photointerpretation, which is more accurate than use of spectral properties alone. Overall image classification accuracy was 93% for the 1987 image and 91% for the 1997 image.

Table 4. Summary of accuracy assessment results.

Class Name	1987		1997	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Water	100	100	100	100
Agricultural	100	100	98.88	100
Rangeland	81.82	94.74	89.86	95.38
Forested	53.85	100	67.86	90.48
Shrubland	75	50	66.67	30.77
LDOW	100	55.56	50	44.44
VLDOW	100	62.50	0	0
Developed/ Built-Up Land	100	100	100	100
Disturbed	100	100	---	---
Residential	100	100	100	100
Seasonal Wetland	100	100	---	---
Gravel Pits	---	---	---	---

<u>Landscape composition, 1987-1997, Grand Prairie section.</u>

The Grand Prairie region of the Ray Roberts Lake study area has been predominantly rangeland, followed by sorghum-wheat agriculture, for the entire study period. The number of patches (NP), class area (CA), mean patch size (MPS), percent landscape (%Land) (Table 5), and landscape level diversity metrics (Table 6) summarize landscape composition. Interpretation of the NP, CA, and MPS metrics is straightforward; the %Land metric is interpreted as the percentage of the landscape comprised of a given patch class.

Table 5. Class-level landscape composition metric values for the Grand Prairie region of the Ray Roberts Lake study area, 1987 – 1997 (terms defined in text).

Patch Class	CA		%Land		LPI		NP		MPS		PD	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Water	33.64	1414.57	0.089	3.720	0.010	3.540	111	130	0.303	10.881	0.292	0.342
Agriculture	10907.80	9887.08	28.711	25.997	0.783	0.740	631	773	17.287	12.791	1.661	2.033
Rangeland	20458.92	19220.36	53.851	50.539	3.278	4.556	3283	2969	6.232	6.474	8.641	7.807
Forested	1172.03	1171.24	3.085	3.080	0.201	0.271	2831	2296	0.414	0.510	7.452	6.037
Shrubland	1702.80	2064.60	4.482	5.429	0.079	0.283	7846	5949	0.217	0.347	20.652	15.642
LDOW	2.62	501.29	0.007	1.318	0.001	0.052	40	2272	0.066	0.221	0.105	5.974
VLDOW	12.87	65.94	0.034	0.173	0.001	0.006	199	460	0.065	0.143	0.524	1.210
Urban/Built-up	2220.53	2521.89	5.845	6.631	1.316	1.468	2347	2262	0.946	1.115	6.178	5.948
Residential	96.33	1156.32	0.254	3.041	0.034	0.117	336	1294	0.287	0.894	0.884	3.402
Disturbed	1381.24	--	3.636	--	3.553	--	19	--	72.697	--	0.050	--

Table 6. Landscape level composition and pattern metrics for the Grand Prairie and Eastern Cross Timbers regions of the Ray Roberts Lake study area (terms defined in text).

Landscape Metric	Grand Prairie		Eastern Cross Timbers	
	1987	1997	1987	1997
Composition:				
SHDI	1.249	1.443	1.897	2.004
SDI	0.620	0.666	0.811	0.834
PR	10	10	12	11
SHEI	0.543	0.627	0.763	0.836
Pattern:				
NP	17643	18674	84968	96563
MPS	2.153	2.037	0.797	0.702
PD	46.439	49.102	125.434	142.547
PSSD	24.693	24.937	32.287	26.555
PSCV	1146.91	1224.20	4051.07	3782.76
MSI	1.357	1.365	1.291	1.287
AWMSI	4.459	4.438	5.795	4.172
DLFD	-23.520	-24.033	-35.976	-37.163

The diversity metrics (Table 6) indicate that the Grand Prairie has become generally more diverse between 1987 and 1997. This is reflected in increased values for both the Shannon diversity (SHDI) and Simpson's diversity (SDI) indices. Both metrics are a function of the number of patch classes (PR) and the total number of patches (NP). Given that patch richness remained constant between study years, the increase observed in SHDI and SDI values can be attributed directly to the increase in NP. Increases in these landscape diversity metrics indicate that the Grand Prairie section of the study area became more heterogeneous during the 10-year period.

The Shannon evenness index also increased during the study period (Table 6). The maximum value of SHEI is 1, indicating a perfectly even distribution of area among the different classes of patches. Thus, while the Grand Prairie section has become more diverse in terms of the number of landuse patches present, the distribution of area among the different classes of patches has become more even. Diversity and evenness indices, however, do not address changes within specific patch classes and they must, therefore, be interpreted in concert with additional landscape composition metrics.

The %Land metric (Table 5) indicates that over half of the Grand Prairie section has been comprised of grazed rangeland during the entire study period, although both the NP and CA metrics decreased from 3,283 patches comprising 20,459 hectares in 1987 to 2,969 patches on 19,220 hectares in 1997. The next most common class was agriculture, which also decreased in class area from 10,907.80 hectares in 1987 to 9,887.08 hectares in 1997. Unlike the rangeland class, however, the total number of agricultural patches increased between study years.

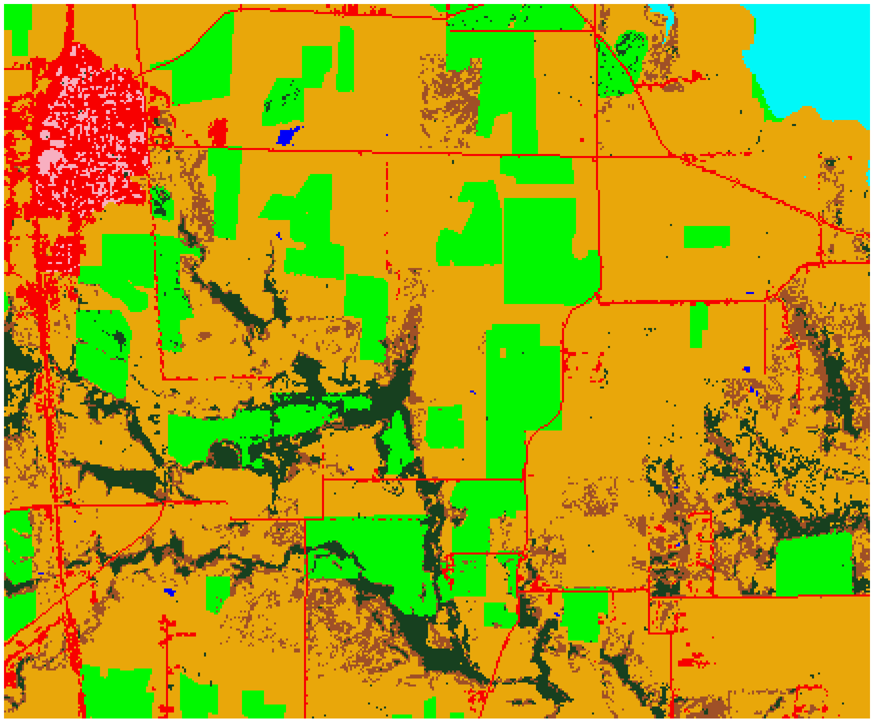
Significant change occurred in the shrubland, transitional woodland (LDOW and VLDOW), and developed classes during the study period. Although the number of shrubland patches decreased from 7,846 in 1987 to 5,949 in 1997, both the class area and the %Land values increased. These trends are reflected in the increase observed in mean patch size (MPS) from 0.217 hectares in 1987 to 0.347 hectares in 1997. Transitional woodland classes (LDOW and VLDOW) also showed significant increase in class area, with corresponding increases in the number of patches and mean patch size.

Comparison of the two Grand Prairie images showed that numerous patches of shrubland disappeared while others appeared across the mosaic between 1987 and 1997. Shrublands are found in rangeland areas in the Grand Prairie section of the study area, occurring as natural riparian habitat or as a transitional stage in overgrazed or abandoned range. Because shrubland cover occurs in grazed range, they are subject to periodic clearing efforts by property owners, possibly explaining the disappearance of some of the patches.

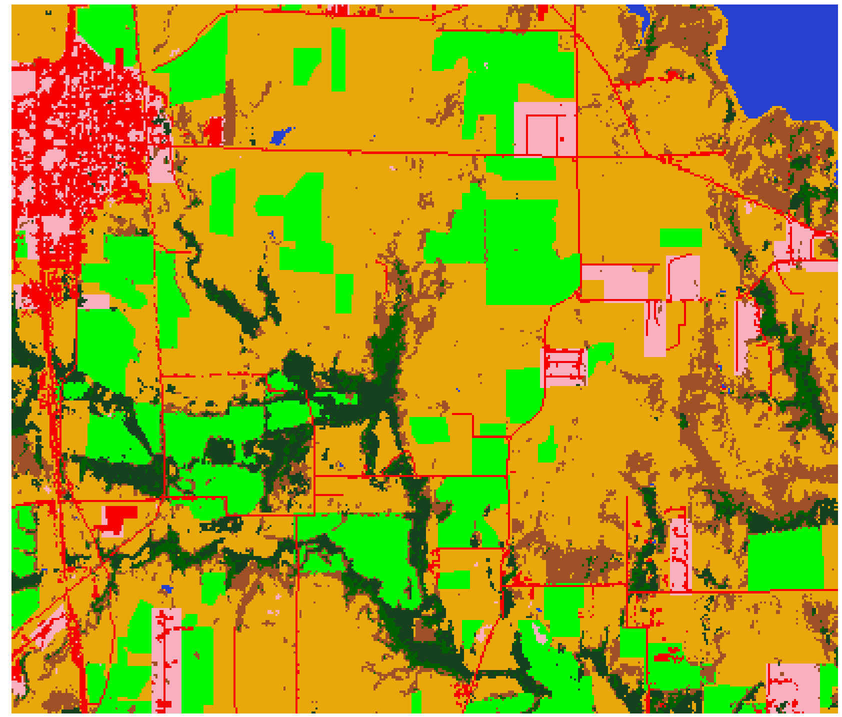
Additionally, some shrubland patches transitioned to low density oak woodlands during the study period, further accounting for the disappearance of some shrubland patches and the corresponding increase in number of transitional woodland patches. Many of the shrubland patches that appeared between 1987 and 1997 occur in abandoned rangeland fields along the margins of Ray Roberts Lake. Some examples of these patch dynamics can be seen in the image subsets shown in Figure 11.

Development in the Grand Prairie section during the 1987-1997 period has consisted primarily of rural development, particularly with the appearance of new housing along lake margins and the expansion of rural neighborhoods. It is, therefore, not surprising that urban/rural residential classes showed increases in the value of all landscape composition metrics (Table 5). It is likely that the increase in the urban/built-up land class reflects the increase in residential development, probably as a result of construction of roads in these areas.

Thus, the landscape composition of the Grand Prairie section of the study area has shown some level of change between study years. This change has been manifested



a.



b.

Figure 11. Subsets from Grand Prairie section showing the distribution of shrublands (dark brown) and low density oak woodlands (medium green) in a) 1987 and b) 1997. Transition of shrublands to low density oak woodlands between study years is evident along the riparian corridors seen in the image subset.

through rural development, continuing transition of some grazed range to shrubland, and transition of some mixed shrublands low density oak woodlands along riparian corridors. These dynamics are reflected in the landscape composition metrics as an increase in the total number of patches on the landscape. Additionally, as the number of patches has increased, the mean size of patches has decreased.

Landscape pattern, 1987-1997, Grand Prairie.

Initial comparison of aerial photographs showed that relatively large patches of grazed range and cropland with a few forested riparian corridors characterized the Grand Prairie in both 1987 and 1997. Furthermore, the boundaries of agriculture and rangeland patches across the Ray Roberts Lake study area were primarily determined by private property boundaries. These boundaries were comprised primarily of fencerows and roads and were generally linear in shape; they did not change visibly from 1987 to 1997.

Several metrics, including some of the metrics used to quantify composition (e.g. NP and MPS), also quantify landscape pattern (Tables 6 and 7). Key to the interpretation of landscape pattern metrics is an understanding of the baseline condition of the landscape being analyzed. A landscape that is disturbed chronically by agriculture, for example, may show the same stability in landscape pattern across a given time period as does an undisturbed landscape. The Grand Prairie's well-documented history of cattle ranching and cash crop production, in concert with interpretation of the landscape metrics for the 1987-1997 period, make it reasonable to assume that the 1987 baseline landscape can be characterized as disturbed.

In general, the total number of patches increased and were distributed more densely across the Grand Prairie portion of the Ray Roberts landscape. Accompanying these increases, mean patch size decreased from 2.153 hectares in 1987 to 2.037 hectares in 1997 (Table 6). According to Forman (1995), increasing patch number and patch density, with associated decreases in average patch size, are consistent with one of two key landscape processes: habitat fragmentation or landscape dissection. However, MacGarigal et al. (1998) point out that while the NP, PD, and MPS metrics can provide an indication of landscape pattern and process, they do not capture explicitly possibly important variations in patch size. Therefore, identification of the processes operating across the Ray Roberts Lake study area also requires consideration of patch variability.

Patch variability is summarized by patch size standard deviation (PSSD) and patch size coefficient of variation (PSCV). PSSD is a measure of absolute variation in patch size while PSCV reflects the variability in patch size with respect to the mean. In comparing two landscapes, it is important to note that PSSD must be interpreted in the context of mean patch size because, while the landscapes being compared might have equal PSSD attributes, the mean patch size may be vastly different. For example, a landscape comprised of large patches may have the same patch size standard deviation as a landscape comprised of very small patches. For this reason, patch size coefficient of variation (PSCV) is often preferred as a measure of patch variability (Macgarigal et al., 1998).

Great variability in patch size was observed for both study years (Table 7). The PSSD increased slightly from 24.69 ha in 1987 to 24.94 ha in 1997, reflecting the slightly smaller mean patch size. Additionally, as shown by values of PSCV, variability in patch size relative to mean patch size was much greater in 1997 than in 1987. Interpretation of increased variability in patch size, with respect to trends in landscape processes such as fragmentation and dissection, requires further consideration of dynamics at the class level.

Not surprisingly, the upland forest class showed little change between study years. The small mean patch size is explained by the fact that in the Grand Prairie section of the study area, this class is generally confined to narrow riparian corridors. The MPS showed a slight increase from 0.4 ha 1987 to 0.5 ha 1997 with corresponding slight increase in patch size variability.

All other patch classes were characterized by high variability in both study years. Interpretation of changes in these patch classes during the study period is most straightforward for the water class. The large increase in MPS and corresponding increase in PSSD and PSCV is easily explained by the impoundment of the Ray Roberts Lake reservoir between 1987 and 1997.

The developed classes were also highly variable. The mean patch size for the urban class increased across the study period, possibly as a result of increased development in the city of Denton. Similarly, the construction of numerous rural residences near the lake as well as expansion of several rural developments may explain the increased MPS for the urban/rural residential class. Intuitively, the size of these properties are highly variable—ranging from single-dwelling homes with acreage to

Table 7. Class level landscape pattern metric values for the Grand Prairie region of the Ray Roberts Lake study area, 1987—1997 (terms defined in text).

Patch Class	PD		PSSD		PSCV		MSI		AWMSI		DLFD	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Water	0.292	0.342	0.573	118.027	189.109	1084.707	1.310	1.361	1.706	4.676	-38.877	-23.236
Agriculture	1.661	2.033	37.190	30.525	215.133	238.644	1.536	1.513	2.109	2.097	-11.873	-13.137
Rangeland	8.641	7.807	47.781	53.169	766.704	821.270	1.417	1.442	5.586	5.411	-15.826	-15.811
Forested	7.452	6.037	2.375	2.940	573.671	576.471	1.311	1.334	2.971	3.106	-32.634	-31.583
Shrubland	20.652	15.642	0.828	2.329	381.567	671.182	1.291	1.306	1.981	2.674	-44.351	-39.657
LDOW	0.105	5.974	0.053	0.849	80.303	384.163	1.158	1.268	1.227	1.899	-189.692	-48.243
VLDOW	0.524	1.210	0.045	0.268	69.231	187.413	1.157	1.233	1.168	1.636	-234.426	-64.649
Urban/Built-up	6.178	5.948	11.531	14.036	1218.922	1258.834	1.523	1.532	10.602	12.375	-25.704	-26.148
Residential	0.884	3.402	0.811	3.098	282.578	346.532	1.343	1.381	2.089	2.209	-38.769	-24.702
Disturbed	0.050	--	309.268	--	425.421	--	1.562	--	4.656	--	-7.733	--

homes on smaller lots in rural neighborhoods—and it is, therefore, not unexpected that both the PSSD and PSCV increased between 1987 and 1997.

