ORIGINAL TEXAS LAND SURVEY AS A SOURCE FOR PRE-EUROPEAN SETTLEMENT VEGETATION MAPPING

A Thesis

by

INDUMATHI SRINATH

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Geography

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Approved by:

Chair of Committee, Andrew Millington
Committee Member, Christian Brannstrom
Charles Lafon
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ABSTRACT

Original Texas Land Survey as a Source for

Pre-European Settlement Vegetation Mapping. (December 2009)

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Chair of Advisory Committee: Dr. Andrew Millington

Past events and present environmental conditions may alter vegetation cover and composition over decadal timescales by exerting persistent effects on modern vegetation patterns and consequently influencing species distribution and abundance. My aim was to reconstruct vegetation and analyze cover during early-European settlement in Brazos County using historical sources, mainly the surveyor's files from the Original Texas Land Survey. The decoded trees from the surveyor's notes resulted in 24 witness and bearing tree species being recorded, the most abundant species on the uplands was Post Oak (*Quercus stellata*) and for bottomlands was Pin Oak (*Quercus phellos*). Using the distances and directions given in the surveyor's notes for witness and bearing trees, coordinates were calculated and species classified according to their National Wetland Indicator' (NWI) status. Indicator kriging was performed to create a continuous vegetation cover of Brazos County by interpolating the point biogeographical data (i.e., witness trees, bearing trees and stake, mound and post locations) that had been spatially located and mapped onto the shapefile.

The vegetation map showed 49% of vegetation in the county was covered by grassland during pre-European settlement. Most of these prairie areas were located in the northern portion of the county along the Old San Antonio Road. The bottomland forests covered 15% of Brazos County along the Navasota and Brazos Bottoms. Major expanses of bottomland hardwood occurred in the northwest of the county and at the confluence of the Navasota and Brazos rivers in the south. The Upland Oak Woodlands, mainly dominated by Post Oaks covered 36% of landscape, occurred mainly towards the western and eastern parts of the county and were interspersed with Grasslands. The vegetation map was verified using old photographs, traveler's accounts and field checking for bottomland hardwoods. This research proves that the OTLS is a valid source for vegetation mapping during Pre-European settlement and for analyzing the tree species present at that time and helps in protecting and conserving our pristine environment at the present time.

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I would like to thank the GLO at Austin, especially Mr. John, for all his cooperation and for pulling out the surveyor's notes from their respective files in the archive section. I would like to thank Dr. Kimber and Dr. Smiens for guiding me and providing me with insights on their deep knowledge on the ecology of Brazos County.

I am thankful to Texas A&M University for providing me with an opportunity to carry out this project. I am very grateful to have had the opportunity to learn from the faculty, staff and students in the Department of Geography and the university as a whole.

Finally, my sincere thanks go to my family; I would like to thank my father (Dr. Srinath) and mother (Nalini Srinath) for their encouragement and support during my Master's program, especially, the love, encouragement and support I got from them during the completion of my project and the writing of my thesis.

My deepest thanks go to my ever-understanding husband (Mallikarjun Lalgondar) and my daughter (Chinmayee) for all the support, encouragement and guidance. I am thankful to both of them for always being beside me and motivating me to complete my program in a successful manner.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Historical contingency plays an important role in determining contemporary vegetation patterns (Philips, 2004 and Wiens, 1989). Past events and present environmental conditions may alter ecosystem composition and structure by changing species composition, biogeochemical cycles, and physiographic properties of soil and resource availability (Bratton and Miller, 1994; Compton *et al.,* 1998; Foster *et al.,* 1998; and Richter *et al.,* 1994). Anthropogenic disturbances affecting vegetation patterns and dynamics (Bellemare *et al.,* 2002) may also lead to dramatic and transient changes in vegetation cover and composition over decadal timescales (Asner *et al.,* 2003) by exerting persistent effects on modern vegetation patterns and consequently influencing species distribution and abundance (Grimm, 1984; Peterken and Game, 1984; Turner 1987). Globally, most natural vegetation has been disturbed or cleared completely due to cultivation; grazing or urban development from the time of early settlement to the present, North America is no exception. Thus, in order to get a better understanding of human influences on the contemporary landscape and the resulting changes, it is important to know the 'original' or 'undisturbed vegetation' of the landscape (Foster, 1992 and Maines and Mladenoff , 2000).

This thesis follows the style of *American Midland Naturalist.*

Researchers have begun to recognize the importance of long-term vegetation studies in many parts of the world (e.g. Verheyen *et al.,* 1999 in Belgium.). But in North America, there has been a long tradition of scientists who have documented the composition and spatial distribution of natural vegetation prior to disturbance by 'EuroAmerican' settlement (Delcourt, 1991). In part, this is due to the relatively late clearance of natural vegetation in North America compared with much of Eurasia, but also because vegetation in the form of witness trees was used extensively in land surveying.

Many studies on pre-European settlement vegetation in the USA have been conducted east of the Mississippi. The focus has been on forest composition (Brown, 1998; Cogbill, 2000; Cogbill *et al.,* 2002; Cowell, 1995; Dyer, 2001; Loeb, 1987; Lutz, 1930; Siccama, 1971; and Whitney, 1982) and the impact of land-use history on forest vegetation dynamics (Foster, 1992; Foster *et al.,* 1998; Glitzenstein *et al*., 1990; Mac Connell, 1973; Medley, *et al.,* 2003; Schneider, 1996; and Turner, 1987). Similar studies in central and western USA are rare.

Texas, located in south central United States, consists of 10 vegetation zones (Correll and Johnson, 1979) ranging from the Pineywoods in east Texas dominated by pines and pine-hardwood forest to western desert. Stephens and Holmes (1989) stated Texas to be a transition zone between the humid, eastern woodlands and the semi-arid ecosystems to the west. The Post Oak savannah which intermingles with the Blackland Prairie is situated between humid east Texas and semi-arid west Texas. The Post Oak Savannah is a transition zone between the Blackland prairies to the west and the Pineywoods to the east. Primarily consisting of Post Oak, grasses and forbs it extends from south central Texas northward into eastern Oklahoma. The Blackland Prairie is a true prairie grassland community which is dominated by a diverse assortment of perennial and annual grasses, supporting true prairie vegetation with Indian grass, big bluestem, switch grass, and eastern gamagrass. The Blackland Prairies extend from the Red River on the north to near San Antonio in south Texas. It is part of a tall grass prairie continuum that stretches from Manitoba to the Texas Coast.

The European settlement in Texas began in 1820s (Moritz, 1913). By the start of the twentieth century Bray (1906) noted that the development of agriculture and its closely related industries had resulted in native prairie and woodlands being replaced by fields and orchards of cultivated species. Given the major land-use changes that have taken place in Texas since European settlement, an understanding of what types of vegetation communities existed during the time of European settlement and what changes have taken place since then in those communities is of great importance to vegetation scientists. Despite this, only two published spatial reconstructions exist to the author’s knowledge. Tremblay et al. (2005) estimated native woodland loss in Cameron County situated in the Gulf prairie and marshes vegetation zone using historical topographic maps and aerial photographs, and Schafale and Holcombe (1983) reconstructed pre-European settlement vegetation in Hardin County situated in East Texas Pineywoods region using OTLS records. Wills (2005) looked at old species lists for Kerr County.

In order to reconstruct the past vegetation various sources of information can be used. For example, traveler's accounts, local histories, photographs, maps, census data, field evidence and manuscript materials like land survey records. Land surveys records in particular provide valuable information that is not available in other forms of data (e.g., photographs and traveler's accounts). They can also, if manipulated correctly, provide evidence of vegetation patterns immediately before the landscape was altered by prior European settlement (Beever, 1981) because they were part of the European settlers' land claims.

The General Land Office (GLO) surveys in each state contain a wealth of ecological information concerning the distribution and composition of pre-settlement and early settlement vegetation (Bourdo, 1956). Importantly they also provide valuable baseline information for estimating the qualitative or quantitative information of pre-settlement vegetation (Whitney, 1994). My research focuses on reconstruction of pre-European settlement in Brazos County, an area that includes Blackland prairies and Post Oak Savannah vegetation zones using Original Texas Land Survey (OTLS) records obtained from the GLO in Austin.

1.2 Aims, Objectives and Hypothesis

I hypothesize that majority of uplands in Brazos County during 1800s were covered by a savannah (Allison and Campbell, 1925) which at one extreme was an open grassland with very few trees (these would mainly be Post and Black Jack Oaks) and at the other was a densely wooded oak savannah. The adjacent Brazos and Navasota river valleys would have dense woodland with a distinctly different composition to the trees on the uplands.

1.2.1 Aim

To reconstruct vegetation and analyze cover during early-European settlement in Brazos County using historical sources, mainly the surveyor's files from the Original Texas Land Survey.

1.2.2 Objectives

a) Map the vegetation cover of Brazos County in the late pre-European settlement period;

b) Conduct an accuracy assessment for the above map;

c) Account for the spatial distribution of vegetation in the late pre-European settlement period vegetation cover map: and

d) Analyze the vegetation map and other ecological data derived from the OTLS survey to gain a better understanding of the savannah and woodland communities present in the late pre-European settlement period.

1.3 Study Area

Brazos County is located in the east central Texas about 242 km north of the Gulf of Mexico and it forms part of southwestern edge of the Post Oak Savannah region. Most of Brazos County is an interfluve between the Navasota and Brazos rivers comprising of 1528.1 km^2 of rolling prairie and woodlands (Handbook of Texas Online). Topography is slightly different compared to adjacent counties with elevation ranging from 60 to 120 m.a.s.l., a surface sloping gently toward the southeast, and an annual rainfall of 939 to 990 mm.

Soils vary from fine sandy loams, clays, and clay loams in the uplands to heavy alluvium clays in the bottomlands. The Navasota floodplain primarily is made up of heavy alluvial clays and supports open hardwood forest of Willow Oak (*Quercus phellos*) and Overcup Oak (*Quercus lyrata*) (Allen, 1974). Since the drainage is exceptionally poor very little cultivation is carried out in these bottomlands. Over 60 years ago the region supported a “heavy growth of trees” (Timmons, 1942). The Brazos river bottoms vary in width, from a broad expanse in the south eastern part of the county to a narrow strip in the central part. Miller clay occupies most of the Brazos river bottoms (Timmons, 1942).

Originally these fertile bottomlands were forested with elm (*Ulmus* spp.), hackberry (*Celtis occidentalis*), ash (*Fraxinus* spp.), pecan (*Carya illinoinensis*) and chinaberry (*Melia azedarach*) (Veatch and Waldrop, 1916). Compared to Navasota bottoms the Brazos bottoms are at the higher level of elevation, resulting in better drainage and they are more conducive to cultivation.

The upland Savannah region is characterized by sandy loam surface horizons and is dominated by an open stand of Post Oak (*Quercus stellata*) and Black Jack Oak (*Quercus marilandica*) (Soil Survey of Brazos County, 2002). During the last several decades these open savannahs have been converted into dense woodlands as a result of overgrazing, abandonment of cultivation and fire suppression (Rideout, 1994). The Blackland Prairies are scattered within the savannah region and comprise clays and clay loams.

The advent of settlement in Brazos County resulted in the clearing of uplands for cultivation. During this development, it undoubtedly the case the prairies were the primary targets. As the demand for more land increased probably more wooded uplands were cleared. In the 1860s the development of cotton plantations on the fertile bottomlands of the Brazos river valley (“Brazos Bottom”) was an important factor in the agricultural growth of Brazos County (Soil Survey of Brazos County, 2002) in addition to some uplands areas were cultivated for cotton, sorghum and wheat. The major land use practices of both uplands and bottomlands — grazing and cultivation — resulted in the deterioration of soil and changes in vegetation. Letters from early settlers say there was a need to plant extensively for the future generation in order to compensate annihilation of timber by past and present generations (Dewees, 1968).

1.4 Thesis Structure

This research is the regional analysis of natural vegetation patterns prior to European settlement using Original Texas Land survey (OTLS) notes for the whole of Brazos County. Chapter II reviews the literature on vegetation reconstruction studies in the USA using historical sources, discusses the OTLS, and introduces the ecology of Brazos County. Chapter III describes methodologies used in assessing the distribution of vegetation prior to pre-European settlement in Brazos County. Chapter IV presents the main results. The vegetation map and other ecological data are analyzed and discussed in Chapter V. Chapter VI summarizes the research and comments on the use of the OTLS as a source for vegetation reconstruction.

CHAPTER II

LITERATURE REVIEW

2.1 Early Historical Documents

In North America many ecological studies and almost all conservation efforts historically have been directed towards protecting ‘natural’ areas that have had low amounts of amounts of human impacts and are richer in native species (Walker et al., 2003) with the main interests being in recognizing pre-settlement type systems. Because these are conceived as being stable and relatively undisturbed by native Americans they are used to provide as a benchmark against which landscapes more heavily impacted by humans after European settlement can be compared. With the help of historical documents such as land surveys, census datasets, maps, photographs and travelers accounts pre-settlement vegetation can be reconstructed. The basis for this is that these documents provide important information about the condition of past landscapes, particularly the status of the vegetation, and can be used to infer the processes that influenced landscapes in the past. Because these historical sources are rich in ecological information analyses of them, along with sources from which later vegetation conditions can be inferred (e.g., air photos, maps, satellite images), present opportunities to document changing vegetation cover through the historical period and to evaluate potential changes in the mix of the factors that have controlled landscape composition over time (Motzkin et al., 1999, 2002).

2.1.1 Census data

Census datasets of the United States are the oldest information source of past land use and resource utilization patterns (Whitney, 1994). Many types of census data sets are available, e.g., population census, tax evaluations, and agricultural and industrial censuses, in state libraries, archives and historical societies. For pre-settlement vegetation studies agricultural census are the most widely used as they provide information on amount of improved and unimproved land, crops, detailed information of forest and farm landscapes of nineteenth century. For example, agricultural census records and tax evaluations have been used to study 300 years of forest and land-use change in Massachusetts (Hall et al. 2002); land-use history and its effects on the environment in New York (Glitzenstein *et al*., 1990); and to estimate the historical changes in croplands across North America (Ramankutty and Foley, 1999). An agricultural census record includes the state of a farm at a single moment in time. Livestock numbers, crops in the ground, and surplus fluctuation by the season or even by the day is not accounted for. They are known to differ from one census period to the next.

2.1.2 Ground photography

Photographs contribute to this body of work by providing excellent visual records of a location, the extent and types of vegetation, and the land-use activities. If photographs are repeated they can be used to analyze changes over time. Ellison (1949) documented changes in vegetation due to past overgrazing using historical photographs and re-photographing them at the same site using the same sun angle and camera position (repeat photography). Historical photographs of monuments also can be used to analyze vegetation changes, Bahre and Bradbury (1978) used photographs of 257 monuments taken after Mexican-American War in 1892 to analyze vegetation and land-use histories along the border. Repeat photography can also be used to monitor succession (Cooper 1928; Stephens and Waggoner, 1980; Foxworthy and Hill, 1982) and comparison of pre-settlement vegetation changes to contemporary vegetation conditions (Hastings and Turner, 1965; Webb, 1996; Meagher and Houston, 1999; Skovlin et al., 2001; and Manier and Laven, 2002). Though repeat photography is a useful technique in analyzing changes over time, many historical photographs are used to monitor vegetation changes using one photograph of the past and one modern photograph with no additional photo points to monitor the trends in vegetation changes over time (Kull, 2005). Other limitations of using historical photographs in vegetation reconstruction are: (i) the difficulty to find photographs from the nineteenth century depicting vegetation or landscapes (rather than buildings in urban settings); (ii) copyright issues; and (iii) retaking photographs at the exact location due to changes in landscapes.

2.1.3 Traveler’s accounts

Traveler’s accounts provide a cross-sectional view of the landscapes of the past, and are also used to compare the landscapes of the past with the landscapes of the present. These accounts are often the earliest descriptions of North American flora and fauna. Early settlers described the extent of forest and woodland; game animals and birds; edible plants; and soil fertility. These accounts provide an 'impression' of the landscape, but they were recorded by untrained (in a systematic ecological or biogeographical sense) individuals who were committed to settling in the North American wilderness. Despite their inherent biases, first-hand accounts do nonetheless contribute to our understanding of past landscapes. They describe the details of the life of early settlers, and the context of vegetation reconstruction, commentaries on vegetation and land use soils and the products that were manufactured from natural resources (and the species used) are paramount. The writings of these early naturalists record the distribution of plant species in a landscape undisturbed by European settlement. Dawdy (1989) used accounts of Spanish expeditions to find out the areal extent of riparian forests in California. Traveler's accounts can also be used to determine pristine vegetation conditions in an area before European settlement (Vale, 1987), and also to estimate the impacts of fire on pre-settlement vegetation (Brown, 1998).

Though these accounts give us first-hand information about the vegetation and landscape of an area, the descriptions of travelers were influenced by their background, training, culture and interests (Whitney 1994). For example, visitors exposed to open landscapes of Europe were likely to overestimate the amount of woodlands in America (Whitney, 1994). Additionally, most of these travelers followed major travel routes along rivers, canals and roads and recorded what they saw on their way which may lead to accounts towards these linear features rather than areas between them.

2.1.4 Land survey records

Early land surveyors records are the most reliable sources of information on pre-settlement vegetation composition (Bourdo, 1956; McIntosh, 1962). The USA is one of the few countries to possess detailed land records which systematically describe vegetation (i.e., GLOs) and that can be used to reconstruct vegetation prior to major alterations by European settlement (Barber 1976). The land surveys were made between the late seventeenth and the early twentieth century for land sale and settlement. Although the data were not collected for ecological purposes, they provide a representation of the vegetation that existed prior to significant European settlement. Most surveys use tree species to record property corners, and many also record fields, roads, streams, landforms, vegetation community types, and large disturbances. These surveys therefore provide a systematic representation of vegetation in a landscape, providing both quantitative and qualitative information, which can be used to map plant communities and species distributions, documenting changes from the pre-settlement period to present time (Noss, 1985). They are also used in estimating species composition, density and size-class structures of pre-settlement vegetation of a region (Whitney, 1994).

There are two major types of surveys. The irregular boundaries system called the ‘Metes and Bounds’ surveys. Much of the eastern United States was surveyed this way. Metes are an act of measuring, or assigning by measures; whereas a bound refers to property boundaries or the limit of ownership (Avery, 1967). This system was based on survey boundaries and land claims on physical features as well as the preferences of those purchasing the land (Carstensen 1976). This survey method soon proved contentious and ineffective, and in 1785 the rectangular gridded system called the ‘Public land survey system’ was mandated by a 1785 ordinance from most of the Midwest. Metes and Bounds surveys are used in pre-settlement vegetation reconstruction to record species composition (Lutz, 1930; Loeb, 1987 and McIntosh, 1962). For example, Lutz (1930) tabulated almost 6,000 witness trees from a survey of northwestern Pennsylvania; he noted that the historical surveys were very similar to the species composition of Heart’s Content, a nearby remnant old-growth forest. The surveys are also used in monitoring patterns of species composition and disturbance (Cogbill et al, 2002; Marks and Gardescu, 1992 and Cowell, 1995), to perform physiographic analysis of aspect to analyze witness tree locations (Whitney, 1994; and Abrams and Ruffner, 1995) in studying pre-European vegetation of a landscape (Gordon, 1940; Russell, 1981; Seischab, 1990; Seischab, 1992); and to monitor changes in vegetation over a period of time (Foster, 1992). Some researchers have used Metes and Bounds surveys to evaluate the influences of Native

Americans on vegetation (Black and Abrams, 2001), and to study species site relationships using parent material, soil drainage, and soil surface texture (Black and Abrams, 2001 and Whitney and DeCant, 2003).

The Public Land Survey System (PLSS) is more widely used in pre-settlement vegetation reconstruction than Metes and Bounds. Researchers have used PLSS to assess changes in forest composition and structure (Dyer, 2001; Shanks, 1953; Wuenscher and Valiunas, 1967; Schwartz, 1994); mapping pre-settlement vegetation (Sears, 1925; Marschner, 1974 and Brown, 1998); comparing old to contemporary vegetation (Iverson, 1988; Fralish, et al., 1991; Frelich, 1995; Van Deelen, et al., 1996; Radeloff et al., 2000); and in analyzing vegetation patterns (Schulte, and Barnes 1996 and Nelson, 1997). Delcourt and Delcourt (1974) used PLSS to determine that the West Feliciana (NE Louisiana) uplands were characterized by late stage succession vegetation species, and that the coastal plains were a secondary successional sequence. Along the same lines Lorimer (1977) determined causes of succession in northern Maine. White and Mladenoff (1994) related successional trajectories with landforms and spatial associations of forest types in a 9,600 ha northern Wisconsin forest.

