USING HISTORICAL NARRATIVES & GIS AS A GUIDE FOR RESTORATION:

A CASE STUDY OF *Juniperus ashei* IN CENTRAL TEXAS

THESIS

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USING HISTORICAL NARRATIVES & GIS AS A GUIDE FOR RESTORATION:

A CASE STUDY OF *Juniperus ashei* IN CENTRAL TEXAS

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CHAPTER 1

INTRODUCTION

The need for conservation and restoration of land in Central Texas is of local and national significance. Land management issues in this region are contentious, because of land fragmentation linked to urbanization and population growth and related land cover change, and hence the threat of extinction for regionally-important endangered species. The questions I will examine only skim the surface of regional growth-related issues that will require significant land-use decisions. In order to establish baseline landcover data, this research used accounts from numerous explorers and early settlers who documented this area; while some recorded the region as grassland, others noted the area as woodland. As such, recent management questions have emerged among diverse stakeholders about whether a shift has occurred from grassland to woodland because of land use decisions, with or without the addition of climate change, or perhaps whether the area is instead converting back to a woodland-dominant landcover. Accordingly, the question of historical Ashe juniper (*Juniperus ashei*) quantity and density is a significant one.

Based upon popular accounts of landcover history in the region, one could predict that data analysis would indicate a change in vegetation cover, namely from grassland to woodland. South of the Balcones Escarpment, research would expect to confirm that the

prairies, once covered with grasses, are converting to woodland from several centuries of overgrazing, fire control, agriculture, and fragmentation, all contributing to juniper expansion. To the north of the Escarpment, it is anticipated that the maps will show a once heavily wooded area that is, at present, still wooded, but less so than witnessed in the 18th century. In the Blackland Prairie, Post Oak Savanna, and Edwards Plateau regions, it is probable that all three will illustrate a significant development of Ashe juniper growth.

This thesis aims to translate textual narratives of historical vegetation observations into a Geographic Information System (GIS) database. Furthermore, this research will examine and map these historical eye-witness accounts of Central Texas' past landscape in this GIS and generate historical and temporal reference maps of the region as a baseline for ecological change. There will be a specific focus on historical Ashe juniper *(Juniperus ashei)* density and following, the creation of historical juniper vegetation maps. Doing so will contribute to more informed management of Central Texas' regional landscape and related vital resources as well as concerned stakeholders such as the Balcones Canyonlands Preserve (BCP).

Background

There are three primary reasons this study is important. First, several federally endangered species, including the golden-cheeked warbler and the black-capped vireo, inhabit Central Texas. Not only does the federal Endangered Species Act mandate habitat protection, but numerous state agencies, federal agencies, and NGOs seek habitat

protection as well. Considering that the onset of rapid climate change is hypothesized to increase annual-mean temperatures by more than 2-3°C and decrease precipitation through the 21st century (Christensen et al. 2007), this research can help identify any potential shift in the critically endangered, as well as other vulnerable species', habitat range.

Second, in a related aim, I also plan to outline juniper range shifts over time. It is argued whether Ashe juniper provides a beneficial role in replenishing aquifers or whether it "steals water" (Keddy-Hector 2000, p 78). As much of Central Texas overlays the Edwards Aquifer, a high conductivity karst aquifer, any regional restoration efforts would have an effect on the amount of recharge the aquifer receives, and similarly the amount and location of any increase in runoff and erosion.

Third, as with any restoration project, it is important to provide a foundation and knowledge of the pre-settlement historic landscape for reference. When addressing landscape management and restoration, decision makers' management decisions are often based upon the historic land-cover of the area as well as what processes occurred before large-scale Anglo-European dominance of the landscape. Through recreating the land-cover of a reference landscape, determining a related historic range of variation will allow for more complete information to better inform regional environmental management decisions. My research will contribute to the literature to construct a more comprehensive juniper land cover history, qualitatively compiling historically-relevant spatial data of landcover through the use of a GIS. As it is a relatively new field, the methodology used in this research is in its infancy and hence this study aims to make a

significant contribution to better understanding the use of fuzzy historical data sets in constructing a GIS of prior landcover conditions.

Balcones Canyonlands Preserve

The Balcones Canyonlands Preserve (BCP) (Figure 1) exemplifies one of the stakeholders concerned with landcover change in the region and represents an important voice for the necessity of this research. The Balcones Canyonlands Conservation Plan (BCCP), a regional permit given to the City of Austin and Travis County, was issued by the U.S. Fish and Wildlife Service (USFWS) on May 2, 1996. Issued for a time period of thirty years, the permit allows for "incidental take" of eight federally endangered species (Table 1) and twenty-seven species of concern. To satisfy the terms of the permit, the City of Austin (COA) and Travis County created the Balcones Canyonlands Preserve, a multi-tract preserve system in western Travis County, to preserve and manage 30,428 acres of habitat for the protection of the federally endangered golden-cheeked warbler *(Dendroica chrysoparia)* and black-capped vireo *(Vireo atricapillus).* The permit also mandates the management of the rare plant species texabama croton (*Croton alabamensis var. texensis*) and canyon mock-orange (*Philadelphus ernestii*) and the protection of six federally endangered kart invertebrates enclosed within sixty-two karst features. Today, the BCP has achieved close to 93% of its 30,428 acre-goal set forth in the 10(a) permit issued by the U.S. Fish and Wildlife Service, in 1996 (COA 2010, Travis County 2009). In general, the BCCP offers agencies and private landowners a simplified and unified option for habitat protection compliance under the Endangered Species Act (COA 2010).

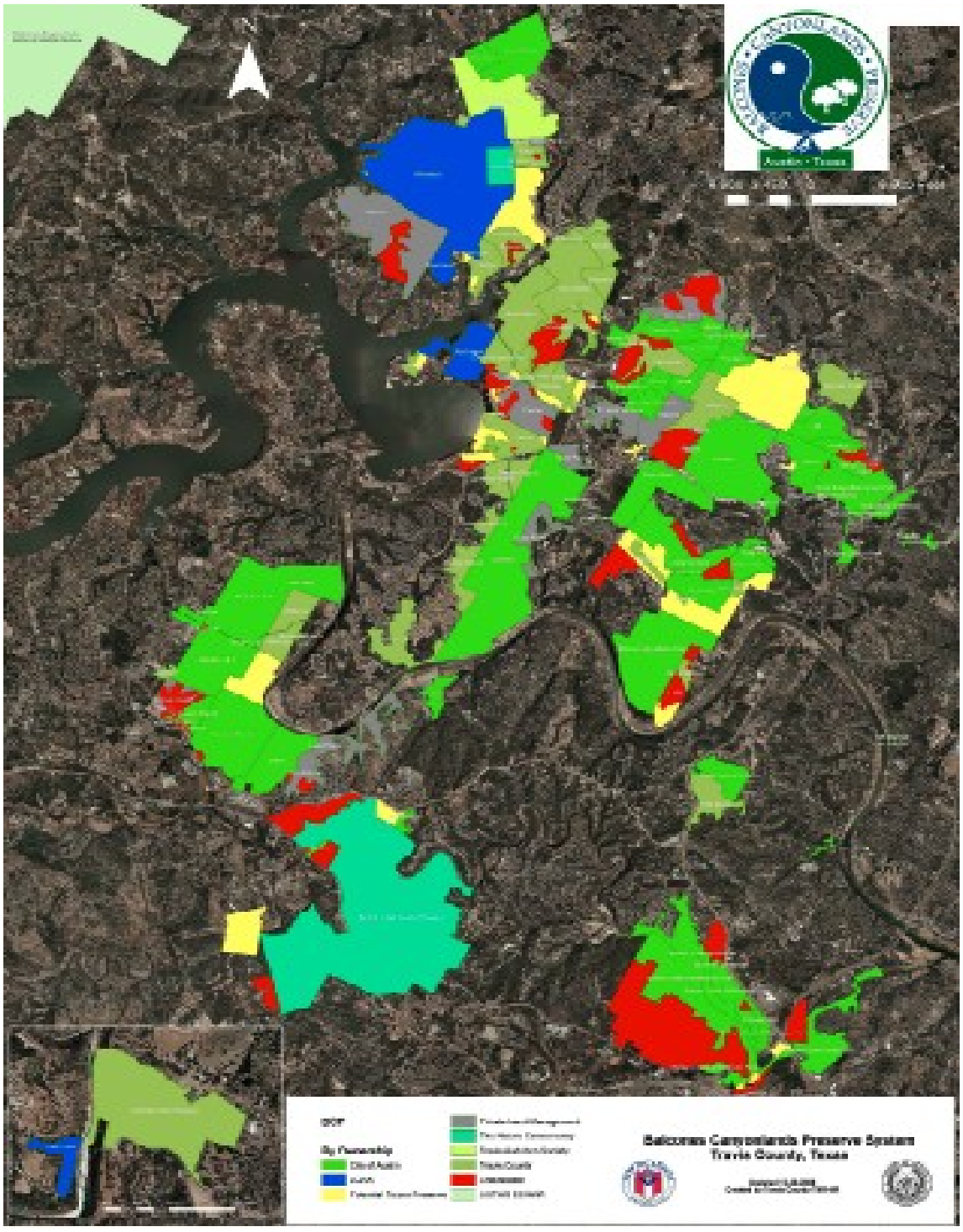

Figure 1- Map of the BCP tracts, S*ource:*
http://www.ci.austin.tx.us/water/wildland/downloads/appc_ar_bcp_map.pdf

Table 1- Eight federally endangered species within the BCP, *Source: http://www.ci.austin.tx.us/water/wildland/bcpspecies.htm*

Golden-cheeked warbler	*Dendroica chrysoparia*
Black-capped vireo	*Vireo atricapillus*
Tooth Cave pseudoscorpion	*Tartarocreagris texana*
Tooth Cave spider	*Neoleptoneta myopica*
Tooth Cave ground beetle	*Rhadine persephone*
Krestschmarr Cave mold beetle	*Texamaurops reddelli*
Bone Cave harvestman	*Texella reyesi*
Bee Creek harvestman	*Texella reddelli*

Table 2- BCP acreage by partner, S*ource: http://www.ci.austin.tx.us/water/wildland/bcppartners.htm*

City of Austin	13,251 acres
The Nature Conservancy of Texas	4,274 acres
Lower Colorado River Authority	4,244 acres
Private BCP Partners	2,750 acres
Travis County	2,707 acres
Travis Audubon Society	680 acres

The City of Austin and Travis County jointly administer the BCCP, each with different roles and functions. COA directs capital improvements, the infrastructure expansion process, and managing the mitigating credit accounting system for participating agencies. Travis County oversees the Public Participation Process, relaying information associated to development activity to USFWS, and issues Participation Certificates to eligible landowners (COA 2010).

Partnering organizations responsible for management of the preserve include the City of Austin, Travis County, The Nature Conservancy of Texas, the Lower Colorado River Authority (LCRA), the Travis Audubon Society, and private owners, all of which have differing interests, missions, and land parcel sizes to contribute to the joint BCP (Table 2).

In addition to protecting habitat for the endangered species, the BCP also aims to maintain, restore, and monitor the landscape when possible and as needed for the best management of the preserve and its original landscape. Habitat management responsibilities include fence construction along boundary lines, patrol by law enforcement, the control of non-native and invasive flora and fauna, and continued scientific research and data collection.

Although the preserve has received praise from conservationists, it has its critics as well. Closures of pathways to bikers and equestrians along edges of the preserve system have caused a disagreement concerning the appropriate balance between public recreational use and habitat/species protection (Oko 2001). Some chosen tracts, which permitted public use preceding the organization of the BCP, allowed such use to continue

through 2009; other pieces of land were, and still are, only accessible through education and outreach programs (COA 2010). As such, the most recent methods of landscape reconstruction possible, coupled with increasing knowledge, must contribute to future management decisions for the BCP.

Partnering Organizations and Land Tracts

The City of Austin manages 46 different tracts of land. Although data are not available reflecting the specific vegetation composition at each parcel, the overall landscape can be characterized as typical of the Edwards Plateau. Woodlands consist of mature juniper and oak (COA 2009).

Travis County manages 37 BCP land tracts. Of these 37 parcels, the Jollyville Unit, about 1,900 acres, the Ribelin tract, around 300 acres, and Wild Basin Wilderness Preserve, at 227 acres, represent close to the majority of Travis County's BCP land. The Jollyville Unit is composed mostly of oak-juniper woodlands, found mainly on slopes and canyons, and occasional grasslands in the valleys. The Ribelin tract, similar to Jollyville, is characterized mainly by slopes and canyons covered in oak-juniper woodlands. This area has been heavily influenced from anthropogenic affects, particularly considering this tract's history of cattle and livestock ranching (Natural Resources and Environmental Quality Division 2010). Wild Basin Wilderness Preserve, their other more prominent territory, contains 227 acres of land and is managed by St. Edward's University. The vegetation in Wild Basin is dominated by a juniper-grassland on uplands and slopes with a discontinuous canopy. On the lowland exists a thicker oak-

juniper woodland with a continuous canopy and meager groundcover. In Wild Basin, cedar brakes (isolated stands of juniper) are divided into two categories. One type of cedar brake is characterized as small, generally spread out, and veiled within the oak-juniper woodland. The second type is larger and located amidst the juniper grasslands. In both stands, the juniper trees themselves are large and other woody species are sparse or absent (Committee for Wild Basin Wilderness, Inc. and St. Edwards University 2009).

The Nature Conservancy holds two of the BCP land tracts, the primary piece being the Barton Creek Habitat Preserve. This preserve, purchased in 1994, is about 4,000 acres in size and helps to protect the Barton Creek watershed. The hilly land consists of oak-juniper woodland and grassland mosaics. Canyon slopes and riparian vegetation generally contain tree species other than juniper and oak (The Nature Conservancy of Texas 2010).

The LCRA manages five parcels within the BCP system. Two priority tracts, McGregor and Westcave Preserve, are comprised of around 360 and 30 acres, respectively. Land on McGregor is heavily forested with mostly juniper, live oak, and some red oak. Westcave Preserve vegetation resembles that of McGregor: primarily forested with juniper and a variety of oaks and other tree species (LCRA 2009).

The Travis Audubon Society owns one of the tracts within the BCP system, Baker Sanctuary. While an additional nine acres purchased in 2007 have not yet been added to the BCP, the current acreage of Baker Sanctuary stands somewhere around 682 acres. The vegetation within this piece of land is characterized by slopes and canyons covered

with mature oak and juniper dotted by fragments of open grasslands, currently invaded by juniper stands (Travis Audubon Society 2009).

I became interested in commencing this study due to my interactions with the City of Austin's BCP biologist, Lisa O'Donnell. Through growing up in the region, interacting with Ms. O'Donnell, and hearing about the needs of the BCP, I began this thesis exploration. The primary objectives of this resulting project are to map historical eyewitness accounts of Central Texas' past Ashe juniper cover in a GIS and generate historical and temporal reference maps of the region as a baseline for ecological change and to guide land management decisions. Doing so will contribute to more informed management of the regional landscape mosaics, described above, and related vital regional resources.

CHAPTER 2

STUDY AREA

For the purposes of this study, twenty-seven counties define the study region of Central Texas (Table 3). The majority of these counties occupy three different eco-regions: the Edwards Plateau (including the Llano Uplift), the Blackland Prairie, and the Post-Oak Savanna (Figure 2). While the transition zones between the Blackland Prairie and the Post-Oak Savanna are relatively smooth, the Balcones Fault Zone creates a sharp distinction between the Edwards Plateau and the Blackland Prairie.