Rangeland and agriculture predominated the landuse character of the Grand Prairie in both study years. In 1987, the rangeland class was comprised of smaller, more numerous patches that were more variable in size than the agriculture class. This observation remained true in 1997 as well, although both classes showed a decreased number of patches and increased patch size variability.

The spatial process of attrition may explain the observed changes in rangeland. According to Forman (1995), attrition is the disappearance of objects such as patches, particularly small patches, and corridors between patches. It is almost always present in a changing landscape, and can overlap both fragmentation and dissection processes. The effects of attrition on the spatial attributes of a landscape, or a specific patch class, are a decrease in patch number and an increase in average patch size. Further support for the conclusion that attrition is the causal process underlying change in rangelands is that fa that the density of the patches on the landscape decreased (Table 5). This is reflective of increasing isolation of patches on the landscape, which is an additional key characteristic of attrition. By contrast, change in the agriculture class is most likely due to fragmentation. This conclusion is supported by the fact that NP increased from 631 patches in 1987 to 773 patches in 1997, while mean patch size and patch density both decreased across the study period.

The final group of indices used to quantify change in landscape pattern were the three shape indices: mean shape index (MSI), area-weighted mean shaped index

(AWMSI), and the double log fractal dimension (DLFD). In the vector version of FRAGSTATS, patch shape is evaluated with respect to a circular standard. The value of the shape index is minimized for circular patches and increases as patches become increasingly non-circular.

A potential problem with using a circular standard in landscapes having a significant dryland agricultural component is that, typically, large cropped fields tend to be square or rectangular. Thus, for this class or for landscapes dominated by this class, the shape index should approach the minimum value of 1.0 as the landscape becomes increasingly simplified. If a circular standard were used, regardless of how simple and homogeneous the landscape may actually be, because of the widespread distribution of dryland agriculture patches, the minimum value of 1.0 would theoretically never be approached because of the geometric disparity between circles and squares.

Another problem that was encountered with the shape indices occurred in the use of the double log fractal dimension (DLFD). The theoretical limits for this metric are 1 for the simplest shapes, and 2 for the most complex. The DLFD values for all landscape classes, however, were negative. This result was unexpected and no immediate explanation was available. Accordingly, the double-log fractal dimension was discarded from the analysis.

Both the MSI and AWMSI show that the overall complexity of the Grand Prairie landscape has not changed considerably during the study period (Table 6). Thus, the results show that the Grand Prairie has undergone dynamic changes as a result of fragmentation and attrition processes, particularly within the agricultural and grazed range patch classes, during the decade between 1987-1997. As these changes have occurred, however, the overall complexity of the landscape has not changed. It is therefore concluded that the Grand Prairie landscape can be characterized as a shifting, but essentially steady-state, mosaic whose patches are maintained by chronic disturbance from human-related activity.

Landscape Composition, Eastern Cross Timbers, 1987-1997.

Similar to the trend seen in the Grand Prairie, the Eastern Cross Timbers has been dominated by grazed rangeland and agriculture for the entire study period. The diversity metrics for the Eastern Cross Timbers (Table 6) show that the region is generally more heterogeneous and diverse than the Grand Prairie. This is reflected in the %Land metric, which shows a comparatively broader distribution across patch classes (Tables 5 and 8) and by relatively higher SHEI values (Table 6).

Like the Grand Prairie, the Eastern Cross Timbers became more diverse betwee 1987 and 1997. This trend is apparent in the increase in SHDI from 1.897 in 1987 to 2.004 in 1997. Similarly, the SDI index also increased from 0.811 in 1987 to 0.834 in 1997. Additionally, the SHEI value increased between study years from 0.763 to 0.836, indicating that while patches on the landscape have become more numerous, they have also become more evenly distributed between patch classes.

At the class level, rangeland occupied approximately one-third of the Eastern Cross Timbers section in 1987. As reflected by the CA and %Land values, however, rangeland declined to 18% by 1997 while agriculture rose during the study period from

21% to 28%. Forested lands were the next most common patch class in both years. Between 1987 and 1997, NP, CA, and %Land values for this class increased while MPS decreased.

Large variation in the water, shrubland, transitional woodland, disturbed, and urban/rural residential classes also contributed to observed change in landscape composition during the study period. As with the Grand Prairie region, variability in the water and disturbed classes is directly related to the impoundment of the Ray Roberts Lake reservoir in 1988. The causes for observed variation in the NP, CA, %Land, and PD metrics for the urban/residential class in the ECT are similar to those of the Grand Prairie. With impoundment of the reservoir, several rural developments have appeared on the landscape during the last 10 years, particularly near the lake.

Interpretation of variability in the shrubland and transitional woodland classes is more complex. The area south of the reservoir dam, west of the Elm Fork river corridor, has been characterized by broad expanses of grazed rangeland and sorghum-wheat-fallow rotation cropping along bottomlands. Shrublands generally occur in three forms: 1) as transitional mesquite shrubland on overgrazed or abandoned range, 2) as transitional mixed shrublands in the seasonal floodplain of the Elm Fork at Lake Lewisville, and 3) as shrublands along riparian corridors.

Table 8. Class level landscape composition metric values for the Eastern Cross Timbers sections of the ray Roberts Lake study area, 1987—1997 (terms defined in text).

Patch Class	CA		%LAND		LPI		NP		MPS		PD	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Water	265.44	1021.57	0.392	15.680	0.188	11.392	484	833	0.548	12.751	0.715	1.230
Agriculture	14390.43	18791.85	21.244	27.741	3.961	1.517	2443	3305	5.890	5.686	3.606	4.879
Rangeland	21139.90	12243.71	31.208	18.074	1.232	0.472	9316	10404	2.269	1.177	13.753	15.354
Forested	8351.37	9499.15	12.329	14.023	0.307	0.212	11459	14309	0.729	0.664	16.916	21.123
Shrubland	4611.26	2330.33	6.807	3.440	0.054	0.050	30650	14790	0.150	0.158	45.247	21.833
LDOW	910.74	3884.08	1.344	5.734	0.011	0.110	9065	14712	0.100	0.264	13.382	21.718
VLDOW	1378.00	1533.10	2.034	2.263	0.007	0.026	14024	14473	0.098	0.106	20.703	21.365
Urban/Built-up	4918.10	4902.21	7.260	7.237	2.044	2.157	4397	4359	1.119	1.125	6.491	6.435
Residential	1130.75	2182.69	1.669	3.222	0.094	0.148	2980	5922	0.379	0.369	4.399	8.742
Disturbed	9701.81	1475.27	14.322	2.178	12.281	0.012	95	13436	102.124	0.110	0.140	19.834
Seasonal Wetland	608.39	--	0.898	--	0.802	--	42	--	14.485	--	0.062	--
Gravel Pits	316.54	289.21	0.467	0.427	0.203	0.150	13	23	24.349	12.574	0.019	0.034

The area east of the Elm Fork corridor, as well as the area north of the lake, has generally been comprised of heavily fragmented upland forests, numerous horse farms of varying extent, and grazing leases. Shrubland occurs primarily as mixed shrubland cover along riparian corridors and in previously cleared gaps in upland forest stands, although some mesquite shrubland has also been observed to occur. Given that the natural vegetation of the ECT is dense hardwood forest, which has historically been subjected to intensive clearing, it is reasonable to assume that the majority of these shrublands are transitional.

The number of shrubland patches showed a significant decrease during the study period, from 30,650 patches in 1987 to 14,790 patches in 1997. Additionally, PD metric values decreased from 45.247 patches per ha in 1987 to 21.833 patches per ha in 1997. Thus, shrubland patches decreased in number and became more isolated between study years.

The dynamics observed within the shrubland class are consistent with the process of attrition, whereby smaller patches disappear from the mosaic across time. Further evidence of this process is shown by the transitional woodland classes, in which increases were observed for all landscape composition metric values. Therefore, identification of attrition as the causal factor in variation in transitional shrubland patches is supported by the fact that as mixed hardwood shrublands transition to woodland, the smaller shrubland patches are likely to have disappeared first. Finally, this claim is supported by the observation that shrubland MPS increased slightly; this is consistent with the disappearance of small patches from the landscape during the process of attrition.

Landscape pattern 1987-1997, Eastern Cross Timbers

Examination of aerial photographs and raw satellite imagery indicates that the Eastern Cross Timbers landscape is more diverse than the Grand Prairie, particularly the portion of the region located north of Ray Roberts Lake. This area is comprised of broken and numerous remnant patches of upland forest, isolated by clearings of variable size. These clearings, once used for cash crop production, are generally used for horse farm pastures or as grazed range. There are frequent gaps, showing various stages of canopy closure, present in the forest stands. Pasture and range patches frequently contain small patches of open woodland, with varying densities of trees. Similar to the Grand Prairie, the boundaries of the Eastern Cross Timbers patches are generally determined by linear property boundaries.

At the landscape level of analysis, the metric values shown in Table 6 indicate that the number of patches on the Eastern Cross Timbers mosaic have increased over time, with an associated decrease in mean patch size. Reflecting more and smaller patches, patch density was also observed to increase from 125.434 patches per ha to 142.547 patches per ha. Patch variability and MSI and AWMSI shape metrics show tha as patches have become smaller they have also become more uniform and less variable. These dynamics are indicative of increasing landscape fragmentation.

Temporal variation in landscape pattern for the Eastern Cross Timbers, however, can be further elucidated by examining class level dynamics. As shown by landscape composition metric values (Table 8), over 50% of the landscape was accounted for by rangeland and agriculture in 1987. Although the percentage dropped to 45% in 1997, the two classes remained the most predominant components on the Eastern Cross Timbers landscape. The NP and MPS values show that although rangeland patches have outnumbered agricultural patches in both years, the mean patch size has been much smaller. In fact, mean patch size for the rangeland class declined during the study period, from 2.27 ha to 1.18 ha, while the size of agricultural patches has ranged from 5.89 ha in 1987 to 5.69 ha in 1997.

Comparison of the Eastern Cross Timbers landuse mosaic for each year shows that numerous rangeland patches have disappeared from the landscape and been replaced with agricultural patches. Additionally, the replacement of cropland patches with rangeland patches has generally been rare. This is probably because it is unlikely that a property owner will remove an area from cash crop production or convert a pasture on a horse farm to rangeland for cattle grazing in the relatively short span of time considered in this study.

The forested class is also an important component of the Eastern Cross Timbers landscape. As the NP and CA metrics show, forested lands have increased by over 1,100 hectares since 1987. Although the number of patches increased, however, the mean pat size decreased slightly from 3.61 ha in 1987 to 3.36 ha in 1997. According to the PSSD and PSCV values (Table 9), large decreases in patch variability occurred between 1987 and 1997. While a marginal increase was observed in MSI value, a more noticeable decrease in AWMSI was found.

Table 9. Class level landscape pattern metric values for the Eastern Cross Timbers region of the Ray Roberts Lake study area, 1987—1997 (terms defined in text).

Patch Class	PD		PSSD		PSCV		MSI		AWMSI		DLFD	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Water	0.715	1.230	5.849	270.487	1067.336	2121.300	1.267	1.307	2.455	6.429	-37.302	-25.660
Agriculture	3.606	4.879	69.274	33.500	1176.129	589.166	1.415	1.439	5.336	3.812	-14.765	-14.648
Rangeland	13.753	15.354	20.140	7.844	887.616	666.440	1.432	1.369	6.862	3.523	-19.767	-24.543
Forested	16.916	21.123	5.428	4.228	744.582	636.747	1.341	1.347	3.606	3.356	-27.843	-29.726
Shrubland	45.247	21.833	0.425	0.628	283.333	397.468	1.251	1.225	0.803	1.104	-59.499	-68.133
LDOW	13.382	21.718	0.165	1.188	165.000	450.000	1.203	1.295	0.677	1.842	-91.630	-43.714
VLDOW	20.703	21.365	0.141	0.227	143.878	214.151	1.201	1.195	0.488	0.472	-92.041	-103.680
Urban/Built-up	6.491	6.435	22.268	23.084	1989.991	2051.911	1.481	1.504	14.301	15.106	-27.006	-27.967
Residential	4.399	8.742	857.535	0.171	839.700	155.455	1.460	1.203	7.920	0.451	-11.818	-96.667
Disturbed	0.140	19.834	1.681	1.995	443.536	540.650	1.382	1.307	2.547	2.074	-33.628	-38.921
Season Wetland	0.062	--	83.838	--	578.792	--	1.355	--	1.958	--	-16.752	--
Gravel Pits	0.019	0.034	37.428	27.029	153.715	214.959	1.778	1.652	2.285	2.672	-19.988	-11.437

In 1987, the disturbed class showed the greatest amount of absolute patch size variability, followed by the seasonal wetland patch class. As shown by the PSCV metric value, both classes also showed high variability relative to mean patch size. This is probably because both classes were represented by a small number of patches that were localized in their distribution on the landscape. In the case of the disturbed patch class, the disappearance of these patches from the landscape was balanced by their replacement with water following impoundment of the Ray Roberts Lake reservoir. The impoundment of the lake also explains the large increase in PSSD and PSCV for the water class.

The urban/built-up land class showed marginal increase in MPS, although the PSCV and PSSD values show that patch sizes were highly variable. The MSI and AWMSI values for this class also increased, which indicates increasing patch class complexity. Comparison of aerial photographs for each year showed that this may be attributed to construction of numerous roads north and southeast of the lake between 1987 and 1997, generally to accommodate new residential development.

The urban/rural residential class showed a marginal decrease in MPS, with much smaller variability relative to the urban/built-up land class. This is probably due to the fact that the majority of the residential development that took place between 1987 and 1997 is accounted for by residential neighborhoods. Because these neighborhoods have typically uniform lot sizes, it is reasonable to expect that the MPS for the patch class would decrease. Similarly, the uniformity of residential areas accounts for the relatively low MSI and AWMSI metric values. Increased representation of this patch class on the landscape also accounts for the observed decrease in shape index values during the study period.

In 1987, the shrubland and transitional woodland (LDOW and VLDOW) classes showed relatively small amounts of absolute variability in patch size. PSCV metric values for these three classes were also smaller than the other patch classes. Between 1987 and 1997, patch variability increased for all three classes, particularly the low-density oak woodland class.

As Forman (1995) observes, the balance between appearance and disappearance of patches on the landscape determines both direction and rate of change in the landscape mosaic. Although characterization of temporal variation in landscape pattern for the Eastern Cross Timbers was more complex than for the Grand Prairie, results of the analysis indicate that the landscape has generally become more heterogeneous over time and that variability in patch size has decreased. Class level metric values indicate that dynamics within the predominant agriculture and rangeland classes, both created and maintained by human activity, may play a role in the dynamics observed at the landscape level. Thus, increased heterogeneity across the landscape and dynamics with those classes associated with human disturbance (e.g. agriculture) seem to indicate that the Eastern Cross Timbers landscape can be characterized as a disturbed landscape.

Vegetation analysis

The objective of vegetation analysis was to determine whether the rangeland, agricultural, shrubland, and forested plant communities comprising the Ray Roberts Lake landscape could be characterized as disturbance-maintained. In general, most plant communities in the Ray Roberts Lake area became more heterogeneous between 1987 and 1997, although most showed no significant change in diversity. Abundance data for trees and shrubs for 1988, 1992, and 1995, were not available; thus, the analysis is limited to herbaceous canopy structure.

Grand Prairie, 1987-1997.

Historical accounts (Bates, 1918; Lebo, 1995) indicate that, during the last 150 years, vegetative communities in this portion of the study area have been subjected to continuing disturbance from cattle grazing, with varying levels of intensity. Additional disturbance during the 20th century has included a growing trend toward production of grain sorghum and wheat. Three transect sections fall within the Grand Prairie region. Of these, CD1 and CD2 are grazed rangeland communities while AB1 is a mesquite shrubland occupying former grazing land.

In general, abundance data for both rangeland and mesquite shrubland communities fit the log series model (Table 10.). The exceptions were in 1987 (AB1) and 1992 (CD1). Rank abundance plots (Appendix A) also show that these communities follow the model, with many species being rare and only a few species being common. These results support the conclusion that rangeland and mixed shrubland communities on the Grand Prairie are disturbed.

Table 10. Results of chi-square goodness-of-fit testing for significance in differences between expected log series abundances and observed abundance data[1].