Apart from studying succession and species composition, PLSS has also been used to determine the influences of Native Americans and fire on changing vegetation patterns (Batek et al., 1999), and the cessation of fire being the trigger for successional change in southern Wisconsin. PLSS also contains information about disturbances (e.g., fire, windthrow) which is used by researchers to determine the influence of catastrophic disturbances on pre-settlement vegetation. Charles and Loucks (1984) reported the frequency and extent of catastrophic windthrow in pre-settlement forests of Wisconsin and analyzed the probable mechanism for this catastrophic windthrow using PLSS. Along the same lines Zang et al., in 1999 discovered a complex interaction existed among the disturbance (fire and windthrow), vegetation and topography which would establish a strong probabilistic relationship among forest cover type, topography, and disturbance frequency. Anthropogenic disturbances on pre-settlement vegetation patterns have also been studied by Nelson et al. (1994) and Whitney (1986). PLSS records have also been used to assess species-site relationships (Siccama, 1971; Leitner, et al., 1991; and Whitney, 1982, 1986 and Barrett, et al. 1995).

Although PLSS and the Metes and Bounds system are widely used in vegetation reconstruction studies, these are concentrated in the eastern United States, and in some western states. Texas, having a unique history as a state, has a combination of PLSS and Metes and Bounds, and therefore has a unique survey called the ‘Original Texas Land Survey’ (OTLS). The OTLS survey notes consist of witness and bearing tree information, topographic features and land cover information, as well as an irregular system of the property plots measured in leagues and labors with the unit of distance measurement being the Mexican vara (see Chapter III). Pre-settlement vegetation reconstruction studies in Texas are very scarce given the size of the state. The only studies of vegetation reconstruction using OTLS is that for Hardin County in east Texas (Schafale and Harcombe, 1983) and part of Kerr County (Wills, 2005), these studies only analyze the vegetation composition of pre-settlement period and compare it to soil types despite the fact that OTLS notes contain potentially useful ecological information which can be used to reconstruct and analyze pre-settlement vegetation.

2.2 The Original Texas Land Survey (OTLS)

The lands of Texas were attractive, and considered a fortune for Americans and Europeans, with the first invaders being the Spanish. They attempted to colonize and set up missions but hardly succeeded in acquiring Texas. They were usually driven back by Indian raids, floods and disease. By the end of 300 years of Spanish rule in Texas (1821) only three towns — Nacogdoches, La Bahia (now Goliad) and San Antonio — had been established.

Land grants were given to many people verbally. Only heads of Spanish families obtained land grants. Foreigners were not allowed to settle in Texas nor obtain land under Spanish rule. The grants ranged in size from a garden plot to four leagues (17,713 acres) (Miller, 1967). The procedure was to petition to the governor, who in turn after the approval would send a commissioner along with petitioner to see the tract, witness adjoining land owners and notarize it. After this the actual survey was made. As noted above, during the Spanish rule the Spaniards shielded Texas from foreign settlers. But in 1820 the 'Spanish Cortes' opened Texas for foreigners who would abide by the Spanish rules and respect their laws and constitution. Moses Austin took this opportunity to settle 300 American families in Texas. At first, permission was refused, but after a meeting with his friend Baron de Bastrop (Miller, 1967), he was able to convince the governor to approve his application to bring Americans to Texas. After he died, his son Stephen F. Austin continued his father's mission.

At the same time Spain opened its borders to Americans, Mexico proclaimed independence and came into possession of Texas in 1821 (Miller, 1967). Stephen S. Austin's grant from Spain was no longer valid by then and it had to be re-approved by the Mexican government. He was granted approval to colonize under imperial colonization act of 1823. An Empresario (agent) got 22 ½ leagues for each 200 families he took to Texas and each settler who obeyed Mexican laws and professed catholic religion was promised one league (4428.4 acres) for grazing and one labor (177.1 acres) for farming. Unlike the American gove-rnment, the Mexicans recognized that more land was needed for grazing than farming. To get the land surveyed and title they charged $27 with a fee $60 for the Empresario. Austin established his first town in San Felipe, on the Brazos River in 1823.

In 1825, the legislature of Coahuila and Texas set up a new colonization law where a foreigner who desired land was required to register with the local municipal government, take oath to obey all the rules and laws of state and federal government, observe religion of land, state his age, marital status, occupation and former residency. Under this act an Empresario received five leagues and five labors of land for each 100 families brought in and for each settler the head of the family received one labor (177.1 acres) for farming and 24 labors (4251 acres) for grazing. Single men received ¼ league, but if married received full amount. A person married to a Mexican woman would receive an additional ¼ league. During this time, Austin obtained another contract to bring in 500 more families to settle in the area of his first grant. His third contract in 1827 for colony named 'little colony' (consisting of 100 families) led to a settlement on East of Colorado river and north of the old San Antonio road. During 1827 Austin had established colonies and allotted land grants covering two thirds of Travis County and half of Bastrop County by charging a minimal fee of 12 ½ cents an acre for surveying (Miller, 1967). By, 1831 Mexico closed Texas to further American colonization but Austin and Samuel Williams got a contract to settle 800 Mexican and European colonists towards north and northwest of their earlier grants.

In Brazos County most of the land surveying was done during Mexican Rule (Fig 2.1). Most of the land surveys were carried out during 1841-1860 (Fig 2.2). This was the time period were most of the land grants were given to people as gifts to settlers, land was also donated to soldiers in revolution, signers of Texas declaration of independence and those who volunteered in war against Mexico (Miller 1967). Colonists at first acquired land near Brazos and Navasota rivers and these lands were said to be fertile and good for cultivation (Dewees, 1968), Whilst, later surveys were being conducted on the uplands of Brazos county.

Surveyors were instructed to establish corners with bearing trees at each principal corner of a property plot, with initials of the owners or surveyors marked on the trees (Taylor, 1955). If a bearing tree did not exist they marked the corners with stakes or posts and mounds, along the corners of each property plot. They were also instructed to mark the lines running through timber and prairie so that they can easily be traced and followed. At each survey corner, one to three witness or bearing trees were recorded. Some of them were marked and the markings recorded.

The species and diameter of each witness tree, as well as the distance and bearing to the corner were recorded. In addition to line trees, surveyors were also instructed to provide descriptions of the ‘face of the country’ along the line, including vegetation (sometimes in order of abundance), transitions between major vegetation types, and suitability for cultivation. Meander corners were set where survey lines crossed rivers and when permanent streams were encountered, the direction and distance of the watercourse was also noted.

When all of these available descriptors are used in conjunction, OTLS surveyor's notes allow for an extensive view of pre-settlement conditions at a landscape scale.

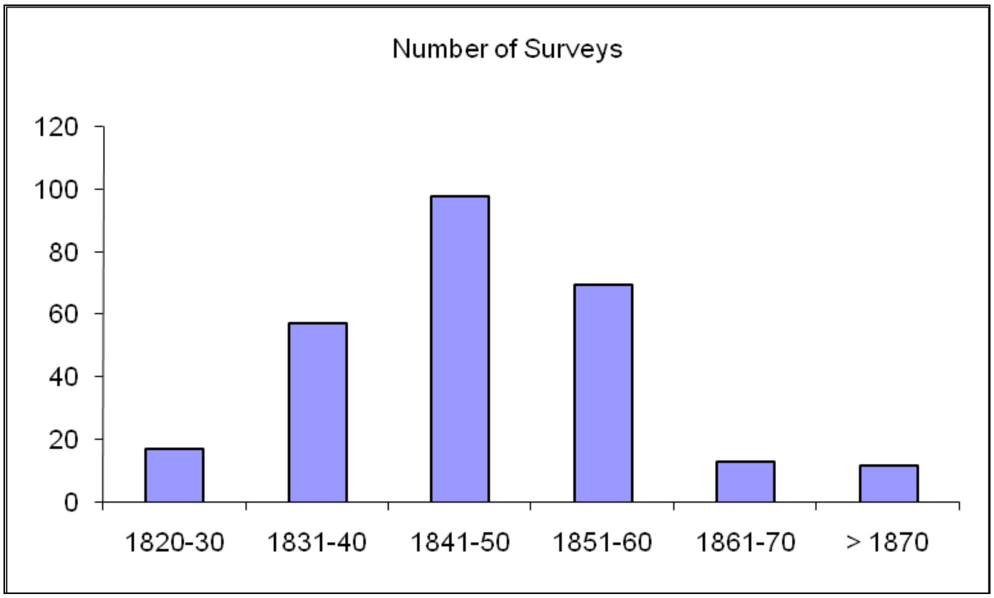


Fig 2.1 Number of Surveys Carried out in Brazos County in 10 Year Intervals.

2.3 The Vegetation of Brazos County

The flora of Brazos County is a subset of that the Gulf coastal plain, and typically represents elements of eastern and western vegetation (Campbell, 1925). The native vegetation types of the county include Bottomland hardwoods, Post Oak Savannah and tall grass-prairie (Gould 1969).

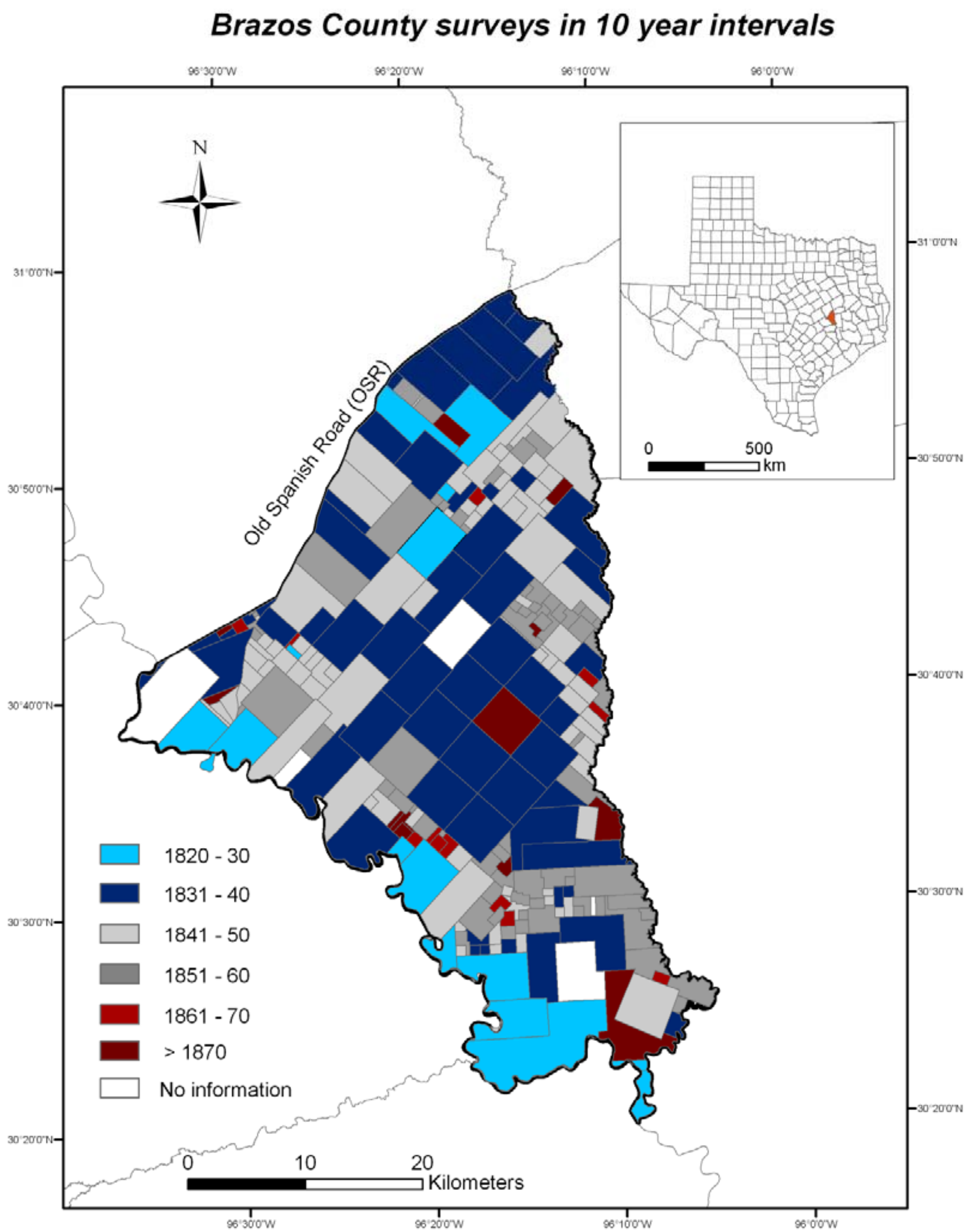


Fig 2.2 Surveys Carried out in Brazos County in 10 Year Intervals

The uplands consist of open stand, scrubby Post Oak and Black Jack Oak and a ground cover of tall grasses.

According to Veatch and Waldrop (1916), much of the uplands were characterized by small, poorly drained, treeless spots or glades. Campbell (1925) argued that the scrubby size of the oaks was probably due to nature of the soil: a fine sandy loam derived from sedimentary deposits (Campbell, 1925) and the location of the county at the western periphery of the Post Oak belt. He noted that a few hundred miles east, Post Oaks attained a tall, clean form.

The advent of settlement in Brazos County resulted in much of uplands being cleared for cultivation. The treeless prairies were probably the first target regions. As the demand for land increased, wooded areas were cleared. Over the years people have described much of the Post Oak uplands as consisting of useless, worn-out and eroded fields, many fields being abandoned permanently or converted into ranches. This may be due to erosion of the sandy upland soils under cultivation and accelerated erosion after the removal of vegetation cover. The deterioration of the soils and vegetation from disturbances such as cutting, burning and overgrazing have led to changes in vegetation in the Post Oak savannah, This has been described as an open savannah is characterized by dense woodland stands of Post Oak, Black Jack Oak, Elm and an understory of Yaupon (Darrow and McCully, 1959).

Nowadays, the Bottomland hardwoods are mainly found along the Navasota river bottoms. The alluvial soils support an open hardwood forest which has been described as being dominated by Cedar Elm and Overcup Oak. The line of demarcation between the Navasota bottoms and the Post Oak uplands is well defined with slopes covered by heavy vegetation growth. Campbell 1925) listed the woody species found along the Navasota River and its western tributaries as comprising: *Juniperus virginiana, Salix nigra, Populus deltoides, Juglans nigra, Carya pecan, C. aquatica, C. arkansana, Carpinus caroliniana, Betula nigra, Quercus stellata, Q. lyrata, Q. macrocarpa, Q. velutina, Q. durandi, Q. shumardi, Q. phellos, Q. marilandica, Q. cenerea, Q. nigra, Q. nigra x cenerea, Ulmus americana, U. alata, U. crassifolia, Planera aquatica, Celtis mississippiensis, Morus rubra, Plantanus occidentalis, Crataegus spathulata, C. viridis, C. crus-galli, Prunus serotina, P. angustifolia, P. caroliniana, P. Mexicana, Gleditsia triancanthos, G. aquatica, Circis canadensis, Zanthoxylum clava-herculis, Ilex opaca, I. vomitoria, I. deciduas, Acer negundo, Tilia floridana, T. americana, Cornus florida, Nyssa sylvatica, Vaccinius arboreum, Diospyros virginiana, Fraxinus Americana, F. pennsylvanica, Adelia pubescens, Symphoricarpos orbiculatus, Viburnum rufidulum* and *Sambucus Canadensis.* The herbaceous flora near the Navasota river is sparse, but on the tributaries it is richer and more mesosphytic than in other parts of the county. The following species are common: *Spiranthes cernua, Geum canadense, Clatonia viriginica, Iodanthus pinnatifidus, Clitoria mariana, Polygala incarnate* and *Viola palmate* (Campbell 1925). The lower Navasota river bottomland is a transitional region between the bottomlands and uplands and has luxuriant forest vegetation and xeric grassland and scrubs (Allen, 1974). At present the bottomlands are being cleared, especially the shrubs to make room for grazing species. Very little cultivation is carried out in these bottomlands due to frequent flooding and poor drainage of soil.

The Brazos river bottoms vary in width from several miles in the southwestern part of the county to a very narrow strip in the central part. Brazos River rises in northwest Texas and flows to south eastward across the state to Gulf of Mexico carrying various sediments from diverse regions giving different soils types than those in the Navasota bottomlands. In 1925 Campbell described the Brazos Bottoms as consisting of mainly *Ulmus crassifolia*. The undergrowth is scanty and comprised mainly *Crataegus spathulata* and *C. viridis* and shrubs and woody vines such as *Sophora affinis, Daubentonia longifolia, Cissus ampelopsis, C. arborea, Tecoma radicans* and *Clematis pitcher.* Originally, these bottomlands were forested with a heavy growth of elm, hackberry, ash, pecan and chinaberry and an undergrowth of yaupon, hawthorn, and thick growth of vines (Veatch and Waldrop, 1916). Nevertheless, as the Brazos bottoms are at the higher elevation than those of the Navasota, they have better drainage and, combined with flood control, this has been to their conversion to arable land. Dewees (1968) in his compendium of traveler's account has described Brazos bottoms being wide, level rich and fertile.

The Blackland Prairies occur as islands within Post Oak savannah consisting of clay and clay loams in zones of level to gently rolling topography. Mainly dominated by prairie species such as big bluestem (*Andropogon gerardi*), Indian grass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*) and switchgrass (*Panicum virgatum*) (Allen, 1974), they possess an almost exclusive cover of grasses compared to most other prairies in the state (Bray, 1906). As a result of disturbances very little of the prairie at present maintains the climax vegetation growth (Allen 1974). If disturbance continues the climax growth of vegetation starts deteriorating and eventually the bluestems are replaced by *Aristida* spp.

At present, the fertile land of the Brazos river valley (the “Brazos Bottom”) is the primary site for crop production (cotton, sorghum and wheat), in addition to some areas in the uplands. Apart from agriculture and ranching the areas’ economy is boosted by Texas A&M University. The county’s population has grown steadily until the 1980s after eighties it has been growing at a rapid rate, in 2000 census the population was 152,415. The development of agriculture, related-industries and urban growth has transformed the native vegetation of native prairies, savannah uplands and bottomlands and there have been invasions of woody and weed species. Abrams (1992) has stated that overall frequency and size of undisturbed Post Oak remnants have been reduced by agricultural clearing, road construction, expansion of towns, intensive cattle grazing, and wildfire suppression. If there is a need to preserve the remaining prairie and savannahs and bottomland forests, and the analysis of the pre-European settlement vegetation in this thesis may be a contribution to work on preservation.

CHAPTER III

METHODS

3.1 Data Collection

Four datasets (Table 3.1) were used to reconstruct the woody vegetation cover of Brazos County:

a) The Original Texas Land Survey (OTLS) surveyor's notes for Brazos County. The surveyor's files containing the notes and deeds for all of the 267 property plats in Brazos County were extracted from the archival record section at the Texas General Land Office in Austin (Appendix 1), and the notes of the surveyors [both original and corrected in some cases] were photographed using a digital camera. The photographed notes of surveyors were downloaded to a PC and file names were based on the property plat owners.

b) The Brazos County OTLS shapefile, showing the boundaries of the original land grants of Brazos County, compiled and drawn by GLO. This dataset is a digital interpretation of the geographic placement of the original land grants. The dataset was published by the Texas Railroad Commission and was used to locate oil and gas wells on property plots. Land survey data has historically been the primary land grid used by the oil and gas industry and regulatory bodies to track oil and gas well locations. Though published by Texas Railroad Commission, the data was available for downloading from the Texas Natural Resources Information System (TNRIS).

c) Digital soil maps produced by the United States Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS). This is the most detailed soil geographic data produced by the National Cooperative Soil Survey. The soil dataset was downloaded from USDA.

d) DEMs for Brazos County. These are produced by USGS and were purchased from ESRI.

Table 3.1 Scale and Source of Datasets in Pre-Settlement Vegetation Cover Mapping

Data	Publisher	Scale	Source
OTLS surveyor's notes	General Land Office, Texas	n/a	General Land Office, Austin, Texas.
OTLS shapefile for Brazos County	Railroad Commission of Texas	1:24000	http://www.tnris.state.tx.us/
Soil Survey Geographic (SSURGO) database for Brazos County, Texas	U.S.D.A. Natural Resources Conservation Service	1:24000	http://SoilDataMart.nrcs.usda.gov/
DEM	USGS	10 m	http://www.esri.com/

Using the OTLS files presented some challenges. The GLO imposes a restriction on photography without flash. Secondly, some of the surveyors' notes were quite old and fragile and were covered by plastic in order to protect them. It was hard to photograph these notes because of glare which made them hard to read. I had to take photographs of every four to five lines on plastic-covered survey notes. Apart from photography issues, locating the correct surveyor's notes for Brazos County was challenging because some property plats in Brazos County are archived under Washington County. Therefore, I had to confirm each property plot's surveyor's notes before photographing them.

