GEOGRAPHIC ANALYSIS OF CURRENT AND HISTORICAL VEGETATION OF EAST TEXAS

A Thesis

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by

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DEDICATION

One of my earliest memories as a young boy was a late afternoon visit to see the stained glass windows of the Old Main Building on the campus of Sam Houston State University. That visit occurred sometime around 1964 and it was the perfect spark for a curious kid that wanted to know everything. At the time, my mom was a student intern at the old University Clinic on 17th Street and my great aunt was a nurse there. They would hide me under a gurney in the back when the doctor made rounds. I still remember his black slacks and shiny leather shoes, not three feet away, as I hid breathless one day under the skirt of a hospital sheet. Other times, they'd let me sneak over the long stonewall just behind the clinic into "Mr. Sam's yard," which, of course, was the historic Sam Houston home place. Those images still linger to this day, and to my five-year-old self, the University was both an enchanted and lofty place where the best of the best things happened. Those days were also somewhat prophetic. Roughly, twenty years later, in April of 1983, I came to Huntsville as a young adult to mow a lawn. I got lost, turned off onto Bearkat Boulevard and found the University. On a whim, I stopped off and picked up an enrollment application. It has been 34 years and a couple of degrees since that day and I am still curious about everything. Fortunately, I was allowed the opportunity to work for SHSU and pursue learning as both a hobby and a career. For that, I would like to dedicate this thesis, first to my parents, just because they come first, but secondly to Sam Houston State University, the supervisors, friends, professors, and mentors I have had along the way. Most people leave college with memories to last their lifetime. I was lucky and allowed to stay. My career at SHSU has been rewarding in so many ways, but the most rewarding part, especially to that five-year-old self, is that I still learn something new every day. Thanks, Mr. Sam.

ABSTRACT

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This study uses two sources of secondary data to compare vegetation communities in East Texas and analyze how they have changed in the past eight decades. The first data source is a hand-drawn timber survey map generated by the U.S. Department of Agriculture circa 1935. The second data source is the Texas Parks and Wildlife Department's *Ecological Mapping Systems of Texas* (EMS-T) finished in 2014. A third data source is used to crosswalk between the two principal sources.

Using digital mapping techniques, classification boundaries of the historic map were digitized creating an overall area of interest. This was used to extract attribute data from the second data source creating a data extent defined by the digitized boundaries of the 1935 map. Although identical, their resulting attribute data contained no mechanism for a data join. The third data source, McMahon's *The Vegetation Types of Texas, Including Cropland* provided this attribute bridge.

This study found that 2.49% of the overall area has been converted to urban use. This shift in land use underscores an overall rise in population, which, in turn, drives the need for natural resources and conversion of ecosystems to other land uses. For example, 34% of the 'Shortleaf, Loblolly, Hardwood' classification is now exclusively devoted to timber production. In the 'Bottomland Hardwood' classification, reservoirs now account for 13% of its total area. Today only 0.07% of the 1935 longleaf pine extent is exclusively longleaf pine and 56% of areas that once were longleaf pine are now pine plantation. Areas of urban growth have had the greatest impact on the 'Loblolly, Hardwood' classification where 10.3% has been converted to urban cover. Invasive species are evident as well. For example, of the ‘Loblolly, Hardwood’ classification, 3.7% is now invasive Chinese Tallow (*Triadica sebifera*).

The resulting analysis allows for comparisons based on “Common Name” attributes, LU/LC value, and associated area values. Beneficially, such comparison allows for general assumptions about environmental impact and provides an analytical mechanism by which to mitigate future loss due to human or natural influences.

KEY WORDS: Historic vegetation, Geographic Information Systems (GIS), Remote sensing, East Texas

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I would like to acknowledge those who have been helpful with both data and advice while writing this thesis. Above all would be Amie Treuer-Kuehn at the Texas Parks and Wildlife Department who, without her years of effort to create the *Ecological Mapping Systems of Texas* (EMS-T), this thesis could not have been written. As portions of this study are based on previous scientific example, I would like to thank Dr. Mark Leipnik and Irene Perry for their published methodology. As I am not a biologist, without their example, reconciliation of the EMS-T data into a manageable analysis set would have been questionable, at best. I would also like to thank each of my committee members for their patience and for being there when I had a question. Dr. Mark Leipnik, Dr. Brian Chapman, Dr. John Pascarella, thank you. In addition, I would like to thank Dr. Samuel Adu-Prah. As my thesis director, Dr. "Samuel" did much to help me through the hills and valleys of writing a thesis. His support, in times when, it seemed, my entire thesis was unravelling, provided a guidepost toward the finish line. As an employee of Sam Houston State University, I would like to thank the various supervisors and Departments along the way who have allowed me to pursue this course toward another degree.

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CHAPTER I

Background

Ever since settlers of the American West first began to populate the densely forested regions of East Texas, dramatic changes have been wrought to both the landscape and its ecological communities. The natural forest, except in small areas of protected Federal and State lands, has undergone tremendous change. Some lands, once cleared for agriculture, have transitioned back to forests, albeit forests of an entirely different composition than their historic predecessors. Other forests have succumbed to the steady spread of cities and urbanization. Forests that were once old growth longleaf pine (*Pinus palustris*) are now loblolly pines (*Pinus taeda*) and other commercially viable species, displacing and often endangering the niche specific flora and fauna that once thrived there. With these changes, an overall decline in species richness is evident (Goldstein 2005 (MacCleery 2011).

As an example, native longleaf pine forests once stretched along the southern coastal plains from East Texas to Virginia, an estimated 90 million acres, but by the 1960's as much as 98% of these original forest were lost (Southern Forests for the Future 2014) (The Nature Conservancy 2016). Around the turn of the 20th century, most remaining areas of longleaf pines in Texas were in the southeastern counties of Jasper, Newton, and Tyler (Miles 2010). According to The Nature Conservancy, longleaf pine has rebounded from a low of 2.8 million acres nationwide up to 3.3 million acres over the past 40 years (The Nature Conservancy 2016).

The first survey of East Texas forest resources was conducted by the U.S. Department of Agriculture during the years of 1934-1935 as part of a much larger, Southern Forest Survey, which cataloged forest resources of the southern U.S. States. Findings and data of the East Texas survey were published in two documents in 1938 and in 1939 (Texas Society of American Foresters 2006). These two publications cataloged timber resources for the two forest survey units in southeastern and northeastern Texas. The publications, with accompanying published "Unit" maps related to the survey, are available through various sources. A surviving map of these areas, based on field surveys made in 1935, showing both Units I and II, was made available by the USDA Forest Survey (Leipnik 1997). The unpublished map is 3' x 5' on paper with printed counties, rivers, roads, cities, and other features. The timber boundaries and their associated map legend are hand-drawn and hand-colored as an overlay to the printed features.

In contrast, the Texas Parks and Wildlife Department (TPWD) has made available new data sources at a very high resolution. The TPWD data, for both Units I and II of the Eldredge/Cruikshank timber survey, represents 4.06 GB of data, or 1.6 million environmentally classified polygons. This increase in data richness provides a level of environmental detail previously not attainable with Landsat or other remotely sensed data.

For this study, the USDA timber survey map was digitized and used as the primary source of boundary information. This boundary information was then used to clip the 10 meter, *Ecological Mapping Systems of Texas* dataset (EMS-T), produced by TPWD. A compositional comparison at the attribute level allowed identification of altered natural environments and areas which are representative of the historical natural environment as described by the Eldredge/Cruikshank survey.

Identification is the first step toward mitigation for these areas and is key to their continued existence as human activity encroaches upon them. Although broadly classified, the Eldredge/Cruikshank classification system shows areas that were dominated by longleaf pine. These have been, in most instances, displaced and replanted with faster growing, commercial varieties of pine such as loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*). The EMS-T data shows areas where longleaf pine survives, and where it once likely lived, both inside and outside, of protected lands. Areas of bottomland hardwoods also show a decrease due to construction of reservoirs and other human encroachments. Urbanization is also evident. Areas classified as 'Urban' significantly influence the fragmentation of forest and proximity to urban areas affect the current land use.

A study from 1997 used the same 1935 USDA map and Landsat multi-spectral imagery to classify vegetation types at a scale of 1:250,000 for both Unit I and II of the Eldredge/Cruikshank timber survey. That study revealed changes in both the relative importance and distribution of vegetation types and emphasized the loss of longleaf pine and bottomland hardwood forest (Leipnik 1997). Through a crosswalk analysis of "Common Name" attribute values, using Leipnik's methodology, results from this study confirm the results found in his previous publication (Leipnik 1997), albeit at a much higher resolution.

This research is significant in that it presents two separate snap-shots, taken decades apart, of the vegetation communities of east, and southeast Texas. One snapshot is very general but offers its provenance (U.S. Department of Agriculture) as a definitive source within the historic literature. The Eldredge/Cruikshank survey and resulting maps were foundation for the first, and every subsequent, forest survey in East Texas as conducted by the USDA (Brandeis 2014). The second data source, the *Ecological Mapping Systems of Texas* (EMS-T), provides the single best snapshot of vegetation communities as they stand today as determined by the Texas Parks and Wildlife Department. With these two sources of information, it is possible to compare current plant communities with broad assumptions about the area's historical ecology. Comparison at this level leads to a better understanding of several ecological implications (Brister 2011). First, we are able to reveal mistaken assumptions about past ecological conditions. Secondly, knowing the historical ecological conditions allows for a measure of change over time. Thirdly, it allows for a measure for separating natural and cultural causes. According to Brister, "By revealing past patterns of ecological change, historical studies can correct mistaken expectations for future change and can identify conditions that may limit the success of land management protocols" (Brister 2011).

These data sources, taken together, and analyzed through a geographic information system, offer an opportunity to identify areas that may be at risk. Identification of the nature, quantity, and location of any remaining historic forest types also quantifies for species richness and habitat. For endangered plants and animals, such as the Texas tortoise (*Gopherus berlandieri*), the Louisiana pinesnake (*Pituophis ruthveni*), Texas golden gladecress (*Leavenworthia texana*), and other niche specific flora and fauna, this study provides a process for locating areas where they may still exist and provides support for other endangered species research.

Statement of the Problem

Ideally, for any given ecosystem, an understanding of its influencing factors would be self-evident by simple observation; however, ecosystems are complex and dynamic and the drivers for any resident change may exist miles away. To understand and identify influencing factors, spatial analysis is used to qualify both the stimuli and the extent of those changes. Geographic Information Systems, remote sensing techniques, the overall availability of reliable data at very high resolution, and most significantly, the ability to process huge amounts of geographic data have emerged as an essential tool for analyzing environmental processes (Nagendra 2004). With the expansion of geographic processing ability, it is possible to ask questions relevant to ecological change on an immediate level and analyze how change, or absence of change, is influenced by human activities (NRC 1999, Nagendra 2004).

The 1997 study, using GIS analysis and historical records to study the forests of East Texas, was limited by the data available at the time and the emerging use of computerized systems to process geographic data (Leipnik 1997). As the 1997 study has shown, significant conversions in forest composition have taken place in the area of interest since 1935. This current study uses methodology established in the 1997 study to make similar comparisons using contemporary (2012) data sources, thereby extending that body of research to a level of detail not previously available. This refinement in established methodology and its associated increase in level of ecological detail, offer insight into the causes for change be they local or regional, manmade or natural.

Objective of the Study

The objective of this study is to use Geographic Information System methodology to quantify differences between the 1935 survey and the Texas Parks and Wildlife, *Ecological Mapping Systems of Texas* data with special attention given to areas that may well retain historic natural characteristics.

Research Questions

The study will address the following questions and hypotheses using the described comparisons:

1. What types of change are evident?

Hypothesis: Overall, forested areas will have declined slightly, however, historic timber cultivation will have significantly changed the dominant timber species. A comparison, based on common attributes and Land Use/Land Cover (LU/LC) values, will identify any general changes.

2. Where are areas of remaining historic vegetation with emphasis given to historic and/or reintroduced longleaf pine?

Hypothesis: Isolated areas of historic forests, such longleaf pine, will be detectable, however, highly fragmented.

Hypothesis: Loss of longleaf pine will be evident, but habitats will not be entirely gone. Comparing the USDA map areas to the current TPWD data an estimation of loss for longleaf will be calculated.

3. What has been the impact of reservoir construction, particularly upon Bottomland Hardwood?

Hypothesis: Substantial areas of Bottomland Hardwood are now under water and many areas near reservoirs will have transitioned to recreation and residential use. Comparing the historical map areas to the current TPWD data an estimation of loss for bottomland hardwoods will be calculated.

4. Where are the major areas of urban growth and how has this growth affected the historical vegetation?

Hypothesis: Urbanization will be evident and reflected in the TPWD data as a new classification not present in the USDA map and less extensively represented in the 1997 study. These areas of change will likely be significant yet concentrated near urban centers, small towns, and major roadways.

CHAPTER II

Literature Review

Forests are resilient and will recover of their own accord given natural processes and time (Thompson 2009). That is fortunate. For three-hundred years, wood was the United States single dominant building product and the primary fuel source for homes, railroads, shipbuilding, and industry (MacCleery 2011). Wood, as a natural resource, was readily available in the United States and very abundant. As a result, little regard was given for deforestation or the ecological impact of timber harvesting (Boundless 2016). In fact, forests were considered a barrier to settlement and migration and any notion of timber shortage seemed impossible (D'Costa 2015). It was not until the 1830's and 1840's, with the Transcendentalist Movement and its romantic image of the natural world, that environmentalism and conservation entered into the public consciousness. It was not until the late nineteenth century, with the Forest Reserve Act of 1891, and later the McSweeny-McNary Forest Research Act of 1928 that environmentalism and conservation entered the American political discourse (Muhn 1992) (Boundless 2016). Growing public concerns elevated the natural world and presented a critique of industrialization and urbanization (Boundless 2016) leading to regulations, conservation, and sustainable forestry practices (MacCleery 2011).

By 1935, the target area of this study, like much of the timberlands of the Eastern U.S., had long been subjected to uncontrolled logging practices. To understand its condition at the time of the 1935 timber survey, it is important to review what is known of the history of the forests themselves and note a few of the organized forest management efforts introduced by political action. Those actions led to the State and Federal forest management organizations and formalized forest management practices of today. It is also important, for the purposes of this study, to understand the history and development of the data examined here.

Condition of the American Forest by 1920

Prior to European settlement, the native forest of U.S. land area, including Alaska, amounted to approximately one billion acres with about three-quarters of that forest covering the eastern third of the country (MacCleery 2011). From the 1600's to 1850, approximately 88 million acres of forest were cleared, but the demand for wood and charcoal was only just beginning. According to MacCleery, during the industrial growth years from 1850 to 1920, approximately 198 million acres of forest were cut. Toward the late 19th century, he estimates forests were being cut at a rate of 13.5 square miles per day. All totaled, from the 1600's to the 1920's, about 286 million acres, or 30% of the total native forests, had been cut and converted to other uses, such as agriculture. Today, due to conservation and sustainable practices, about 70% of that original one billion acres is still forest (MacCleery 2011).