Transect[2]	1987 Expected X^2	1987 Critical X^2	1987 DF	1992 Expected X^2	1992 Critical X^2	1992 DF	1995 Expected X^2	1995 Critical X^2	1995 DF	1997 Expected X^2	1997 Critical X^2	1997 DF
Grand Prairie												
AB1 (SB, Mesquite)	1015.084	18.307	10	4.663	15.507	8	9.089	15.507	8	3.082	15.507	8
CD1 (OF)	10.384	18.307	10	17.076	15.507	8	14.744	15.507	8	10.677	15.507	8
CD2 (OF)	11.666	21.026	12	7.848	16.919	9	10.279	15.507	8	6.951	12.592	6
Eastern Cross Timbers												
AB6 (SB, Mixed)	17.101	18.307	10	11.701	15.507	8	4.159	15.507	8	30.532	14.067	7
CD8 (SB, Mixed)	4.367	14.067	7	10.280	15.507	8	3.939	14.067	7	9.576	14.067	7
CD7 (UF)	7.531	11.070	5	8.379	12.592	6	14.449	12.592	6	11.307	14.067	7
CD9 (UF)	8.044	11.070	5	9.424	14.067	7	6.800	11.070	5	13.764	11.070	5
EF10 (UF)	3.070	12.592	6	30.755	14.067	7	20.199	14.067	7	14.632	11.070	5
CD10 (OF)	6.321	18.307	10	12.535	16.919	9	3.771	15.507	8	11.000	15.507	8
EF1 (OF)	11.473	18.307	10	3.055	16.919	9	8.386	16.919	9	8.804	15.507	8
EF9 (OF)	24.407	15.507	8	8.198	14.067	7	16.075	16.919	9	7.351	12.592	6
GH3 (BF)	19.278	16.919	9	13.436	16.919	9	12.761	16.919	9	11.829	16.919	9

[1] Shaded rows indicate years in which the log series model does not fit abundance data.
[2] Plant communities: Shrubland = SB; Oldfield/Rangeland = OF; Upland Forest = UF; Bottomland Forest = BF

In 1987, the species composition of the mesquite shrubland community clearly indicated its prior landuse as grazing pasture. The predominant species were annual forage grasses, such as *Bromus* sp. and little barley (*Hordeum vulgare*), and perennial rye (*Lolium perenne*) (Appendix B). By 1997, 10 years after removal from grazing pressure, these species had all declined in importance; the community is now dominated by perennial grass and herb species such as bermuda (*Cynodon dactylon*) and western yarrow (*Achillea millefolium*).

These observations are supported by the results of diversity analysis. For example, there has been an overall increase in the number of species between 1987 and 1997 (Appendix B), much of which occurred between 1987 and 1992 as the result of increases in the abundance of herbaceous species. Annual and perennial grasses comprised a majority of the community during the 1987, 1992, and 1995 surveys. Annual herbs increased steadily, however, and in 1997 annual herbs and perennial grasses outnumbered all other groups.

The Shannon diversity index increased during the majority of the study period (Table 11a). However, there has been no statistically significant change in the diversity of the mesquite shrubland between 1987 and 1997 (Tables 12 and 13). Calculation of Simpson's dominance index shows that dominance within the community has decreased, and communities have become more heterogeneous (Table 11b).

Rangeland sections CD1 and CD2 are continuous and have experienced identical patterns of landuse. Prior to impoundment of the lake, there were homes located in the area, and fields were subjected to continuous grazing pressure from cattle. Although the

Table 11a. Shannon diversity values for Ray Roberts Lake vegetation monitoring transects, 1987—1997.

Transect	1987	1992	1995	1997
Grand Prairie				
AB1 (SB, Mesquite)	1.3737	1.8630	2.1899	1.9887
CD1 (OF)	1.4134	2.3400	2.8300	2.2400
CD2 (OF)	0.3300	1.6500	2.7900	2.8000
Eastern Cross Timbers				
AB6 (SB, Mixed)	3.9434	1.6002	2.2500	2.5240
CD8 (SB, Mixed)	1.9342	2.0971	2.4123	2.6846
CD7 (UF)	2.2300	2.0000	2.6400	2.2700
CD9 (UF)	1.5618	1.3425	2.5208	3.0685
EF10 (UF)	1.5700	0.5200	1.8100	2.0500
CD10 (OF)	1.3737	2.1605	2.0858	2.6400
EF1 (OF)	1.5420	1.8400	2.3800	3.2200
EF9 (OF)	2.1100	2.4900	2.3400	2.8900
GH3 (BF)	0.6900	0.3100	0.2500	0.0938

Table 11b. Evenness values for Ray Roberts Lake vegetation monitoring transects, 1987—1997.

Transect	1987	1992	1995	1997
Grand Prairie				
AB1 (SB, Mesquite)	0.404521	0.585264	0.680362	0.597202
CD1 (OF)	0.438041	0.634339	0.719767	0.611427
CD2 (OF)	0.114172	0.480491	0.746454	0.764284
Eastern Cross Timbers				
AB6 (SB, Mixed)	0.217360	0.465931	0.668192	0.815259
CD8 (SB, Mixed)	0.563239	0.594699	0.684071	0.767789
CD7 (UF)	0.823471	0.691953	0.820162	0.649219
CD9 (UF)	1.303496	0.651338	0.455943	0.714834
EF10 (UF)	0.654741	0.290218	0.604193	0.799236
CD10 (OF)	0.475266	0.641625	0.674774	0.731116
EF1 (OF)	0.514065	0.546433	0.714242	0.811024
EF9 (OF)	0.614446	0.725105	0.663574	0.819542
GH3 (BF)	0.254796	0.223618	0.113780	0.101598

homes were abandoned and demolished when the U. S. Army Corps of Engineers purchased the property, cattle have remained.

In 1987, the dominant species were the annual forage grass *Bromus japonicus* and western ragweed (*Ambrosia artemisiifolia*), a native forb that increases under grazing pressure. Vegetation monitoring data (IAS, 1999) show that at the end of the study period, the most dominant species was the native perennial bunch grass big bluestem (*Andropogon gerardii*), although *Bromus* sp. remains an important genus (Appendix B).

A shift from annual forage to native perennial grasses and herbs across the ten-year period may indicate ongoing successional processes interacting with continuing grazing pressure. This observation is supported by the fact that both communities became progressively more heterogeneous during the study period, as evidenced by increasing evenness and decreasing values for Simpson's D (Table 11b).

<u>Eastern Cross Timbers, 1987-1997</u>.

The vegetative communities of the Eastern Cross Timbers portion of the study area have been impacted by anthropogenic factors during the last 150 years. Much of the initial clearing of forests for agriculture that occurred during the settlement period of the 1850s, for example, has been maintained for agriculture, pasture, and residential use in present times. Additionally, farms and pasture leases have become smaller and more fragmented across the landscape. Finally, the construction of Ray Roberts Lake State Park has resulted in cleared upland forest areas being managed and maintained as "oldfield" communities, while shrubland habitat is continually held in transition through periodic controlled burning.

Transect sections CD7 (UF), CD8 (SB), CD9 (UF), and CD10 (OF) fall completely within the Isle du Bois unit of Ray Roberts Lake Park. Vegetation monitoring shows that controlling arborescent layers in upland forest sections are comprised of typical Eastern Cross Timbers species, including post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), and elm (*Ulmus* sp.). The herbaceous canopy is generally discontinuous, or broken, and is dominated by tree seedlings, woody vines and a few perennial grass and herb species.

Rank abundance plots for both of these communities show that they are generally comprised of a few abundant species and several uncommon species (Appendix A). Abundance data for both upland forest communities in the Isle du Bois park unit follow the log series model, with the exception of 1995 for CD7 and 1997 for CD9 (Table 10).

Upland forests in Isle du Bois State Park are subjected to continual disturbance from lakeside fishing, off-trail hiking and biking, and by foot traffic from nearby campgrounds. When abundance data for transect section CD7 was examined according to individual species, no significant difference in Shannon diversity was found (Table 11a). Evenness and dominance indices show an alternating pattern of increases and decreases from one study year to the next which may be explained by the fact that the abundance of annual and perennial herbs fluctuated significantly from year to year (Appendix B).

Similarly, no statistically significant increase in diversity was found for transect section CD9 (Table 12), although community dominance (Table 11b) and evenness decreased across all study years. This may be explained by an increase in species richness, resulting primarily from increases in annual and perennial herbs (Appendix B).

Mixed shrubland (CD8) is characterized as transitional habitat along seasonal drainages and as periodic breaks in upland forest cover. Some portions of CD8 have actually transitioned from shrubland to open woodland during the study period. While many portions of CD8 are left undisturbed by park users, some areas do receive heavy foot traffic from off-trail hikers seasonally. Additionally, park managers periodically burn the area to control underbrush density and fuel buildup.

Vegetation monitoring shows that, in 1987, the herbaceous canopy at CD8 was a mixture of perennial grasses, such as *Dicanthelium* sp., and annual and perennial herbs. In 1997, the most important component of herbaceous canopy was perennial grass species, particularly little bluestem (*Schizachyrium scoparium*), dropseed (*Sporobolus asper*), and bermuda (*Cynodon dactylon*). Additionally, increasing evenness and decreasing dominance values across the study period show that the trend has been toward increasing community heterogeneity between 1987 and 1997.

Comparison of the results of the students-*t* test for variance in Shannon diversity (Table 12) with the abundance data (Appendix B) indicate that increased community heterogeneity has occurred as a result of increased representation of perennial herb species. When variance in Shannon diversity is considered according to individual species abundance, no significant difference in diversity from one year to the next is observed (Table 12). When variance in diversity is considered according to the abundance of annual and perennial grass and herb groups, however, there is a statistically significant difference in diversity between 1995 and 1997 (Table 13).

Table 12. Results of student's-*t* tests for significance in variance of Shannon diversity.

Section	No. of Individuals				Variance				Std. Dev.			
	Y86	Y92	Y95	Y97	Y86	Y92	Y95	Y97	Y86	Y92	Y95	Y97
AB1	7236	1068	1405	1347	0.0002	0.0012	0.0011	0.0010	0.015	0.035	0.033	0.032
AB6	5175	1043	1345	658	0.0021	0.0020	0.0010	0.0026	0.045	0.045	0.032	0.051
CD1	3041	1864	2098	1240	0.0004	0.0009	0.0007	0.0016	0.021	0.029	0.026	0.040
CD2	6958	2772	1915	763	0.0002	0.0008	0.0006	0.0015	0.013	0.028	0.025	0.039
CD7	211	206	380	391	0.0026	0.0084	0.0026	0.0064	0.051	0.092	0.051	0.080
CD8	1085	877	679	725	0.0022	0.0026	0.0027	0.0017	0.047	0.051	0.052	0.041
CD9	85	352	173	360	0.0190	0.0032	0.0035	0.0022	0.138	0.057	0.059	0.047
CD10	3512	1363	1024	1805	0.0002	0.0012	0.0013	0.0008	0.015	0.034	0.037	0.028
EF1	3269	1373	1355	1824	0.0004	0.0012	0.0009	0.0005	0.020	0.035	0.031	0.023
EF9	1530	1074	1427	903	0.0010	0.0011	0.0013	0.0009	0.032	0.033	0.036	0.030
EF10	79	166	574	120	0.0156	0.0075	0.0030	0.0087	0.125	0.087	0.055	0.093
GH3	735	856	988	27	0.0026	0.0009	0.0010	0.0372	0.051	0.030	0.032	0.193

Section	D.F.			*t*-value			Critical-*t*			| *t* | > Critical - *t* [1]		
	Y86-92	Y92-95	Y95-97	Y86-92	Y92-95	Y95-97	Y86-93	Y92-96	Y95-98	Y86-94	Y92-97	Y95-99
AB1	1510.414	2381.657	2751.99	-12.8447	-6.8269	4.3782	1.960	1.960	1.960	x	x	x
AB6	3523.315	1965.567	1184.949	36.7722	-11.8402	-4.5865	1.960	1.960	1.960	x	x	x
CD1	3629.829	3827.168	2267.02	-27.9814	-12.5253	12.4173	1.960	1.960	1.960	x	x	x
CD2	4131.373	4645.224	1439.03	-123.9246	-30.4844	-0.2325	1.960	1.960	1.960	x	x	
CD7	323.8424	334.7159	660.2324	2578.4910	-6.4611	4.3296	1.960	1.960	1.963	x	x	x
CD8	1882.823	1523.394	1303.351	-43.6288	-4.3045	-4.1132	1.960	1.960	1.960	x	x	x
CD9	115.7317	453.6184	385.8149	137.3171	-14.3995	-7.3009	1.980	1.960	1.966	x	x	x
CD10	1943.797	2285.123	2155.291	-79.2826	1.4949	-12.0092	1.960	1.960	1.960	x		x
EF1	2281.921	2678.574	2681.126	-17.6757	-11.6986	-22.0186	1.960	1.960	1.960	x	x	x
EF9	2496.902	2496.641	2325.481	-10.3852	2.9953	-11.6541	1.960	1.960	1.960	x	x	x
EF10	156.1578	311.1799	211.7101	11.9901	-12.6212	-2.1843	1.975	1.960	1.969	x	x	x
GH3	1191.174	1843.99	28.47604	11.2625	1.3931	-5.5787	1.960	1.960	2.048	x		x

[1] Shading indicates statistically significant variation in Shannon diversity.

Examination of abundance data for mixed shrubland CD8 (Appendix B) shows that while abundance of all other groups declined, perennial herbs and shrub abundance increased. The increased representation of these groups within the community thus explains the observed increase in Shannon diversity between 1995 and 1997.

Rangeland in the Eastern Cross Timbers subregion is represented by three sampling transects: CD10, EF1, and EF9. CD10 is located in Isle du Bois park; prior to impoundment of the lake, the section was used as a hay meadow. Park managers maintain the area as part of an equestrian trail system through seasonal burning and mowing. EF1, formerly part of a grazing lease, is part of the Corps of Engineers easement around the lake and receives no disturbance from humans or cattle grazing. EF9, which lies opposite EF1 across the Isle du Bois arm of the lake, is part of the Jordan Park unit of the State Park Complex and is not readily accessible to public use.

In 1987, CD10 was comprised predominantly of perennial bermuda (*Cynodon dactylon*) and annual forbs such as *Plantago* sp. and black-eyed susan (*Rudbeckia hirta*). Comparison of abundance data shows that while the number of annual herb species increased between 1987 and 1997, the total number of individuals in the group declined until 1997 (Appendix B). During field sampling in the spring of 1997, it was noted that CD10 had been burned recently. The large increase in annual species abundance in 1997, therefore, may be explained by this event. Both the number and overall abundance of perennial herb species increased across the study period while perennial grass abundance

Table 13. Significance of variance in Shannon diversity, with data grouped according to annual or perenn

Section	No. of Individuals				Variance				Std. Dev.			
	Y86	Y92	Y95	Y97	Y86	Y92	Y95	Y97	Y86	Y92	Y95	Y97
AB1	7236	1068	1405	1347	0.0002	0.0006	0.0003	0.0004	0.015	0.024	0.016	0.020
AB6	5175	1043	1345	658	0.0001	0.0008	0.0006	0.0019	0.008	0.027	0.025	0.043
CD1	3041	1864	2098	1240	0.0002	0.0006	0.0001	0.0004	0.014	0.025	0.010	0.019
CD2	6958	2772	1915	763	0.0001	0.0002	0.0001	0.0004	0.011	0.015	0.012	0.021
CD7	211	206	380	391	0.0029	0.0022	0.0014	0.0027	0.054	0.047	0.037	0.052
CD8	1085	877	679	725	0.0005	0.0013	0.0013	0.0009	0.022	0.036	0.037	0.031
CD9	85	352	173	360	0.0172	0.0027	0.0007	0.0018	0.131	0.052	0.026	0.042
CD10	3512	1363	1024	1805	0.0000	0.0004	0.0007	0.0002	0.004	0.019	0.026	0.015
EF1	3269	1373	1355	1824	0.0001	0.0003	0.0005	0.0002	0.009	0.017	0.022	0.016
EF9	1530	1074	1427	903	0.0004	0.0005	0.0006	0.0003	0.021	0.022	0.024	0.018
EF10	79	166	574	120	0.0143	0.0065	0.0008	0.0059	0.120	0.080	0.029	0.077
GH3	735	856	988	27	0.0012	0.0009	0.0007	0.0004	0.034	0.030	0.026	0.021

Section	D.F.			t-value			Critical-t			| t | > Critical - t [1]		
	Y86-92	Y92-95	Y95-97	Y86-92	Y92-95	Y95-97	Y86-93	Y92-96	Y95-98	Y86-94	Y92-97	Y95-99
AB1	2068.985	1980.813	2605.295	17.5224	-16.0293	12.3945	1.960	1.960	1.960	x	x	x
AB6	1217.969	2292.734	1063.835	-17.9806	3.1939	0.5881	1.960	1.960	1.960	x	x	
CD1	3021.937	2433.313	1880.226	8.0341	-14.7972	-0.1107	1.960	1.960	1.960	x	x	
CD2	5883.366	4684.28	1330.669	-32.7567	-25.1642	9.9200	1.960	1.960	1.960	x	x	x
CD7	319.131	428.5912	704.2918	-0.8585	-1.2417	3.0961	1.967	1.965	1.963			x
CD8	1471.702	1528.251	1340.308	2.6902	-8.8413	-0.7074	1.960	1.960	1.960	x	x	
CD9	113.3804	498.464	557.2346	3.1460	-18.9569	4.5264	1.981	1.965	1.964	x	x	x
CD10	1520.918	2032.106	1707.671	1.3029	2.4252	-1.6695	1.960	1.960	1.960		x	
EF1	2099.326	2556.935	2452.843	-6.0045	5.3257	-8.9005	1.960	1.960	1.960	x	x	x
EF9	2476.247	2508.519	2329.754	-12.3318	11.0543	-11.6905	1.960	1.960	1.960	x	x	x
EF10	151.7822	210.8877	155.706	0.1265	-8.9458	0.1121	1.975	1.969	1.975		x	
GH3	1513.131	1761.359	1808.236	3.3636	2.7833	3.5667	1.960	1.960	1.960	x	x	x

[1] Shading indicates statistically significant variation in Shannon diversity.

declined. In 1997, the community was comprised primarily of perennial grasses and annual herbs.