Although these three regions (Blackland Prairie, Edwards Plateau, and Post Oak Savanna) are generally quite different in their biologic structure, they share a similar history. The roles played by fire and livestock overgrazing have contributed to enormous modification of the landcover. Fire suppression has created a canvas for both exotic species encroachment and native invasive species expansion. In the Blackland Prairie, the suppression of fire has allowed for the rapid increase of eastern red cedar (*Juniperus virginiana*) and Ashe juniper in the northern and central sections of this region, and of Ashe juniper in the southern section. Pasture grasses, such as K-R bluestem (*Bothriochloa ischaemum*), for cattle ranching have replaced naturally occurring grasses in the Post Oak Savanna. Isolated overgrazing on the Edwards Plateau has reduced

Table 3- Central Texas counties included in study, within their respective ecoregions

Edwards Plateau	Bandera	Bexar	Blanco	Burnet	Comal	Gillespie
	Hays	Kendall	Kerr	Kimble	Llano	Mason
	McCulloch	Menard	San Saba	Schleicher	Travis	Williamson
Blackland Prairie	Bastrop	Bexar	Burleson	Caldwell	Comal	Fayette
	Gonzales	Guadalupe	Hays	Lavaca	Lee	Milam
	Travis	Williamson				
Post Oak Savanna	Bastrop	Bexar	Burleson	Caldwell	Comal	Fayette
	Gonzales	Guadalupe	Hays	Lavaca	Lee	Milam
	Travis	Williamson				

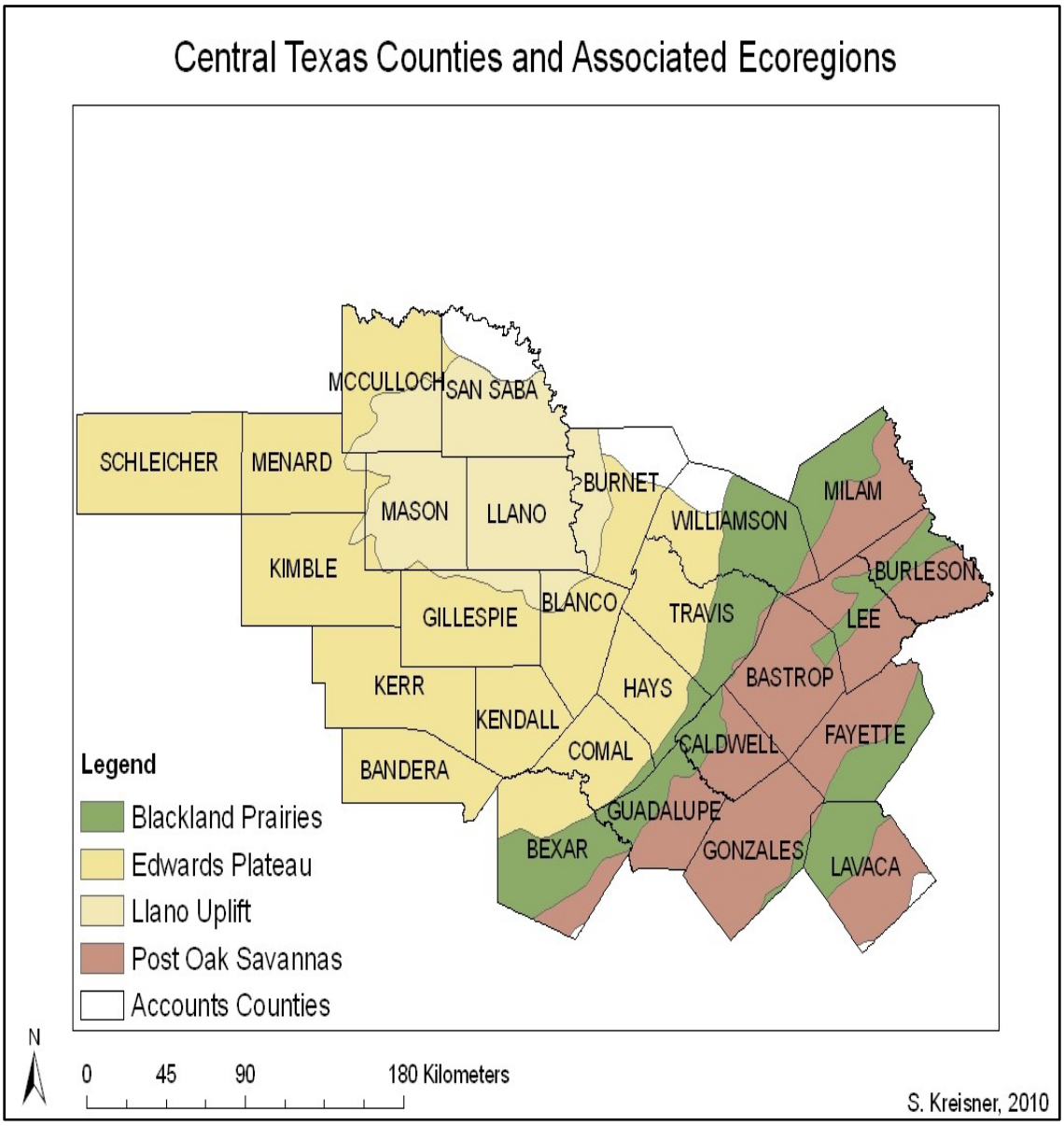

Figure 2- Central Texas Counties and Associated Ecoregions: Map of the involved counties and their respective eco-regions in the study area

grasses that once assisted the spread of wild fires; and again, the lack of fire has amplified the extent of Ashe juniper (Riskind and Diamond 1988).

Today's Blackland Prairie

The Blackland Prairie (Figure 3) ecoregion is a large area divided into four distinct prairies: the Eagle Ford Prairie, the White Rock Cuesta, the Taylor Black Prairie, and the Eastern Marginal Prairie. This area is underlain by Upper Cretaceous chalks, marls, limestones, and shales, which generated the development of the distinguishing black, calcareous, heavy clay soils (TPWD 2008, TFS 2010). Soil types in the Eagle Ford and Taylor Black Prairies consist of Vertisols, while the Eastern Marginal soils are Alfisols and the White Rock Cuesta are Mollisols (Ricketts et al. 1999). The topography ranges from slightly rolling hills to flat plains and elevations range from 90-240 meters above sea level (TFS 2010). Rainfall varies from 88 to 115 centimeters per year in the western and eastern counties, respectively, and the climate is classified as humid subtropical, or Cfa, per the Köppen classification system (Simmons et al. 2007, TPWD 2008, TFS 2010).

Together, these four prairies comprising the Blackland Prairie make up approximately 50,000 km^2, about 7.2%, of the State of Texas (Ricketts et al. 1999). Before European settlement, fire was key to the preservation of the Blackland Prairie. These fires were generally quite large and would burn through the landscape until naturally controlled. While the role of fire is no longer as significant, the lack of wild fires has caused a surge of vegetation (e.g. Ashe juniper) that is quickly propagating

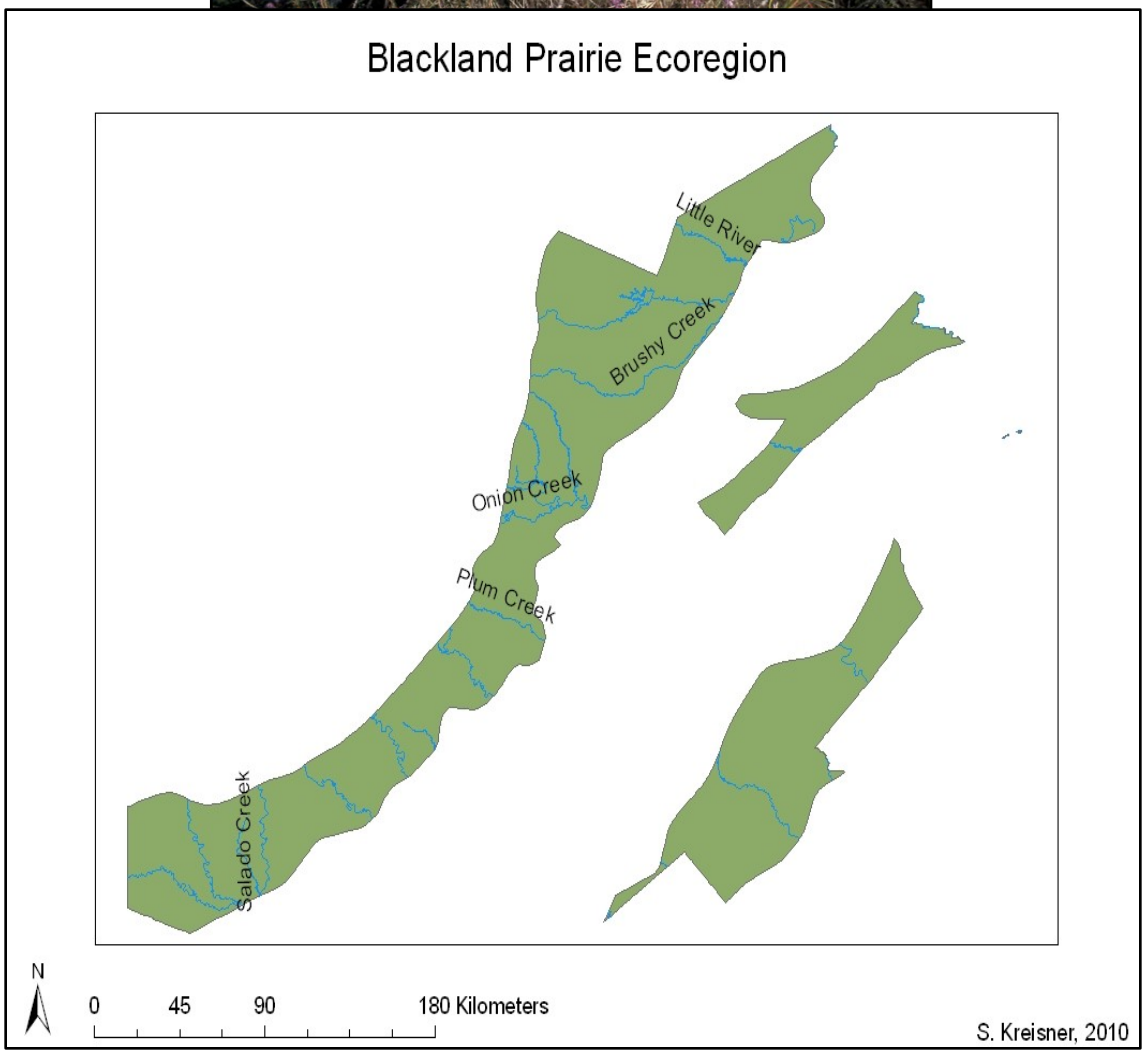

Figure 3- Blackland Prairie Ecoregion: Ecoregion with hydrologic features (bottom); the Blackland Prairies are characterized by grasslands that provide valuable habitat for a variety of wildlife (top), *Source: ftp://ftp.epa.gov/wed/ecoregions/tx/tx_front.pdf*

through this ecoregion (TFS 2010). The expansion of this invasive species with the addition of fragmentation has created a rapid loss of the natural grasslands (Simmons et al. 2007). Today, less than one percent of the original Blackland Prairie vegetation remains (Ricketts et al. 1999). Generally speaking, the Blackland Prairie vegetation is dominantly tallgrass on uplands with good drainage, deciduous woodland forest along creeks and rivers, and also contains occasional wetlands (Ricketts et al. 1999, BLM 2010). This prairie is a grassland community, comprised of a variety of perennial and annual grasses such as big bluestem (*Andropogon gerardii),* little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and sideoats grama (*Bouteloua curtipedula*). Different parts of this region possess a variety of trees, with live oak (*Quercus virginiana*) comprising a large part of this ecoregion. The southern section of the eco-region consists mostly of live oaks and Ashe juniper, while the northern and central parts feature a majority of post oaks (*Quercus stellata*), blackjack oaks (*Quercus marilandica*), and an assortment of elms (Griffith et al. 2004, TFS 2010).

Today's Edwards Plateau

In contrast, the Edwards Plateau is considerably larger, comprising about 61,800 km^2 (Figure 4). This region is an uplifted area formed from deposits of sandstone, limestone, shales and dolomites (TPWD 2008). The early Cretaceous limestone underlying the Edwards Plateau ecoregion contributes to the uniqueness of this region, because of the preservation of the Edwards Aquifer. The Edwards Plateau eco-region can be divided into four categories (only three applicable to this study). The Edwards Plateau

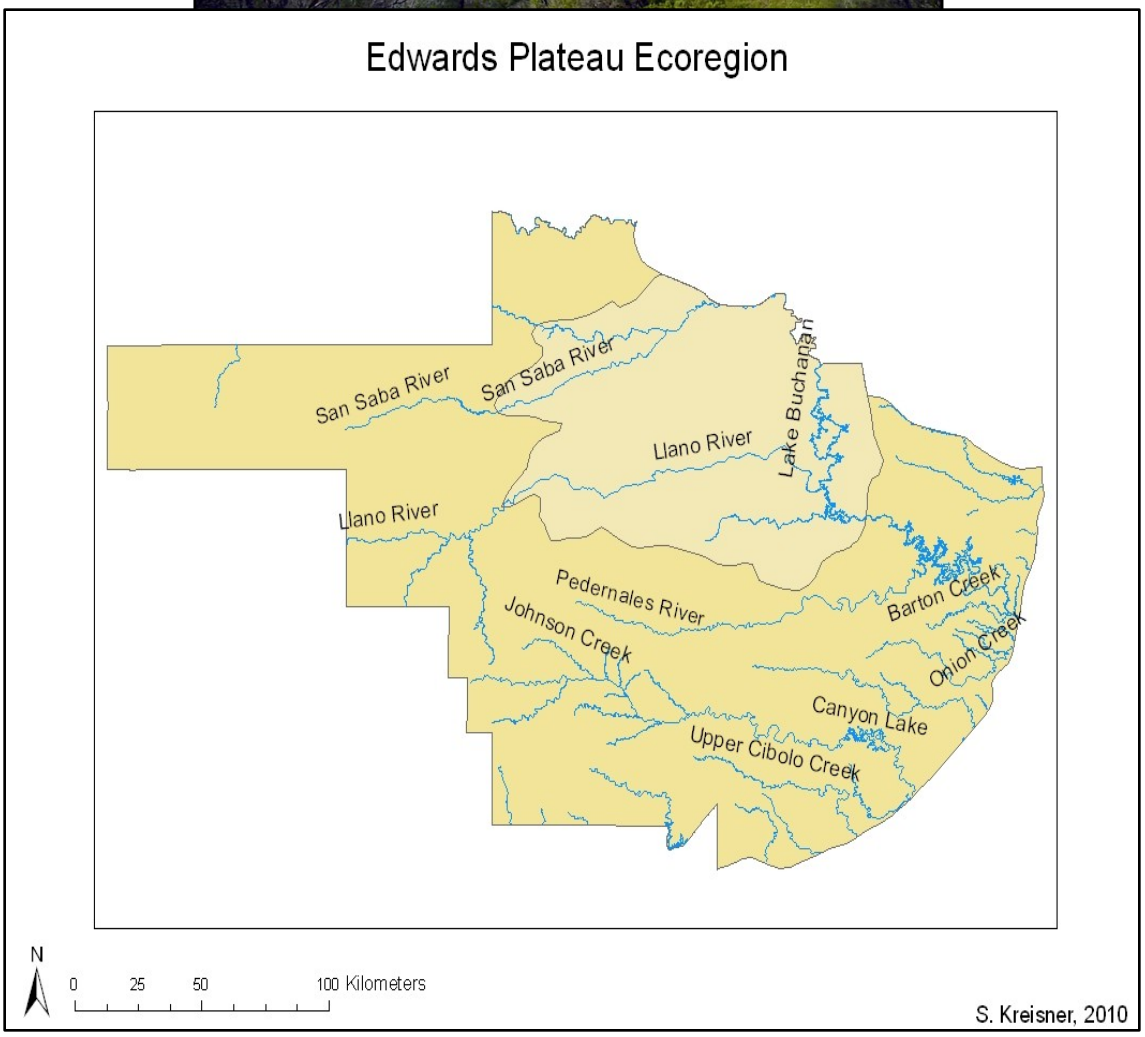

Figure 4- Edwards Plateau Ecoregion: Ecoregion with hydrologic features (bottom); the Edwards Plateau is characterized by deciduous woodlands (top), *Source: ftp://ftp.epa.gov/wed/ecoregions/tx/tx_front.pdf)*

Woodland, the central-western section, continues to be relatively flat, intermittently separated by gently sloping stream divides (TPWD 2008, BLM 2010). This area contains several different types of vegetation patterns such as grasslands, grassland-shrubland, and grassland-woodlands (Riskind and Diamond 1988). The hills in this area are rounded because of increased chemical weathering as well as higher precipitation. Popular history records this section of the Edwards Plateau as having been grasslands with scattered trees (Griffith et al. 2004).