Background to the 1935 USDA Timber Survey

The Forest Reserve Act of 1891 was the United States first step toward protecting public domain timber (Muhn 1992). It contained no specific management provisions or monies but did provide Presidential authority to set aside lands as public reservations. Several public reservations, such as the "Yellowstone National Park Timber Land Reserve" were created. By 1897, approximately 30 million acres had been set aside by Presidential proclamation (Fedkiw 1998). The Forest Service Organic Administration Act of 1897 established management guidance and qualified the purpose of forest reservations (Fedkiw

1998). This act granted the U.S. Department of the Interior authority and rule-making regulations. It allowed the General Land Office to hire employees and opened the reserves for public use. It also gave the U.S. Geological Survey the responsibility for mapping the reserves (Code 1897).

The McSweeney-McNary Forest Research Act of May 22, 1928 authorized a Nation-wide forest survey to obtain essential field information for existing and prospective forestlands. This survey's intent was to aid "in the formulation of guiding principles and policies fundamental to a system of planned management and land use for each forest region" within the United States (Cruikshank 1939). The **Forest Survey** was established under this Act and published numerous timber resources assessments throughout the United States but most significant to this study are two published in association with the Southern Forest Survey, headquartered in New Orleans, La..

Two documents assessing timber resources in Eastern Texas were written and published through the U.S. Department of Agriculture and the U.S. Forest Service. One report detailed resources in Southeastern Texas (Unit I) and the second detailed resources in Northeastern Texas (Unit II). In these, forest area was classified according to forest type-group. These type-groups were pine, pine-hardwoods, upland hardwoods, and bottomland hardwoods. A surviving map associated with these publications was digitized and georeferenced to provide area boundaries for comparison in this study.

Data collection for the survey was conducted in the fall and early winter of 1934-35 for Unit I and April through August for Unit II (Cruikshank 1939, Eldredge 1938). According to the publications, "parallel lines 10 miles apart were run." At 1/8th mile intervals, quarter-acre sample plots were established. Overall, 12,528 plots were identified in Unit II[1]. On the forested plots, which numbered 8,459 total, fieldsmen recorded information about forest type, forest condition, fire damage, density, reproduction, and overall site quality, along with species type and approximate age of any trees found there. "These data furnished the basis for the statistics of area, volume, and growth presented in this report (Cruikshank 1939)." The authors note that most of these areas "are largely second growth, typically found in small tracts intermingled with cultivated land" and that small farms were the leading type of land use (Cruikshank 1939).

The Eldredge/Cruikshank timber survey, its findings, and the resulting maps are significant in that they laid the foundation for all subsequent forest surveys in East Texas within the Forest Service Division of the USDA. To date there have been eight forest survey's and though borders, methods and approaches have changed, the most recent *Forests of East Texas, 2014* still closely mirrors the areas first described in 1935 (Brandeis 2014) as a result of the USDA's Forest Survey timber classification assessment.

East Texas Forest Condition and Timber Production in 1935

By 1935, many of the areas studied by the **Forest Survey** no longer retained their original tree cover. Following the Texas Revolution, the demand for building lumber steadily increased and by 1860 as many as 200 steam sawmills were in operation in Texas (Maxwell 2010). As a result, an estimated 100 million board feet of lumber was produced in East Texas in 1869. However, most of the pine forests of East Texas still remained untouched and boasted individual trees measuring five feet in diameter and 150 feet tall (Maxwell 2010). The "bonanza era" of Texas timber production occurred during the 50 years following 1880 and by 1907 Texas was the third largest U.S. timber producing state.

[1] The plot approximation is not recorded for Unit I, however, field methods would imply a comparable number of sites for Unit I.

An estimated 2.25 billion board feet were produced in 1907. According to Cruickshank and Eldredge, in Unit II of their survey (Southeast Texas) there were “at least” 330 saw mills in operation in 1937. Many were specialty mills by wood type such as pine, hardwood, or mixed wood. Most, about 300 mills, could produce as much as 20 million board feet per day, 24 mills could produce up to 39 million board feet per day, with five mills able to produce more than 40 million board feet per day. An estimated 5.5 billion board feet were produced from Unit II alone in 1935 (Cruikshank 1939). Other mills were devoted to exclusively making crossties, poles and piles, pulpwood, veneers, containers, cooperage, fuel wood, fence posts, handles, shingles, and mine-props (Cruikshank 1939). By the end of the “bonanza era”, which ended about the time of the Great Depression, an estimated eighteen million acres (7,284,342 ha.) of pine timber had been logged producing an approximate 59 billion board feet of lumber (Maxwell 2010). These reckless logging practices and no replanting protocol combined with very little regard for the environment, the discovery oil, and clear cutting of forests for oil production in the early 20th century destroyed much of the remaining native forests in the region (Wikipedia 2016).

As mentioned previously, native longleaf pine forest once stretched from Texas to Virginia, an estimated 60 million acres. By 1985 only 4 million acres remained (Boyer 1985). According the Eldridge Survey, in 1935 just over 600,000 hectares (1.5 million acres) of longleaf remained in Texas. Fortunately, the Texas Forestry Association was established in 1914 and the following year the state legislature established a state department of forestry. Later renamed the Texas Forest Service, the agency instituted programs for fire prevention, selective cutting, sustained yield, and reforestation on both public and private lands (Maxwell 2010). The Eldredge/Cruikshank publications and their generalized timber boundaries, sources used in this study, have a direct connection to those early forest conservation efforts (Rudis 2003).

The *Ecological Mapping Systems of Texas* (EMS-T)

The second major data source connected to this study is a 2012 release of Texas Parks and Wildlife Department's *Ecological Mapping Systems of Texas,* or EMS-T[2]. Developed in association with the Missouri Resource Assessment Partnership (MoRAP) this data represents a 398 classification, 10-meter spatial resolution vegetation, Land Use/Land Cover (LU/LC) map for the entire state of Texas (L. F. Elliott 2014). A combination of 30m satellite image mosaics and soil-mapping units were used to generate attribute image objects from 10-meter resolution air photos. The final mapped vegetation boundaries were generated from a combination of land cover and abiotic variables such as soil groups, elevation, geographic location, percent slope, riparian zones, ecoregion, and solar insolation. The final vegetation legend used the *NatureServe Terrestrial Ecological Systems* classification system to derive naming conventions for the ecological data (Comer 2003).

Forest Condition and Timber Practices Today

The U.S. Forest Service's Forest Inventory and Analysis (FIA) Program is the nation's "Forest Census (Service 2016)." It is the current descendent of the U.S. Forest Survey that Cruikshank and Eldredge worked under and traces its roots to the same McSweeney-McNary Forest Research Act of May 22, 1928. The FIA provides information, like tree species, health, wood production, harvest, and location used to assess America's forest resources (Service 2016). In its words, the program is "charged with

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[2] Ecological systems are defined by groups of plant communities which often occur together in the landscape and share similar ecological process, sub-straits, and environmental gradients (L. F. Elliott 2014).

periodically assessing the extent, timber potential and health of the trees of the United States (Prasad 2003)." Under this program, Elbert L. Little, Chief Dendrologist with the USDA Forest Service, published a series of maps for 135 eastern U.S. tree species between 1971 and 1977. Developed from botanical lists, forest surveys, field notes, and herbarium specimens, Little's map series has become the standard reference for most U.S. and Canadian tree species ranges (Prasad 2003).

According to the Forest Inventory and Analysis Program, in 2014, only about 27% of the trees in southern forests were 60 years old, or older. For timberland, 51% is 40 years old or less with 9% of that being less than 5 years old. This is primarily due to short-rotation yellow pine plantations, which are typically harvested between 25 and 40 years of age (Oswalt 2014).

Despite the devastation of native forests in East Texas, areas of native habitat still exist to this day (Nixon 1977, Schafale 1983). Although rare, these areas offer a glimpse into the climax ecological communities of pre-settlement East Texas. Due to a decreased demand for wood and effective agricultural practices, many areas once devoted to agriculture have been allowed to regenerate naturally in an attempt to bring back its pre-settlement ecosystems (Cox 2012) (MacCleery 2011). Efforts to re-establish longleaf pine are also underway all over East-Texas (The Nature Conservancy 2016). Fortunately, conversion to fossil fuels and conservation practices adopted in the late 19th and early 20th centuries led to sustainable timber usage nation-wide and today forest growth exceeds harvest by 40%. That amounts to an average forest growth of four times greater than in 1920 (MacCleery 2011). In 2014, the total forested area in Southeast and Northeast Texas was 12.2 million acres (Brandeis 2014). The 2014 survey is slightly smaller in total area than the 1935 survey, having eliminated some of the far western counties which were mostly Texas Blackland Prairie and Cross Timbers Ecoregions (Griffith 2004). Though the 2014 survey does not exactly match the areas surveyed in 1935, they both cover the same general region of East Texas. When this region is analyzed using both the primary data sources of this study, i.e. Eldredge/Cruikshank and the EMS-T, forests today account for 14.6 million acres, or 58.7% of the entire study area, according to the TPWD *Ecological Mapping Systems of Texas* polygon coverage.

CHAPTER III

Methodology

In its essence, this is a comparative study between two maps. The first of these is from 1935 representing generalized ecological regions for areas of East Texas. The second map is from a 2012, pre-release version, of the Texas Parks and Wildlife, *Ecological Mapping Systems of Texas* data set. Using the digitized boundaries evident in the 1935 map, the second dataset was digitally clipped to present a matching area of interest. At the database level, a crosswalk between the two maps was designed using logical classification groupings (i.e. LU/LC) and established methodology presented in a previous study. The combination of techniques provides a mechanism by which the generalized assumptions from the 1935 map could be compared to the detailed assumptions of the 2012 data.

Study Area

The study area of this project covers 10,052,731 hectares in Eastern Texas, including portions of 57 counties. The area comprises potions of four broad ecological regions, as described by Omernik: Cross Timbers, Texas Blackland Prairie, Western Gulf Coastal Plain, South Central Plains (Griffith 2004). Figure 1 shows these regions in association with the overall Eldredge/Cruikshank boundary. Table 1 shows the area totals for each of the ecoregions.

Table 1

Area Totals for Ecoregions Spanned by the Eldredge/Cruikshank Survey

Rank	Ecoregion	Area Total
Most	South Central Plains	6,360,590 ha
-	Cross Timbers	2,743,223 ha
-	Texas Blackland Prairie	758,828 ha
Least	Western Gulf Coastal Plain	182,771 ha

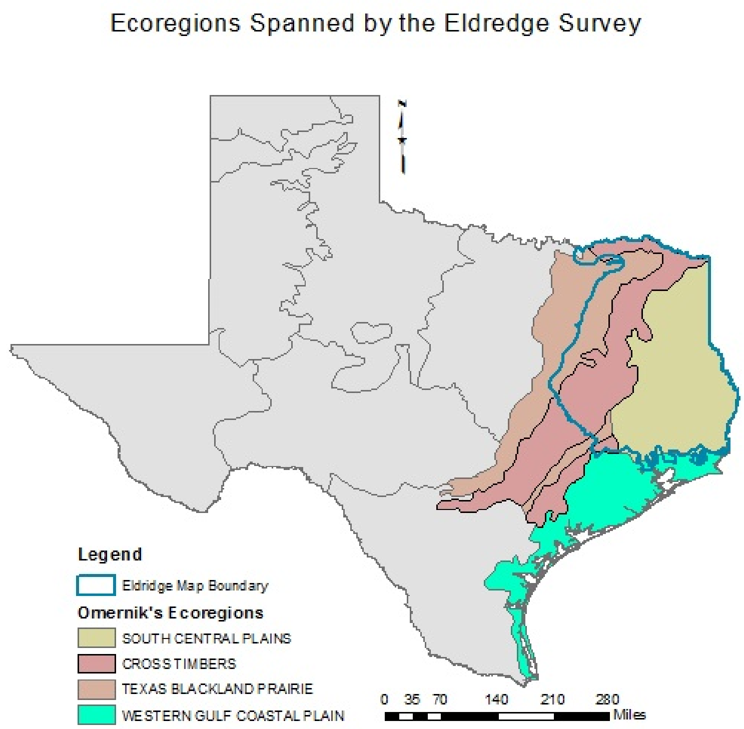


Figure 1. Ecoregions Spanned by the Eldredge/Cruikshank Survey (Omernik)

Western Gulf Coastal Plain Description

The Western Gulf Coastal Plain, Figure 2, is the least represented of the four ecoregions with 182,771 hectares. It is a nearly level region of slowly drained marshes and prairies dissected by streams and rivers flowing into the Gulf of Mexico (TPWD 2016). Texas Parks and Wildlife describes the region as including "barrier islands, along the coast, salt grass marshes surrounding bays and estuaries, remnant tallgrass prairies, oak parklands and oak mottes scatted along the coast, and tall woodlands in the river bottoms.

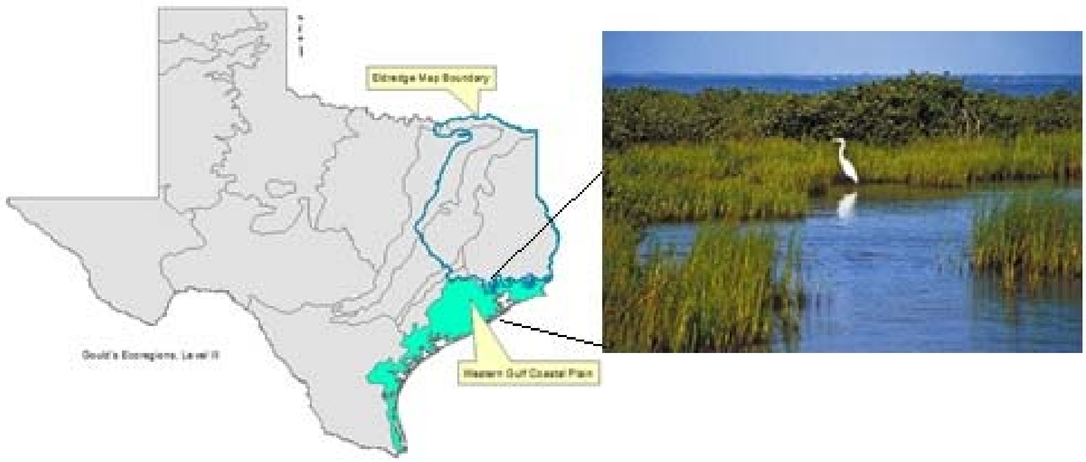


Figure 2. Western Gulf Coastal Plain (TPWD)

Texas Blackland Prairie Description

The Texas Blackland Prairie comprises 758,828 hectares in the area of interest and is characterized by the deep black soils of the region which supports tall-growing grasses such as bluestem, indiangrass, and switchgrass (TPWD 2016). See Figure 3. Much of the area has been converted to food production and forage crops because of the fertile soils and abundant rainfall (TPWD 2016).