A significant decrease in the diversity of CD10 occurred between 1992 and 1995 (Table 12). In 1992, the most abundant species in the community were bermuda (*Cynodon dactylon*), perennial rye (*Lolium perenne*), and plantain (*Plantago aristata*). All of these species declined sharply or were not observed in 1995. Since the Shannon diversity metric is weighted toward the most abundant species it is not surprising that a significant decrease in diversity was observed.

Similarly, a significant increase in diversity among annual and perennial grass and herb groups between 1987 and 1992 (Table 13) may be explained by the appearance of several species in 1992 that were not observed in 1987 (Appendix B). Overall, evenness and dominance values indicate that CD10 has become more heterogeneous with time (Table 11b).

In 1987, EF1 was comprised primarily of annual grasses and herbs such as purple three-awn (*Aristida longispeca*), western ragweed (*Ambrosia artemisiifolia*), and plantain (*Plantago* sp.), although perennial panic grasses (*Dicanthelium* sp.) were also an important component. The abundance of annual grasses decreased steadily during the study period, while perennial grasses showed an alternating pattern of increase and decrease from one study year to the next (Appendix B). Perennial herbs have generally increased in abundance. In 1997, EF1 was comprised primarily of perennial bunch grasses, with the most dominant being big bluestem (*Andropogon gerardii*) and broomsedge (*Andropogon virginicus*), and perennial herbs such as *Lespedeza* sp.

EF9 has been comprised primarily of perennial grasses and annual herbs for the duration of the study period, although perennial herbs have increased steadily in abundance (Appendix B). Analysis of diversity also shows that, while there has been no significant change in overall species diversity in either EF1 or EF9 (Table 12), the distribution of individuals among species has become more heterogeneous and species dominance has decreased (Table 11b). Similarly, both communities conform to the log series model (Table 10).

Transect GH lies south of the dam at Lake Ray Roberts. It contains four sections, made up of two bottomland forest (GH1 and GH3) and two cropped areas (GH2 and GH4). Agricultural fields were excluded from this study because they represent artificial communities. Section GH1 was also eliminated from the study because although it was initially classified as a bottomland forest community, the section is subject to continual disturbance from cattle grazing and the vegetation is more representative of mesquite shrubland.

Section GH3 is part of a bottomland riparian corridor along the Elm Fork of the Trinity River. The community is structurally simple, with an arborescent layer dominated by sugarberry (*Celtis laevigata*), cottonwood (*Populus deltoides*) and elm (*Ulmus* sp.); the herbaceous understory is predominately Canadian wild-rye (*Elymus canadensis*). Monitoring data show that community composition of the herbaceous understory has been driven largely by perennial grass and herb species for all study years (Appendix B). The only statistically significant decrease in Shannon diversity occurred between 1992 and 1995 (Table 12). This decrease in community diversity may be explained by increased abundance of perennial wildrye and a decrease in common perennial herbs during this period, resulting in an overall decrease in plant species heterogeneity and an increase in dominance.

CHAPTER V

CONCLUSIONS

The first objective of this research was to determine whether the Ray Roberts Lake landscape could be characterized as a disturbance landscape. The results of the landscape analysis show that dynamics in the Grand Prairie region of the study area do indicate the continuing presence of disturbance, based on metric values at both the landscape level and class level of analysis. Analysis of the Eastern Cross Timbers was much more complex. Increased landscape heterogeneity and decreased patch variability, combined with increased representation of agriculture on the landscape, seem to indicate that landscape change in the Eastern Cross Timbers between 1987 and 1997 has been driven by activities related to human activity. Therefore, it seems likely that the Eastern Cross Timbers has also been maintained by disturbance during this period.

The second objective of this study was to determine whether plant communities in the study area could be characterized as disturbance-maintained. Fisher’s log series modeling and diversity analysis showed that the plant communities monitored in the Grand Prairie fit this characterization. Similarly, plant communities of the Eastern Cross Timbers did not show any significant change in diversity across the study period. With the exception of oldfield EF9, which has remained relatively undisturbed for many years, all of the communities fit the Fisher’s log series model, indicating that they are undergoing continuing disturbance. Thus, this research has shown that both the landscape mosaic and the plant communities occupying the mosaic patches can be characterized as disturbed.

Finally, the third objective of this study was to determine whether a qualitative relationship could be established between disturbance-maintained landscape dynamics and disturbance-maintained plant community dynamics. Landscape analysis indicates that ongoing dynamics in the agriculture and rangeland classes may be the driving force for landscape change in the Ray Roberts Lake area. Intuitively, both landuses have direct consequence for plant community dynamics and a general relationship between the two can be inferred. Thus, from the perspective of establishing a methodology for integrating plant community dynamics into landscape characterization, this relationship has been tentatively established.

Typically, field assessment of plant community dynamics has not been a component of studies of landscape change because of the impracticality of assessing the innumerable patches comprising a landscape mosaic and the amount of time needed to compile the data (Dunn et al., 1991). Additionally, funding constraints, lack of appropriately trained personnel, inadequate data resources, or lack of time may not permit the integration of intensive fieldwork in landscape characterization. Thus, emphasis may be placed on collection of landuse and landcover data at the expense of collection of plant community data.

Within a single landscape, however, several types of patches may be experiencing change at different temporal and spatial scales. As a result, analyses of landscape dynamics using satellite remotely sensed data, high-altitude aerial photos, or finer scale

GIS coverages may show very different levels of sensitivity to landscape change. Additionally, the scale of plant community responses to disturbance on the landscape may be smaller than traditional landscape analyses can detect. For example, woodlots in a landscape dominated by agriculture may be undergoing secondary succession, even though the gross pattern of landuse is not changing at a noticeable rate (Dunn et al., 1991). Thus, landscape analysis may show that the landscape mosaic is relatively stable even though changes are in fact occurring, as manifested through dynamics in individual habitats. Only a direct analysis of plant community dynamics would verify this level of change on the landscape.

Conversely, the processes underlying observed landscape dynamics over a given time period may yield insight into the general trends observed in the landscape's major plant communities. If a disturbance-related process (e.g. grazing) creates a patch and maintains its presence on the landscape over time, it follows that the same process may control the dynamics of the plant community within the patch. In other words, a landscape mosaic that has been created and maintained by disturbance from human activities should be comprised of plant communities that also reflect, at a given scale, the presence of chronic disturbance from these activities.

While establishing a quantitative correlation between landscape and plant community dynamics certainly requires further investigation, the results of this study do indicate that human disturbance is a driving factor on the Ray Roberts Lake landscape and in the dynamics of major plant communities comprising the landscape. Thus, this study has shown that where collection of such data is practical, inclusion of a plant community diversity component in analysis of landscape change could yield valuable insight into observed variation across the mosaic, providing a far more effective characterization of landscape dynamics.

The methodology developed in this study for integration of plant community dynamics into analysis of landscape change is exploratory. Accordingly, there are several methodological improvements and a number of areas for further investigation that may strengthen the usefulness of the approach. For example, plant community data were taken from monitoring transects established during the ten-year post-impoundment study conducted by the Institute for Applied Sciences (UNT) between 1987 and 1997. These transects were assumed to be representative of the major plant communities across the Ray Roberts Lake landscape. However, alternative random sampling techniques in collection of vegetation data may have yielded more representative samples, resulting in more precise characterization of the landscape's plant communities.

Additionally, analysis of the Eastern Cross Timbers did not include species diversity for the woody overstory because no abundance data was available. Thus, analyses of the Eastern Cross Timbers' plant communities were based solely on characterization of the herbaceous understory. Given that woodlands are a major component of the Eastern Cross Timbers, a more effective analysis would almost certainly have been achieved if abundance data had been collected for the woody overstory. Thus, future study of the relationship between landuse change and plant community dynamics in the Eastern Cross Timbers should include a woody overstory component.

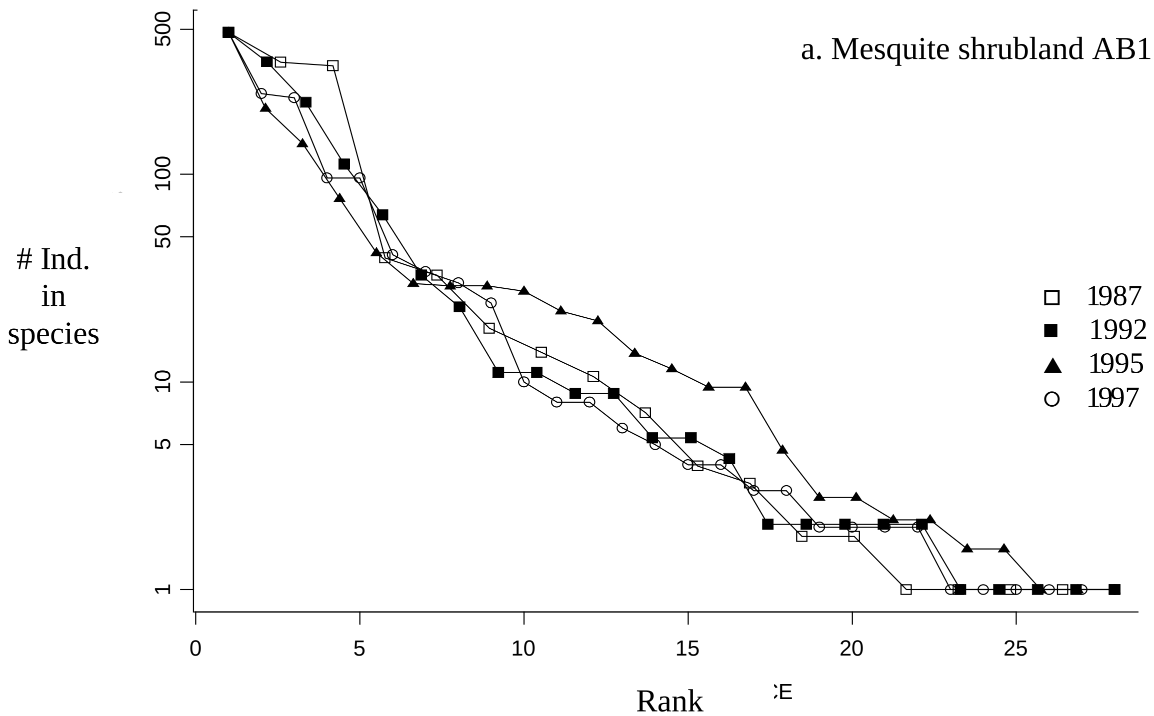
One area of potential research is investigation of the relationship between scale in landscape analyses and scale in plant community dynamics. Landscape analysis in this study was performed using SPOT-1 satellite imagery. But change in landscapes and plant communities occurs across multiple spatial scales, which may be larger or smaller than that obtained with SPOT-1 data. A more effective comparison between landscape dynamics and plant community dynamics, for example, may have been obtained by analysis of aerial photographs.

Determining the scale at which pattern in plant communities is manifested may be accomplished through a suite of quantitative methods, including analysis of variation in species density within a sample plot (Bartlett, 1967) and spectral analysis of spatial pattern in the community (Pielou, 1969; Ripley, 1978; Usher, 1975). Such identification of the scale at which variation in plant communities on the landscape mosaic occurs could represent a valuable tool in selection of appropriate scale and data for landscape analysis.

Thus, while quantitative methods to compare disturbance within a plant community to disturbance on the landscape have yet to be developed, this study has shown that inclusion of plant community dynamics in analysis of change in landscapes can provide important insight into landscape dynamics. Additionally, several avenues of research have been identified that would strengthen the utility of the methodology established through this work.

APPENDIX A

RANK ABUNDANCE PLOTS OF PLANT SPECIES ABUNDANCE



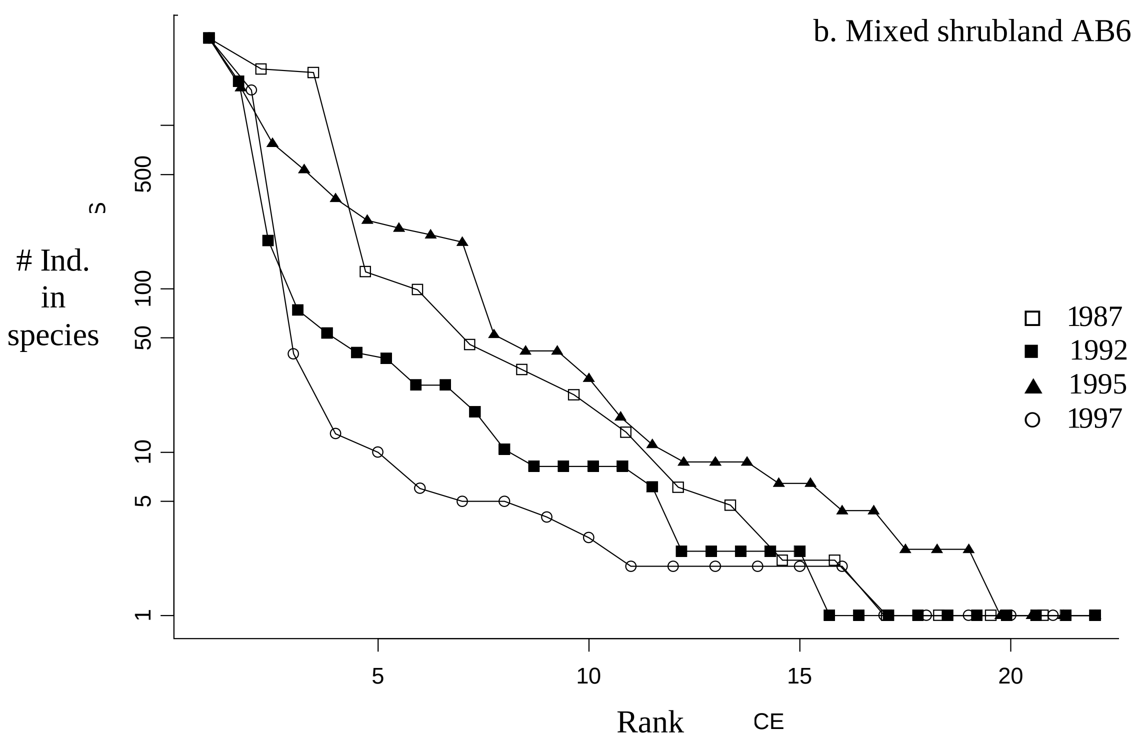


Figure 12. Rank abundance plots of a) mesquite shrubland AB1 and b) mixed shrubland AB6 transect sections in the Grand Prairie region of the Ray Roberts Lake study area, 1987 - 1997.