The surveyor's notes consisted of distance and direction information from one survey corner to the next survey corner of the same survey. Surveyors also recorded markers like posts, stakes or mounds, witness and bearing tree information with distance and direction of witness trees from their respective property plot corner, tree species and diameter information. Some surveyor's notes also had the distance and direction information about prairie/timber boundaries, and distance and direction information of markers (posts, and stakes) placed by surveyors in prairie. All the above information was decoded in an MS Excel spreadsheet after reading through the surveyor's notes for each property plot in Brazos County. An example of an original file and the decoded entry extract from the spreadsheet are shown in Fig 3.1. There were 267 property plots in total.

3.2 Methods

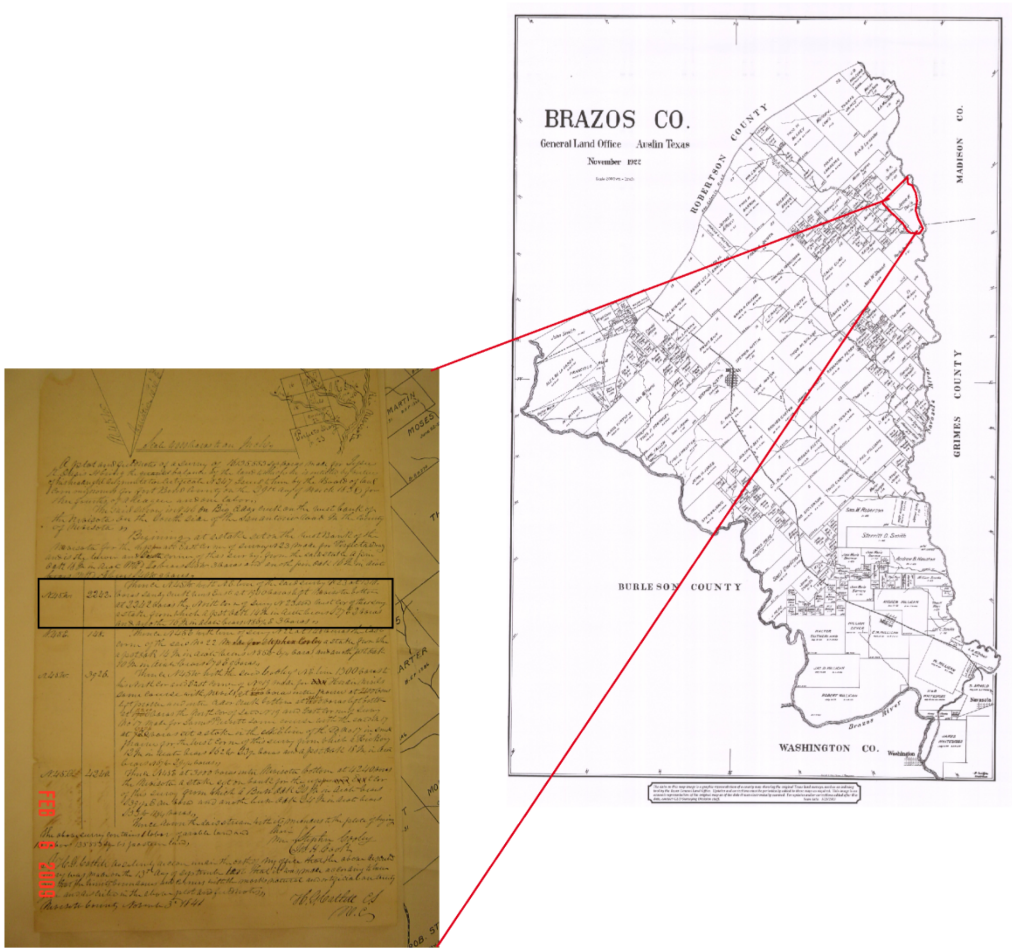
A flow chart of the methods used to convert surveyor's information to the vegetation map for Brazos County using the other data sets (Section 3.1) is provided in Fig 3.2.

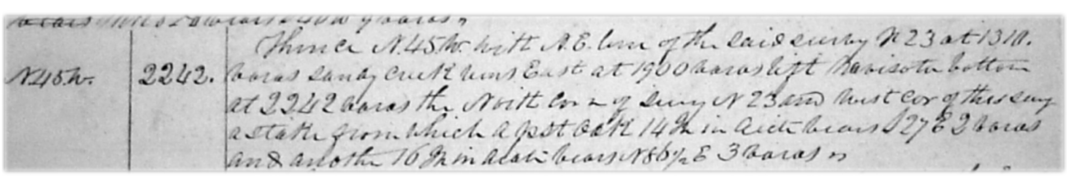
3.2.1 Preparing the OTLS survey notes

A number of tasks had to be carried out before the surveyor's notes could be used in this research.

a) Distances were recorded in varas. This is an old Spanish measure of distance that was used in Mexico and therefore is in the present-day Brazos County. It was used in Spain and Portugal and standardized in 1568 by Phillip II who had a prototype vara made which was kept at Burgos — the 'vara of Burgos'. However, when used in Spanish and Portuguese colonies the vara began to vary in length. The Mexican vara is usually quoted as being equivalent to 83.8 cm. This relates to the Mexican Ordinance for Land and Sea (*September 15, 1837*) in which a value of 837 mm was adopted for the vara. In 1839 this was altered to 838.1 mm, and then by a decree in 1844 to 838 mm. (Editor, n.d.) As these changes were relatively minor given the distances recorded in surveying and more-or-less contemporaneous with the time surveys were being carried out in Brazos County, a conversion of 838 mm was used in this research.
b) Tree dbh was recorded in inches by the surveyors and this was converted to centimetres.

Example of photographed surveyor's notes and decoded information for Jesse K. Davis




N45W. | 2242. | Thence N.45W. with N.E. line of the said survey N 23 at 1310. varas Sandy Creek runs East at 1900 varas left Navisota bottom at 2242 varas the North corner of survey N 23 and West cor of this survey a stake from which a post oak 14 in in dia bears S27 E 2 varas and another 16 in in dia bears N86 1/2 E 3 varas

Distance from one corner to the next corner				Tree information with dbh, distance and direction from this corner of the plot					
Bearing 1	Bearing 2	Bearing 3	Varas(distance)	Witness tree	Diameter (in)	Bearing 1	Bearing 2	Bearing 3	distance (varas)
N	45	W	2242	Post Oak	14	S	27	E	2
N	45	W	2242	Post Oak	16	N	86 1/2	E	3

Fig 3.1 An Example of an Original File and the Decoded Entry

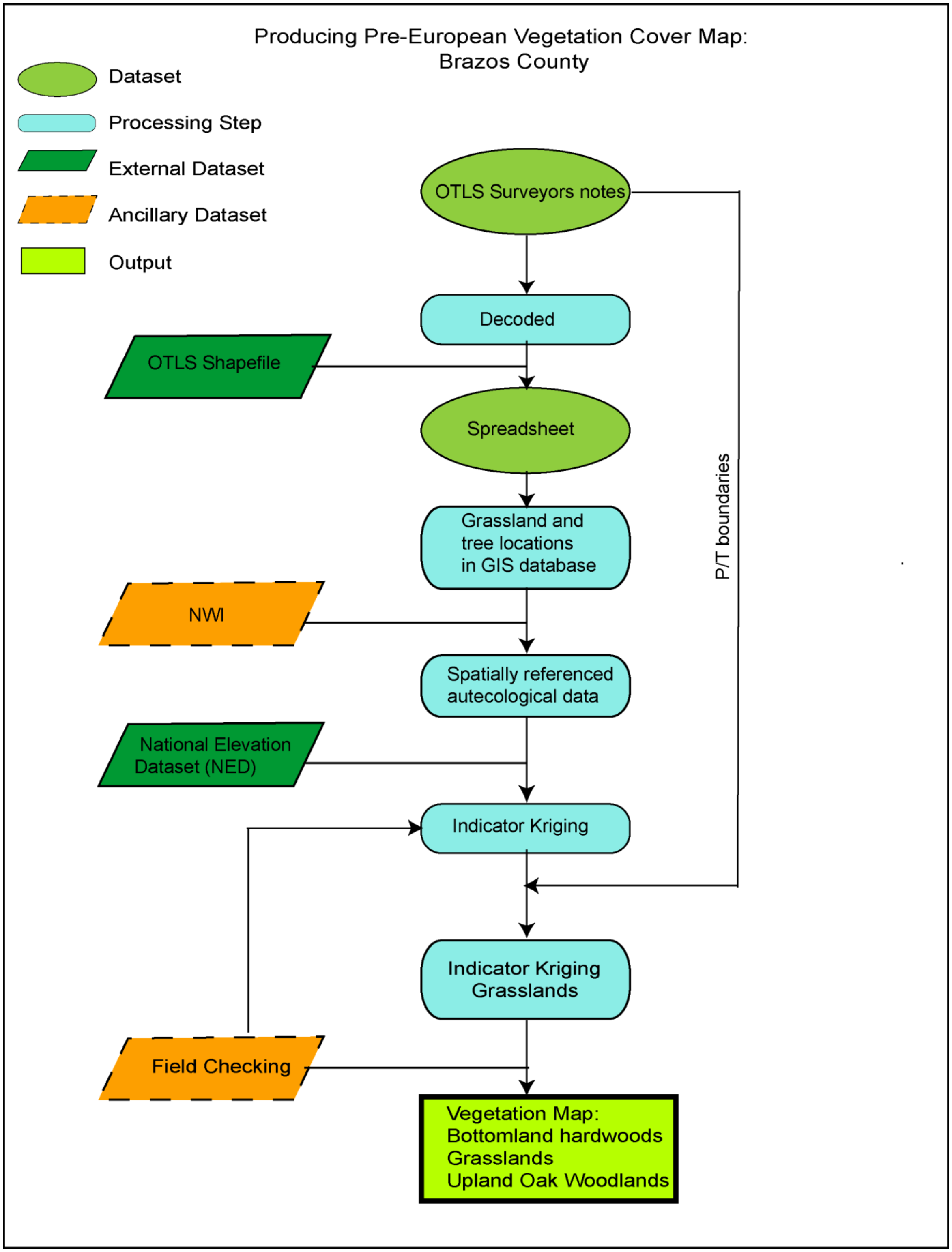


Fig 3.2 Flowchart of the Steps in the Production of the Pre-European Vegetation Map of Brazos County

c) A double recording issue arose during the decoding of the witness and bearing tree information from the surveyor's notes. Some trees were recorded twice, i.e. the same species, distance, direction and diameter, and used to mark plot corners for two adjoining properties which shared the same corner. In these cases only one of the witness and bearing tree information entries was entered in spreadsheet.

d) Surveyors recorded common names for trees and these were converted to standard botanical names using the USDA plants database. In some cases species names could be clearly given, e.g. where Post Oak was recorded, it was unambiguous and converted to *Quercus stellata* Wangenh. Wherein other cases, e.g. the use of the common name Elm, trees could not be designed to a particular species because more than one species of elm occurs in this part of Texas, and only the genus name was used. There were some ambiguities in the way surveyors' recorded certain trees. When 'Jack' was recorded it was considered to be Black Jack Oak (*Quercus marilandica* Muenchh.) as Jack is a known synonym for this tree. Surveyors recorded 23 Spanish Oaks, which is one of the six dominant tree species occurring in Brazos County, but I could not find the species corresponding to Spanish Oak. I consulted Dr. Smeins (ESSM, TAMU) about this and in his opinion was Spanish Oak should be left as it is in the OTLS notes without a species assigned because the only correctly named Spanish Oaks are found much further to the west. Only one entry was recorded as ‘tree’ with no mention of species. This was omitted from the dataset. In total 1582 of individuals of 24 different trees were recorded (Table 3.2).

3.2.2 Spatially locating biogeographical information contained in the OTLS survey

Witness and bearing trees

An extract of the spreadsheet containing only witness and bearing tree information was converted into a GIS-compatible database. Once the GIS database was set up, the shapefile of GLO property plats was downloaded from Texas Natural Resources (TNRIS) website and imported to ArcGis 9.3. The shapefile was projected to the North American Datum 1983, UTM Zone 14, Texas Central State Plane FIPS 4203 Coordinate System. This coordinate system was chosen because it is good for mapping small areas within one zone and is also used in projecting survey data for Brazos County. The co-ordinates for the corners of each property plat were digitized (Wang and Larsen, 2006) using the distances and directions given in the surveyor’s notes. With the plot corner coordinates set, I calculated the witness and bearing tree coordinates by first calculating the sines and cosines of the bearing angles from the property plat corners to the trees, and then calculating the distances recorded in the surveyor’s notes from property corner coordinates to the trees, in order to get the coordinates for tree locations (Fig 3.3). All tree coordinates with species, dbh and distance from the corners data were exported to a GIS compatible database from Excel spreadsheet.

Table 3.2 Witness and Bearing Trees

Common Name	Botanical Name	Tree Count	Frequency as proportion of all trees	Frequency as proportion of all records
Persimmon	*Diospyros virginiana* L	1	0.06	0.05
Redoak	*Quercus falcata* Michx.	1	0.06	0.05
Sassafras	*Sassafras albidium* Nees & Eberm.	1	0.06	0.05
Walnut	*Juglans* spp. L.	1	0.06	0.05
Water Elm	*Planera aquatica* J.F. Gmel.	1	0.06	0.05
Willow	*Salix* spp.L	1	0.06	0.05
Mulberry	*Morus* spp. L.	3	0.18	0.13
Cedar	*Juniperus virginiana* L.	5	0.32	0.23
Black Oak	*Quercus velutina* Lam.	6	0.38	0.27
Holly	*Ilex* spp.L	6	0.38	0.27
Bur Oak	*Quercus macrocarpa* Michx	7	0.44	0.32
Honey Locust	*Gleditsia triacanthos* L	7	0.44	0.32
Overcup Oak	*Quercus lyrata* Walter	7	0.44	0.32
Black Gum	*Nyssa sylvatica* Marsh.	11	0.69	0.50
Water Oak	*Quercus nigra* L	11	0.69	0.50
Hackberry	Celtis occidentalis L.	14	0.88	0.64
Cottonwood	*Populus deltoides* L	16	1.01	0.73
Ash	*Fraxinus* spp. L	20	1.26	0.91
Spanish Oak		23	1.45	1.05
Pecan	*Carya illinoinensis* (Wangenh.) K. Koch	50	2.46	1.78
Elm	*Ulmus* spp. L.	61	3.85	2.78
Pin Oak	*Quercus phellos* L.	83	5.24	3.78
Black jack Oak	*Quercus marilandica* Münchh.	134	8.45	6.10
Post Oak	*Quercus stellata* Wangenh.	1112	70.16	51.0
Grassland sites		67	-	5.68

Other plot corner markers

Some plot corners were not recorded by reference to witness and bearing trees in the OTLS survey files. Rather they were referenced to posts or stakes hammered into the ground, or mounds built to mark corners.

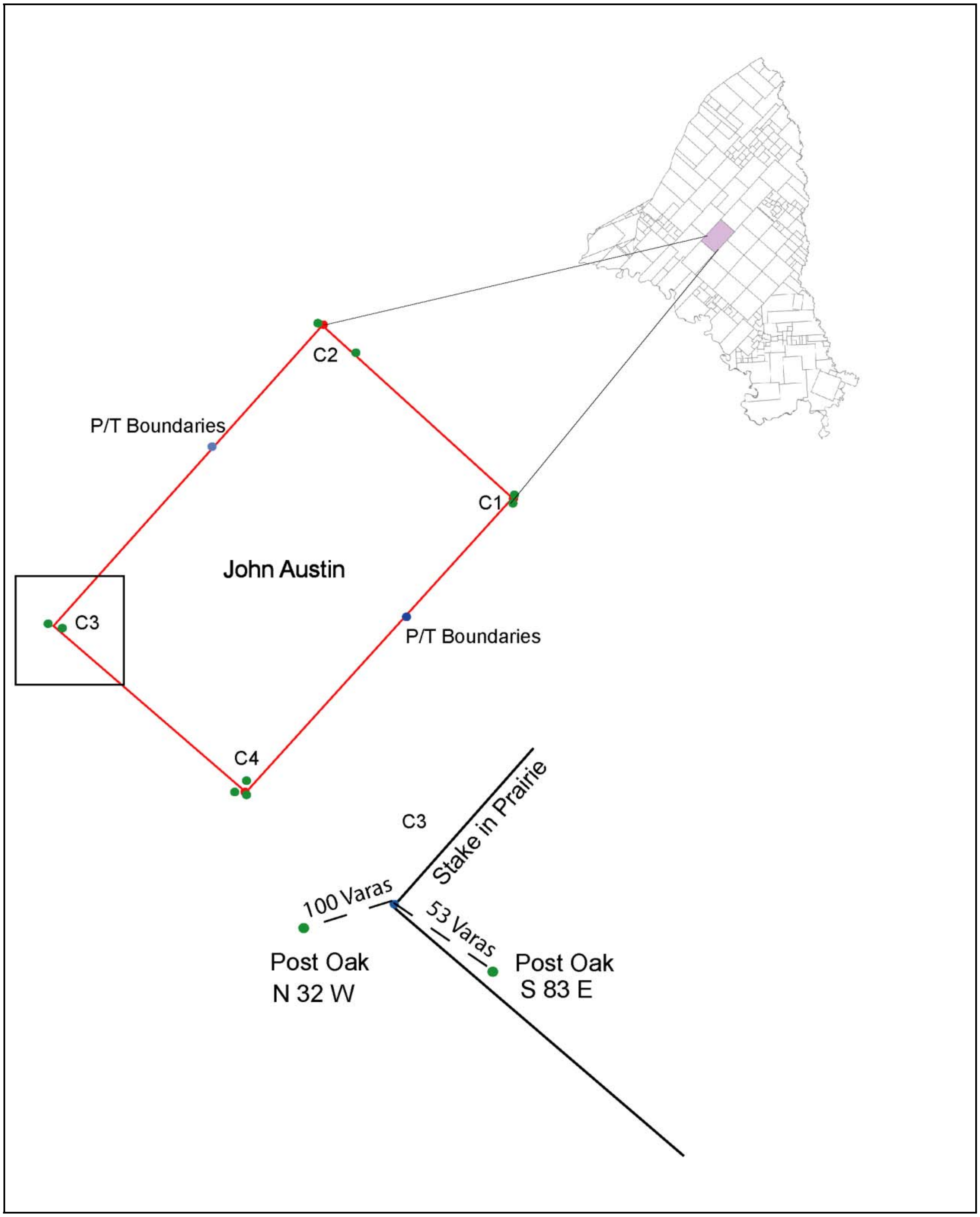


Fig 3.3 Spatially-Located Biogeographical Information for the John Austin Plat. C = corner marker, P/T = prairie/timber boundary, N 32 W is an example of bearing, 32^{o} W of N (or 328^{o}) from the stake at C3

The survey records state that these markers were erected in prairie. These ‘points’ have been taken to indicate open, relatively treeless tracts of land and have therefore been used as the open prairie equivalents. Whilst the tree locations were used to indicate upland and bottomland woodlands depending on the species in question (cf. Section 3.2.3). In total there were 67 locations marked as stakes or mounds in prairie from the OTLS files for Brazos County. These ‘open ground’ locations were spatially located using the methods outlined above (Fig 3.2).

Prairie-timber boundaries

Some surveyors recorded where they had crossed a ‘prairie-timber’ boundary in their notes. It has been assumed that these represent a reasonably distinct boundary between relatively dense woodland and more open, grass-dominated tracts of land. They are always recorded as occurring at a specific number of varas along a bearing line. Of course these would not have been sharp boundaries in the great majority of cases, but given the nature of the data records and the lack of ancillary information on the nature of these boundaries, they have been recorded as crisp rather than fuzzy boundaries as is normally the case in most savannas (Arnot et al., 2004). In total there were 67 prairie-timber boundaries. These boundaries were located mostly along the Old Spanish road (OSR) and also in the southern part of the county, in the vicinity of present-day Millican.

3.2.3 Converting tree information in OTLS to autecological data

The tree species in Table 3.2 were grouped according to their National Wetland Indicator' (NWI) status (Fig 3.4). This information was obtained from the USDA national plants database (http://plants.usda.gov). Tree species whose indicator status was either an obligate wetland species (OBL) (99% probability of occurring in wetlands based on distributional information from the USA); a facultative wetland species (FACW), (67-99% probability of occurrence in wetlands) and facultative species (FAC) (34-66% probability of occurrence in wetlands) were classified as bottomland species. These were Cottonwood (*Populus deltoides*), Overcup Oak (*Quercus lyrata),* Water Elm (*Planera aquatica*), Water Oak (*Quercus nigra*), Elm (*Celtis occidentalis)* and Pin Oak (*Quercus phellos*).