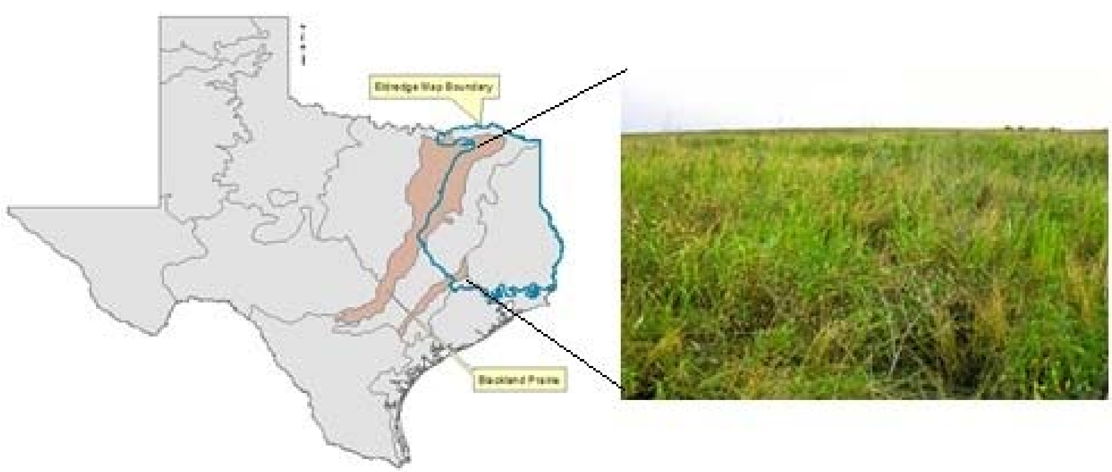


Figure 3. Texas Blackland Prairie (TPWD)

Cross Timbers Description

Cross Timbers, also known as the Post Oak Savannah (Griffith 2004) and as the East Central Texas Plains (Gould 2011), is the transition zone between east Texas pine forests and the blackland prairies. See Figure 4. It extends into the Great Plains northward and into the forests to the east and is described as "gently rolling to hilly, a beautiful mosaic of woodlands, pockets of prairies, cross-cutting streams and rivers on their way to the Gulf (TPWD 2012)." This area is mostly used for range and pastureland with scattered areas of oak (Griffith 2004). Within the area of interest, there are 2,743,223 hectares of the Cross Timbers Ecoregion.

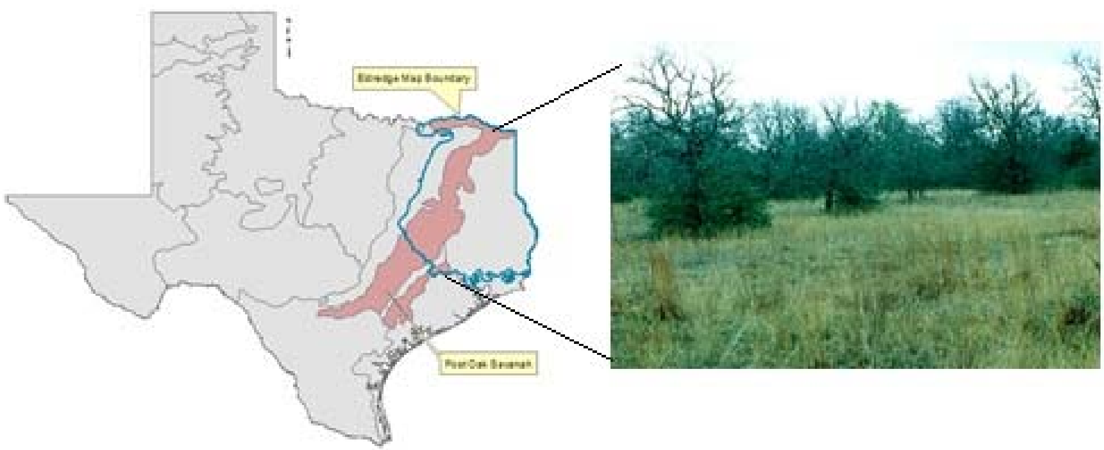


Figure 4. Post Oak Savanah (TPWD)

South Central Plains Description

Areas of the South Central Plains region (Griffith 2004), also known as the Pineywoods (Gould 2011), are characterized by meandering rivers, complex ecological forests, and woodlands. See Figure 5. The Eldredge/Cruikshank survey area contains 6,360,590 hectares of the ecoregion making it the single most represented ecoregion by area. These are the wettest areas of forest in the state, averaging in annual rainfall of 32 to

50 inches yearly (TAMU Forest Service 2014). Typical of this region are shortleaf pine forest, longleaf pine savanna, and bottomland hardwoods (TPWD 2012) with scattered areas of cropland, planted pastures, and native pastures. Timber and cattle production are important industries in the region (TPWD 2016).

Figure 5. Pineywoods/ South Central Plains (TPWD)

Data Preparation

The digitized USDA Map represents generalized assumptions from 1935. The Texas Parks and Wildlife, *Ecological Mapping Systems of Texas* (EMS-T), first published in 2012, represents the contemporary view of the landscape as it exists today. Between the two is a crosswalk of nomenclature values derived from McMahan's, *The Vegetation Types of Texas, Including Cropland* (McMahan 1984). Established methodology for the crosswalk is described in Leipnik's *Geographic Information System Based Analysis of Current and Historical Vegetation Composition in East Texas*. (Leipnik 1997). By crosswalking, the detailed EMS-T common name descriptions may be associated to the much simpler Eldredge/Cruikshank timber types based on mutual nomenclature values described by Leipnik. When examined by timber type boundary, the resultant polygons provide a measure of area for any associated LU/LC values within the EMS-T. This provides a mechanism for calculating a percent of ecological composition.

The first step was to create workspaces and databases to accommodate each of these and to organize their data, databases, and layers into a cohesive working model for analysis. Each data source required a unique and appropriate workflow in order to isolate the required information. For instance, on the one hand, the Eldredge/Cruikshank map existed only in its paper form. On the other hand, the TWPD EMS-T data accounted for approximately one terabyte of digital polygon data delineating ecological systems, on a micro scale, for the entire State of Texas. Between the two, a bridge, or crosswalk process had to be determined. Primary to all was the area of interest, namely the area extent and attributes of the Eldredge/Cruikshank Timber survey map.

Using the USDA map, figure 6, which displays timber communities in East Texas, a GIS layer was generated. This map covers Unit's I & II of the 1935 East Texas Forest Resources Survey. Published versions of the Eldredge/Cruikshank map were sub-divided into each Unit's respective publication and included as a foldout supplement. The historical map has slight nomenclature and refinement differences over the two published versions but offers a composite rendering of the entire two survey units.

As this map only existed in its paper form, the paper map had to be scanned, registered and digitized, figure 7. To preserve area and make analysis of the area polygons valid, the map was scanned and registered to the Albers Equal-Area Conic projection system. To register the scanned map, a series of 367 registration points were identified using features common to the county boundary and riverine features. These two feature layers were downloaded from Texas Natural Resources Information Service (TNRIS).

Once the scanned map was registered and projected, the map's timber type boundaries were digitized resulting in six overall vegetation classes, or timber type boundaries. The generalized vegetation types are presented in Figure 8, representing 81 separate timber type boundaries. One relatively small area of 6,074 hectares that was not identified by the Eldredge/Cruikshank survey, yet enclosed by the overall area of interest was identified and digitized with the classification of "No Classification."

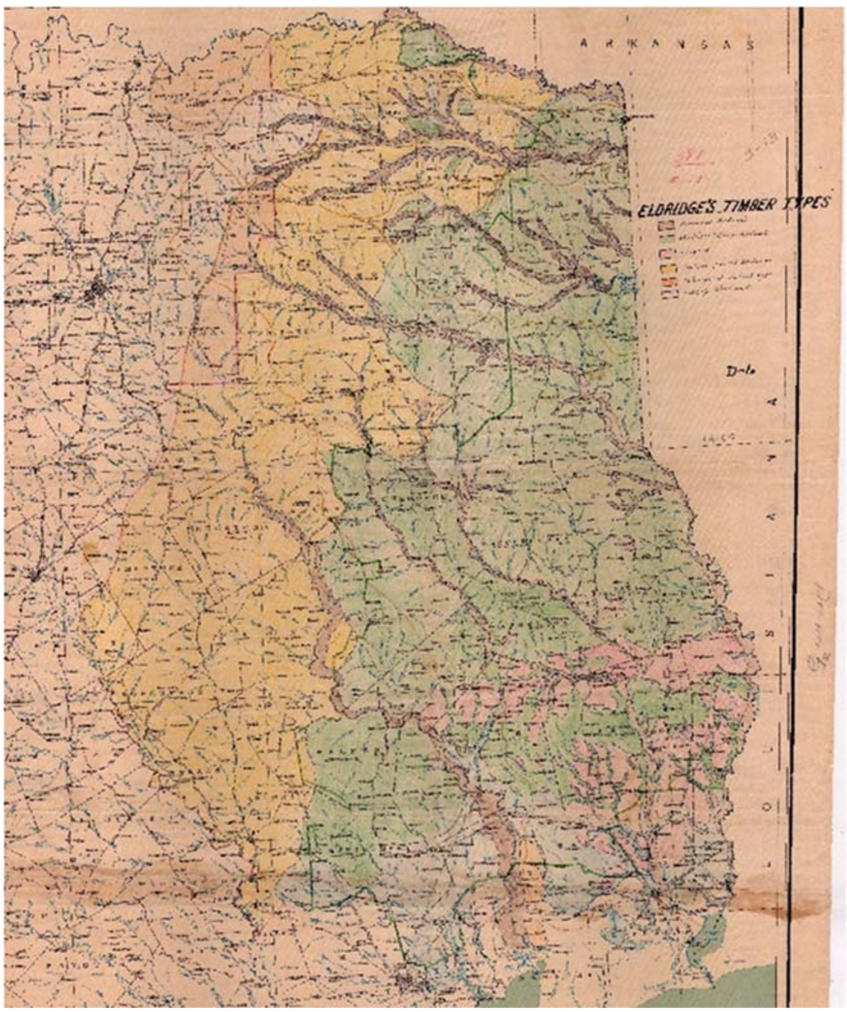


Figure 6. Eldredge/Cruikshank Hand Colored Field Map

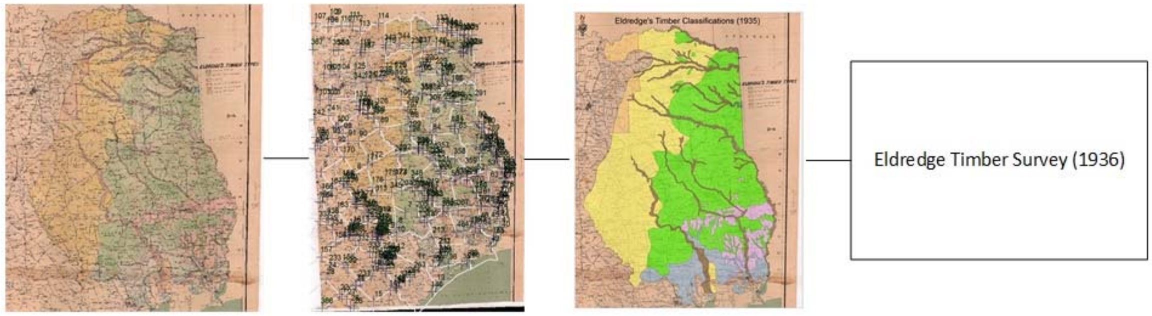


Figure 7. Scan, Registration, and Digitization of the Eldredge/Cruikshank Map (Eldredge/Cruikshank)

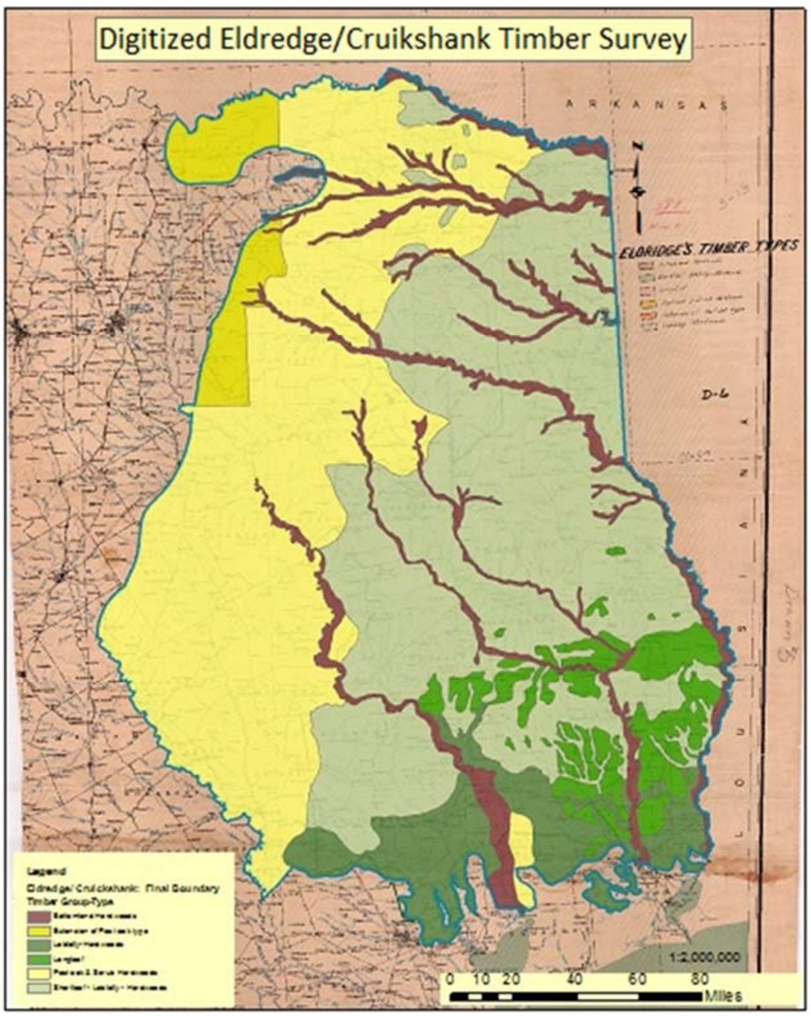


Figure 8. Digitized Eldredge/Cruikshank Timber Types Overlain on the Scanned Field Map (Eldredge/Cruikshank)

The Eldredge/Cruikshank map is classified into six timber types. Each of these classes are described as being at least 75% dominated by the represented species (Cruikshank 1939). In mixed forest, for example, those classified as “Shortleaf-Loblolly-Hardwoods,” the representative vegetation types consist of 25%, or more, of the species indicated (Cruikshank 1939). According to the authors, the **Forest Survey** publications “apply to large areas and should not be interpreted as portraying correctly the forest situation for small sections (Cruikshank 1939).” From this, we may assume its authors made broad assumptions and generalizations from their field data. We also know that their primary concern was timber. These two general assumptions provide the first step towards reconciling its presented data and the detailed data of the EMS-T.

Methods and Approaches

Using data provided by the TPWD, a comparison between current and historic vegetation was made. The TPWD data, called the *Ecological Mapping Systems of Texas* (EMS-T), represents a supervised classification system, based on the *NatureServe Ecological System Classification System*, described by Comer (2003). The TPWD modeling method uses air photos, ecoregions, Soil Survey Geographic Database (SSURGO) soils, Digital Elevation Model (DEM) based variables, and hydrology to develop mapping sub-systems, representing classified polygons, for the *NatureServe Ecological System Classification*. According to Comer, the mapping subsystems were made as precise as possible. The map objects of the TPWD data are generated at a 10-meter resolution, figure 9.