The Llano Uplift region receives its name from the batholiths exposed within the basin. The soil in this area is generally more acidic than the surrounding regions is characterized as a woodland and savanna mixture, where Ashe juniper is not a prevalent species at present. Some desert-type species, such as soaptree yucca (*Yucca elata*), are found in the drier areas of the Llano Uplift and mesquite (*Prosopis glandulosa)* is an ubiquitous species. Today, ranching occupies the majority of the land (Griffith et al. 2004).

The "Texas Hill Country" is the nickname given to the eastern and southern portions of the Edwards Plateau, owing to the hillier and more sloping landscape than the surrounding Prairie and Savanna. This hilly portion is deeply eroded and divided by fast-moving streams through steep-sided canyons and contains a distinct border via the Balcones Fault Line (Griffith et al. 2004, TPWD 2008, BLM 2010). Mollisols are the primary soil type in this ecoregion, characterized by limestone outcrops with deeper soils along river floodplains and valley floors (Griffith et al. 2004, Ewing et al. 2005). Nevertheless, erosion has thinned much of the soil in the Hill Country. In this region, the

elevation varies from 914 meters above sea level, in the western and central portions, down to 180 meters above sea level in the east (TFS 2010). Because of its position, between dry plains to the west and wet prairies and woodlands to the east, this area receives a highly variable average rainfall of roughly 50-83 cm/year, but is within the same climate zone as the Prairie, subtropical/subhumid (Fowler and Dunlap 1986, Simmons et al. 2007, TFS 2010).

The Hill Country is an area distinguished by woodland vegetation such as juniper-oak and thick stands of Ashe juniper known in this region as "cedar brakes", as well as short to tall grasses mostly in valleys (Fowler and Dunlap 1986, Riskind and Diamond 1988, Ewing et al. 2005). Similar to the Blackland Prairie, historically occurring fire originally had a significant influence on vegetation patterns. So too did the lack of fire; fire suppression on the Edwards Plateau lead to the spread of Ashe juniper beyond its historical density (TFS 2010). North and west of the juniper-oak savannas are regions of mesquite and shrub. The south and east is predominantly mesquite-acacia savanna with tree species such as Texas mountain laurel (*Sophora secundiflora*) and Mexican plum (*Prunus mexicana*), to name a few of several dominant species (Griffith et al. 2004, Ewing et al. 2005, TFS 2010). Additionally, the limestone bedrock is the basis and the habitat of many diverse species, including several endangered vertebrates (i.e. Texas blind salamander- *Eurycea rathbuni*), in addition to the largest gathering of non-metropolitan mammals in the world (i.e. Mexican free-tailed bats- *Tadarida brasiliensis*) (Ricketts et al. 1999). Most importantly, the Edwards Plateau is home to the majority of breeding grounds for the endangered golden-cheeked warbler.

Especially for the warbler, it is unfortunate that an estimated two percent of this original habitat remains intact. As previously mentioned, the suppression of fire and overgrazing has lead to dramatic changes in the composition of regional vegetation; the western and southern parts of this eco-region have been drastically modified by the expansion of shrubs, leading to an increase in Ashe juniper and a reduction in grassland. Overgrazing has fragmented the grasslands, causing the encroachment of woodland species into the grasslands. Widespread soil erosion has been a factor in the transformation of riparian communities. The degradation of the Edwards Plateau habitat will continue as long as urban sprawl, invasive species expansion, and overgrazing thrive (Ricketts et al. 1999).

Today's Post Oak Savanna

A transition zone with multiple bands between the Blackland Prairies and the Pineywoods, the Post Oak Savanna (Figure 5) eco-region was once part of a historic oak-belt, covering a transect from Canada to Central America. This landcover is about 52,600 km^2 in area and is distinguishable from the neighboring eco-regions by its increased tree density (Ricketts et al. 1999, Griffith et al. 2004). Soils in this region vary from sandy soils and loams in the uplands to clay loam and clays in the bottomlands (Griffith et al. 2004, TFS 2010). Much of this area has an underlying clay pan that affects water movement and available moisture for plant growth. The topography and precipitation in the savanna are very similar to that of the Blackland Prairie. Elevation

ranges from 90-240 meters above sea level, and precipitation averages about 88-115 cm/year (Griffith et al. 2004, TPWD 2008, TFS 2010).

This eco-region once contained predominately post oaks, but is now a mixture of post oaks, as well as other oaks and hickory, scattered throughout bunch grasses and forbs. Recent changes have brought yaupon holly (*Ilex vomitoria*), sugarberry (*Celtis laevigata*), and eastern red cedar (*Juniperus virginiana*) to the area (Griffith et al. 2004, TFS 2010). Historically, fire in the Post Oak Savanna, as well as vast numbers of bison (*bison bison*) herds, shaped the landscape.

There are a number of reasons for choosing these areas for the study. First, very few (if any) studies similar to this one have occurred in this region. A general understanding of pre-European vegetation patterns exists, but an attempt at mapping historic forest densities has not occurred. In addition, the vast anthropogenic changes, and hence recorded observations, that have affected the ecology of this area should provide sufficient data for such a study. Last, very little exists of the original vegetation structure within these eco-regions and it is important to secure the future of the endangered species that depend upon the original biota in this evolving landscape.

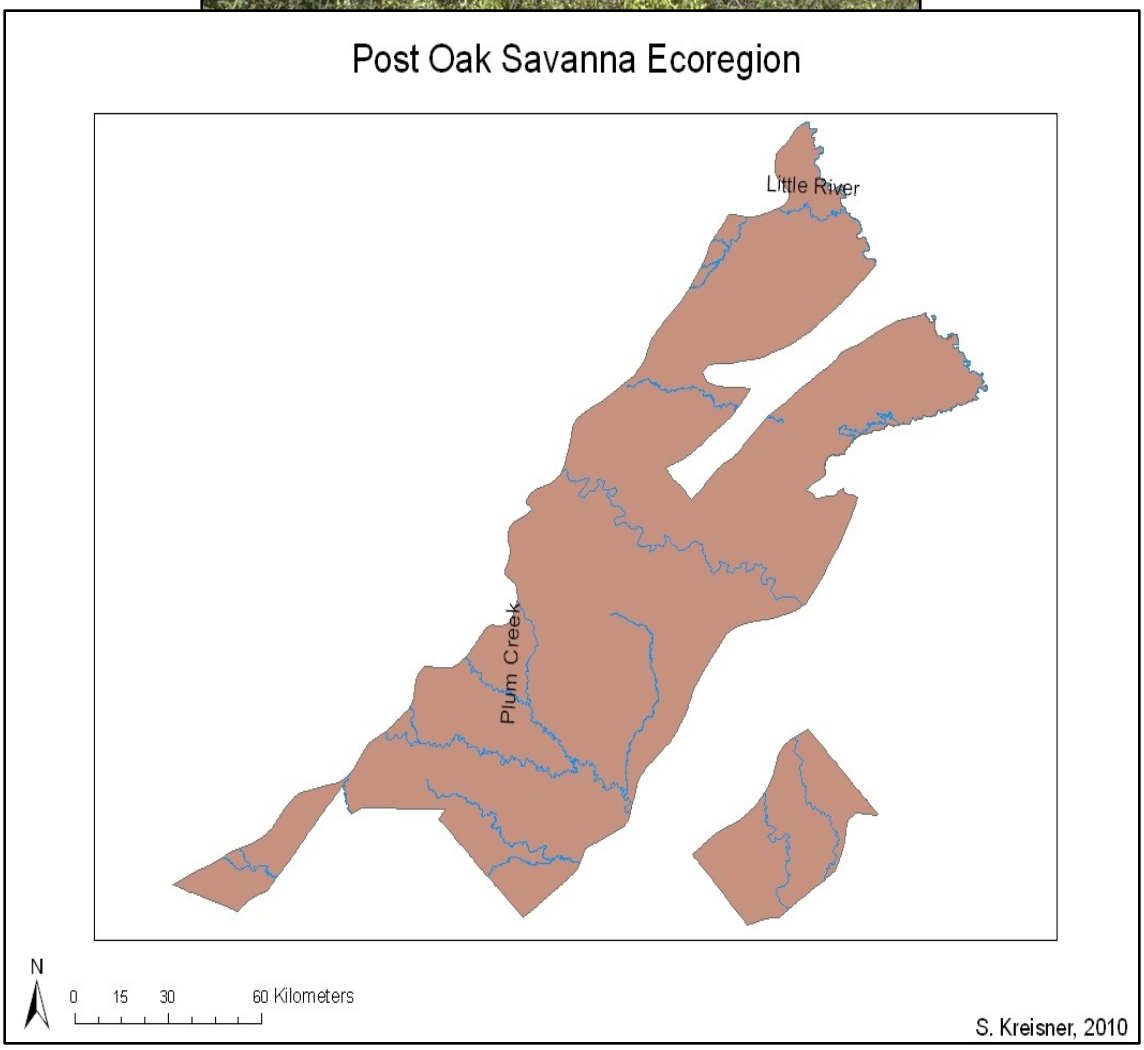

Figure 5- Post Oak Savanna Ecoregion: Ecoregion and hydrologic features(bottom); The Post Oak Savanna region is characterized by alternating belts of woods and savanna (top), ***Source: ftp://ftp.epa.gov/wed/ecoregions/tx/tx_front.pdf***

CHAPTER 3

LITERATURE REVIEW

Ecological Restoration

The Society for Ecological Restoration states: "Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Clewell and Aronson 2007, p 7). Once a landscape has gone through restoration, it should be "self-organizing, self-sustaining, and capable of maintaining itself…" (Clewell and Aronson 2007, p 8) Generally, restoration aims to promote a working ecological system by increasing biodiversity through the protection of native species and the resilience of ecosystems, and should seek to create "specialized habitats for specialized species" (Pickett and Parker 1994, Egan and Howell 2001, Clewell and Aronson 2006, p 426). There are some similar, yet differing views that modify restoration projects' goals, in an endeavor to modify species composition and function within a more advantageous range than current conditions (Palmer 2009). Ecological restoration is a relatively young field drawing from other disciplines such as conservation, landscape architecture, and environmental mitigation, and has been labeled a significant growth industry for the future (Clewell and Aronson 2006, Palmer 2009). Because of its varied background, ecological restoration involves an assortment of applications and approaches (Egan and Howell 2001).

Restoration practitioners generally have two options when attempting to restore an environment. Passive restoration usually involves removing the cause of disturbance; active restoration generally requires an active manipulation of the environment, requiring endless management action (Cole 2000). At a minimum, a practitioner's main goal lies in creating species diversity, seen as the key to long-term ecosystem resilience (Palmer 2009). Regardless of the option pursued, practitioners need to ensure that the process does not end with the restoration work alone, but rather carries through with testing, monitoring, and adjustments, when necessary to guarantee a successful project (Pickett and Parker 1994). As a general rule, ecologists understand that nature is always in flux. Therefore, ecological restoration practitioners must not think of restoration as an isolated event, nor assume that one particular reference condition should advise restoration goals (Pickett and Parker 1994). Furthermore, while the number of involved stakeholders in a given restoration project will always sway the goals of the project, the practice of restoration should be guided by science, rather than agenda (Palmer 2009). Special interest, as well as debate, surrounding the goals and values of ecological restoration exists, particularly with regard to restoring significantly altered human-dominated landscapes (Cole 2000).

Ecological restoration is often seen as an important way for humans to relate to nature, and as a constructive method to counteract the effects of anthropogenic landscape change (Cole 2000, Egan and Howell 2001). Clewell and Aronson (2006) outline five rationales for ecological restoration: 1) technocratic, 2) biotic, 3) heuristic, 4) idealistic, and 5) pragmatic. The technocratic rationale involves government agencies or other

governmental entities attempting to reclaim societal values once offered by an ecosystem, before an environmental degradation/change took place. The biotic impetus stems from the desire to perpetuate species biodiversity, while the heuristic motivation develops from a pedagogic need to further the discipline. The idealistic rationale involves four sub-motivations: reparation for environmental degradation, an attempt to return to nature, restoring cultural environments, and spiritual renewal. Lastly, the pragmatic motivation involves the restoration of natural capital and the compensation for anthropogenic climate change. If the pragmatic rationale is never a factor in restoration, Earth will become less habitable and human society will suffer (Clewell and Aronson 2006).

Spatial Studies in Restoration

In the last twenty years, significant advancements in digital technology have allowed restoration ecologists to take advantage of new methods for obtaining and analyzing spatial environmental data (McEachern and Niessen 2009). Somewhat recently, spatial applications have played a decidedly important role in advancing restoration ecology; these two factors have become significant spheres of influence to ecologists (Egan and Howell 2009). It is not surprising then, that the field of geography plays an important role in restoration. Geography's contribution of spatial studies provides a significant and critical resource for restoration ecology, and as a result has produced recent appeals for the collaboration and support of geographers and ecologists (McEachern and Niessen 2009). Concern for landscape spaces and the biotic changes that occur within those spaces is invaluable for ecological studies. Species composition,

dispersion, and the territory of species in an environment, are all forms of spatial data involved in determining natural processes (Palmer 2009). Furthermore, the advent of Geographic Information Systems (GIS) has provided a wealth of knowledge and resources to the cognate physical and natural sciences. Although each is a very different field, Geography has been a crucial contributor, helping to bridge the theory of Restoration Ecology to the practice of Ecological Restoration.

While traditional cartographic mapping has numerous important applications, the use of GIS for mapping is not limited in the same ways (Howarth & Couclelis 2005). GIS is widespread for use in restoration, often applied for mapping past environments around the world, specifically pre-European vegetation. Particularly, this aids in creating reference conditions for restoration goal-setting. The US General Land Office (GLO) records as well as bearing and witness tree data, have routine use in providing source reference data for past environmental conditions of pre-settlement periods for GIS-mapping applications, using the survey records as representations of stands of vegetation, and providing approximate spatial units (Brown 1998a, He et al. 2000, Fritschle 2008). Generally, point coverage data, as provided by GLO records, is insufficient to describe continuously distributed vegetation, as it does not include areas where vegetation may be present but was not recorded. Therefore, the point data must be interpolated using a GIS; common methods of interpolation include ISOLINE, kriging, and co-kriging (He et al. 2000, He et al. 2007).

Nevertheless, challenges often arise when applying these techniques to GLO point data. Interpolation methods make assumptions about the data, such as being spatially

unbroken, and often ignore biological principles (He et al. 2007). In addition, the uncertainty of boundary representation in such historical records, and following, constructing those boundaries in a GIS, may present complications (Brown 1998b). Furthermore, uncertainty can be recorded and conveyed in a multitude of ways, further decreasing the accuracy of the data (McEachern and Niessen 2009). Technical, or epistemic, error results from the field techniques utilized to gather and document the locations; human, also referred to as linguistic, error occurs when spatial data are recorded incorrectly (McEachern and Niessen 2009). In some cases, multiple resolutions and scales are used for analysis for the most thorough interpretation; while smaller scales protect spatial resolutions, they offer the most conservative valuations but sometimes the most accurate model available (He et al. 2000, Fritschle 2008). Often, data quality tends to be the most limiting feature when applying digital technology to ecological restoration (McEachern and Niessen 2009).