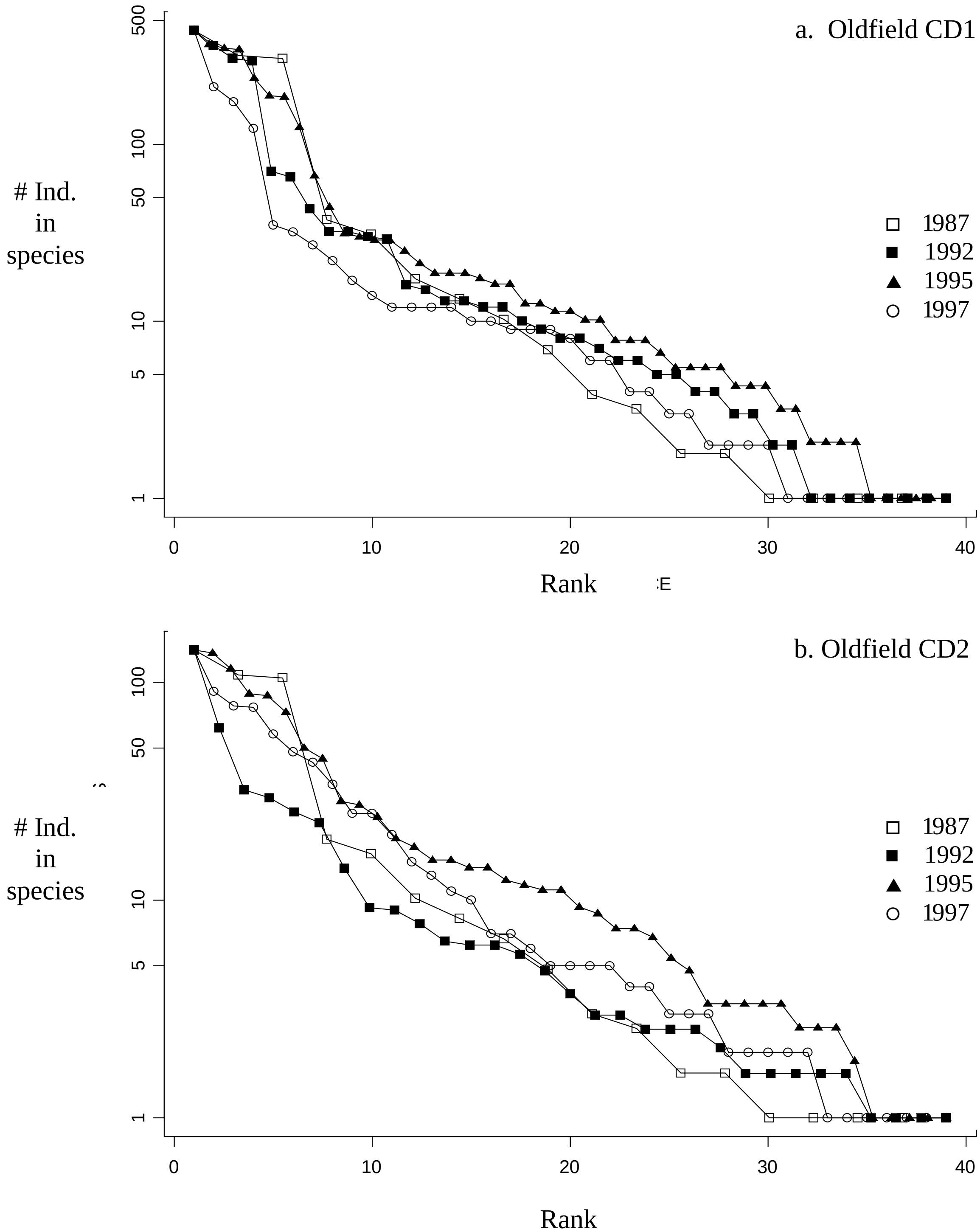
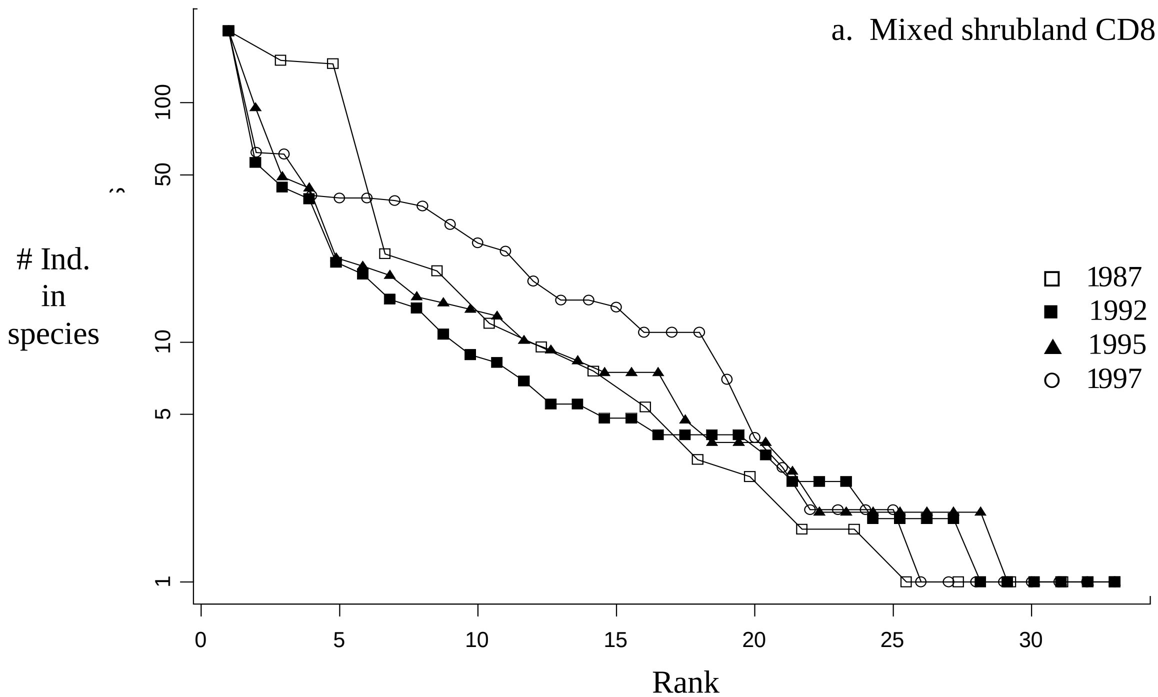


Figure 13. Rank abundance plots of a) oldfield CD1 and b) oldfield CD2 transect sections in the Grand Prairie region of the Ray Roberts Lake study area, 1987 - 1997.



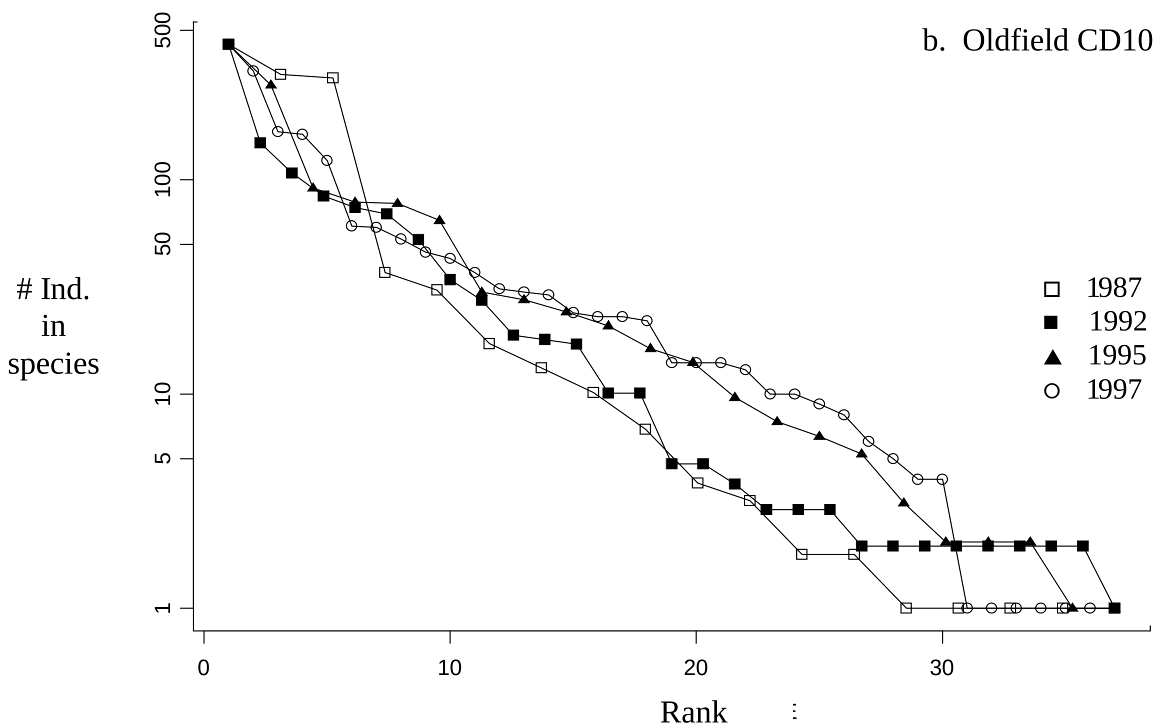
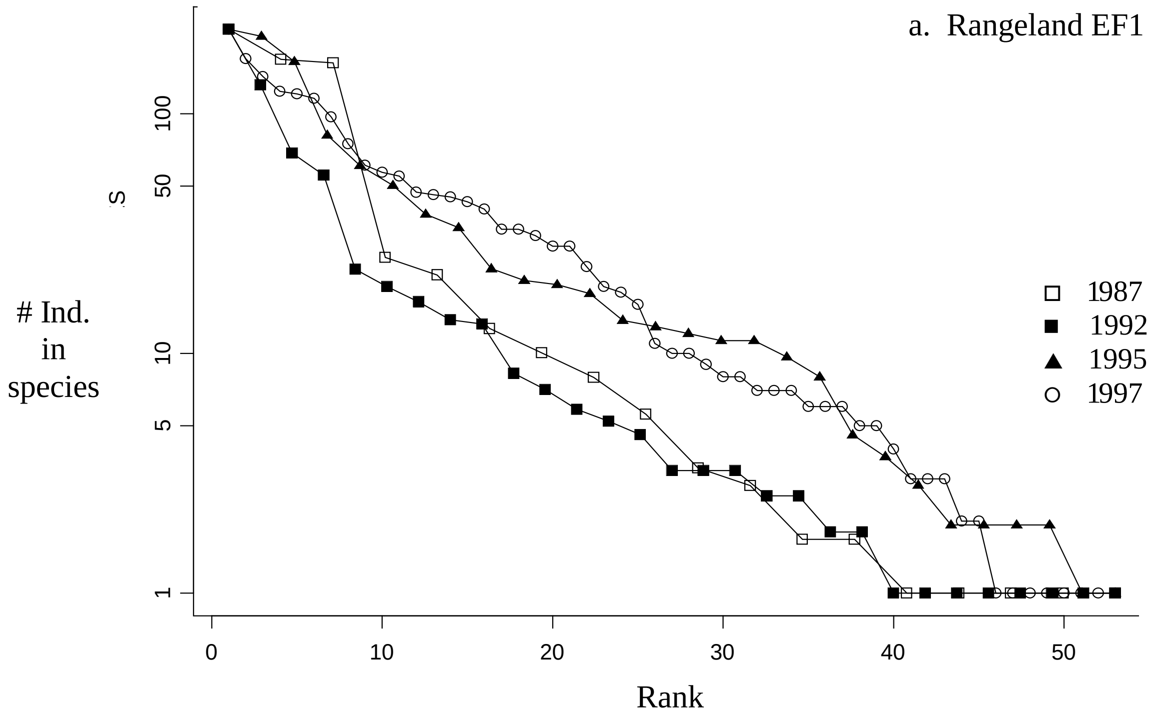


Figure 14. Rank abundance plots of a) mixed shrubland CD8 and b) oldfield CD10 transect sections in the Eastern Cross Timbers region of the Ray Roberts Lake study area, 1987 - 1997.



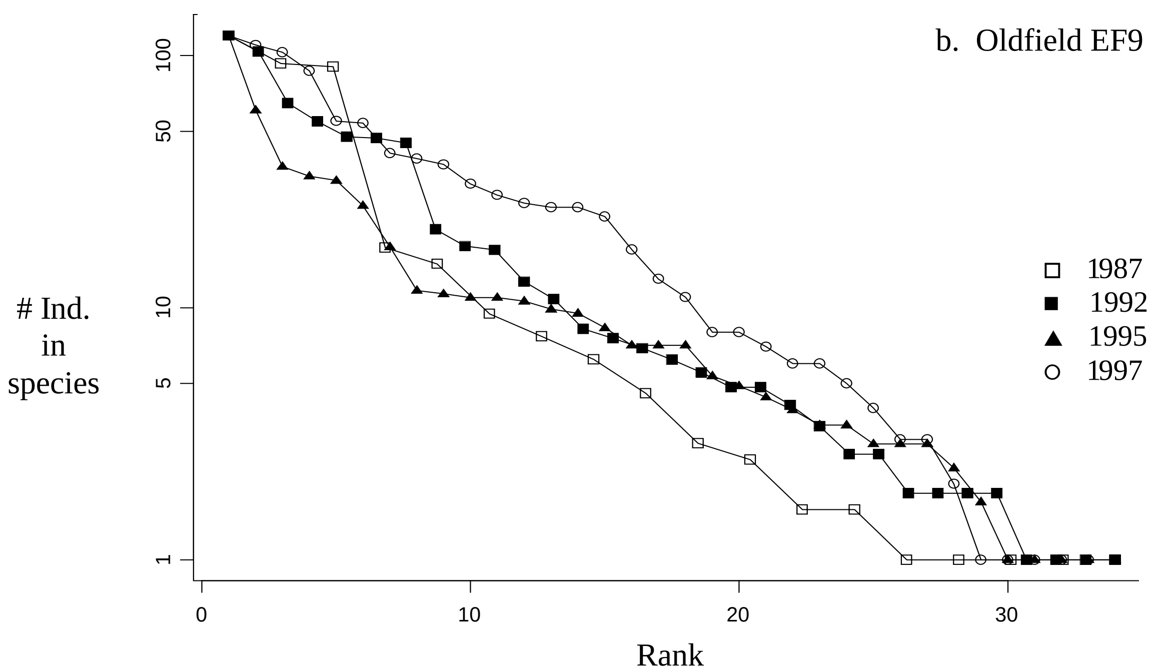


Figure 15. Rank abundance plots of a) rangeland EF1 and b) oldfield EF9 transect sections in the Eastern Cross Timbers region of the Ray Roberts Lake study area, 1987 - 1997.