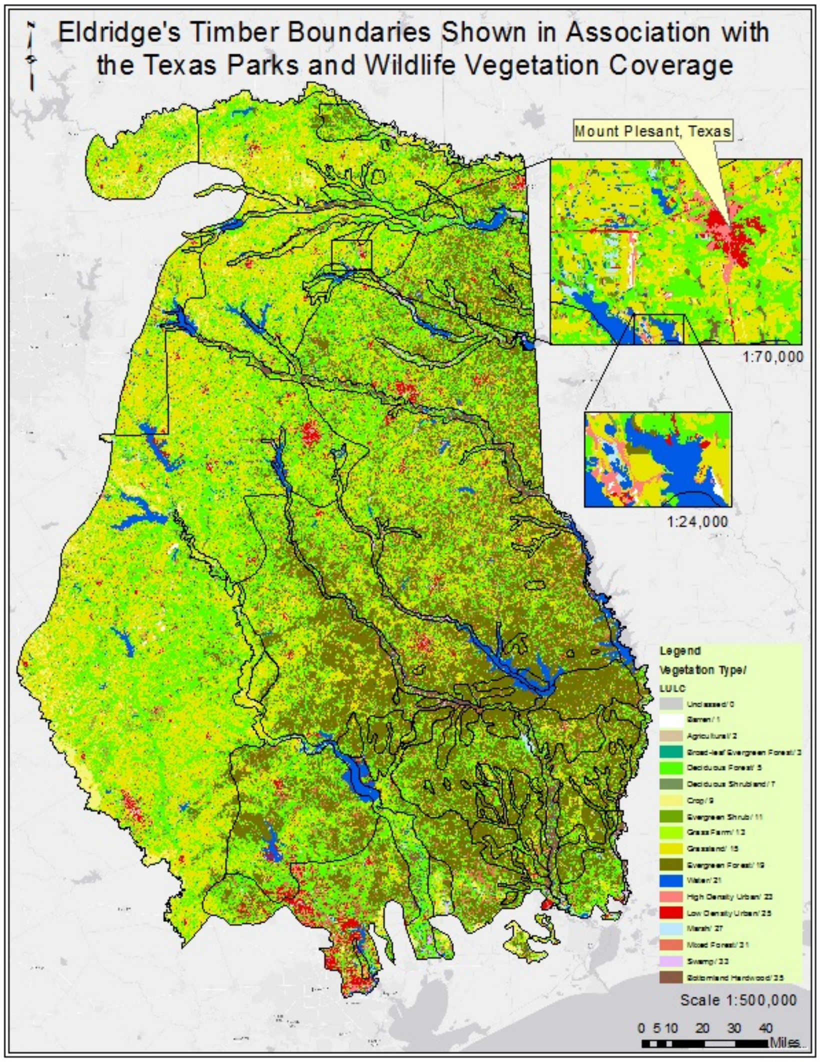


Figure 9. Ecological Mapping Systems of Texas Shown in Association with the Overall Eldredge/Cruikshank Survey Boundary (TPWD)

Ecological regions are areas of general similarity based on type, quality, and quantity of environmental resources (Griffith 2004). Previous classification systems, Levels I – IV, divided North America into ecological regions, each level providing a different hierarchical description of the ecological region (EPA 16). Level I, the coarsest level, divided North America into 15 ecological regions. Level II divided North America into 50 ecological regions. Level III divided the continental United States into 105 ecoregions. Of these, there are 12 level III ecoregions in Texas. The *Ecological Mapping Systems of Texas* classification system extends this to 398 sub-regions representing approximately 17.75 million environmentally classified polygons of vegetation data in Texas although not all of these sub-regions exist in the area of interest.

Once digitized from the original source map, an overlay between the Eldredge/Cruikshank map and the TPWD data presented numerous small areas where the gross boundaries between the two coverages did not match. Some of this may be attributed to naturally occurring meanders and cut-offs that quite likely have occurred since 1935. However, along major rivers, the level of graphic detail was significantly higher along the EMS-T boundary. In other areas, reservoirs now existed where previously they had not. Some amount of error can be expected from the digitization process, however, the cumulative effect of boundary variances initially created significant differences in area calculations between the two geographic layers. To adjust for this, it was noted that some portions of the boundary along the west and south were not intended to follow any natural feature, except those of the timber type boundary being described in the source map. The line-work for these areas were preserved. Other boundaries, such as those along Red and Sabine Rivers were intended to follow, and were drawn in conjunction with, the natural features identified on the 1935 map. We can assume the author's intent was to follow these natural features as accurately as possible and most differences can be attributed to the available source maps of the day. In areas where it was essential to preserve the boundary, the Eldredge/Cruikshank polygons were modified to fit the EMS-T boundary. Using the preserved digitized polygon boundaries of the historical map and the modified line work for the natural features, an overall boundary was created which precisely described the project's area of interest. The greater EMS-T dataset was then clipped using this hybrid combination of digitized line work. This defined the overall boundary outline and area extent of the area of interest. In the end, there was a 7319 hectare difference between the two data sets and their area totals. Most of this, 6074 hectares, may be accounted for by the "No Classification" polygon. The rest, 1,245 ha is accounted for by mapping variations in the EMS-T around Caddo Lake, an existing reservoir feature of Mr. Eldredge/Cruikshank's time and several, small, independent polygons located along the Red River.

Generated from formalized data sources, satellite imagery, soil boundaries, and numerous other validated boundary files, the TPWD EMS-T data represents the highest level of digital accuracy and geographic detail available (Texas Parks and Wildlife Department 2014). The *Ecological Mapping Systems of Texas* data is a 398 class, 10-meter spatial resolution vegetation map of Texas used by TPWD to "help manage and conserve the resources of Texas (L. F. Elliott 2014)." The overall coverage of Texas amounts to approximately one terabyte of polygon data and 17,751,158 individual irregular polygons. Clipping the data to the area of interest resulted in 1,631,531 individual irregular polygons and 4.06 GB of data.

The EMS-T was commenced in 2007 and finished in 2014, consisting of seven development phases (L. F. Elliott 2014). "Land cover from 3-date, 30-meter resolution satellite imagery, and abiotic site types from digital county soil surveys and DEM-derived variables, were used together to model the current vegetation. This was accomplished by attributing land cover and abiotic variables to 10-meter resolution image objects generated from NAIP[3] photographs, and then executing expert rules in the form of: land cover + abiotic variable = mapped type. Hence, each image object was assigned a current vegetation type based on expert rules (L. F. Elliott 2014)." Quantitative ground data samples were collected at more than 12,000 spatially specific locations and additional ancillary data, including road and stream centerlines were included, where required (L. F. Elliott 2014). The naming convention used to develop the legend of vegetation types comes from the *NatureServe Terrestrial Ecological Systems* classification (Comer 2003).

For download and online management, the TPWD EMS-T is offered up by ecoregion. These are defined by Omernik's *Level III Ecoregions of the Continental United States* which describes 105 ecoregions in the in the continental United States. The Eldredge/Cruikshank map spans four of these ecoregions (East Texas Central Plains, West Gulf Coastal, Texas Blackland Prairie, South Central Plains). See Figure 10.

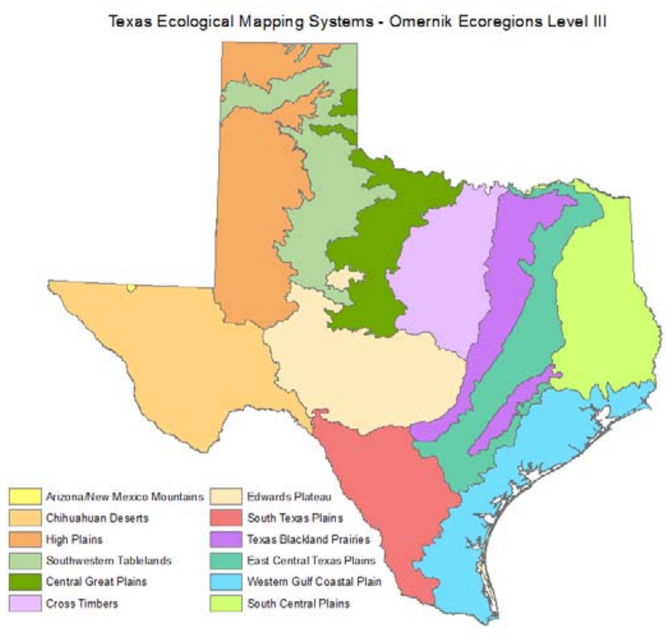


Figure 10. Omernik's Ecoregions Level III for Texas (Omernik).

[3] (NIAP) National Agriculture Imagery Program

The Eldredge/Cruikshank timber classifications and the TPWD classifications represent two ends of a scale that goes from very generalized to precise, figure 11. To associate the descriptive classification information directly required finding commonality between the two datasets. To crosswalk the vegetation classifications a correspondence between the two data sources was determined using methodology developed by Leipnik (Leipnik 1997). That study examined broad associations between the Eldredge/Cruikshank Timber classifications and a Texas Parks and Wildlife map created in 1984 (McMahan 1984). The 1984, *Vegetation Types of Texas, Including Cropland* (McMahan 1984) describes 52 physiognomic regions, of which 12 are present in areas enclosed by the digitized boundaries of the Eldredge/Cruikshank Timber survey, see figure 12. Using the digitized polygons from the Eldredge/Cruikshank survey, the McMahan statewide data was clipped by each of the six timber types to create an area of interest. The resulting vegetation coverages were compared; first, to the results of Leipnik as a general crosswalk guide, then, using a frequency distribution chart and a pivot table of attribute values, an area count was generated for each vegetation type. The resulting graphs were used to confirm vegetation types by quantity in a given area, thus providing both a geographic and a common vegetation association to both the Eldredge/Cruikshank map and the TPWD EMS-T data, figure 12.

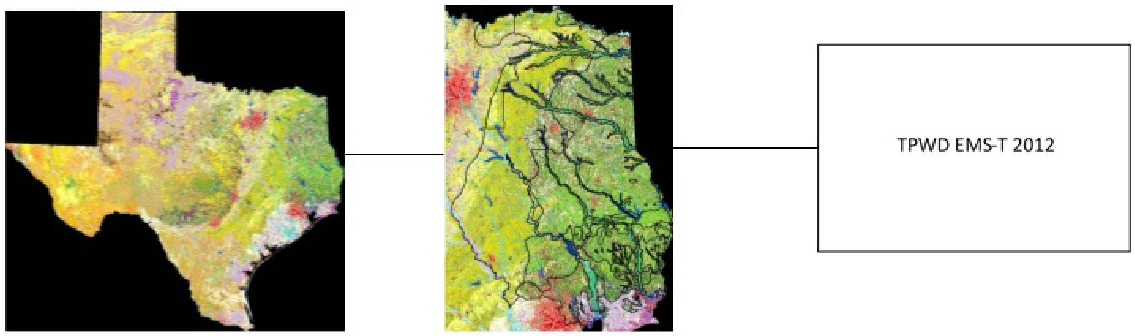


Figure 11. Ecological Mapping Systems of Texas and the Area of Interest (TPWD)

McMahon 1984 selected by 'Post Oak & Scrub Hardwoods'	
Post Oak Woods, Forest and Grassland Mosaic	29.95%
Post Oak Woods/Forest	18.89%
Willow Oak-Water Oak-Blackgum Forest	0.54%
Elm-Hackberry Parks/Woods	5.27%
Water Oak-Elm-Hackberry Forest	3.30%
Bald Cypress-Water Tupelo Swamp	0.04%
Young Forest/Grassland	0.08%
Pine Hardwood	10.48%
Crops	7.29%
Other native or introduced grasses	22.21%
Urban	0.06%
Water	1.89%
	100.00%

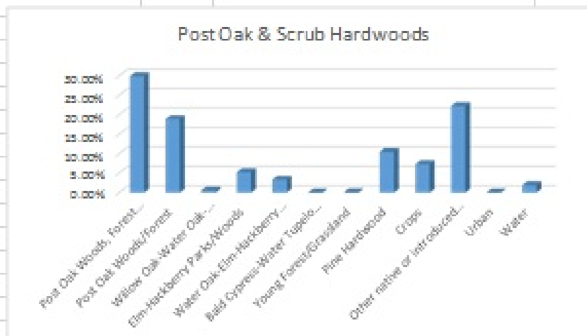


Figure 12. Graph and Summary for the Post Oak and Scrub Hardwoods Classification

The "Common Name" descriptions and associated Land Use/ Land Cover category in the TPWD data provided the best fit for a crosswalk. As an added level of confidence, polygon boundaries of the McMahon map were validated with those of the EMS-T for general name and type consistency. Using this method, the detailed 398 classes of the TWPD EMS-T were reconciled to 18 generalized LU/LC categories. For a conceptual flowchart, see Figure 14.

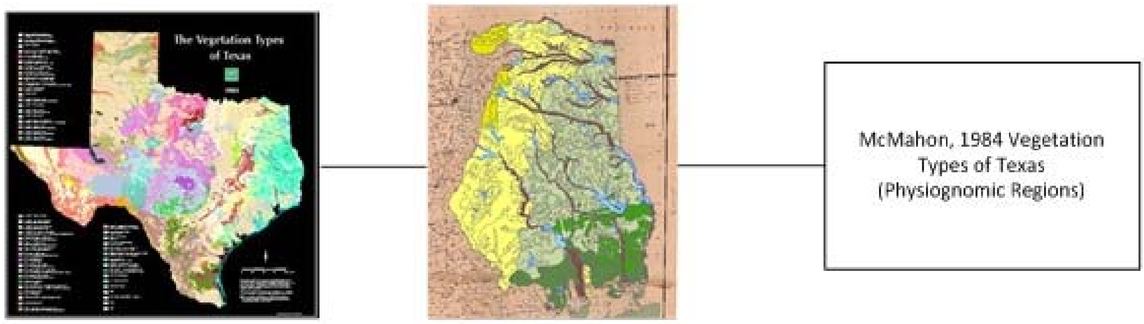


Figure 13. McMahan, *1984 Vegetation Types of Texas* and Eldredge/Cruikshank Area of Interest (McMahan-Eldredge/Cruikshank)

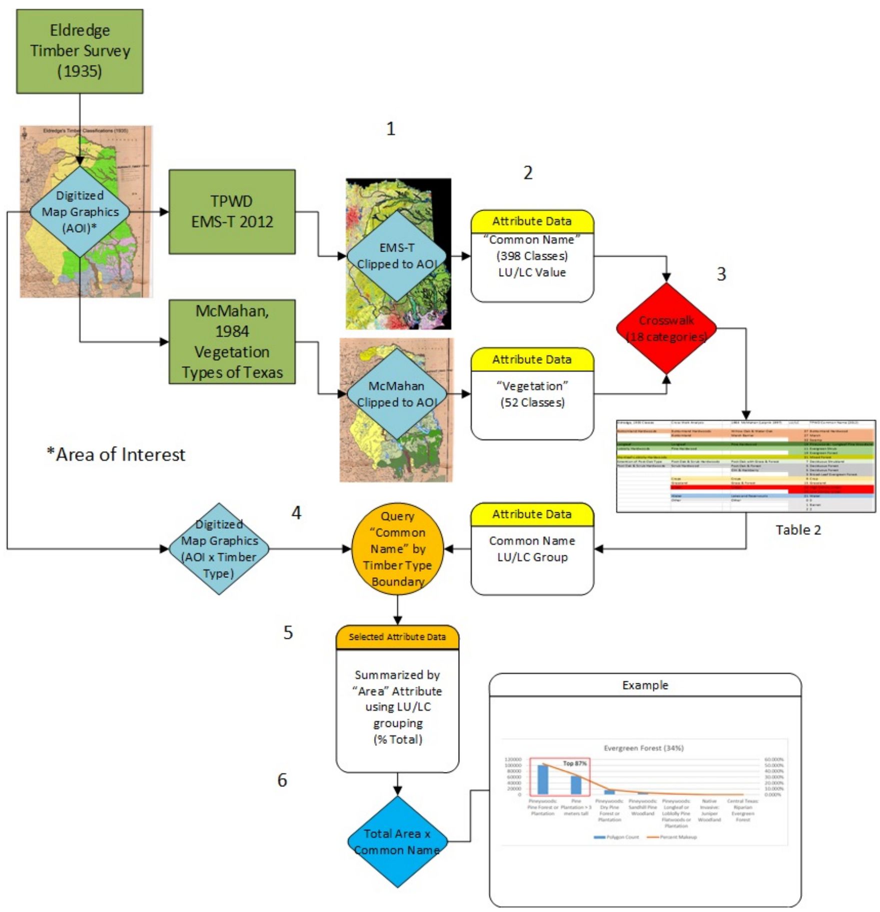


Figure 14. Flow Diagram for Data Analysis.