Historical Ecology

The history of land use, and ecological history, provide a wide variety of information: species reaction to disturbance, a detailing of the development of current vegetation conditions, and records providing evidence for changes that require restoration (Foster 1992, Aronson and Le Floc'h 1996, Foster, Orwig, and McLachlan 1996, White and Walker 1997, Grossinger 1999, Swetnam et al. 1999, Egan and Howell 2001, Jackson and Hobbs 2009). These historical studies allow for new understandings of natural processes and become an essential part of environmental management (Foster,

Orwig, and McLachlan 1996). Furthermore, understanding the history of a particular ecosystem is essential because it corresponds to the degree that humans have the most direct interaction with nature (Aronson and LeFloc'h 1996). From historical vegetation studies, practitioners now understand that restoration must be built on the recognition and expectation of change (Foster, Orwig, and McLachlan 1996).

The process of restoration requires that practitioners obtain an explicit definition for what is termed the "natural state" of ecosystems, for it is only through this historical information that the restoration goal can be set, eventually met, and that preventative measures to guard against future degradation may be devised (Brown 1998a, Cole 2000, Robertson et al. 2000, Fritschle 2008, Jackson and Hobbs 2009). Descriptions of a landscape prior to disturbance constitute an ecosystem's reference, or baseline, condition, and although this information does not suffice as a given restoration project's goals, such historical information, is often essential for setting restoration objectives and situating them within a current context (Foster, Orwig, and McLachlan 1996, White and Walker 1997, Swetnam et al. 1999, Egan and Howell 2001, He et al. 2007, Fritschle 2008, Jackson and Hobbs 2009).

Although invaluable, scientific tools alone are not sufficient to re-create a historical landscape (Robertson et al. 2000, Gaynor and McLean 2008). Archives and documentary sources offer a significant source of historical information outlining pre-European settlement (Grossinger 1999, Swetnam et al. 1999, Jackson and Hobbs 2009). This historical information supplies a cultural context, factual content, spatial context, and motivational value for use in restoration, and thus reconstructing past vegetation

patterns (Robertson et al. 2000). Although historical documentary sources provide an excellent source for ecological history, their limited availability and reliability can interfere with their application (Swetnam et al. 1999).

One such source, the Public Land Survey Records (PLSRs), has seen widespread application for creating pre-settlement vegetation histories (Galatowitsch 1990, White and Mladenoff 1994, White and Walker 1997, Batek et al. 1999, Betts and Loo 2002, Kronenfeld and Wang 2007, Fritschle 2008). For some researchers, only the PLSRs afford reasonable information of woodland and species composition for pre-European settlement landscapes. Since these records reference spatial locations, they can be imported into a GIS with relative ease for analysis (He et al. 2007). Although a number of problems, such as surveyor bias and unreliable notes and description, are possible sources of error for this type of data, the PLS data are an established source for representing pre-settlement vegetation (Batek et al. 1999). Maps using the PLSRs provide a tool for comparison against current vegetation patterns (Brown 1998a).

Climate Change

Studies in climatology portray climate change as an important driver of ecological change (Foster, Orwig, and McLachlan 1996, Millar and Brubaker 2006). The destruction of ecosystems at a progressively faster rate results in the inefficacy of the biosphere to control precipitation, temperature, and other climatic variables (Clewell and Aronson 2006). With specific regard to grasslands, summer drought conditions can lead to considerable negative effects, which should be expected to increase with oncoming

global climate change (Allison 2008). Often regarded as one of the keys to protecting species against the threat of a changing climate, ecological restoration has the potential to counter some of the negative effects of global climate change (Lavendel 2003, Harris et al. 2006). Ecological restoration has been touted as a necessary remedy, regardless the cause(s) of global warming, for its role in carbon sequestration (Clewell and Aronson 2006). It is therefore surprising that while there is much academic discussion and debate over setting restoration goals and reference conditions in restoration ecology, there is notably less discussion of future restoration success in the context of contending with future climate change, especially given the fact that changes in climate have already begun to affect species (Harris et al. 2006, Diaz et al. 2009, Glass et al. 2009). Given that fact, the function of climate change must work its way into the discourse surrounding ecological restoration (Lavendel 2003, Millar and Brubaker 2006). Concerns surrounding climate change often bring to light questions about the uncertainly of restoration and management goals—as it is likely that restoration techniques will change in their efficacy relative to a changing climate (Lavendel 2003, Harris et al. 2006, Diaz et al. 2009, Glass et al. 2009). While this uncertainty has left some land managers hesitant to incorporate climate change into their restoration plans, the pace of climate change alongside increasing habitat fragmentation, and the expansion of invasive species, requires practitioners to act quickly to integrate adaptive techniques for incorporating climate change into restoration goals (Lavendel 2003, Dunwiddie et al. 2009, Glass et al. 2009).

Although some level of uncertainty exists surrounding the potential impacts of climate change, certain models give restorationists general predictions concerning how the climate will transform the Earth, and the challenges associated with these changes. General models for global climate change indicate changes in weather and precipitation patterns, increases in average temperatures as well as extreme events, and an increase in sea level (Harris et al. 2006, Glass et al. 2009). During this century alone, and in some contexts as soon as the next few decades, some areas will experience hotter, drier summers while others will see a shift to wetter, stormier winters. Unfortunately, the difficulty in defining these changes at the local level compounds the problem of uncertainty (Lavendel 2003, Diaz et al. 2009, Glass et al. 2009). These climatic changes will make it progressively more difficult to predict the ranges of threatened species and ecosystems, and once identified, their recovery will be more challenging as well (Harris et al. 2006).

The challenge of uncertainty notwithstanding, our focus should turn to the other most notable challenge: the reduction and/or elimination of utility for current restoration techniques (Glass et al. 2009). For example, using restoration goals such as returning the landscape to historic conditions has critical implications in the wake of climate change and could potentially cause failure of resulting restoration projects (Harris et al. 2006). The potential for hotter and drier weather could prove prescribed burning, the use of fire as yet another restoration technique, gradually more hazardous (Glass et al. 2009). The future value of restoration methods, such as stump treating invasive woody species, girdling trees, and hand pulling and the application of herbicide to invasive weeds, is hard

to predict (Glass et al. 2009). Lastly, current restoration methods can be rendered ineffective in light of other anthropogenic changes in combination with climate changes. Particularly, the increasing of habitat fragmentation does not lend itself many options for mobile species (Lavendel 2003).

Although the majority of researchers have provided too little focus on this topic of climate change effects on restoration, some have offered useful suggestions and guidelines for restoration practitioners. While historically, the accepted practice for landscape restoration involves aiming for species biodiversity to replicate that of the past, restoration scientists overwhelmingly agree that this must not be the target for current restoration goals (Harris et al. 2006, Glass et al. 2009). Given the expectation for species range shifts under a changing climate, both preventing the creation of distinct ecological boundaries and ensuring north-south habitat corridors, thus allowing for the movement of species between habitat pieces, are important functions for restoration (Lavendel 2003, Glass et al. 2009). The majority of recommendations advise restoration managers to create plans that would be flexible and resilient to a large range of potential local climatic changes, thereby creating a built-in insurance policy for the landscape under consideration (Lavendel 2003).

Prior research related to this study has established a framework for conducting studies that rely on historical data to map historical vegetation patterns and then analyze and map the results. This task aids land managers in acquiring a historical baseline of their respective project areas and setting goals for restoration. Although the future effects

of climate change are uncertain, some studies have begun to include this facet into the creation of resilient restoration plans. For the BCP and similar land management entities, the results of a changing climate require the implementation of adaptive strategies for dealing with species range shifts and general vegetation management. Furthermore, while in the BCP the removal of Ashe juniper is not an option given the reliance of the federally endangered Golden-cheeked warbler on this tree species, surrounding land owners and managers interested in restoration may have the option of removal. This study contributes to those ideas through the creation of a GIS database containing historical narrative accounts of vegetation and the mapping of those accounts to produce historical vegetation maps relating forest and grassland cover, in addition to Ashe juniper density.

CHAPTER 4

METHODOLOGY

Site Selection

A number of factors influenced the decision for the proposed research area of Central Texas. First, as previously mentioned, the Balcones Canyonlands Preserve is a prominent stakeholder, heavily invested in land management decisions for this region. As such, a colleague with the City of Austin's Wildlife Conservation Division is working on a similar project and interested in the results of this research, as it will contribute to the City of Austin's knowledge for future land-use decisions. Second, sufficient availability of information and data required for the project existed for the larger encompassing region, if not directly for the current more-limited boundaries of the BCP. Accordingly, I was tasked with helping to compile the City of Austin's GIS-compatible data regarding the historic range and quantity of Ashe juniper (*Juniperus ashei*) as a decision-support tool, in order to better inform BCP management.

Data Collection, GIS, and Juniper Density Assessment

I contacted Lisa O'Donnell, Senior Biologist with the City of Austin, and obtained her compilation of historical accounts used for this research. The accounts

range from 1709-1966 and include reports from explorers, early settlers, and military encampments passing through the area (Table 4). The Texas State Library and Archives Commission holdings supplied reproductions for the majority of materials, particularly the oldest accounts. Most other accounts came from the Austin History Center.

Similar studies attempting to map pre-European settlement vegetation relied on the use of Public Land Survey Records (PLSRs). The most common of these studies takes witness/ bearing tree data and inputs these points into a GIS database to process forest composition and land cover change, among other things. Texas, however, does not have PLSRs with as long of a historical record as most other states. Spain first assigned Texas' oldest land grants, and Mexico awarded later land grants. These land grants were not part of the public domain lands in the United States and were therefore not included in the standard rectangular Public Land Survey System as those used in most of the rest of the country (Galatowitsch 1990). Not until 1836 did the Mexican land grant system end, and the Republic of Texas designated their own land commissioner. Thus, the use of historical accounts in this study serves as an important source of historical information in lieu of long-term PLSRs. More recent General Land Office (GLO) records as well as Railroad Surveys were omitted from this study in an attempt at utilizing non-governmental sources and relying solely on layperson perspective.

Using these accounts, I created a GIS database in ArcGIS with two feature classes, one for point descriptions and another for line descriptions. The inclusion of a particular account to either the point or the line feature class depended on the description given from the historical account. For example plotting the description of the location

Table 4- Examples of the accounts used

Feature Class	Year	Observation
1700s Woodland	1709	The diary mentions water from the rivers crossed on the expedition (Nueces, Frio, Hondo, Medina, San Antonio, Guadalupe, San Marcos, Colorado)…Travelling east along the Colorado River, they encountered many herds of buffalo, wooded riparian areas, a forest "so dense we could not penetrate it…" [Espinosa, Fray Isidro Felis de. 1709. The Espinosa-Olivares-Aguirre expedition of 1709 *in* Preliminary Studies of the Texas Catholic Historical Society (March, 1930), 1(3).]
1800s Mixed	1839	"Entered a valley about ten miles from San Antonio…Today first saw species of wild grass 3 or 4 feet high…This country has a peculiar wildness. The wild pine and juniper grows here..." [Benedict, W.J. 1839. Diary of a campaign against the Comanches. *The Southwestern Historical Quarterly* (1929), 32:300-310.]
1900s Mixed	1904	"It is not to be inferred from what has been said about the timber vegetation of this region that the Edwards Plateau is covered with continuous forest, even in its rougher parts. On the contrary, the timber is very much interrupted by open, grassy uplands…" [Bray, William L. 1904. The timber of the Edwards Plateau of Texas: its relation to climate, water supply, and soil. *U.S. Department of Agriculture, Bureau of Forestry* – Bulletin No. 49. Government Printing Office: Washington.]

from account 3L, in the 1700s woodland category (Table 5), required the location of San Antonio. Knowing they crossed the Balcones Escarpment and the Guadalupe and Blanco Rivers on their way to the Pedernales River, a straight transect was drawn from San Antonio to just across the Pedernales River (Figure 6). The 1800s woodland account 33L (Table 6) required the location of the upper Medina River in order to be successfully mapped (Figure 7).

In order to apply the most literal and equal translation of each account, points and lines were plotted, irrespective of surrounding geography. For point accounts, this was relatively easy, as the observer was, more or less, at the location the point indicates, regardless of surrounding physical and natural features; for line accounts it was more challenging. Some accounts indicated a direction travelled (e.g. northeast), other accounts used point locations (e.g. from San Antonio to San Saba); in these, and similar, instances the most direct route from start to endpoint was mapped with a single line. While the majority of the line transects are straight, the few accounts which describe a change in direction are indicated with the line veering in a different direction. These decisions were made to uphold the integrity of the original accounts and forgo the need for assumptions based on geographic features. Furthermore, I concluded that the observations made of vegetation and surrounding landscape would not significantly change the results of the study.

The use of a single dot indicates the observer referencing a single location; there are a total of thirty-three point features ranging from the years 1722-1956. The use of a

Table 5- Example of account- 3L location description

Unique ID	Location Description
3L	"Going past the Balcones [Escarpment], we arrived at the river they call Alarcón [Guadalupe River]. This [travel]was an effort because of the many hills and some thickets that contain valuable cedar and oak timber…After many hardships because of the many hills, arroyos, and brush, we arrived at a creek generally known as Arroyo Blanco [Blanco River]…In all of this region there are no commodities nor anything except good cedar and oak timber…Crossing many swollen creeks and thickets of cedar and oak timber…we arrived at the Arroyo de los Pedernales" [Miranda, Bernardo de. 1756. Miranda's inspection of Los Almagres: his journal report, and petition. Ed. and translated by Roderick B. Patten, *in* Southwestern Historical Quarterly (October 1970): 74(2):223-251.]

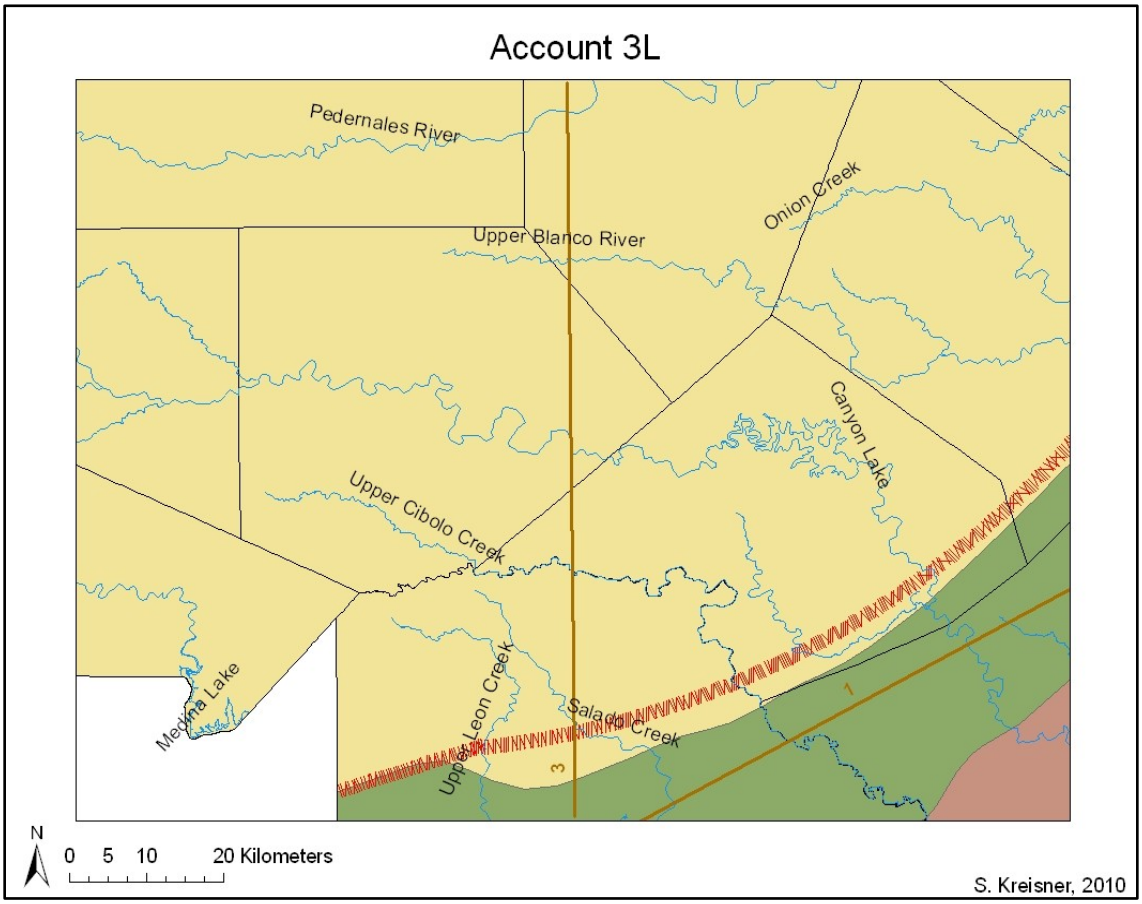

Figure 6- Account 3L: A close-up view of account 3L

Table 6- Example of account- 33L location description

Unique ID	Location Description
33L	"On the upper Medina…timber of the first quality like that in the mountainous regions…" [Bracht, Viktor. 1849. Texas in 1848. Translated by Charles Frank Schmidt. Naylor Printing Company: San Antonio.]