Species occurring in the NWI categories obligate upland (UPL) (99% probability of not occurring in wetlands) and facultative upland (FACU) (67-99% probability of not occurring in wetlands) were classified as upland species. Post Oak (*Quercus stellata),* Black Jack Oak (*Quercus marilandica),* Black Oak *(Quercus velutina),* Cedar (*Quercus falcata*), Walnut (*Juglans* spp.*),* Sassafras (*Sassafras labium*) were characterized as upland species.

Some trees which were recorded by surveyors fell into wide ranges of NWI indicator classes suggesting they may occur in wetlands and uplands. These were *Carya illinoinensis* (Pecan), *Diospyros virginiana, Gleditsia triacanthos*

(Honey locust), *Morus* spp (Mulberry)*, Nyssa sylvatica (*Blackgum)*, Quercus macrocarpa (*Black Oak*) and Salix* spp (Willow).

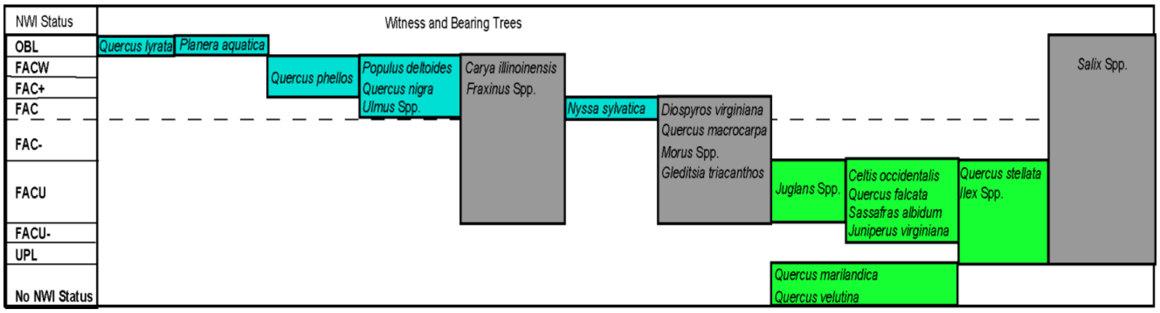


Fig 3.4 Classification of Witness and Bearing trees Based on their NWI Status. The turquoise coded species were considered bottomland species, green coded species are upland species. The gray coded species were excluded from mapping.

3.2.4 Interpolation of biogeographical point data

Indicator kriging was used to interpolate the point biogeographical data (i.e., witness trees, bearing trees and stake, mound and post locations) that had been spatially located and mapped onto the shapefile (Section 3.2.3) to create continuous vegetation cover surfaces (cf. vegetation map on page 52).

Kriging

Kriging uses sample points taken at different locations in a landscape and interpolates a continuous surface based on their distribution. This procedure derives a surface using the values from the measured locations to predict values for each location in the landscape. Kriging strongly relies on the concept of autocorrelation. The semivariogram cloud examines the spatial autocorrelation between sample points, with points that are close to one another statistically being more alike than those that are statistically farther apart. For example, closer locations of the classified tree species falling under a particular vegetation class tend to be more alike, compared to tree locations farther apart, in the semivariogram the close locations should have small values and as distance between pairs of locations increases the semivariogram values increases (Fig 3.5). After a certain distance along the x-axis the cloud flattens out, indicating that the relationship between the pair of locations beyond this point is uncorrelated. The distance along the x-axis from the origin to the point at which the cloud reaches its asymptote is called the ‘range’. Sample locations separated by distances closer to the range are spatially autocorrelated, while locations farther apart than the range are not. The value the semivariogram model attains on the y-axis at the range is called the ‘sill’.

There are a number of different kriging methods: ordinary, simple, universal, indicator, and disjunctive. Indicator kriging was used in this research because it describes the spatial continuity, which is an essential feature for interpreting the natural phenomena, like vegetation (Burrough 1996). Other kriging methods like simple and ordinary needs a constant mean value which could not be generated from this dataset. Universal kriging is used when there is a trend in the dataset, e.g., most of the tree species are located in a particular direction, which was not the case for the case for tree locations in Brazos County. Undoubtly, therefore, the best method to map (or indicate) the presence or absence of a particular class is indicator kriging. This method has been used in capture the spatial patterns of vegetation cover by other researcher (e.g., Burrough, 1996, Brown 1998, Manies and Mladenoff 2000, He et al., 2000). Indicator kriging uses categorical or numerical data that have been transformed to binary (0, 1) values (Wang and Larsen, 2006). It is routinely used to determine other kinds of class membership apart from vegetation mapping, because it has the major advantage of assuming that the data do not follow particular distributions. Therefore in this study it was deemed an effective method to determine the class membership of vegetation types (grassland, upland oak woodlands, or bottomland woodland) of locations where there was no tree, 'open ground' or prairie-timber boundary information.

3.3 Implementation of Kriging to the Brazos County Biogeographical Dataset

Before implementing kriging on the Brazos County dataset, it was necessary to develop semivariogram models for the data. The biogeographical dataset for Brazos County consisted of the locations of individual tree species, open prairie sites or the locations of 'praire/timber boundaries' and after conversion to autecological data (Section 3.2.3) were classified into one of three categorical values: a bottomland species, an upland species or a grassland site.

Kriging was carried out twice, once using tree location data to interpolate Bottomland hardwoods from all upland areas (Grasslands and Upland Oak

Woodlands) and then to interpolate Upland Oak Woodlands and Grasslands. The categorical values in the first kriging ranged from 0 to 1 probability. A value of 0 represented the presence of an upland tree species or grassland at a known location, and 1 represented the presence of a bottomland species. In the second kriging a value of 0 represented the presence of a tree species (bottomland or upland) at a known location, and 1 represented the presence of grassland.

a) After the categorical data had been converted to numerical data, a semivariogram model was visually fitted to the calculated semivariogram from the data points and applied to the interpolation of unknown locations (Isaaks and Srivastava 1989). The following steps were carried out in this research while visually fitting the semivariogram model (cf. Fig 3.5 for the semivariogram for grasslands).
b) A search ellipse that enclosed the data points was used to predict values at unmeasured locations. It consisted of four sectors with a 45 degree offset. This search option was used because it provided more accurate predictions than one sector (circle), while the use of eight sectors gave similar results compared to four sectors options.
c) At least four neighboring points (i.e., a minimum of four) were chosen. This decision was based on the weights and locations of tree species. A threshold was set to exceed 0 when determining bottomland vegetation cover and <1 for upland vegetation cover for the first kriging. During the

second kriging, the threshold was set to exceed 0 when grassland cover and <1 for all wooded locations.

d) The output maps of indicator kriging portray the data as a continuous surface of values ranging from zero to one, with one being interpreted as the highest probability of the class indicated and zero lowest probability.

These analyses were conducted in ArcGIS and its Geostatistical Analyst extension (ESRI 2001).

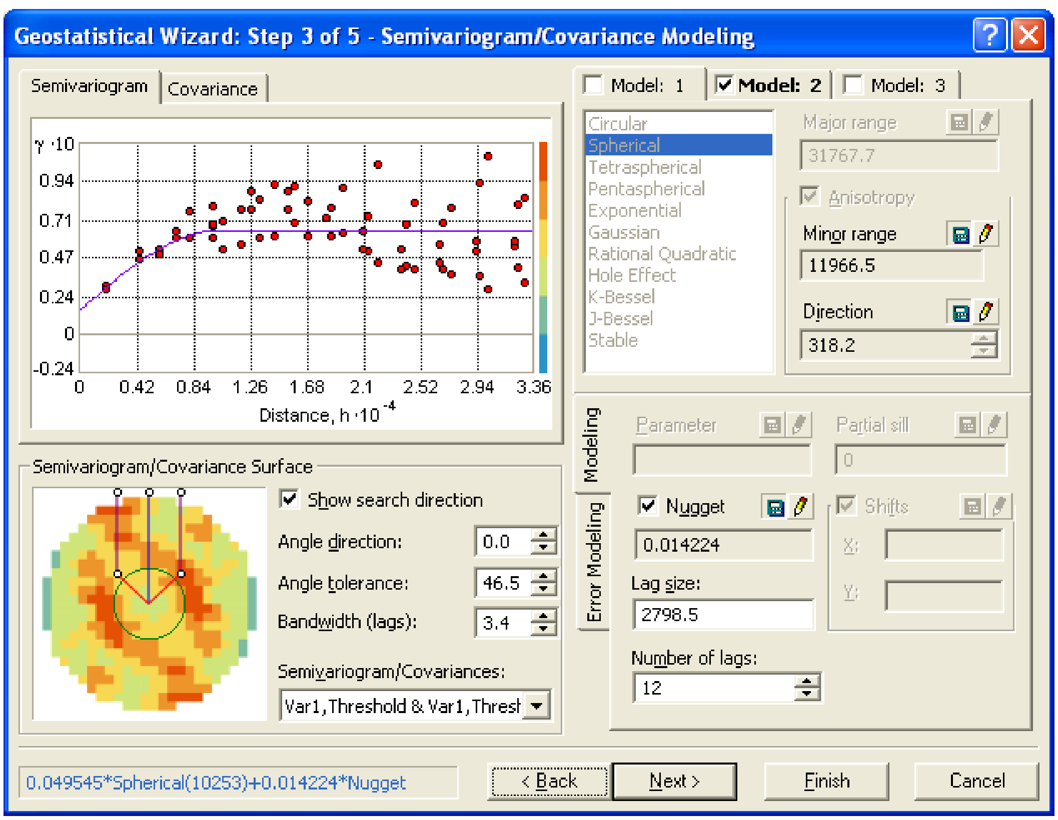


Fig 3.5 Example of Semivariogram Model for Grassland Locations.

3.2.5 Verification

Verification of past vegetation cover maps is problematic. Therefore there are three possible ways of carrying out a partial verification of this map:

although the surveys were made before the routine use of photography and the early uses of photography generally focused on people and built-up areas rather than rural landscapes (this is the case for Brazos County: Srinath et al. 2007), two early twentieth century photographs for the county do have rural background that were useful (Fig 3.6);through historical writings about Brazos County; and reconnaissance in the contemporary landscape, which proved useful for the assessment of the location of the Bottomland Hardwoods/upland boundary.

Out of the collection of historical photographs that I had previously researched at Texas A&M Library and the Carnegie Center for Brazos Valley History (formerly the Carnegie Library) in Bryan, two photographs have backgrounds which clearly shows vegetation cover of early twentieth century. Fig 3.6a is taken on the newly -constrcuted Dexter St. in 1930 and shows an open oak woodland. This area was mapped as Grassland in figure on page 54. Fig 3.6b is taken just north of the present day A&M campus, at intersection of Nagle and university drive, and shows very open praire grassland.

Fig 3.6 Map Verification using Old Historical Photographs. (top) Dexter Dr. facing S (1930) (bottom) Nagle and University Dr (1925). See text for descriptions

One of the letters from early settlers (Dewees, 1968) describes the prairies in the county as follows:

> Imagine for yourself on a vast plain extending as far as the eye can reach, with nothing but the deep blue sky [to] bound the prospect, with lofty trees rearing themselves upon its banks, and you have our prairie.

> Here and there may be seen beautiful clumps of trees, and anon, a little thicket comes in view. (p. 29)

In the same book another letter describes the Brazos river bottomlands being fertile and wooded: “Brazos bottoms are very wide and level, the trees are large and tall! the timber, renders the sight that is more imposing” (p. 27). These two statements were used to help interpret the vegetation classes, but as they had no specific locations attached to them they can only be used in a general sense.

Field checking of the Bottomland Hardwood forest boundaries was accomplished in September 2009 by using the extent of the floodplains as a proxy for these boundaries on the vegetation map. In total 41 points were checked with reference to the maps. GPS coordinates and photographs were taken and field descriptions of topography and contemporary vegetation made. These points were spatially-biased towards the Navasota and extended from the north-east of the county to the southern tip.

3.4 Soil data for Post-Mapping Analysis

The relationship between the vegetation map (Fig 4.1) and the distribution of witness and bearing-tree species, and soil types will be presented in Chapter V. This was done because of the expected strong explanatory power of soil properties on pre-European settlement vegetation (Curtis, 1959; Barrett *et al.*, 1995). Soil data for Brazos County are available in the two readily accessible digital soil data bases from the USDA Natural Resources Conservation Service:

First, the State Soil Geographic (STATSGO) data base is a subset of the U.S. General Soil Map consisting of general soil association units. It was developed by the National Cooperative Soil Survey and supersedes the State Soil Geographic (STATSGO) dataset published in 1994. It consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. Secondly, the Soil Survey Geographic (SSURGO) data base, which was previously archived and distributed as the Soil Survey Geographic (SSURGO) Database. This included detailed soil types (series) and was available in ArcGIS format. In this study, the SSURGO data base for Brazos County was used because it is available at a finer resolution (250m) than STATSGO (1000m) (Chen, 2007). The steps in use of the SSURGO within this research were:

a. The SSURGO data for Brazos County were downloaded;
b. Polygons of same soil types in the SSURGO data base were aggregated to create one class of each soil type.
c. Soils were combined as the ‘soil-ecological sites’ that listed from soil survey of Brazos County (USDA/NCRS, 2002).

The units are Blackland Prairie, Clayey Bottomlands, Claypan Savannah, Loamy Bottomlands and Clayey Bottomlands. A (soil) ecological site is “distinctive landscape with specific soil and physical characteristics that differs from other soil-ecological sites (or units) in its ability to produce distinctive kinds and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances” In the U.S ecological sites are connected to soil map units via spatial data housed at the NRCS. They are linked to one or more map unit components of one or more soil map units (http://usda-ars.nmsu.edu/esd/esdIntro.html). Bearing and witness tree locations were intersected with the ecological site data for the analyses that will be described in Chapter V. These intersections were carried out for upland trees, bottomland trees, and for the five most frequently occurring tree species: Post Oak *(Q. stellata),* Black Jack Oak *(Q. marilandica),* Pin Oak *(Q. phellos*), Elm *(Ulmus* spp.) and Pecan *(C. illinoinensis*).

CHAPTER IV

RESULTS

4.1 Witness and Bearing Trees from Surveyor's Notes

Surveyors working in Brazos County recorded 24 species of witness and bearing trees (Table 3.2). Out of the 24 species recorded, the most abundant species on the uplands was Post Oak (*Quercus stellata*) comprising 70.2 % of the trees recorded and 50.6 % of all locations with ecological information (i.e. recorded trees, and stakes and posts). Black Jack Oak (*Quercus marilandica*) was the second most abundant tree on the uplands comprising of 8.5% of all trees and 6.1 % of tree cover for the entire county. 5.2% of trees were Pin Oak (*Quercus phellos*), and alongside two other 'species' *Ulmus* spp. and *C. illinoinensis* were co-dominants in the bottomlands for the entire county (Table 4.1) Though the woodlands contained other trees, some species, e.g., Blackberry (*Rubus* spp.), Persimmon (*Diospyros virginiana*), Prickly Ash (*Zanthoxylum clava-herculis*), Red Haw (*Crataegus mollis*), Redoak (*Quercus falcate*), and Sassafras (*Sassafras albidum*) were rarely reported. In fact the species in the previous sentence were only mentioned once each in surveyor's notes. This indicates they were either rare, or occurred usually in close proximity to more 'obvious' trees like the five most frequently occurring trees mentioned at the end of Chapter III.

4.2 Pre-European Settlement Vegetation Cover Map

The interpolation of spatially-located autecological information enabled a probability map of vegetation types (Grasslands, Upland Oak Woodlands and Bottomland Hardwoods). The highest probability of interpolation for a particular class (i.e. a probability of 1.0 for Bottomland Hardwood would mean very high confidence in it occurring at that locations) and zero being the least (i.e., a very high level of confidence that it did not occur in there).

The pre-European vegetation cover map is provided as Fig 4.1. At this time 49% of vegetation in the county was covered by grassland. Most of these prairie areas were located in the northern portion of the county along the Old San Antonio Road. The prairies extended southeast towards Carter Creek, with small patches of prairie occurring in the western part of the county along the Brazos Bottoms, and in the southern end of the county near the ‘confluence’ of the Navasota and Brazos river bottomlands. These grasslands also contained small patches of oak woodlands near the northeast side of Old Spanish road and near the then Bryan city limit. The bottomland forests covered 15% of Brazos County along the Navasota and Brazos Bottoms. Major expanses of bottomland hardwood occurred in the northwest of the county and at the confluence of the Navasota and Brazos rivers in the south. The Upland Oak Woodlands, mainly dominated by Post Oaks covered 36% of landscape, occurred mainly towards the western and eastern parts of the county and were interspersed with Grasslands. Cut off points for inclusion of points with autecological data (trees, stakes etc.) into the vegetation types was set at 1.00 to 0.28 for all three classes. This range of cut off points was chosen because if probabilities <0.28 were used the

Table 4.1 Bottomland and Upland Witness and Bearing Tree Species in Pre-European Vegetation Cover

Common Name	Botanical Name	Tree Count	Frequency as proportion of all trees	Frequency as proportion of all records	Classification based on NWI status (cf. Section 3.2.3)
Persimmon	*Diospyros virginiana* L	1	0.06	0.05	Upland
Redoak	*Quercus falcata* Michx.	1	0.06	0.05	Upland
Sassafras	*Sassafras albidium* Nees & Eberm.	1	0.06	0.05	Upland
Walnut	*Juglans* spp. L.	1	0.06	0.05	Upland
Water Elm	*Planera aquatica* J.F. Gmel.	1	0.06	0.05	Bottomland
Cedar	*Juniperus virginiana* L.	5	0.32	0.23	Upland
Black Oak	*Quercus velutina* Lam.	6	0.38	0.27	Upland
Honey Locust	*Gleditsia triacanthos* L	7	0.44	0.32	Bottomland
Overcup Oak	*Quercus lyrata* Walter	7	0.44	0.32	Bottomland
Black Gum	*Nyssa sylvatica* Marsh.	11	0.69	0.50	Bottomland
Water Oak	*Quercus nigra* L	11	0.69	0.50	Bottomland
Cottonwood	*Populus deltoides* L	16	1.01	0.73	Bottomland
Ash	*Fraxinus* spp L	20	1.26	0.91	Bottomland
Spanish Oak		23	1.45	1.05	Bottomland
Pecan	*Carya illinoinensis* (Wangenh.) K. Koch	50	2.46	1.78	Bottomland
Elm	*Ulmus* spp L.	61	3.85	2.78	Bottomland
Pin Oak	*Quercus phellos* L.	83	5.24	3.78	Bottomland
Black jack Oak	*Quercus marilandica* Münchh.	134	8.45	6.10	Upland
Post Oak	*Quercus stellata* Wangenh.	1112	70.16	50.64	Upland
Grassland sites		67	-	5.68	

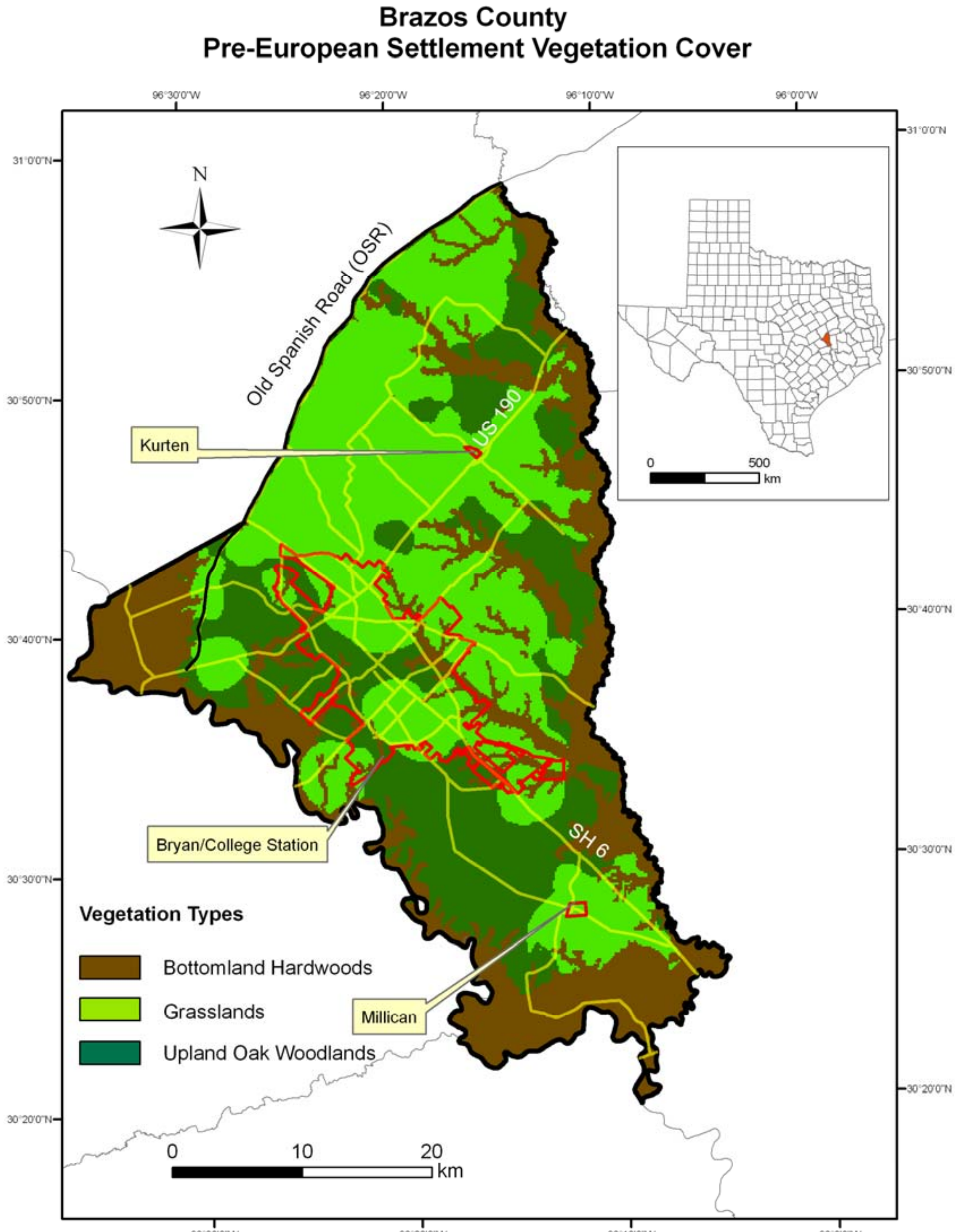


Fig 4.1 Pre-European Settlement Vegetation Cover for Brazos County

spatial distributions of the vegetation types extended far beyond sensible distributions, based on even the slightest glance of topography. The interpolation results indicated a mean prediction error of 0.05 and root mean square standardized error of 0.91 for Grasslands. For Bottomland Hardwoods, the mean error was 0.04 and root mean square standardized was 0.98, while for the Upland Oak Woodlands the values were 0.03 and 1.01. The prediction error is the difference between the predicted and the actual measured value. In case of accurate predictions, the mean prediction error should be close to zero, and if predications are unbiased, the root mean square standardized error should be close to one.