Some areas, such as "Urban High Density" and "Swamp" were not described in the Eldredge/Cruikshank map. In 1984, populated areas are simply described as "Urban," with no distinction for density. "Swamp" is not described in the 1984 map either, however, areas of "Swamp" occurrence were found to be congruent with the "Bottomland Hardwood" classification of the Eldredge/Cruikshank map. Some areas, such as "Bottomland Hardwoods" and "Deciduous Forest" show a direct reference between the two sources of data, via their naming convention. The crosswalk of associated values is presented in Table 2.

Table 2

Crosswalk of Vegetation Types

Eldredge, 1935 Timber Type	Crosswalk Analysis	1984 McMahan (Leipnik 1997)	LU/LC	LU/LC Type
Bottomland Hardwoods	Bottomland Hardwoods	Willow Oak & Water Oak	37	Bottomland Hardwood
	Bottomland	Marsh Barrier	27	Marsh
			33	Swamp
Longleaf	Longleaf	Pine Hardwood	19	Evergreen Forest
Loblolly Hardwoods	Pine Hardwood		11	Evergreen Shrub
Shortleaf-Loblolly-Hardwoods			31	Mixed Forest
Extension of Post Oak Type	Post Oak & Scrub Hardwoods	Post Oak with Grass & Forest	7	Deciduous Shrubland
Post Oak & Scrub Hardwoods	Scrub Hardwood	Post Oak & Forest	5	Deciduous Forest
		Elm & Hackberry	5	Deciduous Forest
			3	Broad-Leaf Evergreen Forest
	Crops	Crops	9	Crop
	Grassland		13	Grass Farm
	Grassland	Grass & Forest	15	Grassland
	Urban	Urban	23	High Density Urban
			25	Low Density Urban
	Water	Lakes and Reservoirs	21	Water
	Other	Other	0	0
			1	Barren
			2	2

With the crosswalk in place, a selection set for each of the six Eldredge/Cruikshank timber classifications was generated to identify relevant areas of the EMS-T. For instance, the polygon boundaries of the “Short Leaf, Loblolly, Hardwoods” classification were used to clip the EMS-T and separate layers were created for compositional vegetation and area calculations.

To compare back to the EMS-T, a summary of the areas of highest percentage was used to identify ecosystem common name. For example, the Eldredge/Cruikshank classification for “Short Leaf, Loblolly, Hardwoods” identifies its major ecosystem as “Evergreen Forest” within the crosswalk. “Evergreen Forest” is 34% of the total area identified or 1,346,933 hectares of the total area of 3,975,983 hectares. The LU/LC value for “Evergreen Forest” is 19. This LULC value equals 34% of the total ecological systems identified by “Short Leaf, Loblolly, Hardwoods.” By crosswalking in this fashion, a compositional makeup was identified in the EMS-T by “Common Name” and a summary count of the polygons which make up that 34%. Figure 15 represents an example. Subsequent application of this process allows for analysis of any of the LU/LC types within the “Short Leaf, Loblolly, Hardwoods” Classification. For each of the six Eldredge/Cruikshank Classifications, this process was used to identify the highest percentage or area by EMS-T “Common Name.” Detailed findings of the major ecosystems, EMS-T “Common Name,” percent of ecological composition, and polygon count, are presented in Appendices A-F.

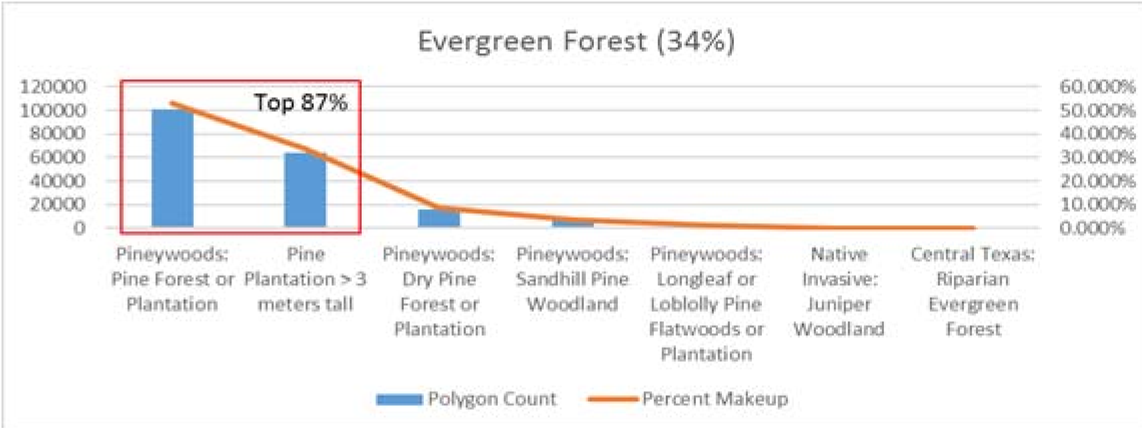


Figure 15. Summary Percentage of the Evergreen Forest (LU/LC 19) Value x Common Name

The methods described above were "hand" tabulated from the various sources and therefore susceptible to recording error. Essentially, in that method, the Eldredge/Cruikshank boundary was used to select values within the EMS-T and their associated LU/LC value was then recorded. As an added measure of confidence, the Eldredge/Cruikshank data tables were modified to include the crosswalked LU/LC value and an additional comparison was made using the Tabulate Intersection tool from the ArcGIS software ArcToolbox. The Tabulate Intersection tool computes the intersection between two feature classes and cross-tabulates the area, length, or count of the intersecting features. By adding the crosswalked LU/LC value to the Eldredge/Cruikshank feature as an attribute, a comparison between the two feature layers was run as an automated process. This automated approach presented slightly different resultant values, but none were greater than 0.07% when compared to the hand-tabulated calculations.

CHAPTER IV

Analysis and Results

Table 4 describes the area extent of each vegetation coverage digitized as polygon boundaries from the 1935 Eldredge/Cruikshank map. The resulting overall area calculation presents 10,052,731 hectares. Of this, 7,319 hectares represent areas not originally surveyed in the 1936. Removing this small portion presents a total calculated area of 10,045,412 hectares within the area of interest.

Table 3

Summary table of area for the digitized Eldredge/Cruikshank timber types

Eldredge Timber Type	Polygon Count	Area (acres)	Area (hectares)	Percentage (ha)
Bottomland Hardwoods	9	2,080,508	841,936	8.375%
Extension of the Post oak type	2	931,697	377,030	3.751%
Loblolly Hardwoods	6	1,831,812	741,294	7.374%
Longleaf	33	1,511,162	611,534	6.083%
Post oak- Scrub Hardwoods	9	8,661,092	3,504,954	34.866%
Shortleaf-Loblolly-Hardwoods	21	9,825,052	3,975,983	39.551%
	80	24,841,305	10,052,732	100%
No Class + Excluded Polygons		18,086	7,319	
Total Sum			10,045,413	99.927%

The 398 TPWD EMS-T classifications resolve to 18 broad classes when taken by their LU/LC description. The resulting broad classes are shown in table 5. The area totals are slightly different, however, the information in table 5 was generated from the final Eldredge/Cruikshank polygon boundaries file which already accounts for the “no class” classification area of 6074 hectares. Adding this small area back into the calculation presents a 1245 hectares difference between the two results, or 3077 acres, which is .07% difference in error. As mentioned previously, when examined in detail these areas were attributed to several independent polygons in the EMS-T, representing island features, along the Red River and slight mapping variations around Caddo Lake. As these could not be reconciled with the USDA map, the areas were excluded from this analysis.

Table 4

LU/LC, Classification, and Area

LU/LC	Classification	Number of Records	Area (hectares)	Percent
0		147	38	0.001%
1	Barren	11,362	17,012	0.170%
2		246	215	0.002%
3	Broad-leaf Evergreen Forest	3,315	215	0/045%
5	Deciduous Forest	589,143	3,061,705	30.497%
7	Deciduous Shrubland	32,789	61,157	0.609%

(continued)

LU/LC	Classification	Number of Records	Area (hectares)	Percent
9	Crop	31,938	249,667	2.487%
11	Evergreen Shrub	46,803	161,867	1.612%
13	Grass Farm	951	1,262	0.013%
15	Grassland	351,486	3,046,015	30.341%
19	Evergreen Forest	268,856	2,139,183	21.308%
21	Water	18,986	294,824	2.937%
23	High Density Urban	19,483	69,269	0.690%
25	Low Density Urban	49,234	181,261	1.806%
27	Marsh	26,932	61,004	0.608%
31	Mixed Forest	146,609	400.957	3.994%
33	Swamp	14,277	57,495	0.573%
35	Bottomland Hardwood	19,514	231,930	2.310%
–	–	1,631,531	10,039,339	100%

Two classes (0 and 2) were initially used as types of barren landscape in Phase 1, of the Texas Parks and Wildlife data acquisition process, then later reclassified into the "Barren" classification for subsequent Phases. The overall Eldredge/Cruikshank boundary spanned sections of the TPWD EMS-T that included Phases 1 and 2.

For purposes of this study, a minimum 80% composition threshold was established for the portions that would be discussed. For a detailed description of each vegetation type within any particular Eldredge/Cruikshank classification, see Appendices A-F.

Findings, EMS-T x Bottomland Hardwood

The digitized boundary for Bottomland Hardwoods contains 841,936 hectares (Figures 16 and 17). Current composition of this area is 31% Deciduous Forest, 18% Grassland, 14% Bottomland Hardwood, 13% Water, 12% Evergreen Forest, and 4% Swamp. This accounts for the top 92% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the six categories comprising this 92%, as described by EMS-T nomenclature, is presented in Appendix A.

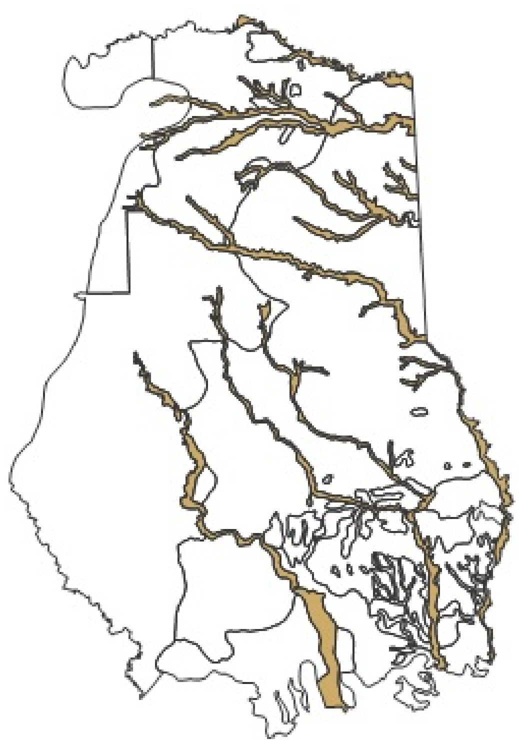


Figure 16. Bottomland Hardwood.

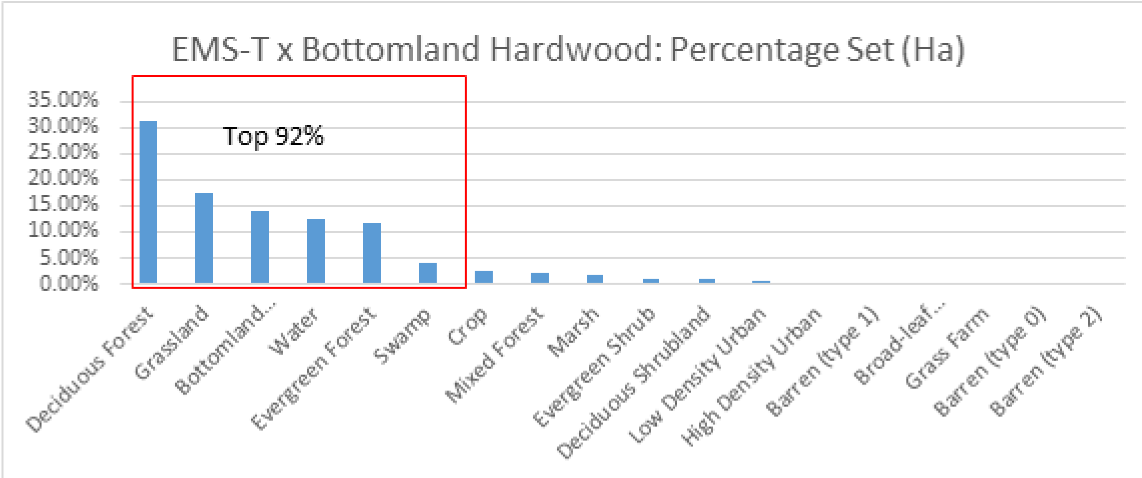


Figure 17. Current Day Ecological Composition of Bottomland Hardwood x Percent.

Findings, EMS-T x Short Leaf, Loblolly, Hardwoods

The digitized boundary for Eldredge/Cruikshank's "Short Leaf, Loblolly, Hardwoods" classification contains 3,975,983 hectares (Figures 18 and 19). Current composition of this area is 34% Evergreen Forest, 29% Deciduous Forest, and 21% Grassland. This accounts for the top 84% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the four categories comprising this 84%, as described by EMS-T nomenclature, is presented in Appendix B.