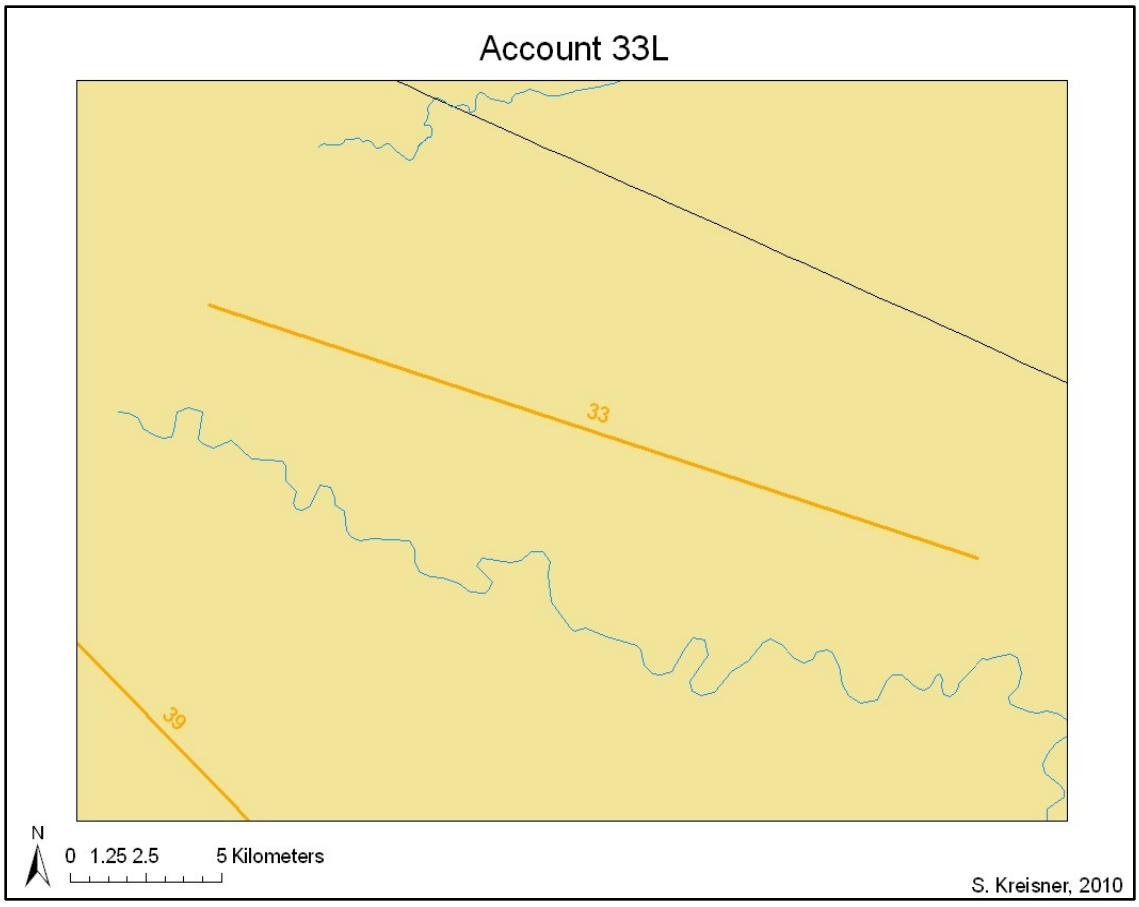

Figure 7- Account 33L: A close-up view of account 33L

line indicates the observer traveling over an expanse between two or more points; there are a total of fifty-five line features ranging from the years 1709-1966 (Figure 8). The attribute table for each feature class contains a brief citation, the observer, any additional comments and the year and/or date of the observation.

After the addition of all accounts to their respective feature class occurred, I created different layers based on the year of observation, and the site description, in order to allow for an analysis classed by century. The division of accounts for both point and line data occurred in three groups: woodland, grassland, and mixed land covers. Woodland accounts were classed as having made no mention of grasslands or prairies and offered descriptions relating to timber, forests, or using similar terminology. Conversely, divided into the grassland category, were narratives that solely described prairies or plains but did not address forests or woods. Lastly, if an account referenced both a grassland-type landcover as well as a woodland-type, it fell into the mixed category.

Different symbols for grassland, woodland, and mixed point and line accounts allowed for a facilitated interpretation of the maps. The color pink was assigned to grassland accounts and the century of those accounts depended on the shade assigned. So, woodland accounts followed with the color orange, and mixed accounts with the color blue. Accounts relating observations of Ashe juniper (cedar), from both the mixed and woodland categories, were also separated from all other accounts and assigned a different symbol, again classed by century.

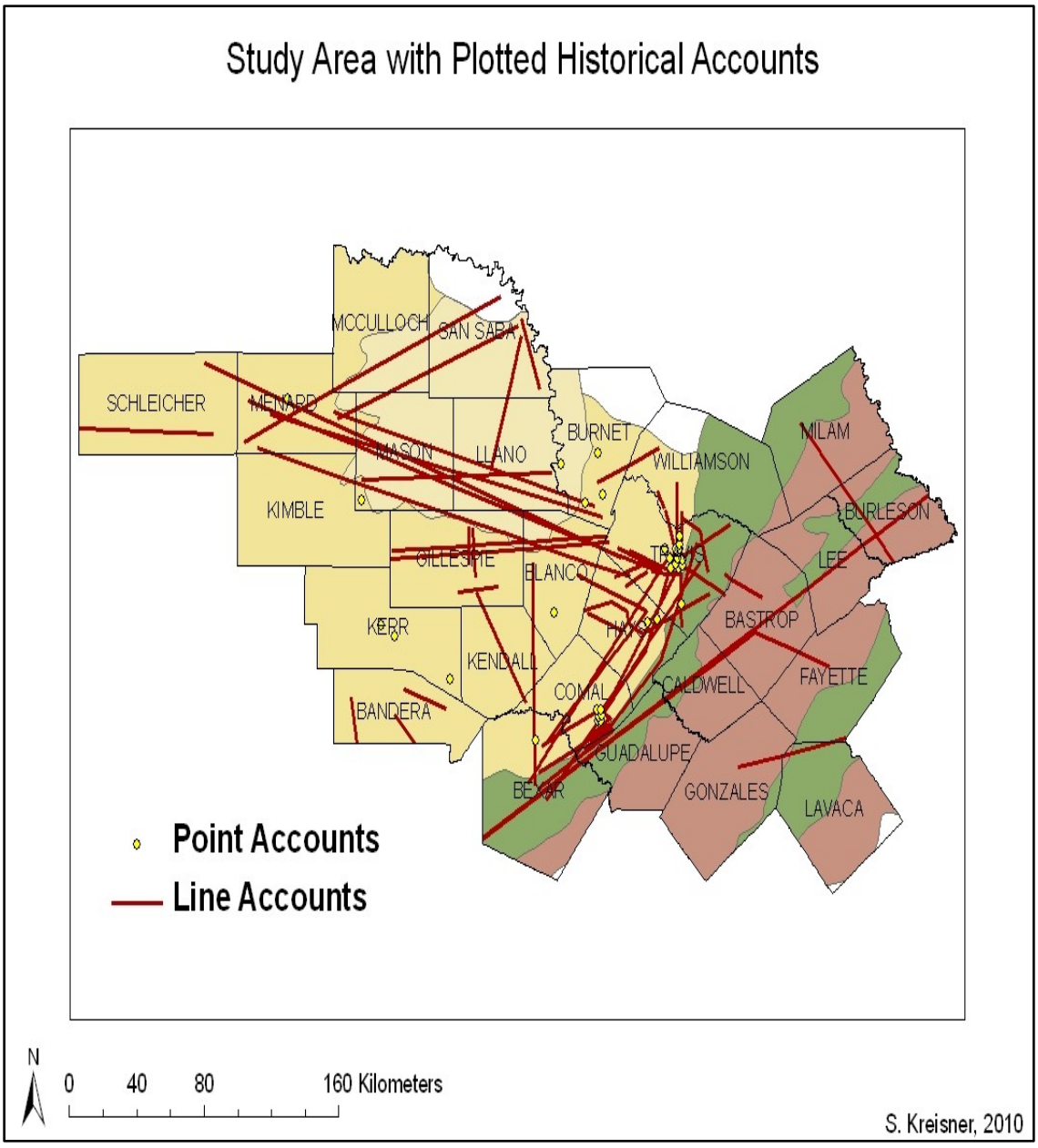

Figure 8- Study area with plotted historical accounts

After the formation of new layers from the above-mentioned selected attributes, the next step was to create maps for the 1700s, 1800s, and 1900s, depicting the grassland versus woodland observations. These maps will allow for a qualitative analysis, by century, of Central Texas' pre-European settlement, early settler, and modern-day land and forest cover. Furthermore, the construction of a map displaying accounts related to the mention of Ashe juniper/cedar will allow for a qualitative assessment of juniper-specific coverage, and accordingly how this coverage has changed since pre-European settlement. This comparison of grassland versus woodland and juniper observations will assess temporal, as well as spatial, change.

Limitations

When analyzing the results of the study, a few concessions must be acknowledged concerning the methods of the study. First, an acknowledgement of interpretation bias is required. When translating written spatial descriptions into mapped locations, it is possible that the researcher's interpreted location is not exactly the same as the meaning of the original narrative in question. Furthermore, this study recognizes the concept of "positional accuracy", and acknowledges that any georeferenced location on the map may be different from the observation's true location (McEachern and Niessen 2009). Lastly, just as GLO PLS records demonstrated with surveyor bias and inconsistency, so too must I recognize potential bias and location inaccuracies with any site mentioned in the accounts.

CHAPTER 5

RESULTS

The results of this study are a depiction of vegetation from each century, reflected as either woodland, grassland, or mixed (that is, containing both observations of grassland and woodland). The results are described here in three sections, broken down by century, with a fourth section outlining the results of those observations that mentioned "cedar" or Ashe juniper.

1700s Vegetation Observations

In the 1700s woodland category (Figure 9), for both point and line, six observations were mapped. Observations 4Line (L), 10Point(P), 13P, and 33P were plotted north of the Balcones Fault Zone (BFZ) within the Edwards Plateau ecoregion, observation 1L traversed the Blackland Prairie and Post Oak Savanna ecoregions from east to west, and the sixth observation, number 3L, landed for the majority north of the BFZ with a small tail-end section in the Blackland Prairie. Five of six of the woodland accounts are recorded as falling within the Edwards Plateau ecoregion, the area more commonly associated with denser stands of trees. Each of the six observations occurs