4.2.1 Map accuracy

Commission-omission errors were calculated for bottomland and upland tree species, and open grassland locations (Table 4.2). The majority of tree and open grassland were located in the correct classes.

Table 4.2 shows that overall accuracy of the map was 78.93%. However, most of the error is accounted for by the inclusion of upland trees (NWI status) in the Grassland class (most of the red points in Fig 4.2). Interestingly, no grassland sites were included in the Upland Oak Woodlands. The reason for this is clear if we bear in mind the two upland classes (Grassland and Upland Oak Woodland)

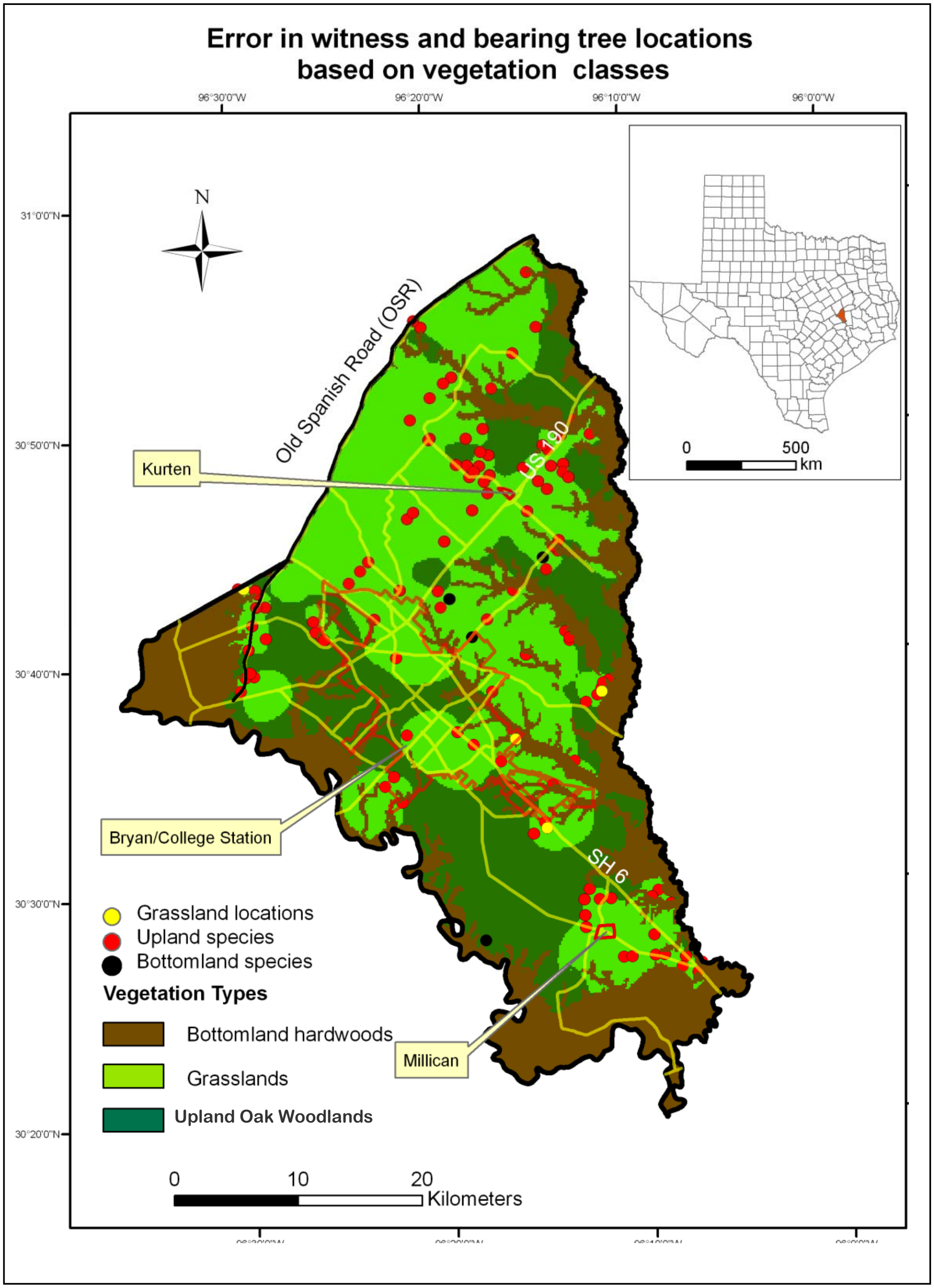


Fig 4.2 Witness and Bearing trees 'Incorrectly' Located by Vegetation Types.

Table 4.2 Commission-Omission Matrix

Spatially-located autecological information	**Vegetation classes**			Row Total
	Bottomland hardwoods	Upland oak woodlands	Grassland locations	
Bottomland tree species	218	1	3	222
Upland tree species	16	932	301	1249
Mounds/posts /stakes	3	0	64	67
Column Total	237	933	368	1538
Overall Accuracy	78.93 %			

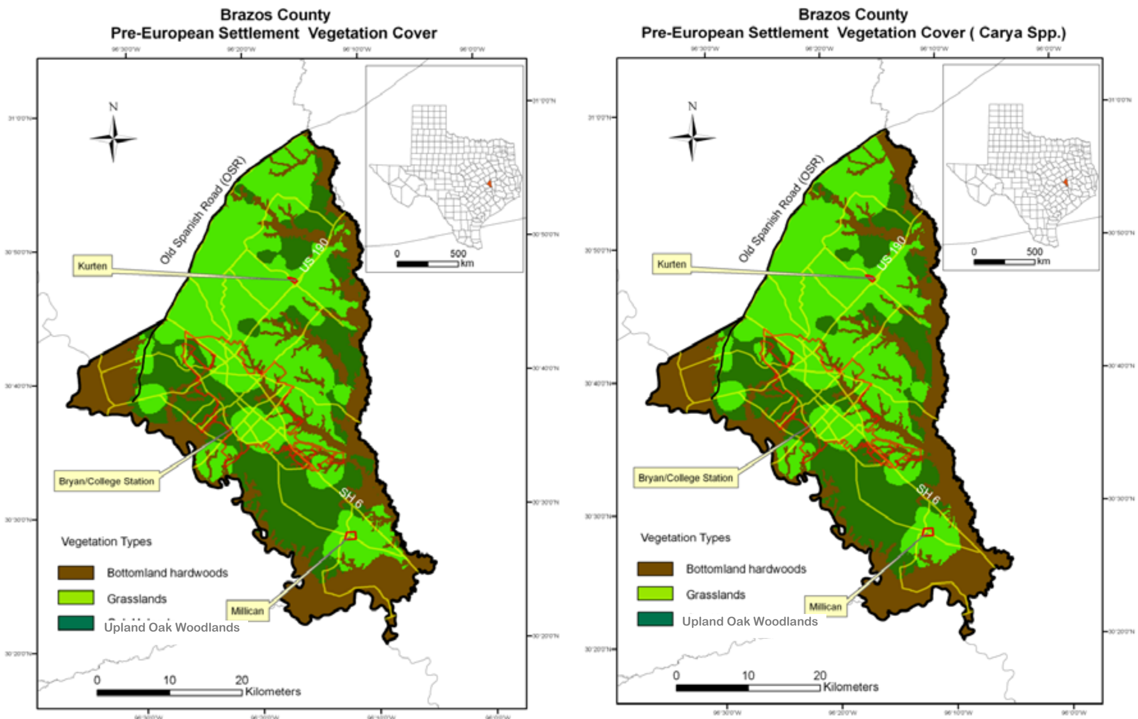
Producer's Accuracy			**User's Accuracy**		
Bottomland tree species=	92%	8 % Omission error	Bottomland tree species=	98%	2 % Commission error
Upland tree species=	100%	0 % Omission error	Upland tree species=	75%	25% Commission error
Mounds/posts /stakes=	17%	83 % Omission error	Mounds/posts /stakes=	96%	4 % Commission error

are not mutually exclusive assemblages of species with a sharp boundary. They are a savannah continuum from open grassland with hardly any trees to dense, wooded oak savannas. The boundary on Fig 4.1 represents an unknown point somewhere along this continuum. The unusual nature of the commission and omission data can be explained thus. In sparsely wooded, open savanna (prairie) surveyor’s were unlikely to walk long distance to trees even though they existed (the evidence that they did exist comes from their inclusion as errors of commission in the interpolated grassland class). In more densely wooded savannahs, surveyor’s expended the effort to walk to trees which were nearer (we assume the tree density was greater) and therefore did not have to resort to making mounds or driving in posts or stakes. Therefore in the Upland Oak Woodlands, there are no errors of Grassland commission.

The only other cell in Table 4.1 that needs a comment is the inclusion of 16 upland tree species in Bottomland Hardwoods. Most of these occur at the boundaries of the Bottomland Hardwoods and Upland Oak Woodlands (the remaining red points in Fig 4.2) and represent boundary error. They are mostly *Q. marilandica* and *Q. stellata*. The Post Oaks account for 13 of the 16 erroneously situated trees, and these can be attributed to true boundary error from inaccurate interpolation, surveyor's measurement error or Post Oaks which are present in the floodplains at the edge of their range of ecological tolerance. The occurrence of the three Black Jack Oaks must be interpolation or measurement errors as *Q. marilandica* does not have a NWI status, it assumed to be an obligate upland tree.

4.2.2. The problem of pecans

When producing the vegetation map, the influence of the 50 Pecans (*Carya illinoinensis*) in the dataset on the spatial distribution of the the interpolated Bottomland Hardwood class became apparent (Fig 4.3). This species was difficult to categorize based on its NWI status range which extended from facultative wetland (FACW) to facultative upland (FACU). It was the only frequently occurring species with this range of NWI status and it was therefore difficult to classify it as bottomland or upland (cf. Section 3.2.3). Initially, based on the location of the individual trees, it was classified as a bottomland species. The probability map, with the cutoff point of 1-0.26 (Fig 4.3b) shows that when it was included as a bottomland hardwood species, the bottomland hardwood region along the Navasota river was much larger than when it was excluded (Fig 4.3a).



(a) (b)

Fig 4.3 Pre-European Vegetation Cover, (a) Pecan Excluded (b) Pecan Included

The difference between the two maps along the Brazos is much less than along the Navasota, and this relates to the fact that most of Pecans recorded by surveyors were along the Navasota. After field checking of the Bottomland Hardwood forest boundaries in September 2009 (using the extent of the floodplains as a proxy for this vegetation boundary) on the maps of vegetation reconstruction (details in Chapter III) it was concluded that Fig 4.3a was much more accurate than Fig 4.3b. On this basis, the final vegetation map (Fig 4.1) excludes *C. illinoinensis* from the list of bottomland species used in interpolation.

CHAPTER V

ANALYSIS AND DISCUSSION

Three vegetation types were mapped from the OTLS data (Fig 4.2): Bottomland Hardwoods, Upland Oak Woodlands, and Grasslands.

Table 5.1 Assemblages of Witness and Bearing Tree Species

	Witness and Bearing trees occurring in Upland Oak Woodlands		**Witness and Bearing trees occurring in Bottomland Hardwoods**	
Witness and bearing tree species	No. of individuals of species occurring in Upland Oak Woodlands	% of total no. of individual species occurring in Upland Oak Woodlands	No. of individuals of species occurring in Bottomland hardwoods	% of total no. of individual species occurring in Bottomland hardwoods
Diospyros virginiana	0	0.00	1	0.32
Quercus falcata	0	0.00	1	0.32
Sassafras albidium	0	0.00	1	0.32
Juglans Spp.	0	0.00	1	0.32
Planera aquatica	0	0.00	1	0.32
Juniperus virginiana	3	0.24	0	0.00
Quercus velutina	6	0.47	3	0.96
Gleditsia triacanthos	0	0.00	7	2.24
Quercus lyrata	0	0.00	7	2.24
Nyssa sylvatica	0	0.00	11	3.51
Quercus nigra	0	0.00	11	3.51
Populus deltoides	0	0.00	16	5.11
Fraxinus spp.	0	0.00	20	6.39
Spanish Oak	0	0.00	23	7.35
Carya illinoinensis	3	0.24	47	15.73
Ulmus spp.	0	0.00	61	19.49
Quercus phellos	0	0.00	83	26.52
Quercus marilandica	131	10.36	3	0.96
Quercus stellata	1099	88.56	13	4.15
Total	1258	100.00	310	100.00

The assemblages of tree species in the bottomland and upland woodlands are presented in Table 5.1.

In this chapter, detail is added to the map to better understand the nature and ecology of these vegetation types. First, their spatial distribution is considered by comparing it to environmental and human influences that affect vegetation distribution. Secondly, the species assemblages for the two woodland units are considered in more detail.

5.1. Spatial Distribution of Pre-European Settlement Vegetation Types

Species distributions reflect both environmental and human factors. Climate is an important factor in species distribution. However, in the case of Brazos County it is probable that it did not have much of an influence on the distribution of vegetation types at the time of the surveys because the whole county has the same regional climate. Climate change may be more important because the OTLS survey was conducted in the nineteenth century and later in this chapter comparisons will be made with contemporary vegetation and those mapped in this thesis. Mean annual temperature shows a small increase from 24.6^{o}C in 1895 to 25.3^{o}C in 2008. Precipitation also increased from 884 mm in 1895 to 948 mm in 2008 (Prism Climate Group, 2009). It can be assumed that these small changes have had little impact on vegetation distribution, making it easy to agree with Frye et al. (1984) who point out that vegetation types have been relatively less responsive to climate change in Brazos County than to human-induced modification. This is particularly important in light of the fact that from the mid-1800s to the mid-1980s, the county went from having undisturbed vegetation to an area that had experienced a cotton boom, ranching and urban growth, and an estimated population of approximately 119,000 in 1984 (Google-US Bureau of Census, n.d.)

Even though used in climate change, annual means are of not much use for understanding vegetation distributions. In trying to understand the spatial distribution of vegetation, the seasonal water balance is more important (Fig, 5.1). Water surpluses are being experienced on an average between mid-December and late April and deficits between mid-May and mid-October (Prism Climate Group, 2009)

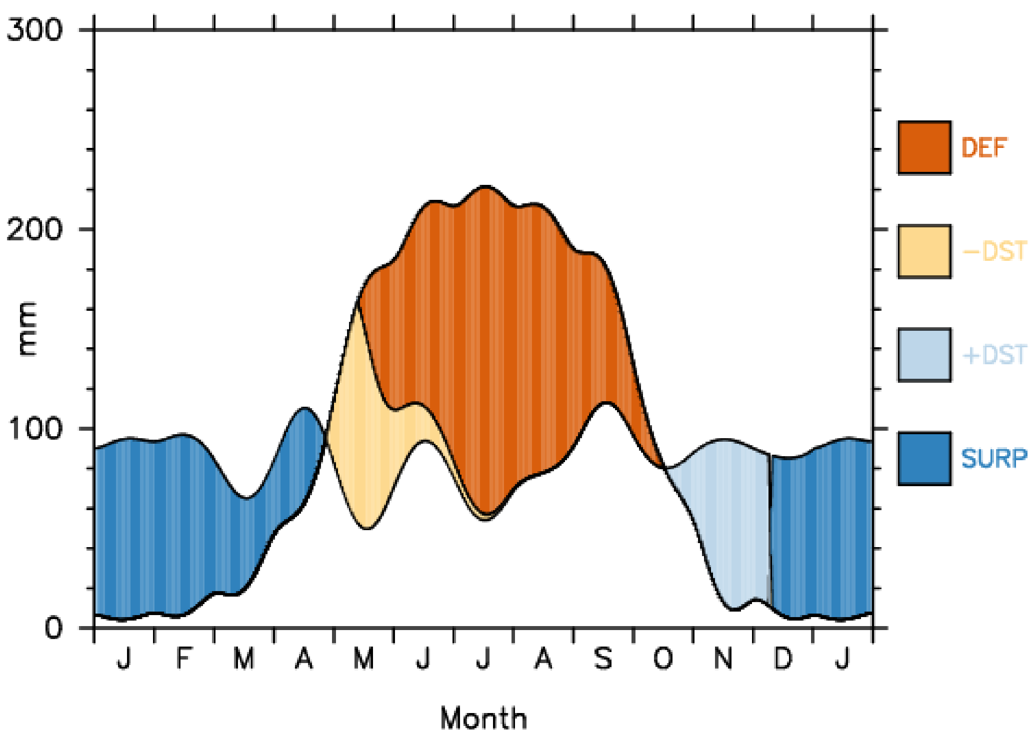


Fig 5.1 Seasonal Water Balance for Brazos County. Calculated from Long-Term Means in the Prism Database (Prism Climate Group, 2009).

Seasonal water surpluses and deficits do not apply uniformly over the county. Topography, hydrology and soil types have strong influences on water availability, and therefore upon vegetation types. The relief is controlled by the Brazos and Navasota rivers that dissected the Texas coastal plain sediments. They have left a broad interfluve in the north of the county between the valleys of the Brazos (west) and Navasota (east). The floodplain of the Brazos is generally broader than that of the Navasota. The confluence of the rivers has created a large low-lying floodplain around the city of Navasota. The interfluves are divided into undulating uplands and level to undulating stream terraces (USDA/NRCS, 2002). The majority of the soils in the county are alfisols, but a small strip of vertisols occurs along the Old Spanish Road in the far north and in patches in the southern region of the county near Millican (Fig 5.2). Alfisols are pedalfers found in temperate to sub-tropical, semi-arid to humid climates; they account for approximately 14% of the lower 48 states of the USA. They have an ustic soil moisture regime, which implies a seasonal water deficit, and are called ustalfs. The alfisols in Texas are somewhat spatially coincident with the Post Oak Savannah, and they commonly have savannah vegetation in other parts of the world. Ustalfs dominate the uplands of Brazos County. Vertisols are common in seasonally humid climates and commonly support natural grassland or grassy woodlands. They also have the ustic regime and are termed usterts. The alfisols in the bottomlands have a humid or udic soil moisture regime, and are called udalfs. The bottomlands also contain areas of vertisols which, as will be pointed out later in this chapter vary in terms of their basic chemistry between the two floodplains.