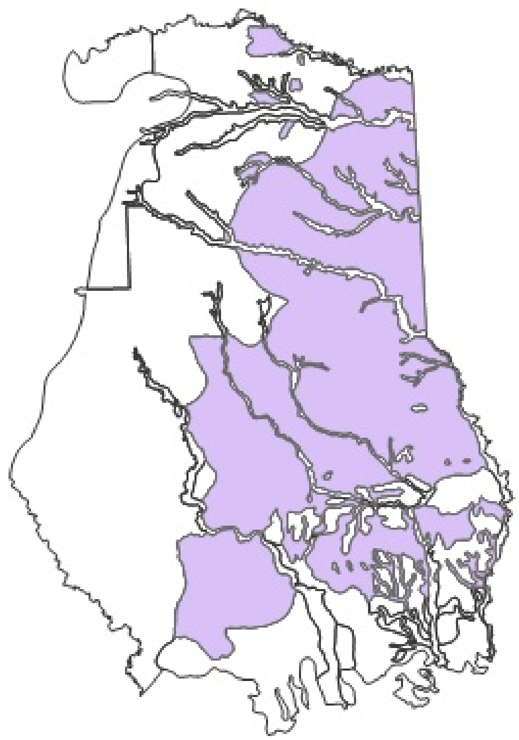


Figure 18. Short Leaf-Loblolly-Hardwoods.

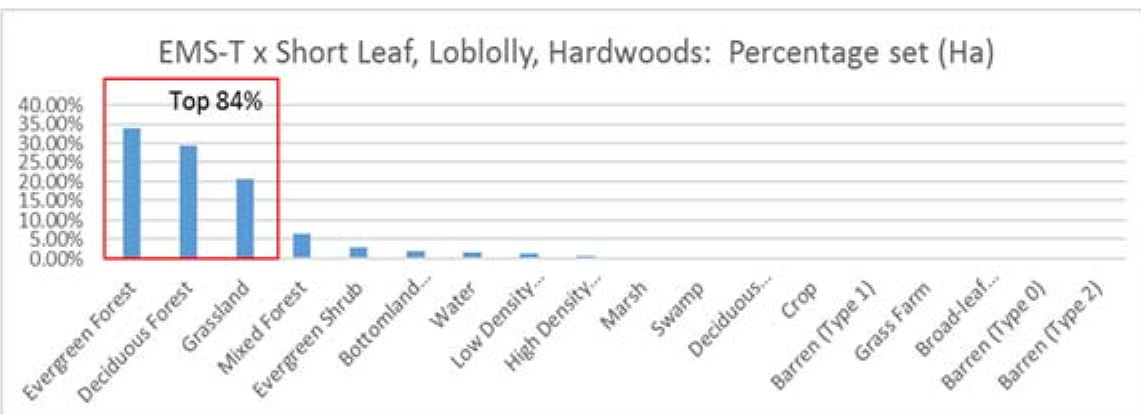


Figure 19. Current Day Ecological Composition of Short Leaf, Loblolly, Hardwoods x Percent.

Findings, EMS-T x Post Oak, Scrub Hardwood

The digitized boundary for Eldredge/Cruikshank's Post Oak, Scrub Hardwood classification contains 3,504,954 hectares (Figures 20 and 21). Current composition of this area is 49% Grassland, 35% Deciduous Forest, 5% Crop, 3% Evergreen Forest, and 2% Water. This accounts for 94% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the five categories comprising this 94%, as described by EMS-T nomenclature, is presented in Appendix C.

Figure 20. Post Oak, Scrub Hardwoods.

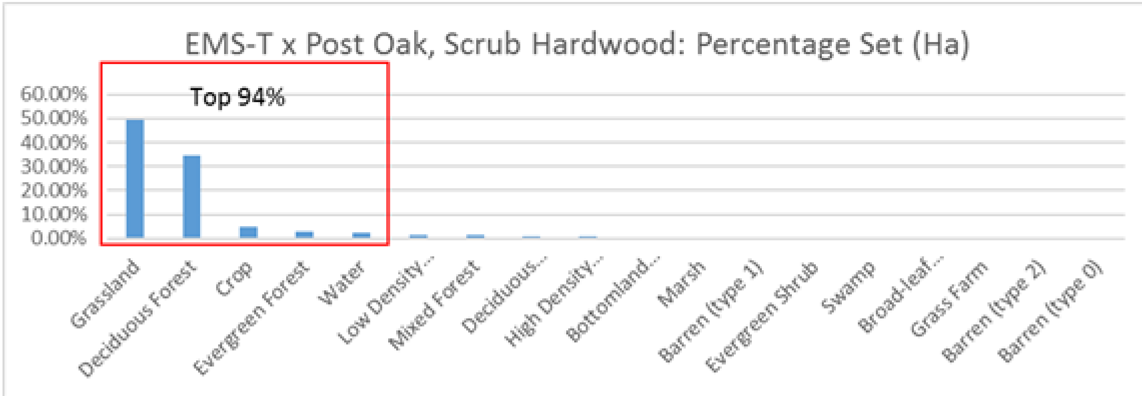


Figure 21. Current Day Ecological Composition of Post Oak, Scrub Hardwood x Percent.

Findings, EMS-T x Longleaf

The digitized boundary for Eldredge/Cruikshank's Longleaf classification contains 611,534 hectares (Figure 22 and 23). Current composition of this area is 63% Evergreen Forest, 15% Deciduous Forest, 9% Grassland, 6% Mixed Forest, and 5% Evergreen Shrub. This accounts for 98% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the five categories comprising this 98%, as described by EMS-T nomenclatures, is presented in Appendix D.

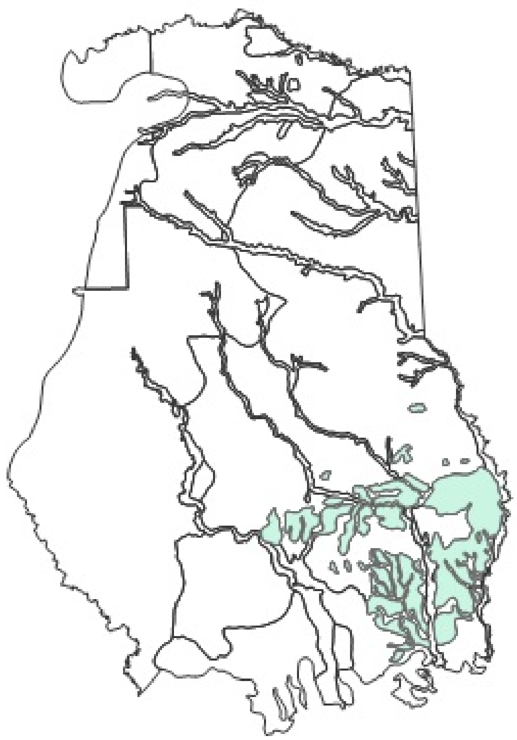


Figure 22. Longleaf.

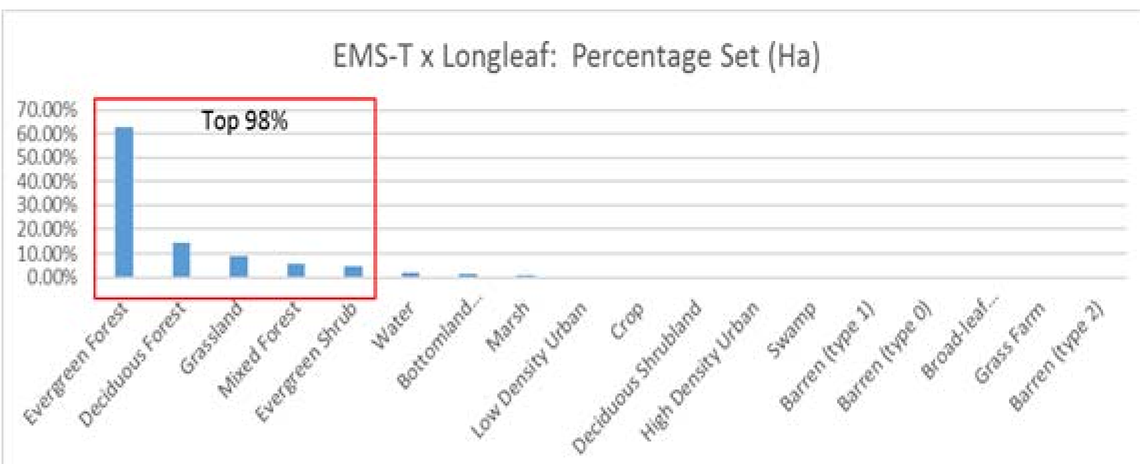


Figure 23. Current Day Ecological Composition of Longleaf x Percent.

Findings, EMS-T x Loblolly Hardwood

The digitized boundary for Eldredge/Cruikshank's Loblolly Hardwood classification contains 741,294 hectares (Figures 24 and 25). Current composition of this area is 31% Deciduous Forest, 29% Evergreen Forest, 12% Grassland, 8% Mixed Forest, 8% Low Density Urban, and 3% High Density Urban. This accounts for 91% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the six categories comprising this 91%, as described by EMS-T nomenclature, is presented in Appendix E.

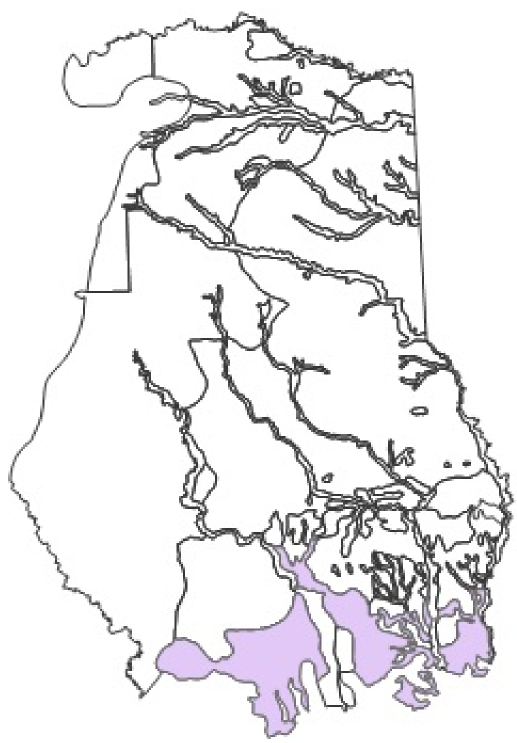


Figure 24. Loblolly, Hardwood.

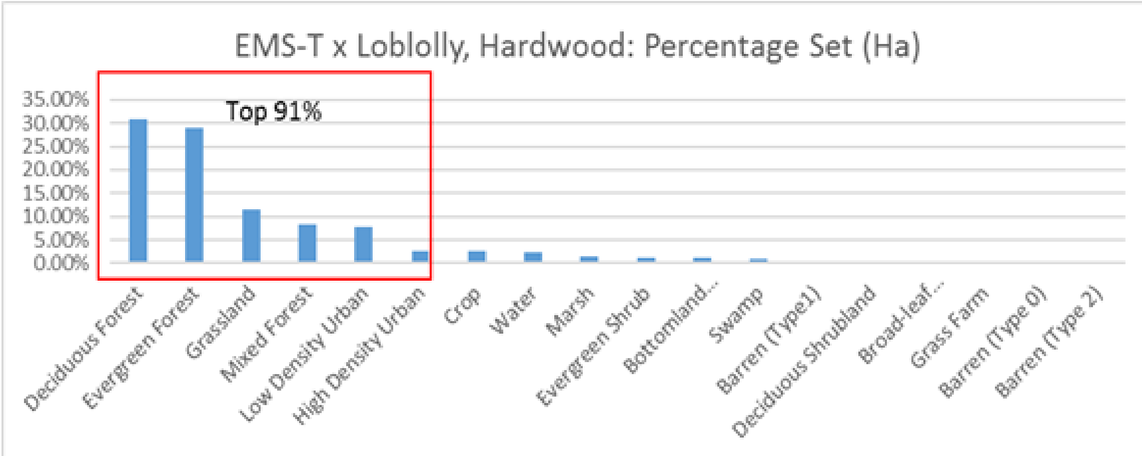


Figure 25. Current Day Ecological Composition of Loblolly Hardwood x Percent.

Findings, EMS-T x Extension of the Post Oak Type

The digitized boundary for Eldredge/Cruikshank's Extension of Post Oak Type classification contains 377,030 ha (Figures 26 and 27). Current composition of this area is 55% Grassland, 26% Deciduous Forest, 9% Crop, 3% Water, and 2% Low Density Urban. This accounts for 95% of its ecological composition as described by Land Use/Land Cover value. A detailed description of the five categories comprising this 95%, as described by EMS-T nomenclature, is presented in Appendix F.

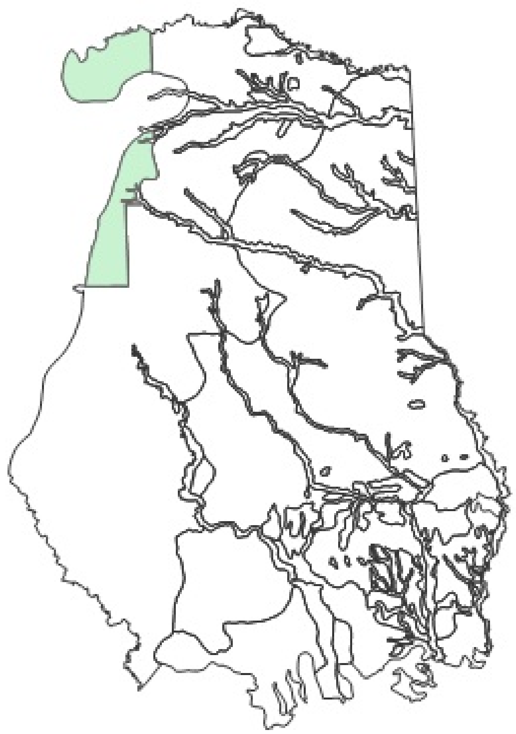


Figure 26. Extension of the Post Oak Type.

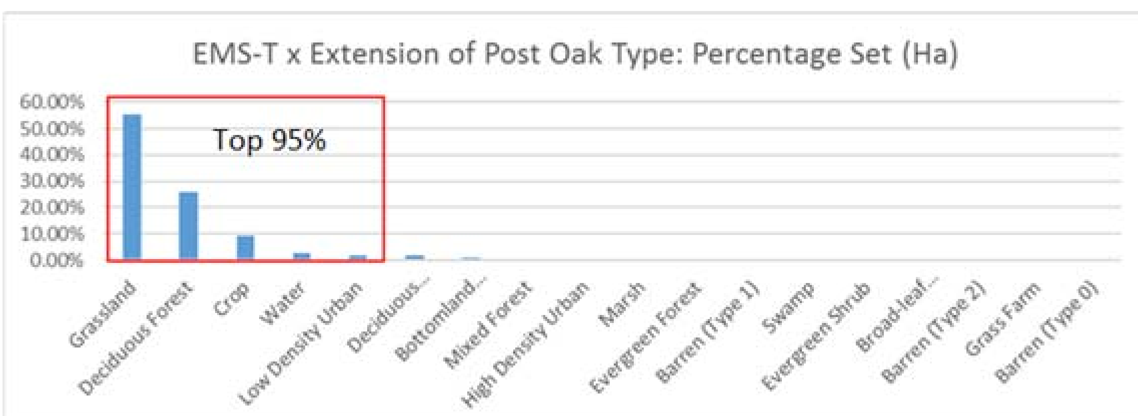


Figure 27. Current Day Ecological Composition of Extension of the Post Oak Type x Percent.