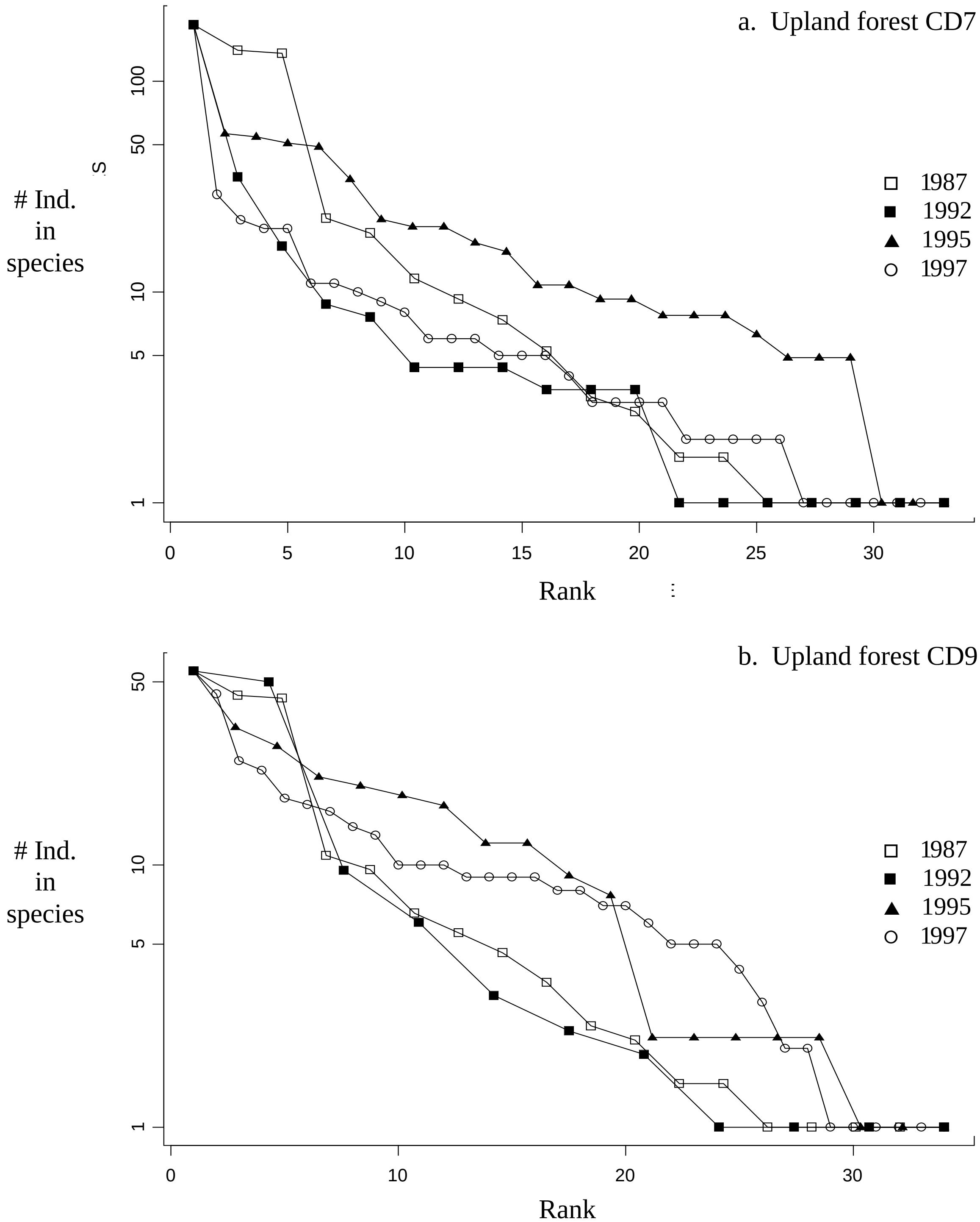
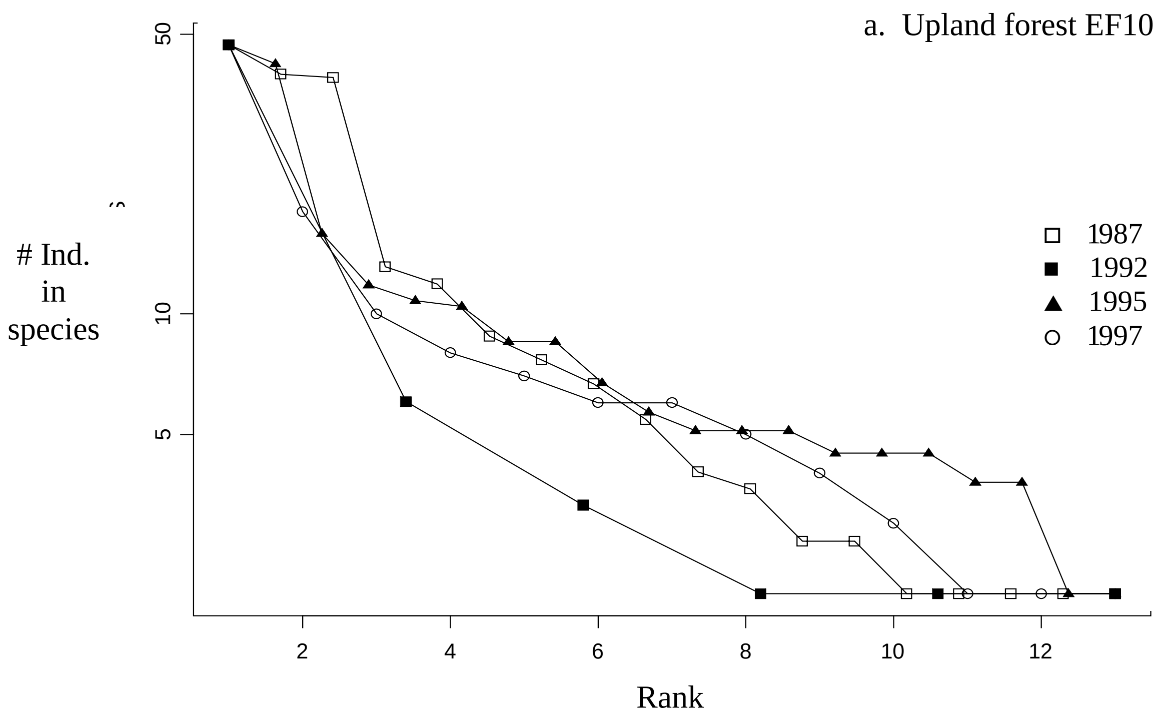


Figure 16. Rank abundance plots of a) upland forest CD7 and b) upland forest CD9 transect sections in the Eastern Cross Timbers region of the Ray Roberts Lake study area, 1987 - 1997.



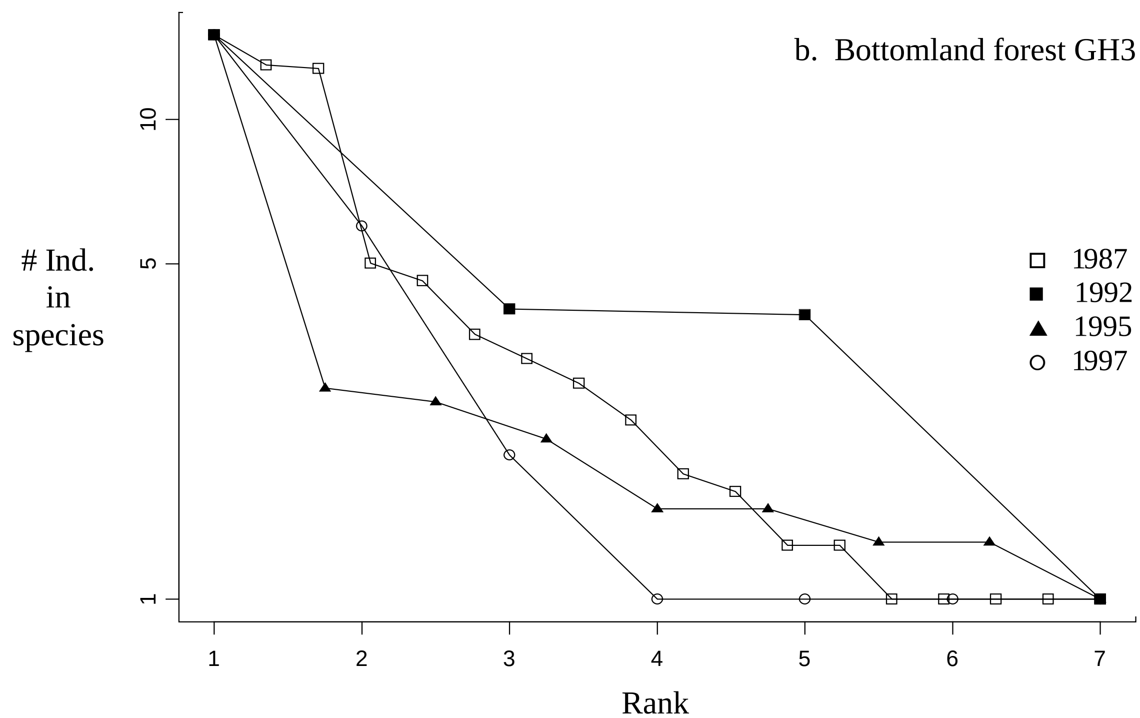


Figure 17. Rank abundance plots of a) upland forest EF10 and b) bottomland forest GH3 transect sections in the Eastern Cross Timbers region of the Ray Roberts Lake study area, 1987 - 1997.

APPENDIX B

PLANT COMMUNITY ABUNDANCE DATA

Table 14. Species abundance for Grand Prairie Mesquite Shrubland AB1, 1987-1997.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Herbs, Perennial					**Herbs, Annual**				
A. millefolium	.	.	.	34	*A. artemisiifolia*	2	2	169	245
A. americana	.	.	2	1	*C. monanthogynous*	.	2	2	.
A. viridis	.	.	2	.	*G. pulchella*	.	.	42	.
A. ericoides	.	.	15	3	*G. aparine*	.	.	5	2
C. muhlenbergii	.	4	5	1	*G. virgatum*	.	1	.	.
C. horridulum	.	.	3	3	*H. amarum*	.	2	.	.
C. texanum	.	.	4	.	*H. annuus*	.	5	.	.
C. dactylon	.	269	24	482	*L. virginicum*	.	.	21	1
D. pusillus	.	.	39	24	*M. minima*	25	.	.	.
Desmanthus sp.	.	8	.	.	*P. patagonica*	.	2	.	1
J. marginatus	.	.	.	2	*P. virginica*	.	.	57	234
L. canadensis	.	5	.	.	*Polygonaceae sp.*	.	.	.	1
O. dilenii	.	2	4	8	*P. multicaulis*	1	2	.	6
P. nuttalii	.	.	.	1	*R. hirta*	.	.	41	4
S. carolinense	7	.	.	.	*T. biflora*	.	.	.	96
S. dimidiatum	.	.	32	5					
S. elaeagnifolium	.	1	.	.					
Solidago spp.	.	.	.	1					
T. officinale	.	.	3	.					
T. bentonicifolia	.	.	8	.					
V. bipinnatifida	1	.	.	.					
V. halei	1	1	.	.					
Grasses, Perennial					**Grasses, Annual**				
B. ischaemum	.	91	.	.	*B. japonicus*	5239	367	51	8
B. saccharoides	.	1	.	.	*B. uniloides*	731	.	.	.
B. rigidiseta	.	.	18	3	*H. pusillum*	327	1	15	2
D. oligosanthes	.	8	.	41					
L. perenne	684	175	.	2					
P. setaceum	.	53	.	.					
S. halepense	.	.	98	96					
S. asper	.	1	41	.					
S. leucotricha	218	28	29	4					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	9	290	141	565	Herbs, Annual	28	16	337	590
Grasses, Perennial	902	357	186	146	Grasses, Annual	6297	368	66	10
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	3	7	12	12	Herbs, Annual	3	7	7	9
Grasses, Perennial	2	7	4	5	Grasses, Annual	3	2	2	2
Total Individuals	7236	1031	730	1311					
Total Species	11	23	25	28					

Table 15. Species abundance for Grand Prairie Rangeland CD1, 1987-1997.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Herbs, Perennial					**Herbs, Annual**				
A. millefolium	2	1	14	9	*A. artemisiifolia*	186	43	267	35
A.viridis	.	1	16	1	*C. maculata*	.	.	9	1
A. ericoides	8	8	316	174	*C. monanthogynu*	.	.	16	.
C. muhlenbergii	.	6	18	2	*Cuscuta sp.*	.	.	5	9
C. undulatum	2	1	3	1	*D. amplexicaulis*	.	12	.	.
C. arvensis	.	.	1	.	*E. spathulata*	.	1	2	.
C. croceus/ovularis	1	.	1	.	*G. virgatum*	.	29	1	12
D. pusillus	.	32	.	.	*G. suffulta*	.	.	11	2
E. montevidensis	.	7	.	.	*G. carolinianum*	1	1	7	6
E. philadelphicus	.	.	5	.	*H. amarum*	7	.	.	.
E. corrolata	.	.	14	1	*L. hirsutus*	.	3	.	.
F. puberula	.	3	1	.	*L. virginicum*	.	.	2	12
G. sinuata	3	.	.	.	*L. texana*	.	.	16	3
G. canadense	.	.	1	.	*L. sulcatum*	.	.	11	.
J. marginatus	3	.	.	.	*M. minima*	1	.	.	.
K. lanceolata	.	8	4	1	*M. punctata*	12	7	.	.
L. canadensis	58	12	.	.	*P. americana*	.	.	7	.
M. caespitosa	.	2	.	.	*P. patagonica*	.	.	.	6
M. biflora	.	.	4	1	*P. virginica*	.	.	142	8
N. lutea	2	32	.	.	*Polygonum sp.*	.	2	.	.
N. bivalve	.	.	.	1	*P. geiseri*	.	1	.	.
O. macrorhiza	.	.	1	.	*P. multicaulis*	.	.	4	.
O. dilenii	1	13	25	4	*R. hastatulus*	1	.	.	.
P. polygonoides	.	.	2	.	*S. asper*	.	.	7	.
P. rhombifolia	.	5	.	.	*S. inermis*	.	16	176	1
R. humilis	.	4	.	.	*T. biflora*	.	1	24	12
S. uncinata	.	.	6	22	*X. texanum*	.	4	.	.
S. roemeriana	.	1	.	.					
S. angustifolium	.	.	1	.					
S. ulmifolia	.	.	.	2					
T. canadense	.	.	.	17					
T. bentonicifolia	2	5	21	14					
V. bipinnatifida	.	.	9	.					
V. halei	1	.	.	.					
V. missouriensis	.	6	.	.					
Z. aurea	.	.	5	3					
Grasses, Perennial					**Grasses, Annual**				
A. gerardii	477	15	254	439	*B. japonicus*	1592	65	53	211
A. virginicus	.	.	.	1	*H. pusillum*	.	9	5	.
A. ludoviciana	27	.	.	9					
B. saccharoides	4	.	.	.					
B. rigidiseta	.	13	.	.					

Table 15. Species abundance for Grand Prairie Rangeland CD1, cont'd.

Species	No. of Individuals 1988	1992	1995	1997	Species	No. of Individuals 1988	1992	1995	1997
Grasses, Perennial									
B. dactyloides	.	.	1	2					
C. cylindrica	1	3	26	.					
C. dactylon	.	.	2	123					
D. oligosanthes	611	3.4	14	12					
E. longifolium	.	.	3	.					
L. cognatum	.	.	24	4					
S. scoparium	.	436	.	32					
S. geniculata	29	1	.	.					
S. nutans	.	.	.	1					
S. halepense	.	.	15	.					
S. asper	.	293	.	.					
S. leucotricha	9	359	96	27					
Shrubs									
R. toxicodendron	.	.	36	.					
R. foliosa	.	.	25	1					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	83	147	468	253	Herbs, Annual	208	120	707	107
Grasses, Perennial	3146	3115	2430	2647	Grasses, Annual	1592	74	58	211
Shrubs	.	.	61	1					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	11	18	21	15	Herbs, Annual	6	12	17	12
Grasses, Perennial	3	5	5	5	Grasses, Annual	1	2	2	1
Shrubs	.	.	2	1					

Table 16. Species abundance for Grand Prairie Rangeland CD2, 1987-1997.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
A. millefolium	4	.	23	2
A. ludovicianus	43	4	.	48
A viridis	.	.	7	.
A. ericoides	.	.	139	78
C. muhlenbergii	1	.	21	2
C. croceus	.	.	16	2
D. pusillus	.	27	6	.
E. pinnatifida	.	.	1	7
E. philadelphicus	.	.	4	.
G. pilosum	.	2	.	.
H. nigricans	.	.	.	15
K. lanceolata	.	.	.	4
L. canadensis	3	2	.	.
L. cognatum	.	.	1	.
M. biflora	.	.	1	.
M. officinalis	.	.	17	.
N. lutea	.	15	.	5
O. dilenii	1	15	236	.
P. polygonoides	.	.	.	2
P. viscosa	.	1	.	.
P. rhombifolia	.	4	.	.
R. humilis	.	.	3	1
R. foliasa	.	.	3	.
R. crispus	.	.	4	.
S. uncinata	.	.	.	1
Scutellaria sp.	.	.	.	2
S. angustifolium	.	.	23	.
S. dimidiatum	.	.	1	.
S. elaeagnifolium	.	1	.	2
S. ulmifolia	.	.	.	7
Solidago sp.	.	.	1	.
S. ulmifolia	.	.	18	43
V. bipinnatifida	.	.	3	4
Z. aureus	.	.	4	1
Grasses, Perennial (PG)				
A. gerardii	.	.	17	58
B. saccharoides	84	.	.	.
B. rigidiseta	17	171	.	.
B. dactyloides	.	151	21	.
C. cylindrica	.	.	12	.
C. dactylon	1	.	.	25
D. oligosanthes	33	21	79	141
L. perenne	2	2	9	1

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
A. artemisiifolia	194	121	285	6
A. trifida	.	.	39	.
Apium sp.	.	.	.	3
C. indivisa	.	.	9	.
C. americana	5	.	.	.
C. albomarginata	.	.	.	5
Coreopsis sp.	.	.	.	25
C. monanthogynous	.	3	13	1
E. leavenworthii	.	.	.	3
G. virgatum	.	13	.	5
G. suffulta	.	1	4	.
G. carolinianum	.	4	2	.
G. purpureum	.	.	4	1
H. hispidum	.	.	.	1
H. annuus	1	.	27	.
L. virginicum	.	.	3	.
M. lupulina	.	16	.	3
M. minima	.	5	.	.
M. orbicularis	.	1	.	.
Monarda sp.	.	7	.	.
P. virginica	.	.	47	.
P. ciliata	.	5	.	.
P. multicaulis	.	.	1	.
S. officinale	.	2	.	.
S. rostratum	.	.	1	.
S. asper	.	2	.	.
S. inermis	.	.	.	13
T. arvensis	6	.	.	.
X. texanum	.	.	.	1
Grasses, Annual (AG)				
Bromus japonicus	6538	1535	296	91
Hordeum pusillum	.	26	45	5

Table 16. Species abundance for Grand Prairie Rangeland CD2, cont'd.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Grasses, Perennial (PG)									
S. scoparium	5	453	.	77					
S. halepense	.	5	16	11					
S. leucotricha	1	1.2	174	34					
Shrubs (SH)									
G. triacanthos	1	1	.	.					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	52	71	532	226	Herbs, Annual	206	180	435	67
Grasses, Perennial	2131	2796	2323	2344	Grasses, Annual	6538	1561	341	96
Shrubs	1	1	0	0					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	5	9	21	18	Herbs, Annual	3	12	12	12
Grasses, Perennial	6	6	6	6	Grasses, Annual	1	2	2	1
Shrubs	1	1	.	.					