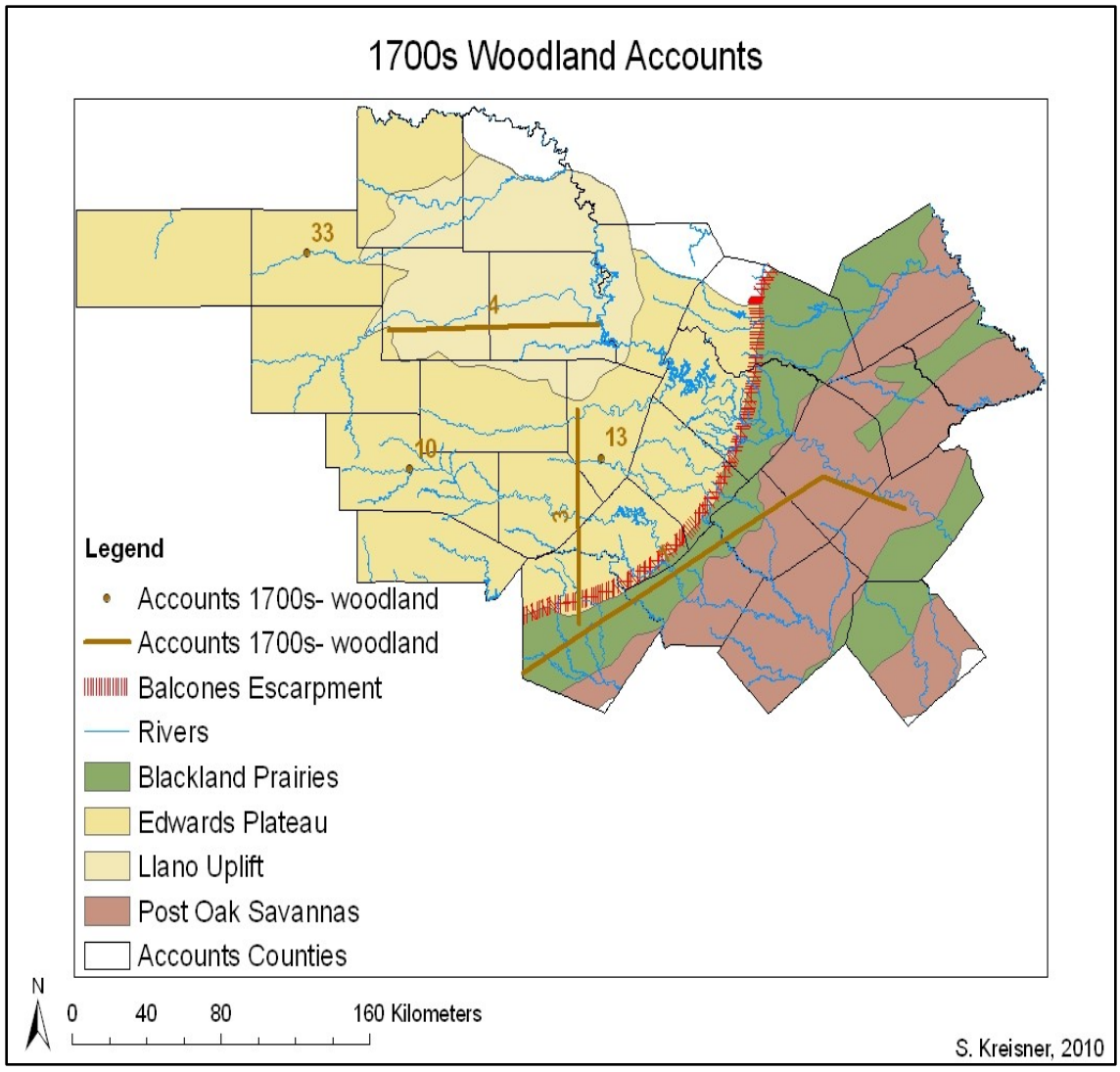

Figure 9- Map of the 1700s Woodland Accounts

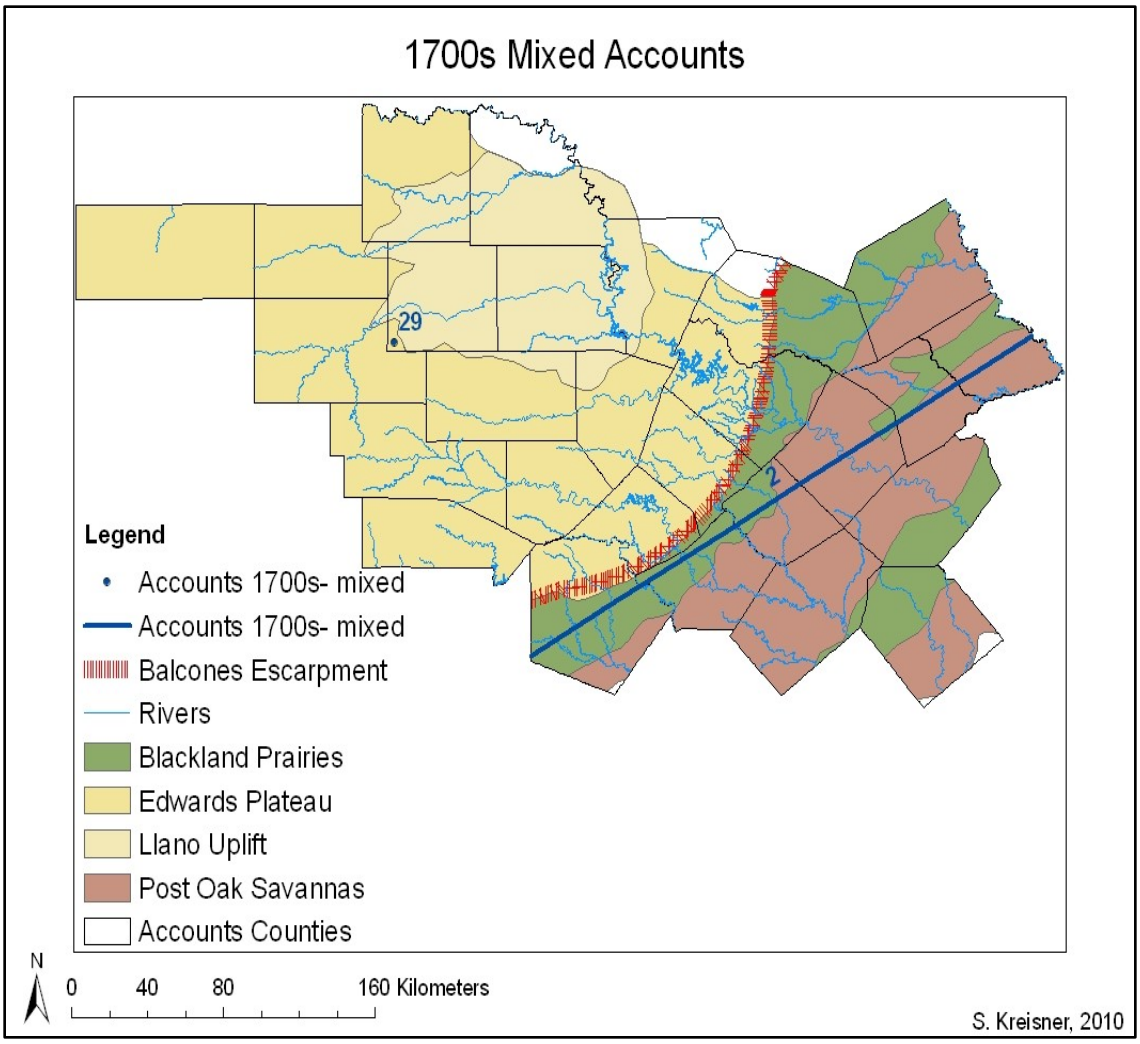

Figure 10- Map of the 1700s Mixed Accounts

within proximity to at least one river, and in some cases across as many as nine rivers. Observers made comments such as “heavily wooded” and “timber…in considerable amount” and indicated that the density of trees often obstructed their routes.

Although there were no grassland observations for the 1700s, there were two accounts for the mixed category (Figure 10). Observation 29P landed in the northern territory of the Edwards Plateau while observation 2L crossed the Blackland Prairie and Post Oak Savanna on an east-west trajectory. These observations also occurred near water and they describe “little plains surrounded by trees” and grasslands with nearby cedar. Altogether, the majority of woodland observations, save one, were located within the Edwards Plateau region.

1800s Vegetation Observations

A total of forty-seven accounts were plotted for 1800s woodlands observations (Figure 11). Of these observations, only numbers 5L, 14P, 25L, and part of 14L fell outside of the Edwards Plateau. There are three of the Edwards Plateau accounts in the northern area (12L, 17L, 36L), four in the southwest corner (8P, 33L, 39L, 40L), two in the center of the ecoregion (30L, 31L), three towards the northeast of the study area (28P, 30P, 31P), and the majority are clustered just north of the BFZ. The few accounts that occur south of the BFZ reference timber and cedar, with a couple of the accounts referencing the hilly, timber covered slopes in view on the side of the Balcones Escarpment, opposite of where they travelled. The accounts within the Edwards Plateau

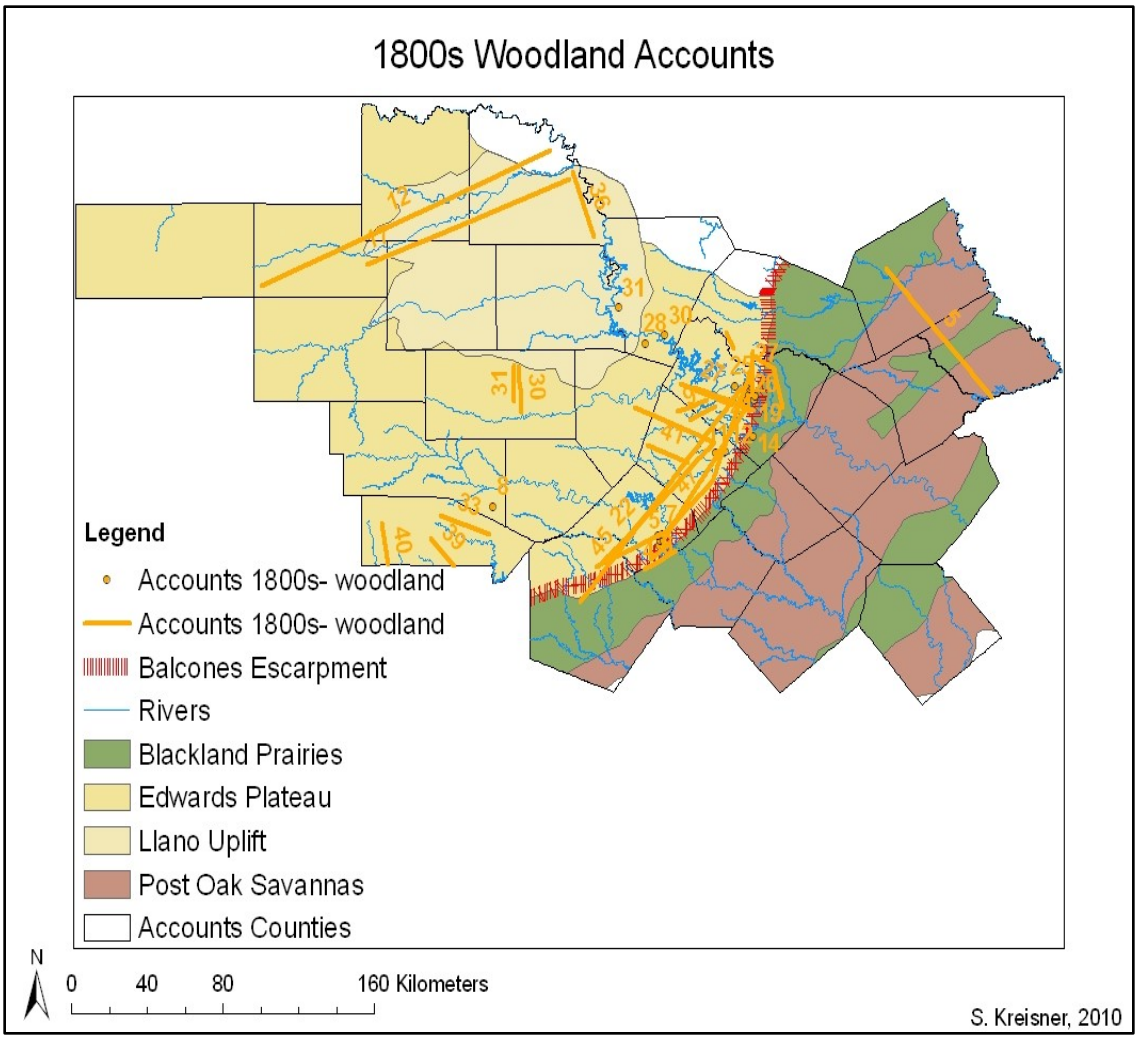

Figure 11- Map of the 1800s Woodland Accounts

describe hills “covered with heavy timber” and “cedar-covered mountains”.

With several exceptions, the majority of these observations occurred near rivers or streams. With a total of ten accounts, the grassland observations are primarily bunched around the BFZ (Figure 12). Accounts 28L and 34L are the two exceptions, with both line segments occurring away from the BFZ in the Edwards Plateau. While some accounts (23L, 24L, 26L) are solely in either the Plateau region or the Prairie region (with the exception of 26L which slightly crosses into the Post Oak), the remaining five accounts (18L, 21L, 43L, 44L, 46L) all expand into both the Blackland Prairie and Edwards Plateau ecoregions.

The mixed category accounts for fourteen observations and are much more dispersed than the grassland observations (Figure 13). Account numbers 6L and 13L are south of the BFZ, traversing across both the Blackland Prairies and the Post Oak Savanna. On the opposite side, five accounts (8L, 11L, 16L, 29L, 32P) are located towards the north of the Edwards Plateau region. Only account 15L crosses the BFZ to end in both the Plateau and Prairie. The remaining six accounts (1P, 3P, 7L, 10L, 15P, 20P) are all in the Edwards Plateau however, they reside somewhat close to the transition zone into the Blackland Prairie.

1900s Vegetation Observations

Found within the Edwards Plateau are all six of the woodland observations (9P, 48L, 51L, 52L, 53L, 54L) (Figure 14). While number 9P is located towards the