CHAPTER V

Discussion and Conclusions

A completely accurate accounting of East Texas landscape change since pre-settlement times would likely be impossible. Any given location would have a thorough mix of influences, most of which could never be known, simply because they were temporary and never observed, or if they were observed, not recorded. However, with appropriate data and tools it is possible to make assessments and inference to the causes for change. Much of the alteration in East Texas since pre-settlement center around human influence (Green Facts 2016). Fortunately, some of that influence has been both observed and recorded, contemporaneously, then passed down to current times in the form of maps, documents, journals, and recorded observations. The Eldredge/Cruikshank Timber Survey of 1935, as luck would have it, is one such source from which we may compare the known with the unknown and speculate as to how and why things have changed.

Research Questions

What types of change are evident?

Human influence is evident. According to the United States Census Bureau on December 12, 2016, at 8:05 a.m., the population was 325,067,746 (U.S. Census Bureau 2016). Five minutes later the population had increased by 17 people. This small, but steady increase in population underscores the need for resources and this is one of the indirect driving forces for change in the natural world (Green Facts 2016).

Population growth, and associated urban growth, account for the greatest human impact. Approximately, 80% of the U.S. population live in urban areas (Oswalt 2014). The population of the entire Eldredge/Cruikshank Survey area in 1930 was 1,262,000

(Cruikshank 1939) (Eldredge 1938). Today that number stands at 3,316,350 people according to ESRI's Community Analyst and data from the 2010 U.S. Census. That is an increase of 2,054,350 people in 80 years, or 163%.

The most obvious indicator of ecosystem change has been deforestation and conversion of lands to other uses. Urban growth within the Eldredge/Cruikshank survey area accounts for 2.49% of the overall conversion or 250,530 hectares. Though small in comparison with the overall study area, this urban growth is an indirect driver for deforestation and conversion to both agricultural lands and timber production. The 'Shortleaf, Loblolly, Hardwood" area is composed of 64% forest and 34% of its 4.0 million hectares is devoted to some form of timber production. The remainder of this area is grassland (21%), cropland (2.49%; 248,667 ha.), grass farms (0.01%; 1,262 ha.), and water in the form of reservoirs (3%). For Edlredge's 'Bottomland Hardwood' classification, reservoirs now account for 13% of its total 841,936 hectares, or 105,330 hectares.

Other areas show evidence of invasive species. For instance, native invasives such as Juniper (*Juniperus spp.*), Mesquite (*Prosopis spp.*), Common Reed (*Phragmites australis*), and Non-native invasives such as Chinese Tallow have moved into areas that were, historically, associated with different vegetation types. See Figure 28. Within the 'Loblolly Hardwood' classification, deciduous forest accounts for 31% of the total area of 741,294 hectares. Of this 31% (229,801 ha.), 12% of it is 'Non-Native Invasive: Chinese Tallow Forest, Woodland, or Shrubland.' That amounts to 27,577 hectares of Chinese Tallow in areas that were once deciduous forest.

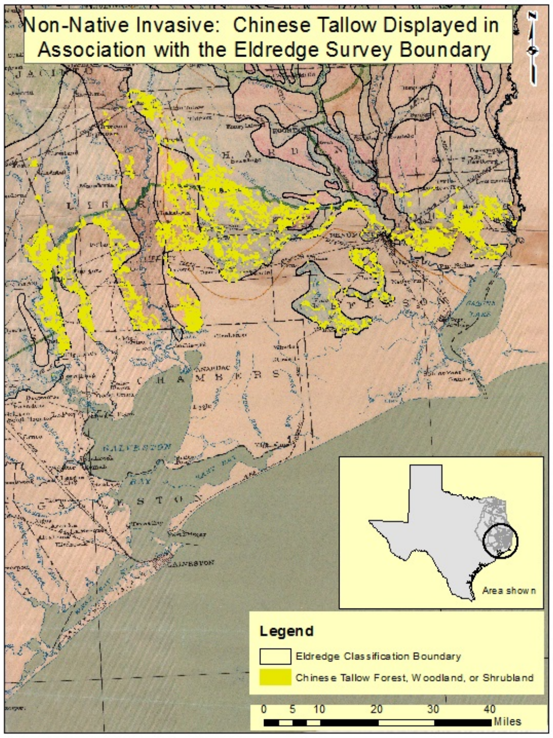


Figure 28. Non-Native Invasive: Chinese Tallow Forest, Woodland, or Shrubland (Eldredge/Cruikshank-TPWD).

Where are areas of remaining historic vegetation with emphasis given to historic and/or reintroduced longleaf pine?

Fragmentation of forests is caused by human activity and natural processes and can lead to species isolation, loss of species, degraded habitat quality, loss of gene pools, and reduction in a forests' capability to sustain natural processes required for overall ecosystem health (Oswalt 2014). With this in mind, both public and private entities have set aside management areas intended to counter forest fragmentation.

One such area is Boggy Slough, which encompasses 20,000 acres (8093 ha.) of forests and wetlands, as well as 18 miles of Neches River frontage just west of Lufkin. The T.L.L. Temple Foundation, The Conservation Fund, and International Paper agreed in 2013 to conserve Boggy Slough rather than subdivide it. Their agreement creates an area of approximately 31 square miles of undivided habitat. The Conservation Fund also has easements and land acquisitions protecting 82,458 acres (33,369 ha.), or roughly 129 miles in other areas along the Neches River (Joyce 2015).

Wildlife Management Areas (WMA's) account for 900,306 hectares, or 364,341 acres, at 27 different locations within the area of interest. These areas are state or federally owned and "were acquired for research and demonstration and to provide protection for unusual wildlife species and habitats (Association 1999)." Most notable among these are portions of the Sam Houston National Forest at 65,218 hectares (161,154 acres), the Moore Planation 10,834 hectares (26,772 acres), and White Oak Creek WMA 10,431 hectares (25,777 acres). In addition to the WMA's, there are 83 Local, State, and Federal Parks in the area of interest accounting for 791,725 hectares (1,956,395 acres). See Figure 29. These areas may or may not represent historic vegetation, however, their reservation accounts for 8% of the Eldredge/Cruikshank survey area and likely contain areas most representative of pre-settlement ecosystems.

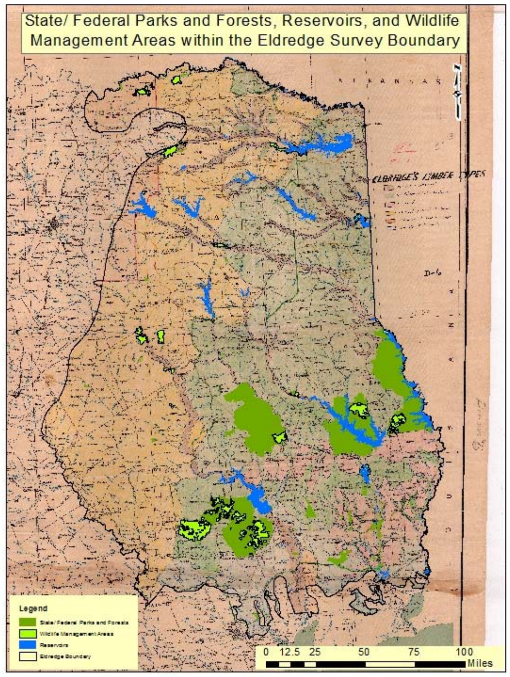


Figure 29. State/Federal Lands, Reservoirs and Wildlife Management Areas (Eldredge/Cruikshank-ESRI).

Longleaf pine (*Pinus palustris*)

Longleaf pine is the longest lived of all southern pine species (The Longleaf Alliance 2016). According to the Longleaf Alliance, individual trees can reach 250 years of age with documented trees in excess of 450 years old. Mature trees, those over 30 years old, can grow up to 110 feet tall in fertile soils and “old growth” trees, from historical accounts were often 120 feet tall and 3 feet in diameter (The Longleaf Alliance 2016). In 1867, John Muir, the Naturalist, described them as such, “In ‘pine barrens’ most of the day. Low, level, sandy tracts: the pines wide apart; the sunny spaces between full of beautiful abounding grasses, liatris, long, wand-like solidago (goldenrod), saw palmettos, etc., covering the ground in garden style. Here I sauntered in delightful freedom, meeting none of the cat-clawed vines, or shrubs, of the alluvial bottoms (Muir 1868).”

The 1935 range of longleaf dominate woodlands in the Eldredge/Cruikshank area of interest was concentrated in Southeast Texas primarily in Newton, Jasper, Hardin, Chambers, Orange, Polk, Liberty, Trinity, Angelina, San Augustine, and Sabine Counties (Little 1971). The areas described by Little are generalized when compared to those described by Eldredge/Cruikshank, however, a few isolated longleaf forests appear in Little that are not consistent with the Eldredge/Cruikshank survey. The areas not surveyed by Eldredge/Cruikshank are located in Chambers and Liberty County and are presented in Figure 30. The Liberty County area is consistent with the EMS-T as an area containing longleaf or loblolly. In the Eldredge/Cruikshank survey this area is suggested as Loblolly or Hardwood, consisting of 31% Deciduous and 29% Evergreen forest as proposed by the EMS-T. The area in Chambers County was not included in the Eldredge/Cruikshank survey; however, when analyzed within the EMS-T includes areas of pine plantation, which is suggestive of previous Evergreen forests.

The EMS-T identifies 12 vegetation groupings within the Pineywoods classification as containing longleaf pine. Three of these contain significant enough amounts of longleaf to be given a “Longleaf” classification within the nomenclature, however, only one is described exclusive of associated species. Table 5 shows the 12 vegetation groupings.

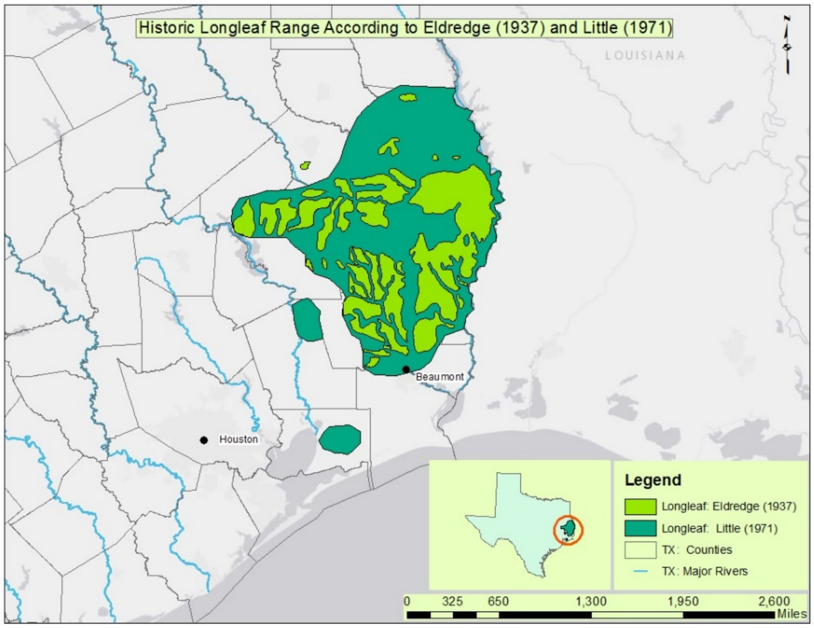


Figure 30. Historic Longleaf Range According to Two Sources (Eldredge/Cruikshank-Little).

Table 5

Vegetation Groupings Containing Longleaf pine

EMS-T Common Name
Pineywoods: Catahoula Herbaceous Barrens
Pineywoods Catahoula Woodland or Shrubland Barren
Pineywoods: Dry Pine Forest or Plantation
Pineywoods: Hardwood Flatwoods
Pineywoods: Herbaceous Flatwoods Pond
Pineywoods: Longleaf or Loblolly Pine – Hardwood Flatwoods or Planation
Pineywoods: Longleaf or Loblolly Pine Flatwoods or Plantation
Pineywoods: Longleaf Pine Woodland
Pineywoods: Pine Forest or Plantation
Pineywoods: Sandhill Oak – Pine Woodland
Pineywoods: Sandhill Pine Woodland
Pinewoods: Seepage Swamp and Baygall

The "Pineywoods: Longleaf Pine Woodland" classification represents 1634 hectares of longleaf pine, or 4040 acres, found in northwestern Newton County. This area is located along Hurricane Creek, just south of the Sabine National Forest, and corresponds with areas described by the 1935 map as longleaf pine. This is the single largest contiguous stand of longleaf in Texas according the EMS-T. Taken on its own and compared to the original volume estimates from the Eldredge/Cruikshank survey, data would suggest that 609,900 hectares, or 1.5 million acres, of longleaf have been lost since the mid-1930's. Today, only 0.07% of the original Eldredge/Cruikshank survey classification for longleaf can be considered exclusively as longleaf.

Two additional vegetation groupings showing a significant makeup of longleaf are also present in the EMS-T. These, less dense, occurrences of longleaf are distributed throughout southeast Texas, both inside and outside of reserve areas and exhibit a mix of longleaf and other dominant species. Longleaf within these areas is significant enough to be noted, however, contiguous stands are small in size. Adding these two classifications (Pineywoods: Longleaf or Loblolly Pine - Hardwood Flatwoods or Plantation, and Pineywoods: Longleaf or Loblolly Pine Flatwoods or Plantation) to the previously examined classification for exclusive longleaf pine presents a significant increase in potential area of occurrence. Area totals for the three longleaf classifications equal 216,206 hectares, or 534,258 acres, of mixed longleaf and loblolly forest.

Nine additional vegetation groupings contain minor occurrences of longleaf. Taken with the three vegetation groupings previously presented, the area where longleaf may occur is 2,056,535 hectares, or 5,081,807 acres.

Assuming this is an accurate assesment of longleaf's historic range, the highest concentrations are in southeast Texas and coincide with Eldredge/Cruikshank's Longleaf classification. Areas outside of the Eldredge/Cruikshank Longleaf classification show high concentrations to the west, north, and northwest and much of the remaining habitat has been set aside as either National Forest, National Preserves, or State Parks. The four largest of these are the Sam Houston, Davey Crockett, Angelina, and Sabine National Forests.

What has been the impact of dam building and reservoir construction, particularly upon Bottomland Hardwood?

It is estimated that Bottomland Hardwood forests in Texas support at least 273 species of birds, 116 species of fish, 31 different amphibians, 54 reptiles, and 45 different mammals (Texas Conservation Alliance 2016). According to the Texas Conservation Alliance, more than 85% of Texas' original bottomland hardwood forests have been "converted to pasture and pines and drowned by dozens of reservoirs." It is unknown how the Texas Conservation Alliance estimate was calculated, however, the finding of this research paper, based off of Eldredge/Cruikshank's timber survey, confirms the areas today are something other than strictly Bottomland Hardwood, placing the calculation at 86%.

The Eldredge/Cruikshank's Bottomland Hardwood classification contains 841,936 hectares, or 2,080,470 acres. These areas lay along the course of ten major riverine systems and supply water to 15 major reservoirs. See Figure 31. All of these reservoirs are man made with the exception of Caddo Lake, which, according to Caddo Indian legend, was formed in 1813 as a result of the New Madrid earthquake (Lentz 2012).