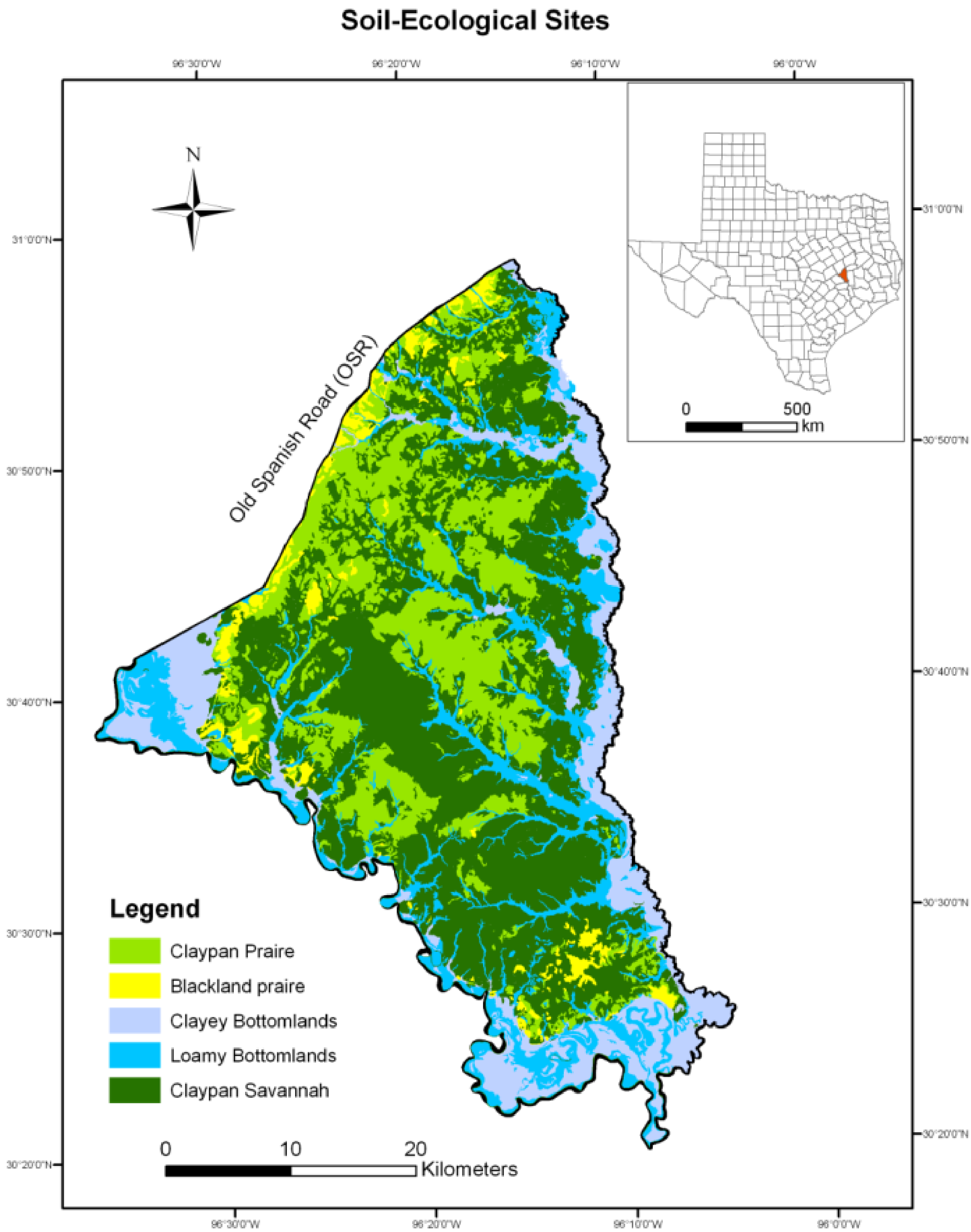


Fig 5.2 Soil – Ecological Sites of Brazos County

The vegetation mapped for the mid-1840s can be related to whether it is generally found on udalf, ustalf or ustert. However, the USDA does not map units such as these on its county maps, instead it maps many local soil series that are limited in spatial extent. It was noted in Section 3.3 that these soil series were extracted from the USDA/NRCS Soil Survey of Brazos County and combined into five soil ecological units (Table 5.2) Broadly speaking on the uplands these were the usterts (Blackland Prairie soil-ecological unit) and ustalfs (Claypan Savannah and Claypan Prairie) have dry seasons with especially well-developed water deficit months. The soil moisture deficits are most pronounced in the upper soil horizons, and can exceed the wilting point for many grasses and herbs that die back. However, deeply rooted woody vegetation — the case with many trees — is less impacted by the low topsoil moisture in water deficit months as it taps soil moisture in the lower horizons.

The udalfs and vertisols in the Brazos and Navasota bottomlands differ from the upland soils in that soil water deficits are probably quite rare and anyway restricted to sand-rich soils (most probably some of the udalfs) developed on floodplain features with slightly elevated topographies such as bars and levees. Most soils are, however, clay-rich, have a high water table, flood (if not controlled) in periods of water surplus, and have udic soil moisture regimes. These comprise the Loamy and Clayey Bottomland soil-ecological units.

Most of the vegetation types have spatial relationships with soil-ecological sites (cf. Fig 5.2) (Table 5.2). Most Grassland was found on Claypan Prairie, with the remainder almost entirely being split between the Claypan Savannah (11.33%) and the Blackland Prairie. Though only accounting for just over 10% of the area of Grassland, Blackland Prairie is very important in the context of this vegetation type because neither of the other two vegetation types occur there. The Upland Oak Woodlands are most common on the Claypan Savannah, most of the remainder occurring in the Claypan Prairie. Whilst most of the Bottomland Hardwoods are, as expected, restricted to the bottomland soil-ecological units, the Clayey Bottomland dominates the distribution of these woodlands.

Table 5.2 Proportion of Vegetation Types Occurring in each Soil-Ecological Unit

Soil type	**Soil-ecological unit**	**Proportion of each vegetation type**		
		Grassland	**Upland Oak woodlands**	**Bottomland hardwoods**
Usert	Blackland Prairie	10.22%	0%	0%
Ustalf	Claypan Prairie	74.42%	15.02%	1.13%
	Claypan Savannah	11.33%	83.81%	1.40%
Udalf and Udert	Loamy Bottomland	1.03%	1.18%	16.48%
	Clayey Bottomland	0%	0%	81.06%

In Chapter IV it was noted that the crisp vegetation boundary between the Grassland and Upland Oak Woodland was in all likelihood a continuum with the two ‘classes’ grading into one another, However, Axelrod (1985) provides evidence that the crisp boundary mapped in Fig 4.2 might have been closer to reality than the continuum model suggests. He states that pre-settlement Post

Oak Savannah was a prairie grassland bordered by forests dominated by oak species that were maintained by recurring fire: "Fire frequency in this area is thought to have been on one to ten year intervals and was a function of lightning strikes and Native American activity". The dominant spatial pattern in Fig 4.2 is in fact generally one of open grassland bordered to the west, south and east by oak woodlands that grade into the bottomland hardwoods.

5.2 Spatial Distribution of Species According to Vegetation Types

Attention is now turned from the spatial distribution of vegetation types to the species which occur in them. Table 5.1 lists witness and bearing trees that were ascribed to each vegetation type after kriging. Table 5.3 summarizes the occurrence of these groups of the trees classified according to NWI status in each soil-ecological unit.

Strong trends are found in the spatial distributions of the trees found in the bottomlands and uplands, and grassland sites, and the five soil-ecological units (Table 5.3). Trees classified as occurring in the bottomland forests are almost equally distributed between the Loamy Bottomlands (48.4%) and Clayey Bottomlands (41.8%). A few bottomland trees (3.08%) are found in Claypan Prairies. These may have arisen because of boundary issues where a Claypan Prairie abuts a bottomland unit; wider tolerance ranges than the USDA plants database indicates; GIS operator error; or surveyor error. A further 6.6% are found in the Claypan Savannah unit. They are more easily to explain in terms of boundary errors or extended ecological ranges. No bottomland species were ‘found’ in the Blackland Prairie.

Most species defined as ‘upland’ (91.9%) were found in the three upland soil-ecological units (Table 5.3). The vast majority (75.4%) were restricted to the Claypan Savannah, confirming the finding from the earlier spatial analysis of soil-ecological and vegetation units, that Claypan Savannah was the most wooded of the three upland soil-ecological units. Claypan Prairie with its area larger had significantly more trees (14.6%) than Blackland Prairie (1.6%), indicating the latter unit probably had the most open grassland at the time of European settlement. This corresponds with the fact that vertisols globally generally support grassland cover. That this area is spatially co-incidental with the Old Spanish Road is important for it appears that the Spanish and Native Americans used the most open ground to traverse the north of Brazos County, rather than cut a trail through more wooded landscapes.

Less than 10% of upland trees occurred in bottomland soil-ecological units and can probably be explained by boundary errors or extended ecological ranges. However, it is worth noting that upland trees occurred in the Loamy Bottomland units but not the Clayey Bottomland unit (Table 5.2). This indicates that the more loamy alfisols and vertisols in the bottomlands in Brazos County supported slightly different tree cover than the more clay-rich soils. The most likely explanation being that the loamy soils had slightly better drainage conditions than the clay soils.

Table 5.3 Occurrence of Classified Species on Different Ecological Sites (as defined by USDA) for Brazos County

	Soil-ecological units				
Tree species and grassland sites	**Loamy Bottomlands (Udalfs)**	**Clayey Bottomlands (Udalfs)**	**Claypan Prairie (Ustalfs)**	**Claypan Savannah (Ustalfs)**	**Blackland Prairie (Usterts)**
Bottomland Hardwoods	48.4%	41.8%	3.08%	6.6%	0%
Upland Oak Woodlands	5.9%	2.2%	14.6%	75.4%	1.6%
Grasslands	0	0	59.0%	22.9%	3.2%

Seventy-five percent of upland tree species occurred in the Claypan Savannah unit, and 14.6% in Claypan Prairie unit. In both units two trees — *Q. stellata* and *Q. marilandica* — dominated. Again this suggests that the soils of the Claypan Prairie unit supported more grassland than woodland savannah. A slightly higher percentage of *Q. marilandica* (79.1%) — an obligate upland species — occurred in the claypan savannah unit than *Q. stellata* (74.1%) (Table 5.4). This might be due to the strong ustic soil moisture regime which would favor a greater proportion of obligate upland species rather than those with wider ranges (which include less severe soil moisture regimes) such as *Q. stellata*. This argument lacks further support in the data. For example, we would expect more *Q. marilandica* than *Q. stellata* in the Claypan Prairie, which we would assume to have an even stronger ustic regime than the Claypan Savannah, when in fact there opposite is the case (13.4% of *Q. marilandica* occurred there, compared to 16.6% *Q. stellata*). Of course, the trees in the OTLS survey are the result of a purposive sample for different reasons then tree sampling for twenty-first century biogeographers and the differences in the proportions of these two oaks does not vary that much between units. Consequently, we can only say the ustic soil regime has a tendency to indicate the different distributions in these two oaks and that it needs to be researched in adjacent counties. What is clear, however, is that the Grassland class and the Upland Oak Woodland class do seem to be differentiated based on soil moisture availability.

Table 5.4 Occurrence of the Five Most Frequently Occurring Tree Species on Different Ecological Sites (as defined by USDA) for Brazos County.

Species	**Loamy Bottomlands**	**Clayey Bottomlands**	**Claypan Prairie**	**Claypan Savannah**	**Blackland Prairie**
Carya illinoinensis	53.8	7.6	2.5	35.8	0
Ulmus spp.	52.7	47.2	0	0	0
Quercus phellos	48.1	36.1	7.2	8.4	0
Quercus marilandica	4.4	2.9	13.4	79.1	0
Quercus stellata	5.6	1.1	16.6	74.1	2.3

The three most-frequently occurring bottomland tree species: Pin oak (*Q. phellos*), Elm (*Ulmus* spp.) and Hickory (*Carya illinoiensis*) occur on both the Loamy and Clayey Bottomland units (Table 5.4). The two bottomland ‘species’ *Ulmus* spp. and *Q*. *phellos* occur on the wetter, Clayey Bottomlands whereas *C. illinoiensis* is much rarer on this unit. All three, however, are found extensively on the slightly better drained Loamy Bottomlands. In fact it appears that these three species, which dominated the tree flora of the Bottomland Hardwoods form a clear gradient with *Ulmus* spp. being restricted to the wetter soils (it is entirely restricted to the bottomlands), followed by *Q. phellos* which occurs extensively in the bottomlands, but also occurs in the upland units. *C. illinoiensis* adapts to a wide range of soil moisture regimes (from the wettest Clayey Bottomlands to the dry Claypan Prairie), though most individuals (89.6%) are found in the ‘intermediate’ soil moisture units and are probably most frequently found on the stream terraces, bars and levees in the Loamy Bottomland soils and on the moister depressions in the Claypan Savannah. This wide range accounts for the issues that Pecan posed when mapping vegetation types (Chapter IV).

5.3 Pre-European Vegetation Composition

The species list of trees occurring in the Upland Oak Woodlands is dominated by *Q. stellata* and *Q. marilandica*, other species like Black Oak (*Q. velutina*), which occurred less frequently in the surveyors notes also occurred on Claypan Savannah ecological sites. *Q. stellata* and *Q. marilandica* also dominate the species list of trees that occur in the grassland class. It was noted earlier that the uplands were probably a continuum ranging from dense, oak-dominated wooded savannah, to grasslands with very few trees. The oak savannas were generally found adjacent to the floodplain forests and the largest extent of open grassy areas being on the usterts along the Old Spanish Road; though these grasslands extended in a V-shape south into the ustalfs, and there was a large area in the south of the county. We can therefore assume that grasses were widely disturbed because the area is described as a savannah, and that they would also form the understory of the wooded savannas. However, we have no information on the grass species present in the mid-1800s.

To test the differences in tree densities that would be found on the tree-grass (savannah) continuum, witness and bearing tree densities were calculated using the nearest individual method. This method measures all distances for all species in a class, sums them, and then divides them by the number of individual trees to yield one average distance for the class. Density of all (witness and bearing) trees per hectare is then calculated by the formula 10000/2 (average distance in meters)^2 (Barbour et al. 1999) . The continuum is divided into two classes in Fig 4.2, and the densities are as follows: in the Upland Oak woodlands it was 19 (witness and bearing) trees/ha and in the Grasslands 5 trees/ha. These densities, along with the fact trees occurred in both mapped classes do indicate that the Brazos uplands to be a true savannah (i.e., it has grass and tree layers). These densities, especially for Upland Oak Woodlands are calculated for the trees having only distance information. As 100 trees did not have distance information, these calculations were based on 1482 trees.

After settlement these savannahs were converted through various types of land transformations. In some cases trees were cleared for agriculture (and later urban development), and in other cases trees were planted in woodlots resulting in high-density wooded areas that can be found in the landscape today (Scifres, 1982). Despite these land-use conversions, and the potential localized impacts on tree density, *Q. stellata* and Q. *marilandica* are still the dominant overstory species. The wooded savannas range from very open tree savannas with high tree densities and little understory, e.g., to the south-west of College Station extending toward Millican. But sometimes there are impenetrable thickets, with much yaupon (*Ilex vomitoria*), winged elm (*Ulmus alata*), woollybucket bumelia (*Bumelia. lanuginosa*), spiny hackberry (*Celtis. pallida*), buckbrush (*Symphroicarpos orbiculatus*), tree huckleberry (*Vaccinium. arboretum*) which restricting the growth of grasses (Scifres 1982*).* This species list is interesting to compare the trees noted by surveyors in the Upland Oak Woodlands over a century earlier. Only 11 individuals of hackberry and six of holly (*Ilex* spp.) were reported by the surveyors in their notes for Brazos County. None of the other species listed above were recorded. This means that at least some of the species now found in denser, woody savannas currently had their origins in the vegetation before disturbance. For other species, the situation is ambiguous. However, it is possible they were present (as they are recorded in other Post Oak Savannahs) but unrecorded, not because they were absent but because many of them grow as shrubs and surveyors who were looking for trees did not consider them suitable markers. Even when they do grow as trees their trunks are smaller than many oaks. In either case they may have been growing in the area, but ignored. Alternatively, they might have been there in lower numbers than at present, and the higher numbers now might be the result of human modification on vegetation due to overgrazing, cultivation and/or fire suppression. Schmidly (2003) notes that there was minimal human disturbance prior to European settlement in Texas. However, after European settlement, frequency of fire and intensity decreased, resulting in conversion of most of the original prairies and savannahs to dense woodlands (Abrams, 1986).

The method used to calculate tree density used on the uplands was also used for these forests giving a density of 100.9 trees/ha and indicating the bottomlands were very much more densely wooded than oak upland woodlands (19 trees/ha). This accords with the following description: “Brazos bottoms are very wide and level, the trees are large and tall! and the timber, renders the sight that is more imposing” (Dewees, 1968: 28). Although, the bottomlands were equally widespread on the Brazos and Navasota floodplains at this time (unlike now where these ancient woodlands are restricted to the

Navasota) some species were more common in one floodplain than the other. On the one hand, Overcup Oak (*Q. lyrata*), Burr Oak (*Q. macrocarpa),* Blackgum (*N. sylvatica)* and Spanish Oak only occurred along the Navasota and its tributaries. Whilst on the other hand, Cottonwood (*P. deltoides),* Red haw *(C. mollis)* and Water Oak *(Q. nigra)* occurred on the Brazos bottoms. Differences such as these were noted as early as 1925, when Campbell stated that Cedar Elm dominated the Brazos river bottoms and was less dominant on the Navasota, where the characteristic species were Overcup Oak (*Q. lyrata*) and Willow Oak (*Q. phellos*). These differences were probably due to much of the Navasota floodplain composed of Entic Paleuderts, which are non-calcareous, acidic and poorly drained soils, compared to the Chromuderts in the Brazos bottomlands which are calcareous, basic and moderately drained (Fred Smiens, ESSM, TAMU, personal communication, 2009). Another reason might be the occurrence of periodic fires that may have occurred during summers when the bottomlands were relatively dry and had a big fuel load from grasses that had grown as a response to warming up and flooding in spring. This would have favored thick-barked, fire-resistant oaks like Pin oak (*Q. phellos)* compared to oaks with thin bark like *Q. lyrata* and *Q. nigra* that are susceptible to fire. This may be the reason that the bottomland species list (Table 5.1) had more *Q. phellos* (53) than *Q. lyrata* (7).

Diameter measurements of the five most frequently occurring species listed in Table 5.5 shows how these particular species were distributed when surveyed based on the diameter classes. All of the five most frequently occurring species had most individuals in the 20- 40 cm dbh classes. The dbh range of Q. *stellata* recorded by the surveyors was 10.16 to 91.44 cm. The maximum value is significantly lower than the current state record, a 208 cm tree in Bowie County (Texas Forest Service, n.d.). The largest oaks were old, but nowhere near as old as they could be but this may be due to the severe ustic moisture regimes and some of these trees would likely be very mature individuals. The largest specimens of Post Oak (>40cm) appear in all the largest areas of Upland Oak Woodlands (Fig 5.3). The lack of any discernable spatial pattern in the dbh distribution for this species suggests these Upland Oak Woodlands were relatively undisturbed (by human influences or any large magnitude, low frequency natural factor).

Fig 5.4 shows the species distribution of *Q. marilandica*. The dbh ranged for this species ranged from 10.16 to 50.18. Hatch and Pluhar (1989) state that in savannah vegetation the diameter of Black Jack Oaks rarely exceed 41cm. Some of the individuals on *Q. marilandica* must therefore have been very old for this species and as they occur alongside *Q. stellata* their age range inferred from the dbh distribution supports the argument made in the previous paragraph that the Upland Oak Woodlands were undisturbed.

Q. phellos, the most frequently occurring bottomland species, had a dbh range of 12.70-83.82 cm. Fig 5.5 shows the distribution of pin oak based on dbh classes. The largest trees generally occurred in the topographically lowest bottomland soils and as moisture must be readily available in the soil during the growing season for best pin oak growth (http://www.na.fs.fed.us/pubs/silvics_manual/ Volume_2/quercus/phellos.htm) this accounts for the distribution of the largest Pin Oaks. Fig 5.6 shows *Ulmus spp.* mainly occurred on the floodplains of Navasota and its tributaries. It had the dbh range from 7.60-80.5cm. Fig 5.7 shows the spatial distribution of *Carya illinoensis*, mainly species in the range of 20.6-40.5 cm being seen along the Navasota river.

Table 5.5 Diameter Ranges, dbh Class Distributions and Mean Distances for the Five Frequently Occurring Tree Species

Trees	No. of trees	No. of trees with a dbh record	Mean distance to corner of plot (m)	Number of trees in each dbh class (cm)					
				Minimum and maximum dbh recorded	0-20	20-40	40-60	60-80	>80
Carya *illinoinensis*	38	33	5.78	10.16-76.20	10	20	1	2	
Ulmus spp.	55	40	6.34	7.62-66.04	15	24	0	1	0
Quercus phellos	83	64	9.37	12.70-83.82	10	39	9	5	1
Quercus marilandica	134	114	11.16	10.16-50.8	23	87	4	0	0
Quercus stellata	1125	976	13.07	7.62-91.44	53	634	215	69	5

Fig 5.8 shows the mean distance surveyors went to use trees of the five most frequently occurring species as witness and bearing trees. It appears from the distributions of *C. illinoinensis*, *Q. phellos* and, possibly, *Ulmus* spp. that there was no bias in their sampling. Given all three of these species occurring extensively in the dense bottomland forests this is unsurprising and increases the level of confidence in the dbh and density analyses of the Bottomland Hardwoods. However, the same cannot be said for the Upland Oak Woodlands.