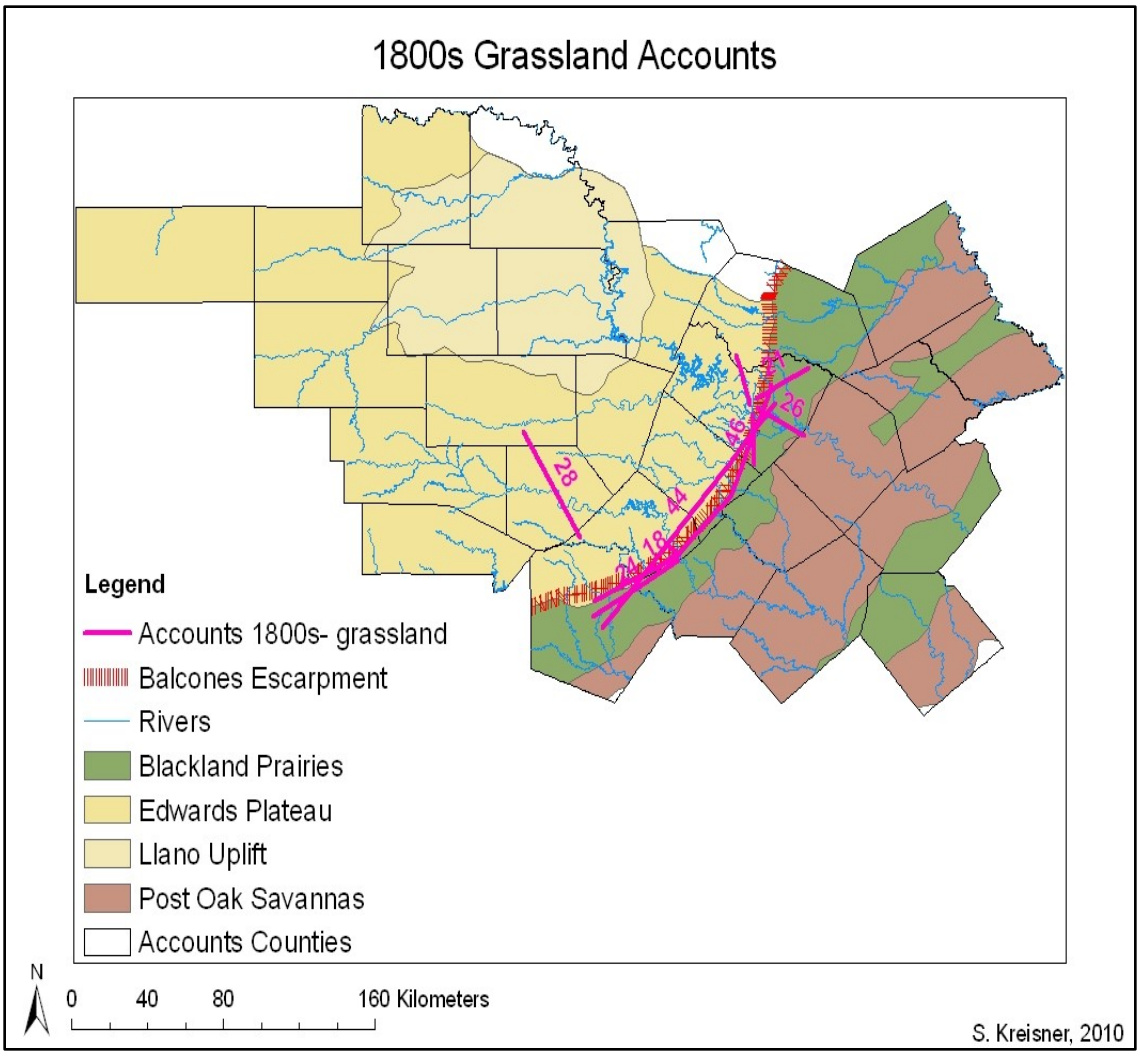

Figure 12- Map of the 1800s Grassland Accounts

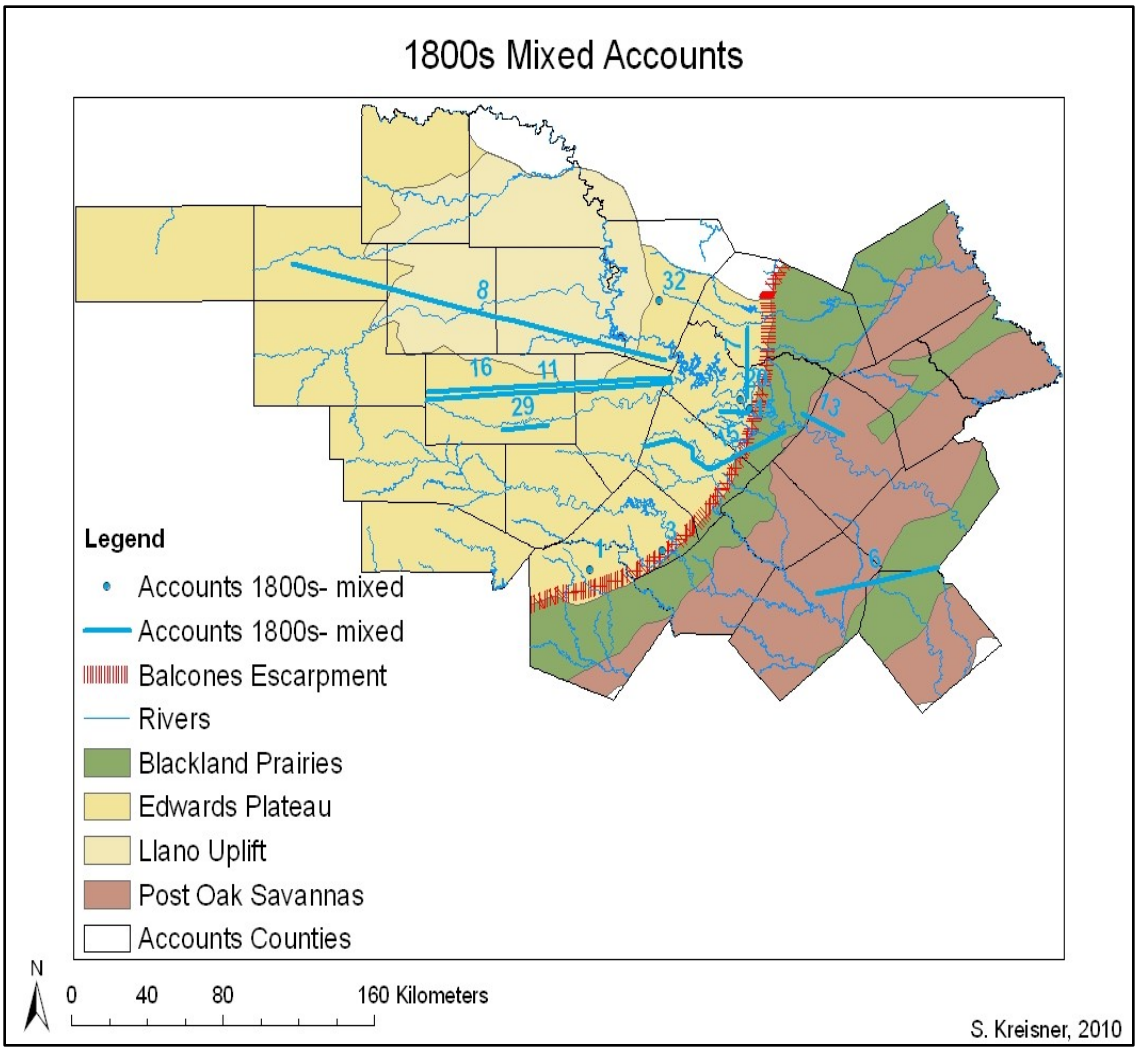

Figure 13- Map of the 1800s Mixed Accounts

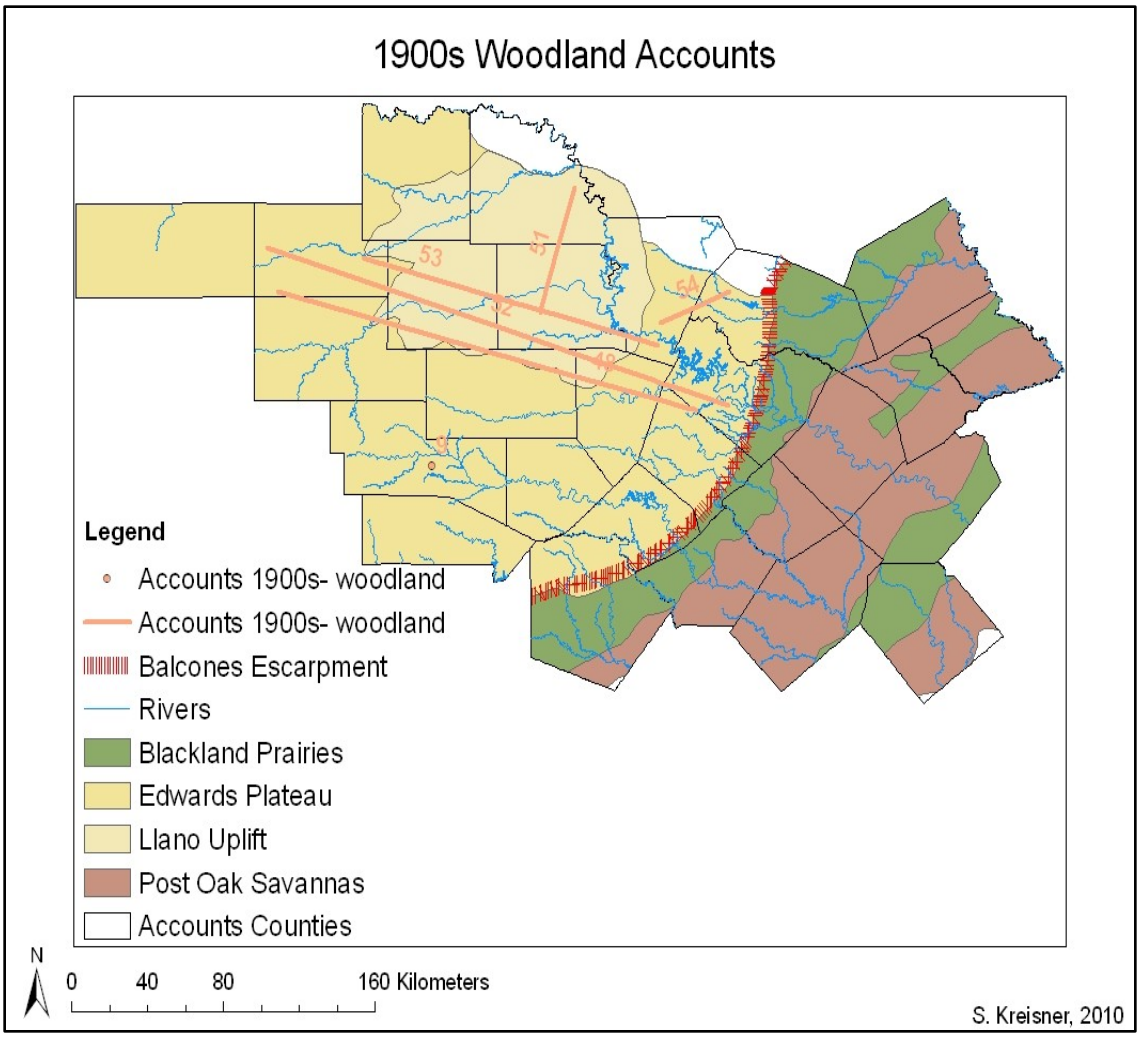

Figure 14- Map of the 1900s Woodland Accounts

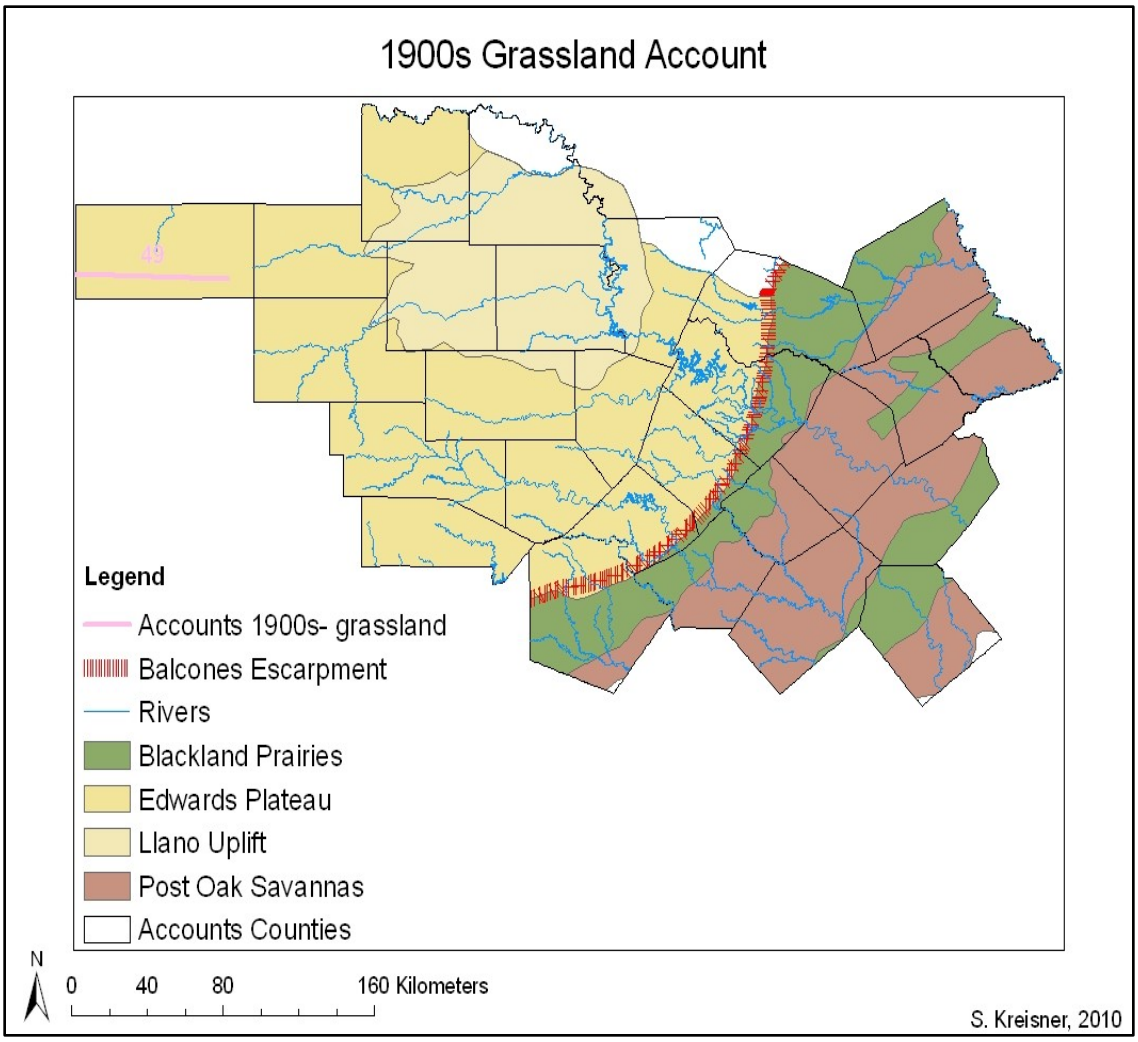

Figure 15- Map of the 1900s Grassland Account

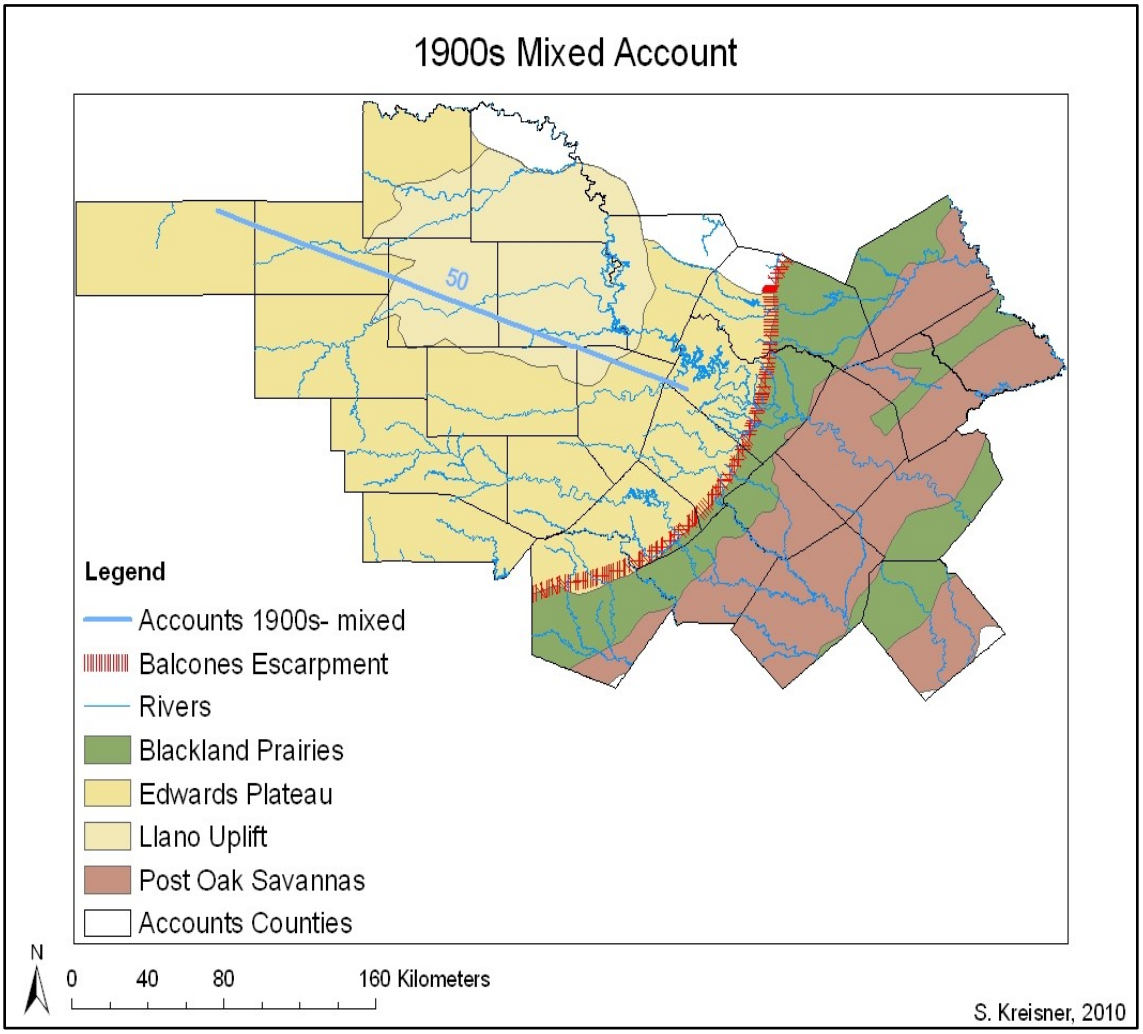

Figure 16- Map of the 1900s Mixed Account

southwest portion of the region, the remaining five accounts are situated towards the top half and further east, in the Plateau. Interestingly, the sole account for grassland (Figure 15) observations (49L) is located in the Edwards Plateau as well, positioned in the leftmost top corner of the study area. There is only one account for the mixed category (50L) (Figure 16) and it begins in the northwest corner of the Plateau and travels southeast, not quite arriving at the BFZ.

Ashe juniper Observations

Of eighty-eight total accounts, forty-five reference 'juniper' or 'cedar' (Figure 17). The majority of cedar observations occurred in the 1800s, with the 1700s accounts mentioning cedar three times and the 1900s referencing cedar five times. Seven of the 1700s and 1900s accounts are located completely within the Edwards Plateau, with the tail end of one account (3L), crossing the BFZ, into the Blackland Prairie.

The accounts of cedar in the 1800s are predominately to the north of the BFZ, with the exception of four outliers which are located completely in the Blackland Prairie (14P, 25L), partway in the Plateau and part in the Prairie (14L), and partly in the Prairie and partly in the Savanna (5L). There are a cluster of accounts within 25 miles north of the BFZ; the remaining observations are dispersed throughout the region in the southwest, north, northeast and central portions of the Edwards Plateau.