Table 17. Species abundance for Eastern Cross Timbers Upland Forest CD7, 1987-1997.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
A. verticillata	.	.	.	1
A. viridis	.	.	.	1
C. muhlenbergii	.	1	14	.
Carex sp.	26	96	.	.
C. piliculmis	.	16	.	.
D. spicata	2	6	.	.
D. tweedyi	.	.	4	.
G. volubilis	.	.	34	.
H. rosmarinifolium	.	.	5	11
H. hirsutus	.	9	.	.
K. lanceolata	.	.	.	1
L. candensis	.	.	1	11
L. tenuifolia	.	.	22	8
L. virginica	.	.	.	5
N. lutea	.	.	7	.
O. laciniata	.	2	.	.
O. dilenii	.	2	.	2
P. quinquefolia	.	.	15	2
P. lutea	.	.	.	4
P. murrayanus	.	5	.	.
R. humilis	.	.	33	.
S. bona-nox	1	2	.	3
S. hispidus	.	.	.	1
S. petiolaris	17	.	.	.
S. ulmifolia	.	5	.	.
S. biflora	.	.	3	.
V. bipinnatifida	.	.	8	.
Grasses, Perennial (PG)				
B. curtipendula	.	.	.	5
C. dactylon	.	.	.	185
D. acuminatum	.	.	14	.
D. laxiflorum	13	28	8	1
D. lindheimeri	3	.	.	.
D. linearifolium	.	.	6	22
D. sphaerocarpon	.	5	7	.
D. oligosanthes	4	.	6	1
L. perenne	.	.	.	5
P. setaceum	1	.	.	.
S. asper	.	.	96	29
S. leucotricha	.	.	12	.
T. flavus	1	.	.	.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
C. fasciculata	.	.	.	3
C. asteroides	.	6	.	1
C. albomarginata	.	.	.	3
D. teres	.	2	.	9
G. pilosum	2	.	.	.
G. virgatum	.	.	4	.
G. parviflora	.	.	31	6
G. purpureum	.	.	.	1
H. hispidum	.	2	.	.
H. petiolaris	48	.	.	.
L. sulcatum	.	.	.	2
P. virginica	.	6	.	2
R. hirta	.	.	1	2
S. campestris	.	.	4	.
Strophostyles sp.	.	2	.	.
Grasses, Annual (AG)				
A. longispeca	3 .	.	.	

Table 17. Species abundance for Eastern Cross Timbers Upland Forest CD7, cont'd.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Shrubs (SH)									
C. texana	1	.	.	.					
C. laevigata	.	2	.	.					
Q. macrocarpa	.	.	1	.					
Q. marilandica	1	.	6	2					
Q. stellata	.	.	.	2					
R. toxicodendron	.	.	11	6					
S. orbiculata	.	.	.	6					
U. crassifolia	7	.	.	3					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	46	144	146	50	Herbs, Annual	50	18	40	29
Grasses, Perennial	22	33	149	248	Grasses, Annual	3	.	.	.
Shrubs	48	39	37	19					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	4	10	11	12	Herbs, Annual	2	5	4	9
Grasses, Perennial	5	2	7	7	Grasses, Annual	1	.	.	1
Shrubs	3	2	3	5					
Total Individuals	169	234	372	346					
Total Species	15	19	25	34					

Table 18. Species abundance for Eastern Cross Timbers Shrubland CD8, 1987-1997.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
A. millefolium	.	2	.	.
A. ludoviciana	.	3	.	2
A. ericoides	2	29	.	3
C. plantaginea	.	7	.	.
C. muhlenbergii	.	.	8	.
C. texanum	.	.	1	.
C. arvensis	.	.	1	.
C. croceus	.	.	3	2
D. pusillus	2	3	.	1
D. tweedyi	.	.	1	.
E. philadelphicus	.	1	2	1
G. volubilis	.	5	.	.
H. nigricans	.	.	.	31
H. rosmarinifolium	.	6	11	37
H. pseudomaculata	2	.	.	.
I. miniata	2	.	.	.
J. marginatus	3	.	4	.
L. tenuifolia	.	.	23	.
L. hirta	.	22	.	62
L. repens	.	.	9	61
L. stuevei	.	12	.	.
N. lutea	21	.	5	41
O. heterophylla	4	.	.	.
O. laciniata	1	.	.	.
O. dilenii	1	5	.	11
O. violaceae	.	.	2	11
P. quinquefolia	.	.	8	.
S. ciliata	.	1	.	.
S. bona-nox	.	.	1	1
S. biflora	.	4	56	.
T. bentonicifolia	.	2	2	26
V. bipinnatifida	.	.	2	.
V. halei	4	5	.	.
Grasses, Perennial (PG)				
A. gerardii	1	.	238	.
B. ischaemum	38	11	.	.
B. saccharoides	4	.	.	.
B. curtipendula	.	6	.	.
C. dactylon	.	98	16	4
D. lanuginosa	.	15	.	.
D. linearifolium	.	.	.	15
D. sphaerocarpon	.	33	21	15

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
A. artemisiifolia	84	9	5	2
A. nuttallianus	6	.	.	.
C. fasciculata	19	.	.	.
C. indivisa	.	.	2	.
D. teres	.	1	.	.
G. suffulta	.	.	1	.
G. purpureum	.	2	.	.
H. hispidum	.	.	.	1
H. amarum	8	.	.	.
H. annuus	.	1	.	.
L. sulcatum	.	3	17	39
L. rigidum	55	.	.	.
M. punctata	1	.	.	.
P. aristata	28	.	.	.
P. patagonica	15	.	.	.
P. verticillata	.	.	.	1
P. multicaulis	.	1	.	.
R. hirta	9	.	.	4
R. hastatulus	1	.	.	.
S. campestris	2	.	15	18
Grasses, Annual (AG)				
A. hiemalis	.	.	8	1
B. japonicus	.	2	.	.

Table 18. Species abundance for Eastern Cross Timbers Shrubland CD8, cont'd.

Species	No. of Individuals 1988	1992	1995	1997	Species	No. of Individuals 1988	1992	1995	1997
Grasses, Perennial (PG)									
D. acuminatum	.	.	14	.					
D. oligosanthes	569	66	25	7					
P. setaceum	6	7	.	11					
S. scoparium	1.1	414	.	199					
S. halepense	.	.	4	1					
S. asper	19	75	111	4					
S. clandestinus	.	.	.	24					
S. cryptandrus	2	.	.	.					
T. flavus	2	.	.	.					
Shrubs (SH)									
J.virginiana	.	.	.	1					
Q. marilandica	.	1	.	.					
Q. stellata	.	.	2	2					
R. copallina	1	.	.	.					
R. toxicodendron	.	.	1	.					
R. trivialis	.	5	4	.					
U. crassifolia	.	2	2	14					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	42	107	139	290	Herbs, Annual	228	17	40	65
Grasses, Perennial	2630	2717	2424	2277	Grasses, Annual	0	2	8	1
Shrubs	1	8	9	17					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	10	15	17	14	Herbs, Annual	11	6	5	6
Grasses, Perennial	9	9	7	9	Grasses, Annual	.	1	1	1
Shrubs	1	3	4	3					
Total Individuals	2901	2851	2620	2650					
Total Species	31	34	34	33					

Table 19. Species abundance for Eastern Cross Timbers Upland Forest CD9, 1987-1997.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
C. muhlenbergii	.	.	6	.
C. virginianum	.	.	.	25
C. incisa	1	.	.	.
C. mariana	.	.	9	1
C. erecta	.	.	2	5
C. texana	.	.	2	.
D. paniculatum	.	2	.	.
D. virginiana	.	.	.	23
G. pilosum	2	23	.	.
H. rosmarinifolium	.	.	.	13
L. canadensis	1	.	1	5
Lespedeza sp.	.	.	.	1
L. hirta	.	2	.	.
L. virginiana	.	.	.	8
O. macrorhiza	.	.	1	1
O. dillenii	4	4	2	9
P. quinquefolia	1	.	22	.
S. bona-nox	1	2	34	1
S. petiolaris	.	14	.	.
V. missouriensis	.	.	.	6
Grasses, Perennial (PG)				
D. laxiflorum	.	153	.	.
D. lindheimeri	24	.	.	1
D. linearifolium	.	.	.	45
D. oligosanthes	.	.	19	.
D. sphaerocarpon	.	.	14	.
Dichanthelium sp.	.	.	.	1
E. canadensis	.	.	.	7
P. setaceum	42	.	.	9
S. scoparium	.	138	.	55
T. flavus	2	.	.	.
Shrubs (SH)				
Q. macrocarpa	.	.	7	2
Q. marilandica	1	.	1	5
Q. stellata	.	5	2	7
R. copallina	1	.	.	.
R. toxicodendron	.	.	.	1
S. orbiculatus	1	.	.	.
U. crassifolia	.	.	2	.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
A. artemisiifolia	1	.	.	2
A. leptophyllum	.	.	.	1
A. nuttallianus	.	7	.	.
C. fasciculata	.	.	.	16
Clover	.	.	.	4
D. teres	.	.	.	14
G. aparine	.	.	12	.
G. virgatum	.	.	15	9
L. sulcatum	.	.	.	8
M. punctata	.	.	.	1
P. aristata	.	.	.	17
P. geiseri	.	2	.	.
R. hirta	.	.	.	18
S. campestris	.	.	.	3
Grasses, Annual (AG)				
Agrostis hiemalis	.	.	13	.
Bromus japonicus	3	.	9	9

Table 19. Species abundance for Eastern Cross Timbers Upland Forest CD9, cont'd.

No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	10	47	79	98	Herbs, Annual	1	9	27	93
Grasses, Perennial	68	291	33	118	Grasses, Annual	3	0	22	9
Shrubs	3	5	12	15					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	6	6	9	12	Herbs, Annual	1	2	2	11
Grasses, Perennial	3	2	2	6	Grasses, Annual	1	0	2	1
Shrubs	3	1	4	4					
Total Individuals	85	352	173	333					
Total Species	14	11	19	34					

Table 20. Species abundance for Eastern Cross Timbers Rangeland CD10, 1987-1997

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
A. millefolium	.	.	6	13
A. viridis	.	.	.	1
A. ericoides	.	2	68	37
C. croceus	.	.	.	14
D. pusillus	.	3	.	.
D. leptolobus	.	31	.	.
E. philadelphicus	1	.	2	1
H. rosmarinifolium	.	2	.	.
I. miniata	.	1	.	.
J. marginatus	.	3	22	29
L. canadensis	1	.	.	.
L. tenuifolia	.	.	.	4
L. repens	.	.	.	53
O. laciniata	.	21	.	.
O. dilenii	.	3	1	9
R. acetosella	.	87	.	.
R. pulcher	.	.	2	.
S. uncinata	.	.	.	6
S. biflora	.	11	1	.
T. canadense	.	.	.	22
T. bentonicifolia	.	.	9	1
V. halei	.	5	5	.
Grasses, Perennial (PG)				
A. virginicus	.	.	234	163
B. ischaemum	3	2	15	.
C. cylindrica	.	.	19	.
C. dactylon	956	536	357	168
D. sphaerocarpon	1	.	.	.
D. oligosanthes	6	99	25	3
E. intermedia	.	2	.	.
L. perenne	.	179	.	1
P. setaceum	22	.	.	24
S. panicum	.	.	.	14
S. scoparium	.	.	.	123
S. leucotricha	.	.	27	.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
A. artemisiifolia	1	81	8	46
Apium. sp.	.	.	.	4
C. fasciculata	16	.	.	.
C. indivisa	.	4	.	1
C. asteroides	.	2	.	.
C. canadensis	2	.	.	.
C. capitatus	.	61	.	.
D. teres	.	2	.	.
E. leavenworthii	.	.	.	6
G. fastigiata	.	.	3	.
G. carolinianum	.	2	.	.
G. purpureum	.	.	.	23
H. hispidum	.	19	.	14
H. amarum	2	.	.	.
H. pilosa	5	.	.	.
L. imbricatum	.	2	.	.
L. sulcatum	.	.	.	1
M.o lupulina	.	.	.	1
M. clinopodioides	1	.	.	.
M. punctata	.	.	7	5
P. aristata	916	128	.	.
P. rhodosperma	.	.	2	322
P. virginica	.	2	.	.
P. carolinianus	.	.	.	1
R. hirta	4	.	.	43
S. campestris	.	.	13	61
S. inermis	75	.	69	429
T. dubium	.	11	.	.
Trifolium sp.	.	.	.	31
X. texanum	.	.	.	1
Grasses, Annual (AG)				
A. hyemalis	.	.	.	23
Aristida sp.	14.9	.	.	.
B. japonicus	.	39	57	8
H. pusillum	1	5	.	.

Table 20. Species abundance for Eastern Cross Timbers Rangeland CD10, cont'd.

No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	2	169	116	190	Herbs, Annual	1022	314	102	989
Grasses, Perennial	988	818	677	496	Grasses, Annual	16	44	57	31
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	2	11	9	12	Herbs, Annual	9	11	6	15
Grasses, Perennial	5	5	6	7	Grasses, Annual	2	2	1	2
Total Individuals	2028	1345	952	1706					
Total Species	18	29	22	36					

Table 21. Species abundance for Eastern Cross Timbers Oldfield EF1, 1987-1997.