Whereas *Q. marilandica* appears to have little surveyor bias in choice of individuals, the relatively long distances that some surveyors went to mark large Post Oaks is apparent.

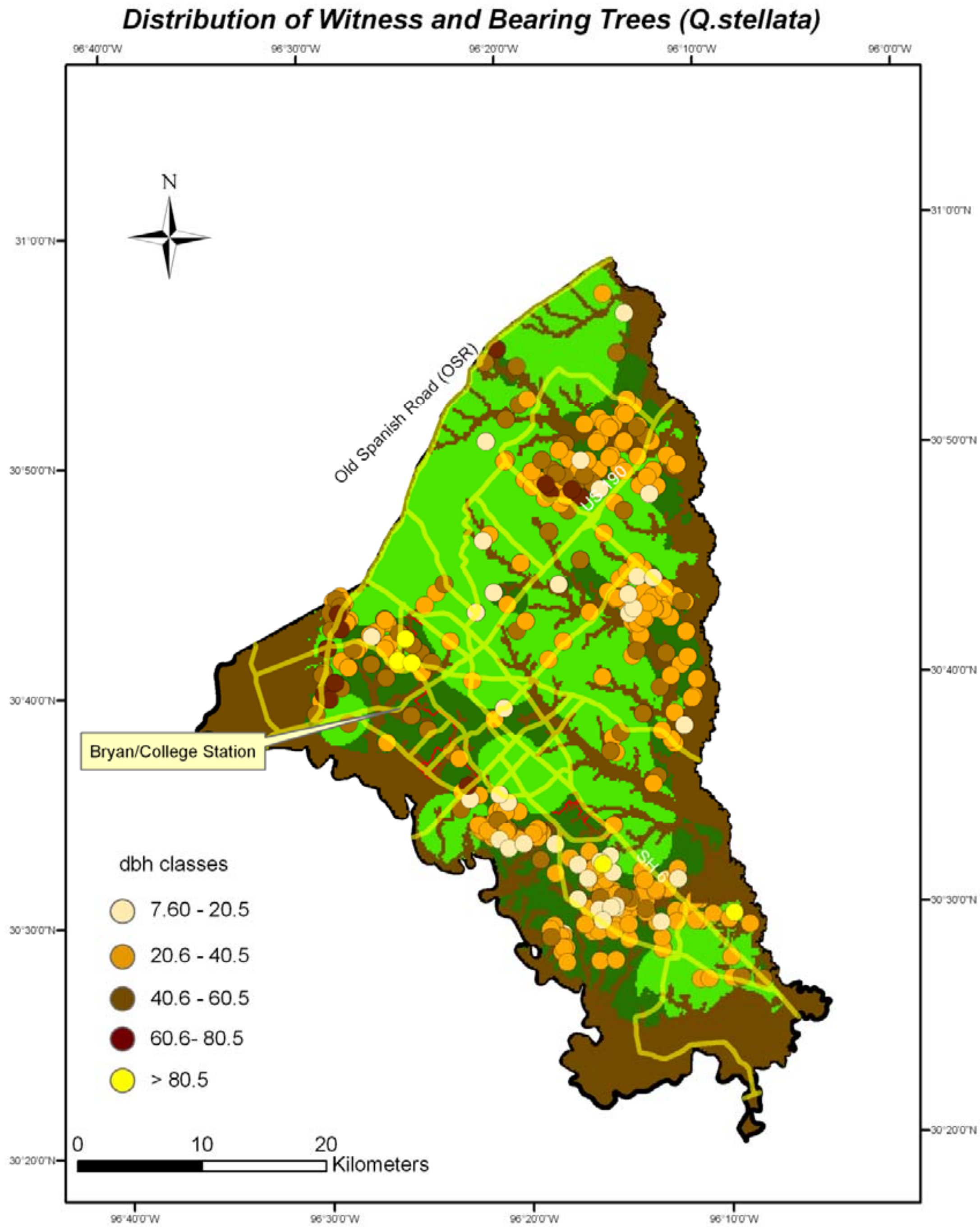


Fig 5.3 Spatial Distribution of *Q. stellata* by dbh Class

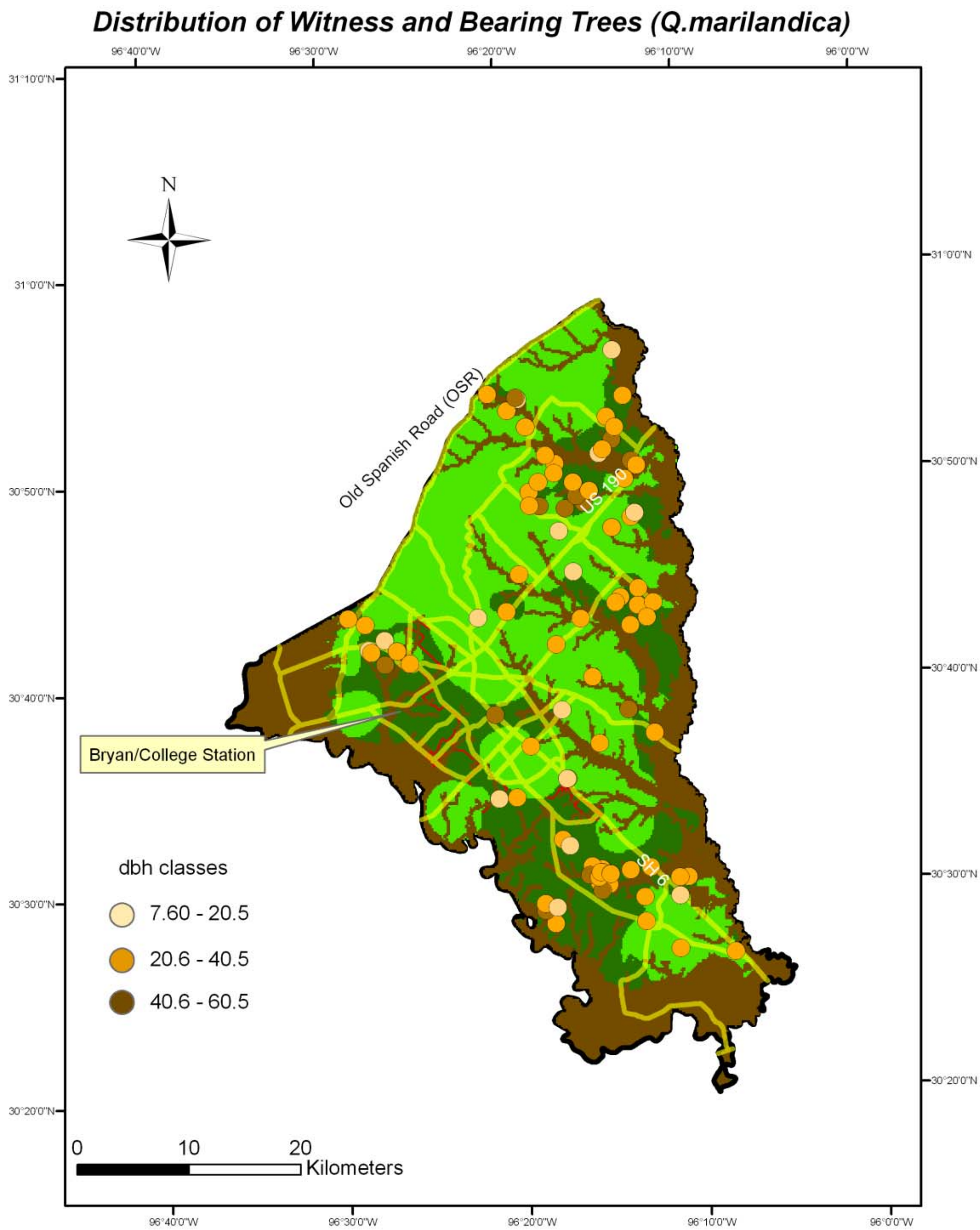


Fig 5.4 Spatial Distribution of *Q. marilandica* by dbh Class

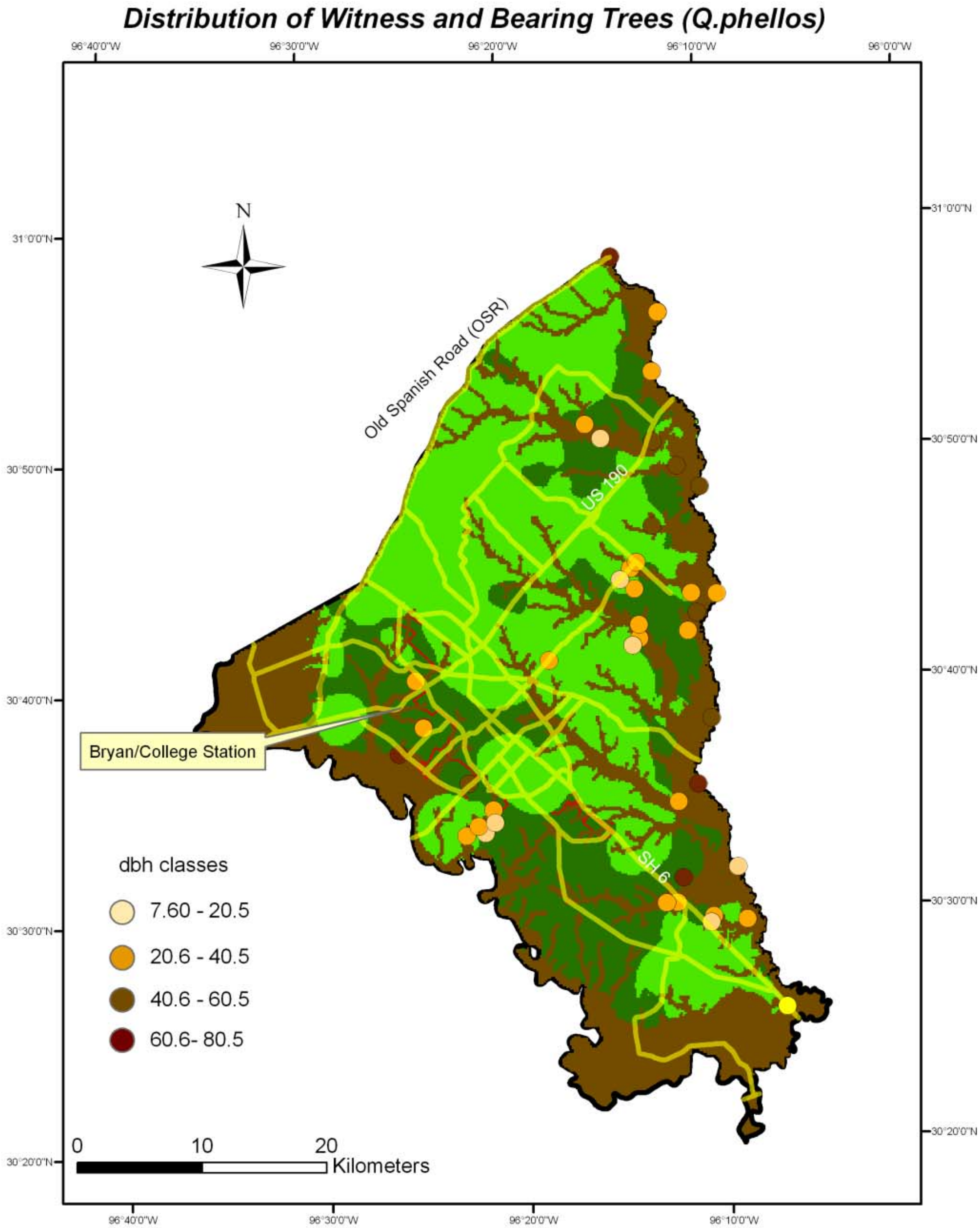


Fig 5.5 Spatial Distribution of *Q. phellos* by dbh Class

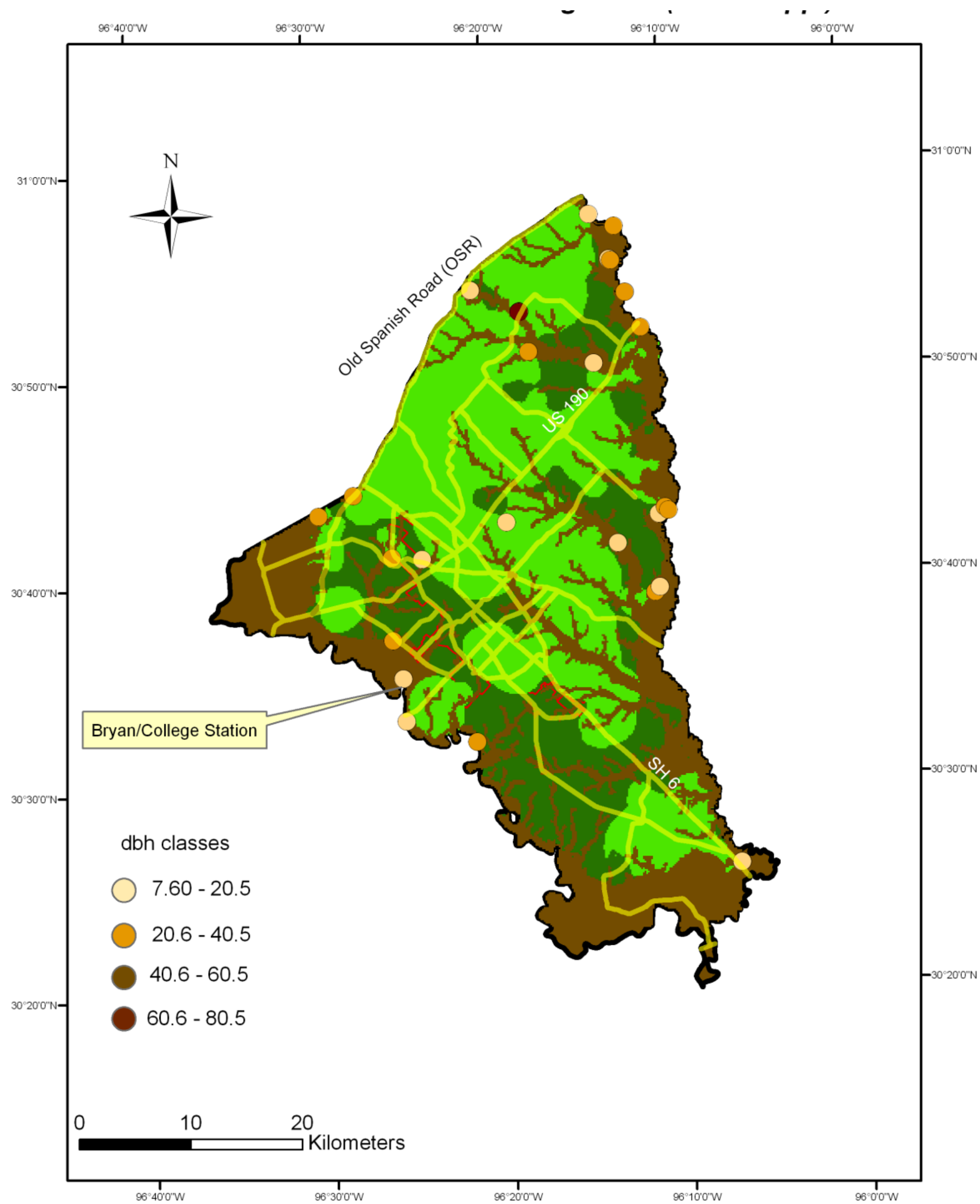


Fig 5.6 Spatial Distribution of *Ulmus* spp. by dbh Class

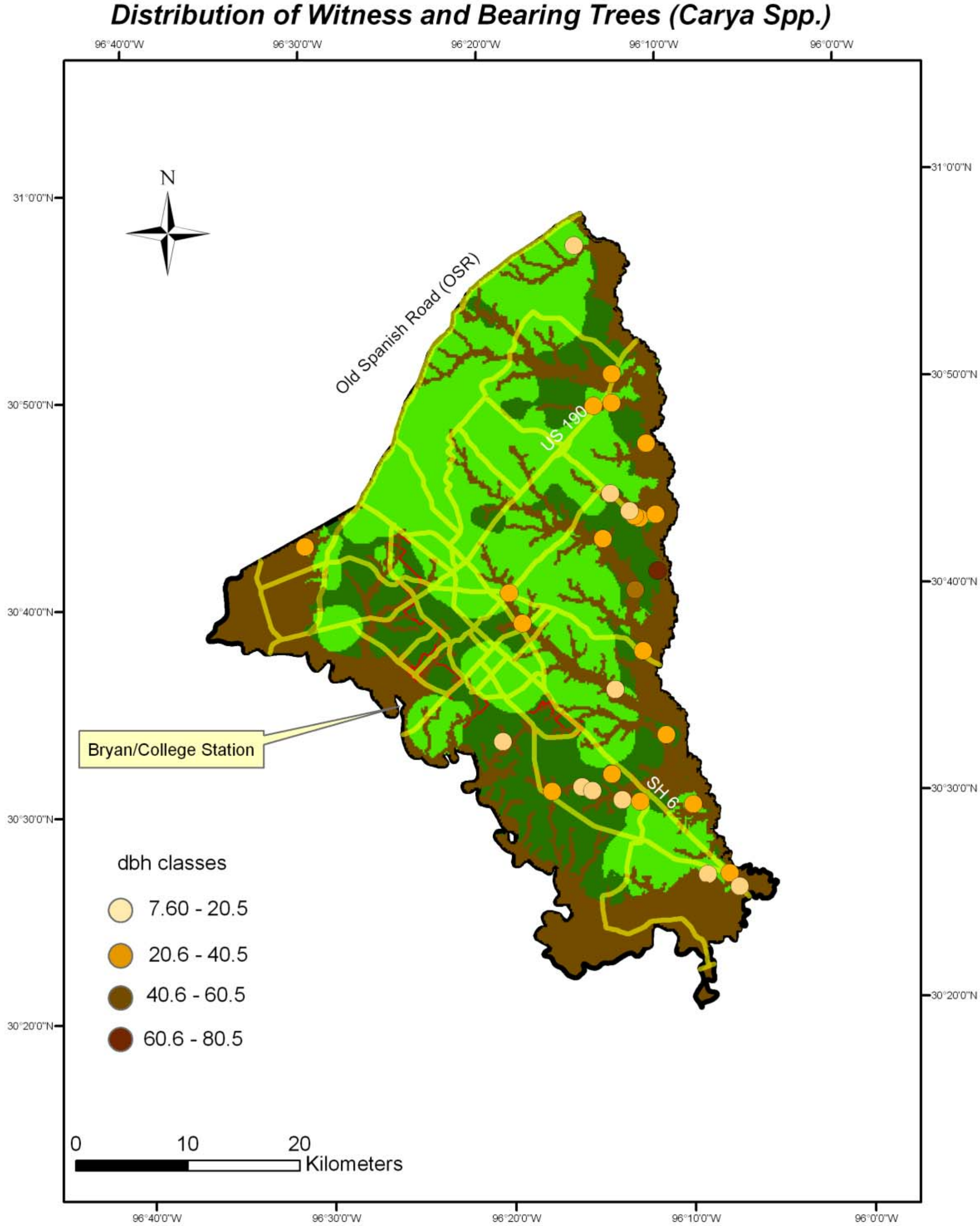


Fig 5.7 Spatial Distribution of *Carya illinoinensis* by dbh Class

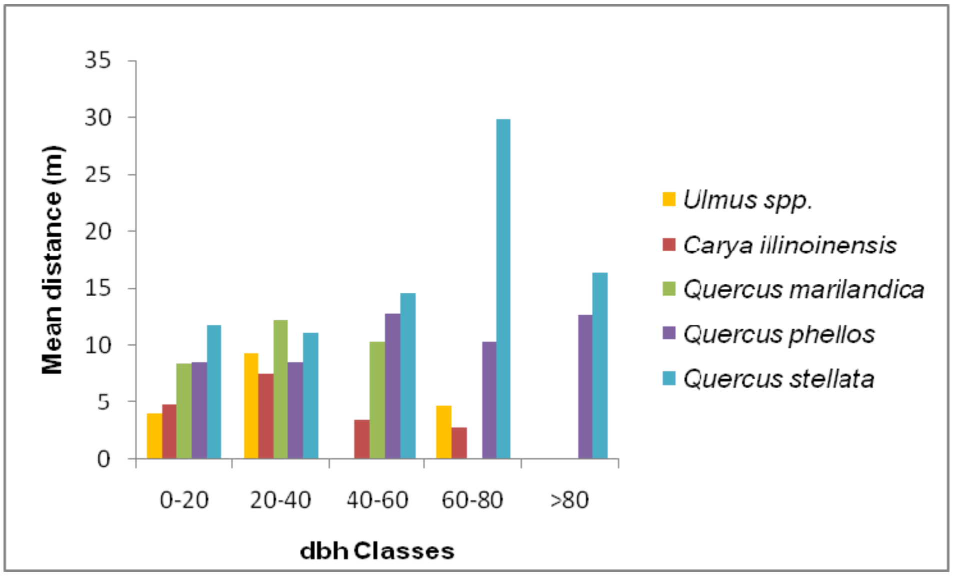


Fig 5.8 Diameter Class to Distance for the Five Most Frequently Occurring Species

CHAPTER VI

SUMMARY

In Chapter I it was hypothesized that the majority of the uplands in Brazos County during the 1800s were covered by a savannah which at one extreme was open grassland with very few trees (these would mainly be Post and Black Jack Oaks) and at the other was a densely wooded oak savannah. In addition, the Brazos and Navasota river valleys would have supported dense woodlands with a distinctly different composition to the adjacent densely wooded uplands. The results in thesis indicate that this was probably true, but there are caveats.