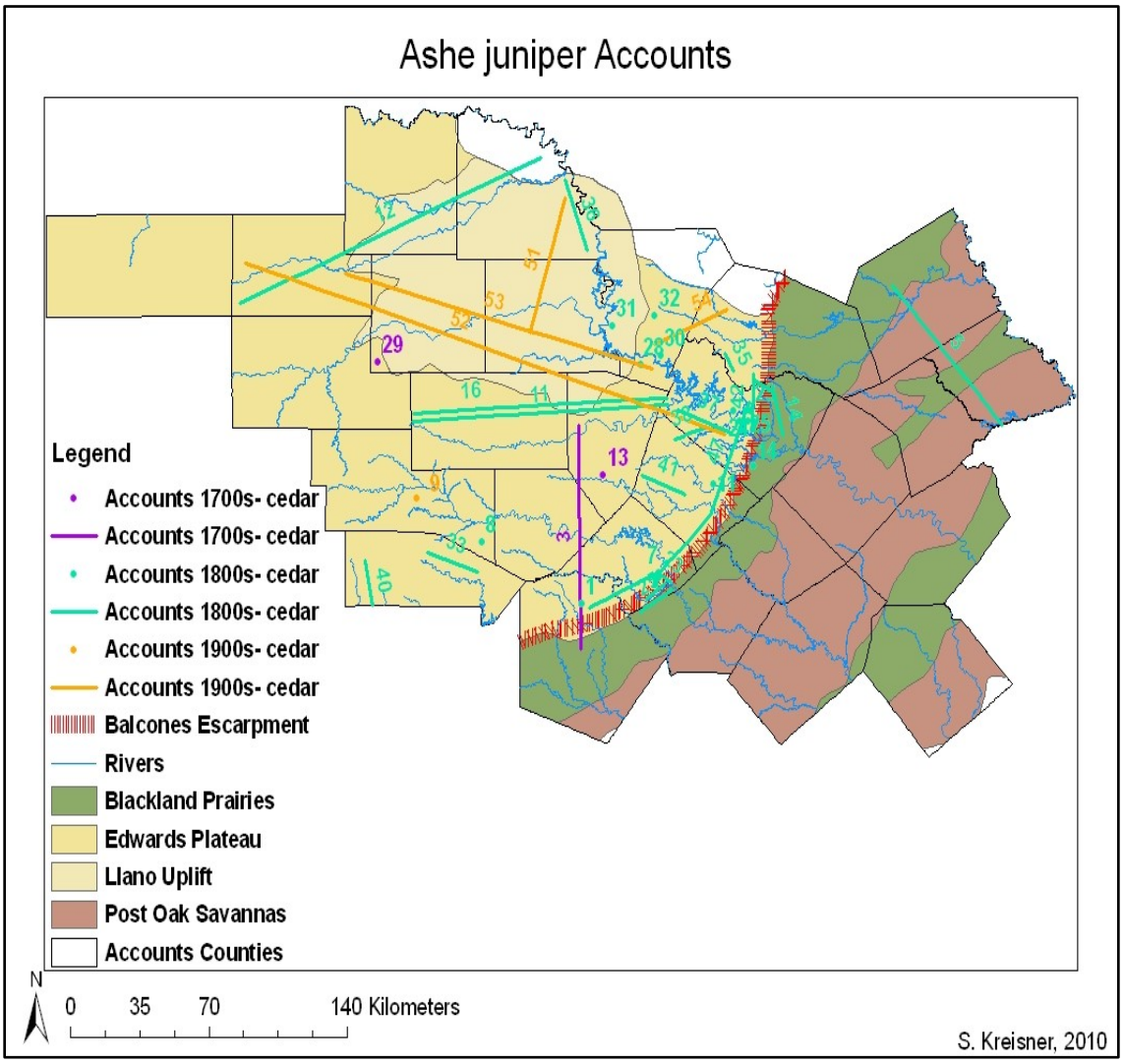

Figure 17- Map of the Ashe juniper Accounts from the 1700s, 1800s, and 1900s

Historical Reference

When acquiring historical data, it is oftentimes useful to have other scientific measures available to compare the results of a study. For this research, paleo-vertebrate reports could provide a useful tool for such a comparison. The Miocene Mammal Mapping Project (MIOMAP) at the University of California Museum of Paleontology combined data with FAUNMAP from the Illinois State Museum to combine one centralized database to provide an updated distribution of mammal species in the late Quaternary period (Carrasco et al. 2005). The FAUNMAP database does not provide fossil records for dates any later than the Quaternary period within the Blackland Prairie or Post Oak Savanna ecoregions, however there are several fossil records from within the Edwards Plateau. Excavation records show that grass-dependent species such as the Steppe Bison (*Bison priscus*), Yesterday's Camel (*Camelops hesternus*), and the Long-legged llama (*Hemiauchenia macrocephala*) were all found within the Edwards Plateau (Carrasco et al. 2005). This would indicate that the Edwards Plateau region could not have been historically composed of mainly woodlands. Rather, in order to support multiple species that relied on grass for their diet, that area would have had to contain significant grasslands as well. Furthermore, and more recently, reports of range sheep in Texas indicates that the Edwards Plateau supported as many as 376,000 sheep in 1880, after slowly being brought in from Mexico and gradually moving further north (Carlson 1982). This too would have to indicate a solid availability of grasslands, at least through the 1800s.

In addition to the existence of mammals and their diet requirements providing vegetation evidence, so too might past climatic events offer a useful tool to understand historical vegetation. Climate cycles such as Glacial and Interglacial periods have documented effects on past vegetation distribution. Paleo-ecological records have shown that during multi-millennial climate cycles in mountainous areas, species shift by elevation, while on more level ground species shift along either the north or south latitude. Additionally, species inhabiting patchy mosaic landscapes usually responded through an oscillation in population size while making minor location shifts (Millar and Brubaker 2006).

One such climate cycle, the Little Ice Age (LYA), dating from about 1450-1920, was a climate interval characterized by increasing glacial ice advances and a general global cold period (Millar and Brubaker 2006). While not every species' climatic shifts have been documented, what is known is that every species provides an individual response to climatic variability. Although the role that anthropogenic change plays on the landscape is important and vital to understanding how vegetation has changed, it is important to note that often, species changes in geography can be a result of climate. It has been argued that expanding *juniperus* in rangelands is emerging as an adaptive response to climate change, rather than an invasive spread (Millar and Brubaker 2006).

For this particular study area, 300 years is not long enough to see changes such as latitudinal range shifts of Ashe juniper. However, given the trajectory of present and future global climate change, we can expect that there is a significant likelihood that the locations of the historical Ashe juniper mapped in this study will see range shifts over the

next several hundred years. With continued anthropogenic disturbance and fragmentation alongside a warming climate (for this particular study area) it is expected that the Ashe juniper native range will shift.

CHAPTER 6

DISCUSSION

The previous chapter detailed study results; this chapter follows with an assessment of the meaning of those results. As they stand, some of the accounts and observations are what one would expect; however, it is not clear whether the results obtained from this study align well with popular history of the region. As the motive behind each observation will never be perfectly understood, we must attempt to draw reasonable conclusions from the results in order to analyze these materials and better understand their meaning so that they may be used for regional decision-making regarding landscape management.

Woodlands

During the time the Spanish explorers travelled Texas in the 1700s, their priorities were on obtaining the lay of their land as well as the composition and location of commodities from which they could expect to gain a profit. When travelling across the state, the six observations from the 1700s denoting trees and woodland-type features are widely located throughout the study area. The research shows that observers at the time found their travels sometimes obstructed by trees and described some areas as having thickets of trees and warbling songbirds. There are multiple explanations for these

results. First, the observers, having found heavily forested areas, could have a descriptive bias. These Spanish explorers were travelling into the Central Texas region from southwest Texas and Mexico, in and around the Chihuahuan Desert; the stark contrast between what they had been travelling through and what they came to find in this region may have resulted in a hyperbolic description. Second, each of the observations occurred near a river. The descriptions given are demonstrative of expected riparian vegetation. Last, the frequency of forest and tree descriptions may be the result of the search for timber as a valued commodity, as the explorers made less, if at all, note of any other natural feature unless of value at the time.

The observations made in the 1800s were not from explorers, but rather early settlers, interested in finding land to set up homesteads, and military encampments passing through different areas. Twenty-six of the woodland observations, alone, were recorded from a distance of no greater than twenty miles in and around Austin, Texas. A vast number of the other observations indicated the presence of trees within the mountains, slopes and hilly areas; this is especially true of observations made within the Edwards Plateau "Hill Country". Thick cedar brakes and dense stands of deciduous vegetation are common to those areas. While not clustered or necessarily close to major urban centers, the majority of the other observations were located within close proximity to nearby water sources, such as artesian springs or rivers. As previously stated, one would expect to find woodlands dominating the riparian vegetation. Similar to the Spanish explorers, the settlers during this time would have been documenting their newly settled lands, and concomitantly, what resources they had found. Lumber mills were a

prominent industry in the region during the 1800s, so it would not be surprising then that these settlers would have made note of the monetary source they saw in the vast amounts of surrounding timber.

Found primarily in the northern section of the Edwards Plateau, the observations of woodlands from the 1900s reside in and around the Llano Uplift. Explorers, different from those in the 1700s, made these observations. Although there was some interest in knowing the present status of timber wealth, the primary objective for these explorers was to obtain an understanding of the lay of the land. These explorers were interested in the geography, geology, and biology of their land. It is understandable then, that the majority of these accounts were recorded along rivers, thus lending themselves to reports of dense tree stands. The reduced woodland observations from the 1800s to 1900s would also have resulted from the widespread timber chopping that occurred by the early settlers; Ashe juniper, as well as other woody species, would have been chopped down and used for building construction.

The number of woodland observations from the 1800s dramatically increases compared to the number of accounts from the 1700s, most likely as a result of wide-spread fire control, leading to an increase and spread of woody vegetation. Furthermore, the number of accounts relating descriptions of woodlands dramatically decreases from the 1800s to the 1900s. Those accounts made in the 1900s are no longer centered around urban areas or out in the open, but rather along riparian corridors. This is most likely the result of widespread lumber harvesting around cities, along with concurrent widespread agricultural cultivation and livestock overgrazing in the open areas.

Grasslands

Although this research provides no accounts solely relating observations of grasslands in the 1700s, their existence is indisputable. It is probable that the lack of mention for grassland and prairie-type vegetation lies in the previously mentioned fact that early explorers would have been searching for anything of value and for them, unremarkable grasslands would not have accounted for such value.

Most of the grassland observations in the 1800s relay images of the rolling plains of the Blackland Prairies. Again, more motivated by searching for homesteads and commenting on the territory travelled, the observers from these accounts found the extent and unending appearance of the savannas remarkable. The sole account from the Edwards Plateau region describes hills with dry grass and occasional trees, typical of that part of the eco-region.

The only description of prairies in the 1900s is located in the upper northwest corner of the study region and marks an area of transition from the Edwards Plateau Woodland to a more arid savanna eco-region further west. From the 1800s to the 1900s, there was an increase in livestock overgrazing and agriculture, which potentially lead to the feel of fewer woodlands and more savannas of this time.

Mixed Vegetation

A couple of observations from the 1700s, indicating both plains and trees, reinforce the existence of grasslands. One particular observation characterizes the Blackland Prairie and Post Oak Savanna as forests that alternate with grasses and clear

plains. The other mixed observation indicates "good grasslands" with nearby cedar in the northern section of the Edwards Plateau; this would have been typical of this area.

The mixed accounts from the 1800s do the most justice to characterizing the Edwards Plateau, Blackland Prairie, and Post Oak Savanna. The accounts that fall within the Prairie, Savanna, Llano Uplift, and Edwards Plateau Woodland-proper, all offer descriptions relating an expected mixture of grasslands and woodlands. Those accounts from the Hill Country, within the Edwards Plateau, relate equally accurate descriptions of hills covered in trees and heavily forested bottomlands.

The only mixed description from the 1900s falls within the Edwards Plateau and is described in much the same way it was described in the 17- and 1800s: as grassy with scattered forest. The mixed accounts from each of the three centuries probably offer the best descriptions of the original pre-European settlement-European settlement vegetation, as none of the eco-regions can truly claim only one type of vegetation composition (e.g. only prairie grasslands).

Ashe juniper

"Cedar" accounts were few in number in the 1700s, but not in relation to the number of woodland and mixed accounts altogether. The number of Ashe juniper observations decreases from the 1800s to the 1900s; however, the locations of those sightings in the 1900s are concentrated. While a plethora of juniper observations from the 1800s occurred around Austin, and just north of the BFZ, considerably fewer, if any occurred in the same place in the 1900s. This is most likely the result of urbanization,

deforestation from the timber industry, and timber clearing for agriculture and grazing. While the control of fire and the increase in overgrazing should produce an increase in Ashe juniper, these particular accounts do not reflect that trend.

CHAPTER 7

CONCLUSION

The results of this study show documented vegetation from the time of early Spanish explorers in the 1700s, to early settlers in the 1800s, through those who settled the region in the 1900s. Analysis of the data show a potential change in vegetation structure over time, however it may not be clear as to whether the results are a reflection of true vegetation change or perhaps an "observer" bias. While not much change is depicted from the 1700s to 1800s, the range and frequency of observations changes from the 1800s to 1900s. Far less woodlands are noted around the Balcones Fault Zone as are far fewer accounts of "cedar". Furthermore, it appears that the descriptions of mixed vegetation accounts relay the most accurate portrayal of what historic vegetation composition would have reflected.

While some accounts of popular history report the Edwards Plateau region as woodlands, this research shows that it would have to have been a woodland-grassland mosaic. Although it is not clear whether there has been a change in Ashe juniper density within the Plateau, it seems certain that the juniper is invading into the grasslands. General historical knowledge usually depicts the Blackland Prairie as an un-ending field of grasses, however this research provides reasonable belief that occasional mottes of

trees were present in the Prairie region. Like the Edwards Plateau, it is also clear that the Blackland Prairie is experiencing an expansion of Ashe juniper. While the Post Oak Savanna eco-region was named so because of its groves of Post Oaks, most of the historic Post Oaks have been replaced by live oaks and other tree species. Although a loss of its native tree species, this ecoregion too is experiencing a loss of grasslands as a result of increasing woody species.

Each of these three ecoregions is significantly altered from the time of pre-European settlement. Massive anthropogenic change resulting from the introduction of livestock grazing, and the resultant overgrazing, has allowed for the encroachment of Ashe juniper in all three ecoregions and a loss of original grasses. Furthermore, human control of wildfire has played a considerable role in altering the vegetation in this area; lack of fire has allowed for the expansion of Ashe juniper and other woody species into the grasslands.

While the role of future global climate change and its implications for restoration is still uncertain, what we do know is the need for adaptive and resilient restoration plans is essential. Past climatic events have demonstrated that species will shift their ranges given certain climatic variables and we can expect that to be true for Ashe juniper in the future. Furthermore, increases in habitat fragmentation and increased urbanization will continue to alter the landscape. Although livestock overgrazing and wildfire control is currently less of an issue than in the past, they have already contributed to widespread vegetation change and will continue to do so in the future. The information provided in

this study allows for land managers and owners to be better informed regarding historical vegetation conditions in order to plan for future changes.

Contributions

This research has contributed to the fields of geography and ecological restoration through its attempt to use qualitative research and GIS. While other research pertaining to historic vegetation patterns in this region have referenced of some of the same, and similar, historical accounts, seemingly none have consolidated the accounts and translated them into a GIS database. This study may also provide a useful tool for future similar research, expanding upon the methodology to include science-related data collection methods and a quantitative analysis.

Regardless of the findings from this study, the City of Austin BCP division, as well as Central Texas land managers interested in habitat restoration, will be better informed and hence equipped to deal with current and future restoration and management plans. Although it is not practical to attempt to restore a landscape to a time before European settlement, the results of this study will supply a historic landcover baseline, contributing to the ability of local land managers to create adaptive landscapes, more compatible for a range of conditions in an uncertain future.

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