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Perennial (PH)				
A. millefolium	.	.	4	1
A. cannabinum	2	.	.	.
A. viridis	1	.	2	8
A. ericoides	.	1	13	61
C. muhlenbergii	.	12	.	.
C. undulatum	.	.	.	1
C. croceus	.	.	2	5
Cyperus sp.	.	7	.	.
Eliocharis. sp.	.	.	.	6
E. corrolata	.	.	1	7
H. rosmarinifolium	.	1	3	1
J. marginatus	.	3	63	43
L. cuneata	.	2	13	23
L. hirta	2	.	.	.
L. repens	.	.	23	33
L. virginica	1	.	.	45
N. lutea	2	8	14	4
O. dilenii	.	1	27	57
P. rhombifolia	.	2	.	.
S. uncinata	.	.	.	3
Scutellaria sp.	.	.	.	1
S. carolinense	1	.	.	.
S. elaeagnifolium	.	4	.	.
S. biflora	.	1	.	.
V. halei	.	4	2	1
Sedge	.	.	.	1
Grasses, Perennial (PG)				
A. gerardii	.	.	3.7	116
A. virginicus	.	.	221	225
B. ischaemum	.	.	41	33
B. saccharoides	.	27	.	97
B. curtipendula	.	.	.	19
B. dactyloides	.	.	.	7
C. verticellata	.	3	.	.
C. cylindrica	.	21	15	1
C. dactylon	.	32	21	31
D. linearifolium	553	.	.	.
D. sphaerocarpon	96	.	.	.
D. oligosanthes	222	313	286	121
L. cognatum	.	.	.	55
L. perenne	.	.	.	11
P. dilatatum	.	.	.	18

Species	No. of Individuals			
	1988	1992	1995	1997
Herbs, Annual (AH)				
A. artemisiifolia	7	145	24	143
C. fasciculata	3	.	.	.
C. indivisa	.	.	.	1
C. drummondii	.	1	.	.
C. monanthogynous	.	1	.	.
D. teres	23	22	.	1
G. purpureum	.	.	.	47
H. hispidum	.	.	.	3
H. amarum	.	.	.	46
K. striata	.	1	.	.
L. virginicum	.	1	.	.
L. medium	42	.	.	.
L. sulcatum	.	.	47	28
M. clinopodioides	3	.	.	.
M. punctata	.	.	1	3
P. incarnatum	.	.	.	4
P. multicaulis	.	.	.	2
R. hirta	2	4	11	1
S. campestris	3	.	16	28
S. inermis	.	.	5	.
Trifolium sp.	.	.	.	6
Plantago sp.	.	.	.	2
P. aristata	493	39	77	124
P. patagonica	.	.	.	8
P. virginicus	.	.	9	16
Grasses, Annual (AG)				
A. hiemalis	.	.	.	5
A. oligantha	.	.	.	17
Aristida sp.	166	.	.	.
B. japonicus	81	588	1.5	6

Table 21. Species abundance for Eastern Cross Timbers Oldfield EF1, cont'd.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Grasses, Perennial (PG)									
P. setaceum	9	6	2	.					
Paspalum sp.	.	.	.	7					
S. scoparium	.	.	.	75					
S. leucotricha	.	113	.	9					
Shrubs (SH)									
G. triacanthos	.	1	.	.					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	9	46	167	301	Herbs, Annual	576	214	190	463
Grasses, Perennial	880	515	590	825	Grasses, Annual	247	588	2	28
Shrubs	.	1	.	.					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	6	12	12	18	Herbs, Annual	8	8	8	17
Grasses, Perennial	4	7	7	15	Grasses, Annual	2	1	1	3
Shrubs	.	1	.	.					
Total Individuals	1712	1363	948	1617					
Total Species	20	29	28	53					

Table 22. Species abundance for Eastern Cross Timbers Oldfield EF9, 1987-1997.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Herbs, Perennial (PH)					**Herbs, Annual (AH)**				
A. millefolium	11	.	5	.	*A. virginica*	.	5	.	.
A. americana	.	.	.	1	*A. artemisiifolia*	36	95	9	54
A. viridis	.	.	1	.	*C. fasciculata*	2	.	.	8
A. ericoides	.	.	13	1	*C. indivisa*	6	.	.	.
Baptisia sp.	.	8	.	.	*C. monanthogynous*	.	2	.	.
Carex sp.	4	.	.	.	*D. teres*	.	.	.	39
C. horridulum	.	.	1	.	*G. fastigiata*	.	2	4	13
C. croceus	.	6	.	.	*G. volubilis*	9	.	13	23
D. sessifolium	18	.	.	.	*G. purpureum*	.	.	1	6
E. philadelphicus	1	.	1	1	*Hedeoma* sp.	.	3	.	.
H. nigricans	.	.	5	3	*H. amarum*	3	.	.	.
Hedyotis sp.	.	2	.	.	*L. medium*	8	.	.	.
H. rosmarinifolium	.	31	2	55	*L. sulcatum*	.	7	42	37
J. brachycarpus	.	1	.	.	*M. punctata*	.	.	2	1
J. marginatus	1	6	23	.	*P. aristata*	2.1	.	.	.
J. tenuis	1	.	.	.	*P. patagonica*	.	4	.	5
K. lanceolata	.	.	3	.	*P. rhodosperma*	3	3	4	.
L. cuneata	.	.	1	.	*P. virginica*	.	.	16	25
L. repens	.	.	7	2	*P. carolinianus*	.	1	.	.
Lespedeza sp.	.	1	.	.	*P. multicaulis*	2	.	.	.
N. lutea	3	26	19	31	*R. hirta*	32	11	69	28
O. dillenii	.	.	13	4	*R. hastatulatus*	46	.	.	.
P. procumbens	2	.	.	.	*S. campestris*	4	1	25	6
S. ciliata	.	9	.	.	*T. campestre*	4	.	.	.
Sedge	.	.	.	11	*V. octoflora*	2	196	.	.
S. bona-nox	.	.	.	1					
S. carolinense	1	.	.	.					
Thelesperma sp.	.	15	.	.					
T. auriculata	.	.	.	1					
T. bentonicifolium	.	2	8	7					
V. bipinnatifida	1	.	.	.					
V. halei	3	.	6	.					
Grasses, Perennial (PG)					**Grasses, Annual (AG)**				
A. gerardii	.	.	24	8	*B. japonicus*	.	.	22	11
A. virginicus	.	.	98	17					
B. ischaemum	352	18	526	1.3					
C. cylindrica	.	1	.	3					
C. dactylon	.	76	11	25					
D. linearifolium	.	81	93	87					
D. oligosanthes	5	232	216	26					
D. sphaerocarpon	476	8	4	.					
P. setaceum	182	25	23	41					

Table 22. Species abundance for Eastern Cross Timbers Oldfield EF9, 1987-1997.

Species	No. of Individuals 1988	1992	1995	1997	Species	No. of Individuals 1988	1992	1995	1997
Grasses, Perennial (PG)									
S. scoparium	1	115	.	12					
S. obtusata	2	.	.	.					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	46	107	108	118	Herbs, Annual	159	330	185	245
Grasses, Perennial	1018	556	995	220.3	Grasses, Annual	.	.	22	11
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	11	11	15	12	Herbs, Annual	14	12	10	12
Grasses, Perennial	6	8	8	9	Grasses, Annual	.	.	1	1
Total Individuals	1223	993	1310	594					
Total Species	31	31	34	34					

Table 23. Species abundance for Eastern Cross Timbers Upland Forest EF10, 1987-1997.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Herbs, Perennial (PH)					**Herbs, Annual (AH)**				
C. muhlenbergii	.	.	17	.	*C. glandulosa*	2	.	.	.
C. mariana	.	.	.	2					
C. erecta	.	.	5	.					
C. croceus	.	.	3	2					
D. spicata	6	.	.	.					
E. philadelphicus	.	.	4	.					
G. volubilis	.	.	12	3					
J. marginatus	.	.	21	.					
L. candensis	.	.	1	.					
L. tenuifolia	.	.	4	.					
L. cuneata	.	.	4	.					
O. dilenii	2	2	18	.					
P. quinquefolia	.	.	5	.					
S. bona-nox	1	9	8	.					
S. hispidus	.	.	3	.					
V. thapsus	.	4	.	.					
Grasses, Perennial (PG)					**Grasses, Annual (AG)**				
A. gerardii	.	.	6	.	*B. japonicus*	.	.	186	18
C. latifolium	.	.	.	1					
C. dactylon	.	2	.	.					
D. laxiflorum	14	.	.	.					
D. lindheimeri	4	.	.	.					
D. linearifolium	.	147	.	7					
D. oligosanthes	.	.	224	47					
D. sphaerocarpon	.	.	35	.					
P. setaceum	1	.	.	.					
S. clandestinus	.	.	.	6					
T. flavus	1	.	.	.					
Shrubs (SH)									
C. occidentalis	.	.	.	4					
Q. marilandica	1	.	.	2					
Q. stellata	1	.	5	8					
R. toxicodendron	.	.	12	6					
U. crassifolia	1	2	1	5					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	9	15	105	7	Herbs, Annual	2	.	.	.
Grasses, Perennial	20	149	265	61	Grasses, Annual	.	.	186	18
Shrubs	3	2	18	25					

Table 23. Species abundance for Eastern Cross Timbers Upland Forest EF10, cont'd.

No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	3	3	13	3	Herbs, Annual	1	.	.	.
Grasses, Perennial	4	2	3	4	Grasses, Annual	.	.	1	1
Shrubs	3	1	3	5					
Total Individuals	34	166	574	111					
Total Species	11	6	20	13					

Table 24. Species abundance for Eastern Cross Timbers Bottomland Forest GH3, 1987-1997.

Species	No. of Individuals				Species	No. of Individuals			
	1988	1992	1995	1997		1988	1992	1995	1997
Herbs, Perennial (PH)					**Herbs, Annual (AH)**				
A. cordata	1	.	.	.	*A. trifida*	1	.	3	.
C. flaccosperma	25	.	.	.	*Helianthus* sp.	.	.	.	2
C. muhlenbergii	2	.	.	.					
Carex sp.	.	.	7	.					
C. texana	3	.	.	.					
M. gonocarpa	.	.	.	1					
P. quinquefolia	.	.	3	.					
P. pubescens	.	.	.	1					
R. humilis	14	31	13	6					
R. strepens	3	.	.	.					
S. bona-nox	2	29	11	1					
S. hispidus	.	.	2	.					
T. urticifolia	2	.	.	.					
V. vulpina	1	.	.	.					
Grasses, Perennial (PG)					**Grasses, Annual (AG)**				
C. latifolium	19	.	.	.	*B. japonicus*	5	.	.	.
E. virginicus	634	795	946	85					
Shrubs (SH)									
C. laevigata	2	.	.	.					
R. coppallina	.	.	.	1					
R. trivialis	.	.	2	.					
S. canadensis	.	.	1	.					
S. orbiculatus	3	.	.	.					
U. crassifolia	.	1	.	.					
No. of Individuals (*n*)					**No. of Individuals (*n*)**				
Herbs, Perennial	53	60	36	9	Herbs, Annual	1	.	3	2
Grasses, Perennial	653	795	946	85	Grasses, Annual	5	.	.	.
Shrubs	5	1	3	1					
No. of Species (*S*)					**No. of Species (*S*)**				
Herbs, Perennial	9	2	5	4	Herbs, Annual	1	.	1	1
Grasses, Perennial	2	1	1	1	Grasses, Annual	1	.	.	.
Shrubs	2	1	2	1					
Total Individuals	717	856	988	97					
Total Species	15	4	9	7					

REFERENCES

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geologic Survey Professional Paper 964. Washington D. C.: U. S. GPO. 28 p.

Bartlett, M. S. 1967. Some remarks on the analysis of time series. Biometrika, 54: 25-38.

Bates, E. F. 1918. History And Reminiscences Of Denton County. Denton: McNitzky Printing Company. 412 p.

Bierregaard, R., Jr., T. E. Lovejoy. 1989. Effects of forest fragmentation on Amazonian understory bird communities. ACTA Amazonica, Vol 19.

Bridges, C. A. 1978. History Of Denton, Texas: From Its Beginning To 1960. Waco: Texian Press.

Brower, J. E., J. H. Zar, C. N. vonEnde. 1989. Field And Laboratory Methods For General Ecology, Third Edition. Dubuque: Wm. C. Brown. 237 p.

Clements, F. E. 1936. Nature and the structure of the climax. Journal of Ecology. 24: 252-284.

Dunn, C. P., D. M. Sharpe, G. R. Guntenspergen, F. Stearns, Z. Yang. 1991. Methods for analyzing temporal changes in landscape pattern, 173 – 198. *In* Quantitative methods in landscape ecology, M. G. Turner and R. H. Gardner, Eds. New York: Springer-Verlag

Dyksterhuis, E. J. 1946. The vegetation of the Fort Worth Prairie. Ecological Monographs, 16: 1-29.

Forman, R. T. T. and M. Godron. 1986. Landscape Ecology. New York: John Wiley.

Forman, R. 1995. Land Mosaics: The Ecology Of Landscapes And Regions. United Kingdom: Cambridge University Press. 632 p.

Frohn, R. C. 1998. Remote Sensing For Landscape Ecology: New Metric Indicators For

Monitoring, Modeling, And Assessment Of Ecosystems. New York: Lewis Publishers. 99 p.

Gleason, H. A., A. Cronquist. 1964. The Natural Geography of Plants. New York: Columbia University Press.

Grieg-Smith, P. 1983. Quantitative Plant Ecology, Third edition. Berkely: University of California. 359 p.

Hill, M. O. 1973. The intensity of spatial pattern in plant communities. Journal of Ecology. 61: 225-235.

Innovative GIS Solutions, Inc. 1998. FRAGSTATS*ARC: Landscape structure and spatial pattern analysis for ARC/INFO. User Manual, Release 1.0, Incomplete Draft. Available from http://honeybee.helsinki.fi/gis/y197/manual/usermanual.html.

Institute of Applied Sciences, University of North Texas, 1988. Ray Roberts Lake Pre-Impoundment Environmental Study. Ft. Worth District, U.S. Army Corps of Engineers. 157 p.

Institute of Applied Sciences, University of North Texas, 1993. Ray Roberts Lake Post-Impoundment Environmental Study, Year-Two. Ft. Worth District, U.S. Army Corps of Engineers, 222 p.

Institute of Applied Science, University of North Texas, 1995. Ray Roberts Lake Post-Impoundment Environmental Study, Year-Six. Ft. Worth District, U.S. Army Corps of Engineers

Institute of Applied Science, University of North Texas, 1999. Ray Roberts Lake Post-Impoundment Environmental Study, Year-Ten. Ft. Worth District, U.S. Army Corps of Engineers.

Institute for Environmental Studies, North Texas State University. 1972. A Systems Evaluation Of The Enviornmental Impact Of The Aubrey Reservoir Project On Elm Fork Of The Trinity River In North Texas. 314 p.

Jensen, J. R. 1986. Introductory Digital Image Processing. Englewood Cliffs, N. J. Prentice-Hall

Johnson, L. 1990. Analyzing spatial and temporal phenomena using geographical information systems: A review of ecological applications. Landscape Ecology. 4(1): 31 – 43.

Kendall, G. W. 1845. Across The Great Southwestern Prairies. March of America Facsimile Series No. 78, 1966. Ann Arbor: University Microfilms, Inc.

Kershaw, K. 1964. Quantitative And Dynamic Ecology. New York: Elsevier. 183 p.

Krebs, C. 1994. Ecology: The Experimental Analysis Of Distribution And Abundance, Fourth Edition. New York: HarperCollins. 801 p.

Krummel, J. R., R. H. Gardner, G. Sugihara, R. V. O'Neill, P. R. Coleman. 1987. Landscape patterns in a disturbed environment. Oikos 48: 321-324.

Lebo, S. 1995. Archaeology And History Of The Ray Roberts Lake Area Of Northcentral Texas, 1850-1950. Institute of Applied Sciences, University of North Texas. 589 p.

Leduc, A., Y. T. Prairie, Y. Bergeron. 1994. Fractal dimension estimates of a fragmented landscape: sources of variability. Landscape Ecology. 9(4): 279-286.

MacGarigal, K., B. Marks. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. USDA Forest Service – General Technical Report PNW-GTR-351.

MacGurran, A. 1988. Ecological Diversity And Its Measurement. New Jersey: Princeton University Press. 179 p.

Mandelbrot, B. B. 1983. The Fractal Geometry of Nature. New York: W. H. Freeman and Company.

McDonough, T., S. Atkinson. An assessment of the spatial distribution of atrazine runoff-vulnerability for a regional reservoir watershed using remote sensing and GIS modeling. Manuscript in preparation.

Olsen, E. R., R. D. Ramsey, D. S. Winn. 1993. A modified fractal dimension as a measure of landscape diversity. Photogrammetric Engineering and Remote Sensing, 59 (10): 1517-1520.

Pielou, E. C. 1969. An Introduction to Mathematical Ecology. New York: Wiley.

Quattrochi, D. A., R. E. Pelletier. 1991. Remote sensing for analysis of landscapes: An introduction, pp 51-76. *In* Quantitative Methods In Landscape Ecology, M. G. Turner and R. H. Gardner, Eds. New York: Springer-Verlag.

Rice, C. G., S. Demarais. 1996. A table of values for Fisher's α log series diversity index. Texas Journal of Science, 48 (2): 147-158.

Riiters, K. H., R. V. O'Neill, C. T. Hunsaker, J. D. Wickham, D. H. Yankee, S. P. Timmins, K. B. Jones, B. L. Jackson. 1995. A factor analysis of landscape pattern and structure metrics. Landscape Ecology, 10 (1): 23 – 39.

Ripley, B. D. 1978. Spectral analysis and the analysis of pattern in plant communities. Journal of Ecology. 66: 965-981.

Sugihara G., R. M. May. (1990). Applications of fractals in ecology. Trends In Ecology And Evolution. 5: 79-86.

Tivy, J. 1993. Biogeography: A Study Of Plants In The Ecosphere. United Kingdom: Longman Group. 452 p.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annual Review Of Ecology And Systematics, 20: 171-197.

Turner, M. G., R. H. Gardner. 1990. Quantitative Methods in Landscape Ecology. New York: Springer-Verlag.

U. S. Census Bureau. Agriculture Census: 1870. Washington D.C.: U.S. Government Printing Office.

Usher, M. B. 1975. Analysis of pattern in real and artificial plant populations. Journal of Ecology. 63: 569-586.

Watt, A. S. 1947. Pattern and process in the plant community. Journal of Ecology, 35: 1-22.