First, as stated above what was hypothesized proved more-or-less correct, but it is only based on a sample of tree and grassland locations and prairie/timber boundaries present in the dataset created from surveyor's file. This data set is fit-for-purpose but some key issues remain: (a) the surveyors were not biogeographers and they did not foresee the benefits of the data they collected for vegetation mapping, as a consequence not all the data we would have liked to have been collected are in the files, and (b) sampling issues are a problem and, at the scale of the entire county, some parts had denser surveys than others due to location of variations in size of property plots (cf. Chapter II). There are four clusters of small plots with a greater witness and bearing tree densities compared to the areas of larger property plots in the remainder of the county (Fig 3.1).

Secondly, boundaries are an issue. The Bottomland Hardwoods proved to be accurate when surveyed using floodplain extent as a proxy. There is a bigger question as to whether the pre- European settlement vegetation map is accurate in portraying the grassland and wooded savannas as two classes separated by a crisp boundary. Nevertheless, due to interpolation technique used and the availability of the prairie/timber boundaries and stakes in prairie at certain locations recorded by the surveyors, the vegetation map does show a distinct boundary between the Upland Oak Woodlands and the Grasslands, i.e. it is not mapped as a continuum.

6.1 Progress Towards Objectives

The first objective was to map the pre-European vegetation cover of Brazos County. This was done and the map is provided in Fig 4.1

The second objective was to carry out an accuracy assessment by verifying the map through external sources (c.f. Chapter III). I found two photographs from the 1930s (Section 3.2.5.) which provided locations for an open prairie and a relatively open oak savannah. Both were taken some decades after the 'date' of the map, but the possible validity of the vegetation information on these photographs is that they were taken in the beginning phases of urban development. The letters from early settlers also proved useful, by describing the vegetation in the grasslands, oak woodlands and bottomlands. Finally, field checking the floodplains proved the accuracy of the Navasota bottomland woodland boundary.

Accuracy assessment was also done by internal verification of the map through calculation of the commission-omission matrices, with an overall accuracy of approximately 79%. This was lower than expected, but was due to the commission of upland trees in the grasslands: of course if we are to believe a continuum model for this boundary, these are not really commission errors at all and the map is far more accurate.

A third objective was to account for the spatial distribution of vegetation in the late pre-European settlement period vegetation cover map (Chapter IV). There are strong spatial relationships between the vegetation types and soils. The soil-vegetation situations, particularly the link between soil moisture regimes and vegetation types provide strong explanatory relationships.

The fourth objective was to gain a better understanding of the savannah and woodland communities present in the late pre-European settlement period. Species lists provided evidence that, of the woody species marked by surveyors, Post oak and Black Jack Oak dominated the upland vegetation which had low species diversity and the tree density ranged from five (Grassland) to 19 (Upland Oak Woodlands) trees/ha . The Bottomland Hardwoods were more diverse, the co-dominants were *Q. phellos, Ulmus* spp.

and *C. illinionensis* and the tree density was >100 trees/ha. There were differences in the floristic composition of the Brazos and Navasota bottomland woodlands. An analysis of dbh distributions for the five most frequently occurring species indicated that the Upland Oak Woodlands were relatively undisturbed by human influences or large magnitude natural events.

6.2 Preliminary Evaluation of OTLS as a Source for Vegetation Mapping

Original Texas Land Survey records proved to be effective in mapping the pre-European vegetation cover, as they provided detailed witness and bearing tree information recorded by the surveyors. It was easy to spatially locate these tree species and change them into spatially-located autecological information in order to produce a map.

The OTLS data is easy to acquire. It is located at GLO in Austin where all surveyors' notes are also found in a single place. This is unlike the PLSS or other Metes and Bounds surveys which are difficult to find in a single location (AAG, 2008). The staffs at GLO in Austin were welcoming, helpful and encouraging to researchers. I had some minor decoding problems, especially with the plastic-covered notes when photographing them digitally. I had to reconfirm my decoding on successive visits to GLO. In total, I made three one-day visits to GLO to obtain and check all these data.

The OTLS is generally a good source for reconstructing Pre-European vegetation. Based on this study from Brazos County; it appears there is adequate information and few surveyors' notes failed to record the witness and bearing trees, dbh and bearing information. However, these are some other issues. Surveyors were not consistent while surveying. As a result of lack of specific guidelines, some surveys were very detailed and elaborate compared to others. This was probably the surveyor's preference. For example, the distance and direction of every meandering was recorded by some, other survey notes hardly had any information.

As for the limitations of the surveyors' notes, assumptions have to be made, e.g., that dbh measurements were taken at the breast height. Some researchers (e.g., Bourdo, 1956) have pointed out similar surveyors' biases while using notes for Metes and Bounds and PLSS for vegetation reconstruction. He states that for PLSS and Metes and Bounds surveys the surveyors' records were biased toward specific witness and bearing tree species because they were easy to mark compared to other tree species or they were often nearer survey corners. In addition, surveyors usually excluded trees that were young and had low dbh. Some researchers (Cogbill et al, 2002; Marks and Gardescu, 1992 and Cowell, 1995) have also pointed out that the distance to witness and bearing tree measurements from the survey corner points are biased toward a particular tree community.

Some of the above-mentioned biases were likely biases in the OTLS data for Brazos County. For example, selecting a particular tree species for surveying was rarely seen in the bottomland surveys, but majority of the upland tree species were Post Oak which may show a bias to the preference in recording witness and bearing trees of this species by the surveyors in the uplands. However, this region was dominated by Post Oak savannah, and the original tree species composition was biased toward Post Oaks and Black Jack Oaks (Rideout, 1994). Also, surveyors' biases in the distance to witness and bearing tree measurements from the survey corner point for a particular tree community were examined. There was no evidence of bias in the Bottomland Hardwoods; but the bias often seen in reconstructions using PLSS data — that surveyor's preferentially sought large trees — was evident in the Post Oak's surveyed.

Only two studies have been conducted in Texas using OTLS, one in Hardin county (Schafale, and Harcombe. 1983) and the other in Kerr Wildlife Management Area, Kerr County (Wills, 2005). Both of these studies are 'incomplete' in that one relies on hand-drawn boundaries of plant communities (Hardin County) and other only lists the plant species present during the pre-European settlement period. Neither of these studies have spatially located witness and bearing tree locations or used those data to produce a map using a geostatistical technique.

In conclusion, my research proves that the OTLS is a valid source for vegetation mapping during Pre-European settlement and for analyzing the tree species present at that time. This study can be used by researchers in future to analyze the changes in vegetation patterns from 1800s to present time. Apart, from usefulness to conservationists, wildlife managers, and city planners to protect and preserve pristine and native vegetation of Brazos County. All that is needed now are 253 more Masters students to work on the remaining counties in the state!

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APPENDIX I

Archives and Records File Pull Slip
General Public Only – Employees Must Use Extempore

LAND DISTRICT: Bxs
CLASS: D
FILE NUMBER: 24
DATE PULLED: 02/05/09
YOUR NAME: Indu

3/17/05

Archives and Records File Pull Slip
General Public Only – Employees Must Use Extempore

LAND DISTRICT: Bxs
CLASS: S
FILE NUMBER: 14
DATE PULLED: 02/05/09
YOUR NAME: Indu

3/17/05

Archives and Records File Pull Slip
General Public Only – Employees Must Use Extempore

LAND DISTRICT: Bxs
CLASS: S
FILE NUMBER: 15
DATE PULLED: 02/05/09
YOUR NAME: Indu

3/17/05

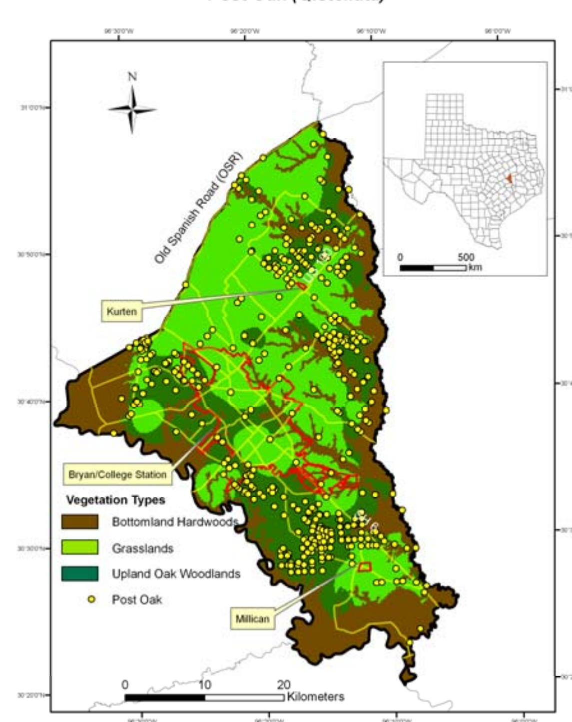
Archives and Records File Pull Slip
General Public Only – Employees Must Use Extempore

LAND DISTRICT: Bxs
CLASS: B
FILE NUMBER: 13
DATE PULLED: 02/05/09
YOUR NAME: Indu

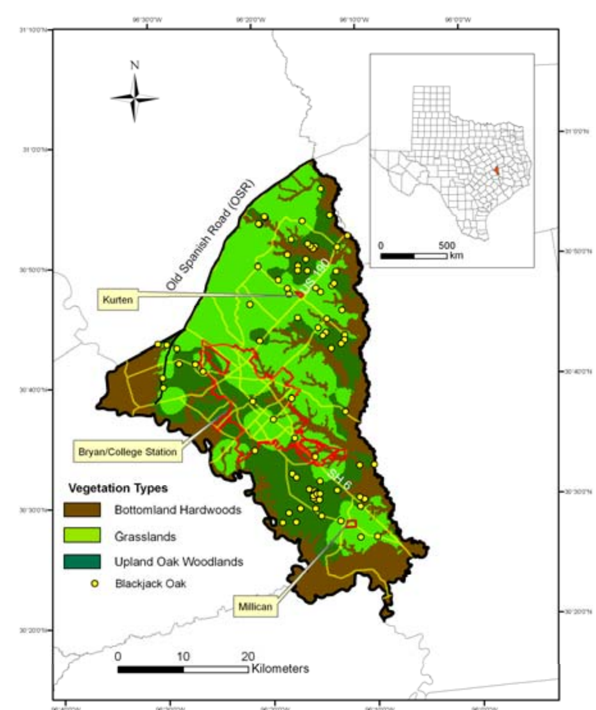
3/17/05

APPENDIX 2

Post Oak (Q.stellata)

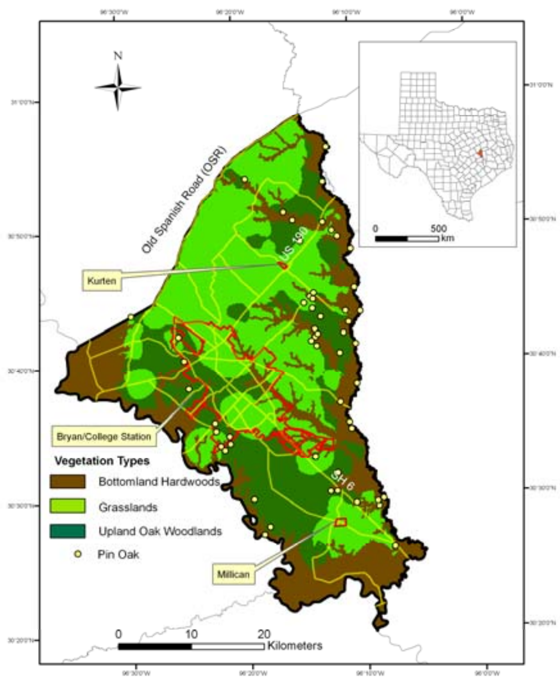


Blackjack Oak (Q. marilandica)

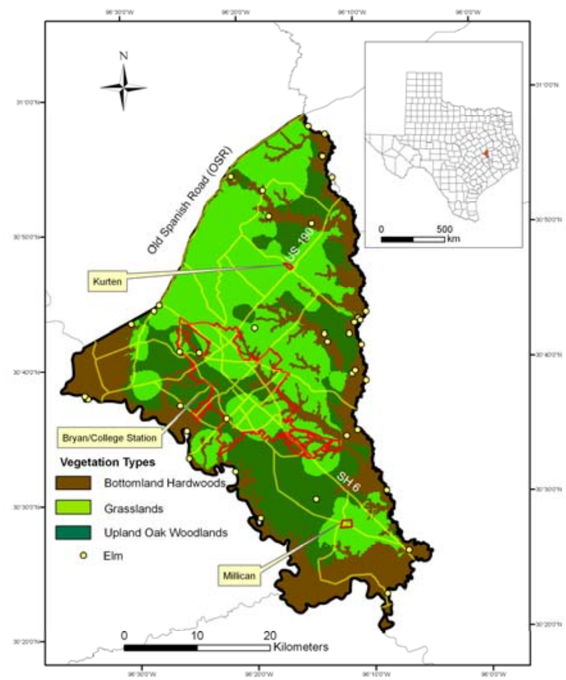


APPENDIX 3

Pin Oak (Q. phellos)

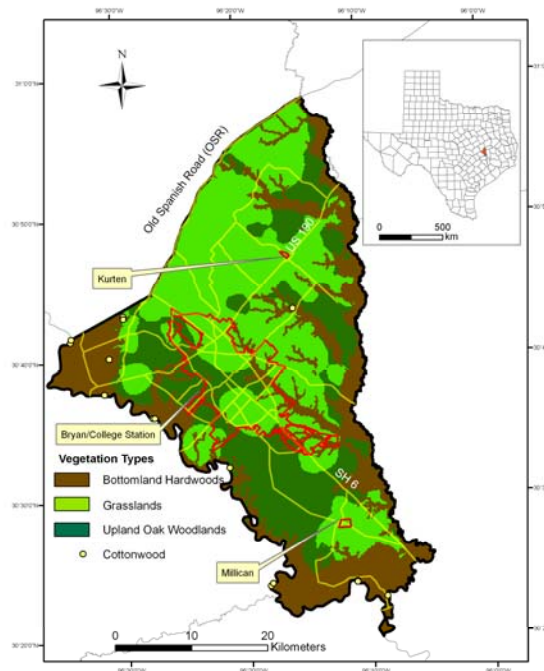


Elm (Ulmus spp.)

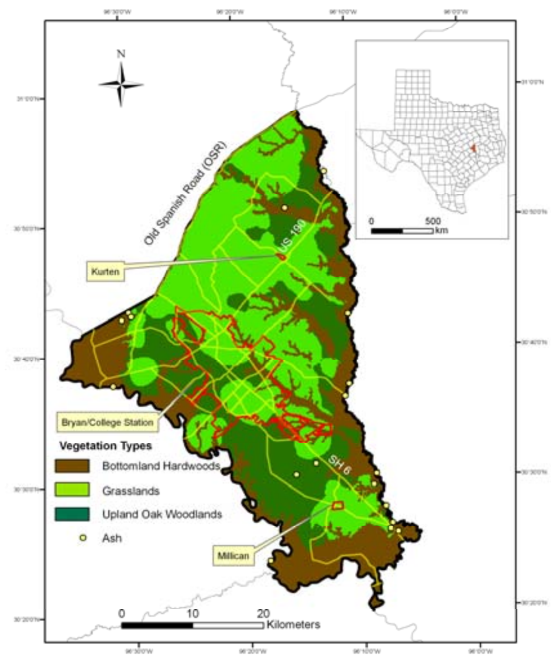


APPENDIX 4

Cottonwood (Populus deltoides)

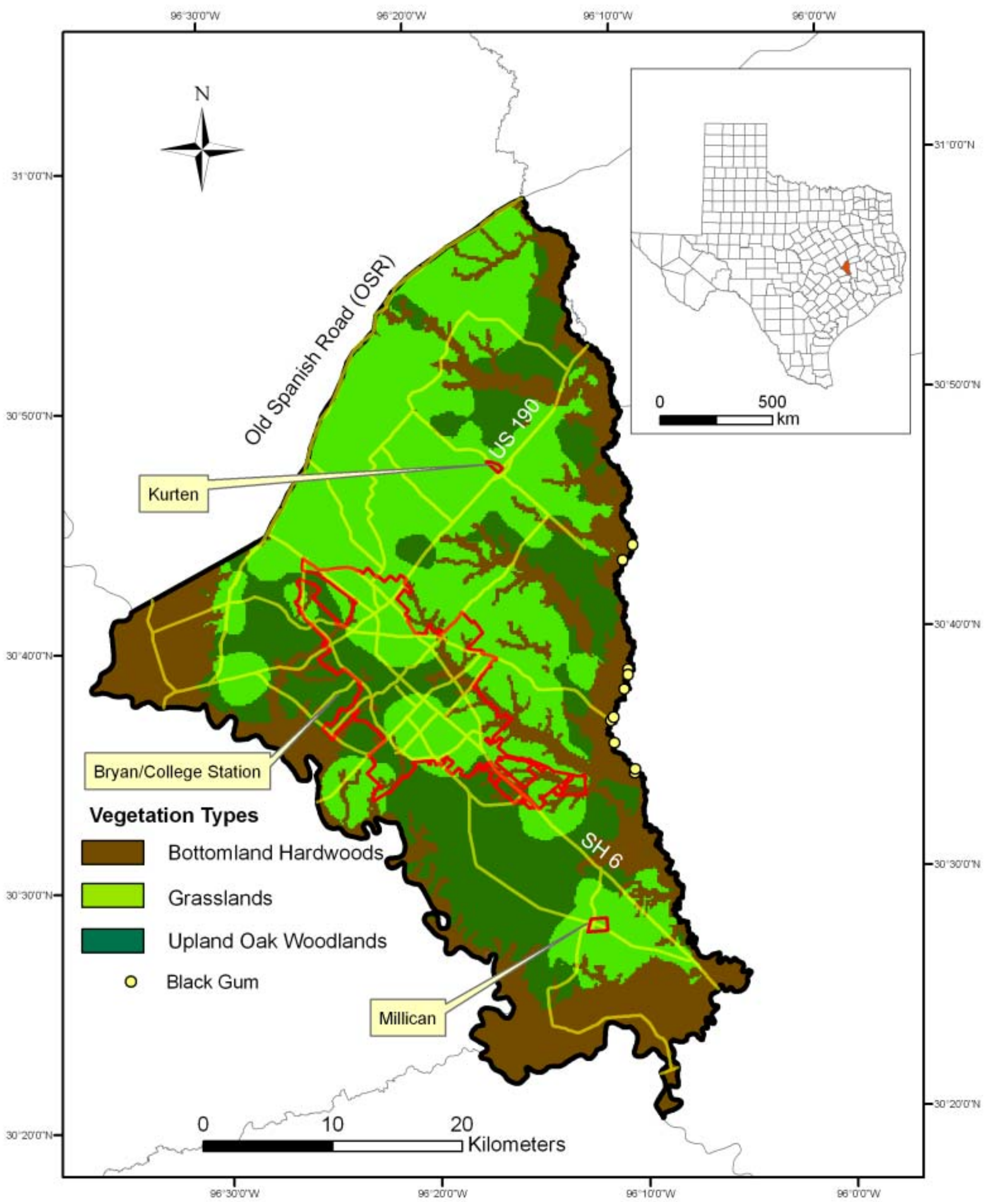


Ash (Fraxinus spp.)



APPENDIX 5

Black Gum (Nyssa sylvatica)



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