Today, 13% of the Bottomland Hardwood as mapped by Eldredge/Cruikshank is classified as "open water" which means approximately 105,330 hectares, or 260,276 acres, that were once forest have now been converted to impounded reservoirs. Of the total 2.1 million acres suggested by Eldredge/Cruikshank, Bottomland Hardwood is now only 14% whereas 31% is considered deciduous forest and 18% is considered Grassland. Urban conversion, for both low and high density areas, accounts for 6789 hectares, or 16,775 acres.

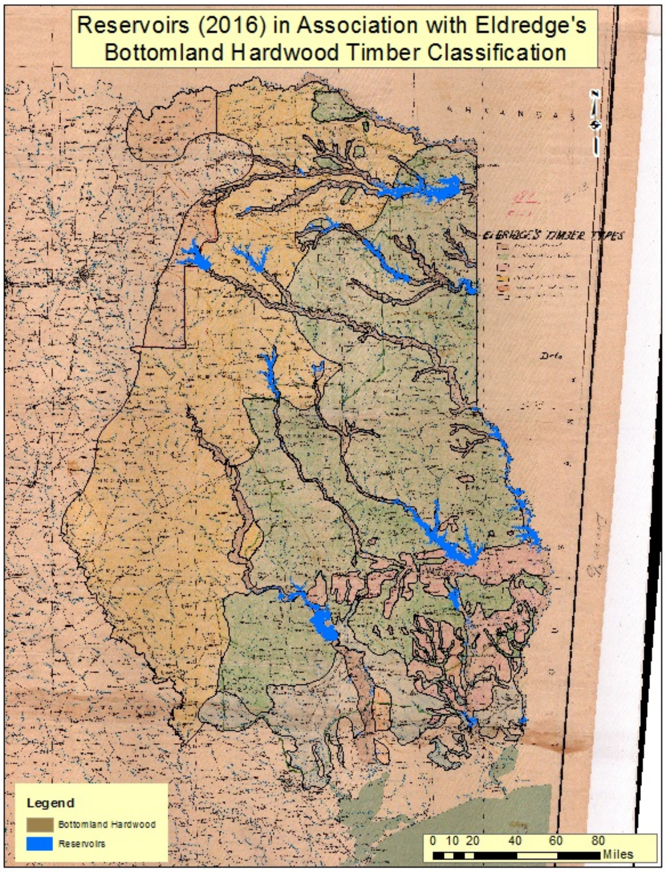


Figure 31. Impounded Reservoirs in Association with the Eldredge/Cruikshank Survey Boundary.

Where are the major areas of urban growth and how has this growth affected the historical vegetation?

Nationally, urban areas are defined as having a population density of at least 500 people per square mile (Oswalt 2014). According to Oswalt, more than 80% of the U.S.

population live in urban areas and these areas, on average, are 35% tree cover (D. Nowak 2012). The effects of urbanization include loss of trees and forests, increases in population density, increases in human activity in and near forests, and an increase in urban infrastructure all of which affect forest and forest management (Oswalt 2014). Urban trees remove an estimated 711,000 metric tons of pollution, such as ozone, particulates, nitrogen dioxide, sulfur dioxide, and carbon dioxide, from the environment annually and account for storage of 643 million metric tons of carbon nationally (D. J. Nowak 2013).

The EMS-T accounts for two types of urban growth. High density growth is concentrated near cities and towns and along major highways. According to the Texas Parks and Wildlife description, "This type consist of built-up areas and wide transportation corridors that are dominated by impervious cover (L. Elliott 2014)." Low density growth is also concentrated near cities, towns, and roadways. Elliott describes these areas as "built-up but not entirely covered by impervious cover, including most of the area within cities and towns (L. Elliott 2014).

According to ESRI data in 2016, 1136 cities and small towns exist within the boundary of the Eldredge/Cruikshank survey. See Figure 32. These cities contain a population of 3,316,350 people according to Community Analyst and the 2010 U.S. Census. Largest among these are portions of Houston and Beaumont. Other areas of significant urban growth include Montgomery County (The Woodlands and Conroe), Tyler, Longview, Bryan-College Station, and Lufkin. The 2010 U.S. Census indicates that these six cities alone, excluding Houston and Beaumont, support a population of 548,778 individuals.

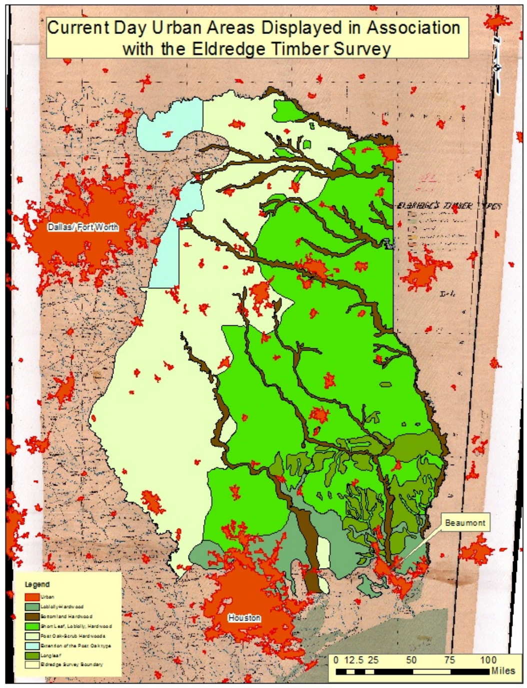


Figure 32. Urban Areas in Association with the Eldredge/Cruickshank Survey Boundary (Eldredge/Cruikshank-ESRI)

Of the Eldredge/Cruikshank vegetation types, the “Loblolly, Hardwood” classification has been most affected by urban expansion. This classification covers 741,294 hectares, or 1.8 million acres, and of that 10.3% has been converted to urban cover. Most of these areas are around Beaumont and Houston.

The “Shortleaf, Loblolly, Hardwood” classification consists of approximately 4.0 million hectares, or 9.8 million acres. Urban cover in this area is 1.93%, 77,014 hectares, or 190,306 acres. The larger cities within this classification are Conroe, The Woodlands, Lufkin, Longview, and Texarkana.

Areas within the “Post Oak, Scrub Hardwood” classification account for 3,504,954 hectares, or 8.6 million acres. Of this, urban cover is 2.2%, 76,996 hectares, or 190,261 acres. Larger urban areas within this classification include Tyler, Bryan-College Station, and Palestine.

Areas within the "Longleaf" classification contain 41 small towns but only two areas of significant urban cover. Those include the northern reaches of Beaumont and the City of Silsbee. The "Longleaf" classification is 611,535 hectares, or 1.5 million acres. Of this, 4648 hectares, 11,485 acres, or 0.76% is considered urban coverage.

The "Extension of the Post Oak Type" classification contains 57 small towns. Consisting of 377,030 hectares, this classification is the smallest of all areas within the Eldredge/Cruikshank survey. Urban coverage accounts for 2.34% of its landcover with 8,793 hectares, or 21,727 acres. The largest towns within this classification are comparatively small with populations of less than 8,000.

Taken as a whole, the Eldredge/Cruikshank Survey area is 10,052,731 hectares. Of this, 10,045,412 hectares was used in this analysis. Total area of urban coverage for the entire Eldredge/Cruikshank survey is approximately 2.49% and accounts for 250,530 hectares, or 619,073 acres. This includes both the Low Urban Density and High Urban Density classification. Taken separately, Low Urban Density is 1.80% and High Urban Density is .69%.

Primary Findings

- Invasive species, such as Chinese Tallow, have displaced native species in locations where the dominant, historic species have been removed due to timber harvesting
- Roughly 8% of the area studied is devoted to conservation and preservation of natural ecosystems
- Approximately 1.5 million acres of longleaf pine have been lost since the 1930's

- Only 0.07% of the original Eldredge/Cruikshank survey classification of longleaf pine can now be considered as exclusively longleaf pine
- Approximately 86% of Bottomland Hardwood has been converted to something other than Bottomland Hardwood
- Today, 13% of the Bottomland Hardwood is classified as 'open water' suggesting that approximately 260,276 acres (105,330 ha.) have been converted to impounded reservoirs
- Urban use, both high and low density, accounts for 2.49% of the study area or 250,530 hectares.

Limitations

As with the Leipnik study of 1997, this study was limited by the data available and the processing ability of current equipment (Leipnik 1997). Most notable was the size of the *Ecological Mappings Systems of Texas* dataset. Overall, for the entire extent of the State of Texas, the dataset was approximately one TB of irregular polygon data. Even after paring that down to just the areas covered by the Eldredge/Cruikshank survey, the dataset was 4.06 GB. This sorely taxed the computers and network on which it was installed. Regeneration and clipping processes for the early work often took as much as 45 minutes for one refresh of the data and up to 6 hours for a clipping process. The merge process, which combined the four target area phases prior to the final clip of those phases to the Eldredge/Cruikshank boundary, required 10 hours. At the time, the data resided locally on a 3 Tb external hard drive. To improve performance, a raster graphic of the EMS-T was substituted in map sessions that did not require computation. For those that did require computation an ArcGIS Server environment and Microsoft SQL Server were created to offload some of the processing to a background server. Although this worked well, regeneration times often would take up to 12 minutes and clipping processes upwards of 30 minutes. Fortunately, by the time much of the in-depth analysis was being performed, the data had been pared down to the 4.06 GB target area data, thereby speeding up the overall processing requirements and eliminating roughly 6 GB of data external to the target area of interest.

Another limitation was in the use of updates to the data. The EMS-T was first obtained in 2012, two years before the project's completion date in 2014. The overhead of a very large dataset and the prospect of revisiting an extensive merge and clip process on any updated data prevented any updates to the EMS-T data whatsoever during the course of this study. All the work of this study was therefore completed on a dataset which could potentially have changed before the final public release. The multiple "Barren" classifications from Phase 1 that were excluded in future phases is one example of data that had to be accounted for during the analysis process.

Future Work

The USDA map is unique in that it still exists today and was generated from studies of Texas' timber conditions conducted over 80 years ago by the U.S. Government. This current study used it as well, applying the general assumptions it offers to the analysis of highly detailed, current day, geographic and remotely sensed data. This study simply noted the similarities and differences between the two data sources. Future study could focus on any one of the six vegetation classes as an in-depth course of study related to forest recovery, species richness, diversity, or adaptation to changing ecosystems. For forest managers, it offers an opportunity to study ecological succession and provides some measure confidence for forest restoration efforts, especially those relevant to endangered and threatened species. For agricultural management, it offers insight into forest conversion to agricultural use, one of the primary findings of Eldredge/Cruikshank timber survey (Cruikshank 1939) (Eldredge 1938). For urban planners, it offers insight into the major areas of urban growth and the indirect causes for ecological change that drive loss of habitat. Another potential study might involve an in-depth comparison to the 1984 McMahan study with emphasis on types of change from 1984 to the present.

Conclusion

Ecosystems change, quite often at the whim of humans. A good example of that is Jackson Park, Chicago, home of the 1893 World's Columbian Exposition. The Exposition, oddly enough, has at least one direct connection to the forests of Texas.

Before the Exposition, much of the Jackson Park area was underwater or "swampy swales, shoreward projections of Lake Michigan, and long sand hills with oaks and scrub (Jackson Park Advisory Counsel 2014). By the time the fair opened in May of 1893, its 633 acres contained 65,000 exhibits, restaurants to seat 7,000 people, 14 main buildings with 63 million square feet of exhibition space, 200 additional service buildings, and hundreds of concessionaires (Rose 1996). Among the buildings was a "handsome building on the right of the north entrance to the Exposition grounds," celebrating the history, culture, and natural resources of Texas (W. B. Conkey Company 1893). The structure, funded by the Women's World Fair Exhibit Association of Texas, cost $30,000 to build. Conkey describes it as such, "In the treatment of the design of the Texas Building the architect has not deflected from the history of the Lone Star State, which, from its foundation, has been marked by a Spanish tinge, whose architectural inclination and handsome botanical effects lay down a chain of thought far too beautiful to be forsaken for that of the present day; therefore, the building was designed for colonnades, grounds, fountains, foliage, etc. It contains an assembly room 56 feet square, 28 feet high, provided with art glass skylight in the ceiling, with a mosaic Texas star in the center. The rostrum, anterooms, etc., **are furnished in the natural woods of Texas**…. (W. B. Conkey Company 1893)." See Figure 33.

An estimated 28 million people, nearly one-quarter of the entire countries population, attended the exposition before it closed six months later, on October 31, 1893 (Rose 1996). With the exception of a comfort station, the North Pond Bridge, the Osaka Japanese Garden, and the Palace of Fine Arts, nothing of the World Columbian Exposition exists today. Much of it is either golf course, park, or marina. However, one area, 'The Wooded Island' of Exposition days is currently under meticulous restoration by the Army Corps of Engineers to become restored native woodland and coastal habitat (Cholke 2015). It will be a small urban ecosystem, roughly 140 acres, intended to attract waterfowl, surrounded by a city of 2.7 million people. It is an attempt to give back some small measure of its former self to nature. As insignificant as that may seem, just to the west, across the lagoon, and across South Cornell Avenue, about 390' away from 'The Wooded Island,' will lie The Obama Presidential Center (The Obama Foundation 2016).

Figure 33. The Texas Building at the World Columbian Exposition in 1893 (Conkey).

The indirect driving forces for change almost always come from multiple sources and interactive processes driven by cultural, economic, political, and industrial influence (Green Facts 2016). Using geographic analysis tools and good source data, it is possible to answer questions about virtually any location on Earth without ever having set foot in the region. Various levels of map data exist on almost any topic, from general to specific, for almost every corner of the planet. However great this warehouse of information may be, we are still left to infer much and can only look back as far as our data, evidence, and learned experiences allow.

Above all the calculations, tables, graphs, and findings, ultimately this study describes a data mining process by which we may compare empirical information between two map sources. That is not necessarily new, but what is new is the data behind the study. This study builds on existing methodology and extends it to a new data source. Any findings are a by-product of the process, but in the end, those findings also serve to validate aspects of the scientific record that we already know, i.e., that humans affect the environment. Methods presented here aid in the endeavor to discover where, how much, and why.

This study attempts to both expand and explore ecological information in a specific region of Texas, from two points in time, based on recorded historic observation and current sources. The two primary sources are a hand-annotated map created by the U.S. Department of Agriculture, circa 1935, defining generalized timber ranges and a highly detailed dataset of remotely sensed polygons representing geographic locations for 398 vegetation communities in Texas from 2012. Time is the defining variable between the two and time is the one thing that, apparently, never stands still. Except, perhaps, every now and then, within the context of a map.

REFERENCES

Association, Texas State Historical. 1999. "Handbook of Texas Online." *TSHA: Texas State Historical Association.* 2 15. Accessed 12 2, 2016. http://www.tshaonline.org/handbook/online/articles/gbw02. .

Boundless. 2016. *Boundless.com.* Sept 12. Accessed Sept 29, 2016. https://www.boundless.com/u-s-history/textbooks/boundless-u-s-history-textbook/the-market-revolution-1815-1840-13/the-industrial-revolution-110/industrialization-and-the-environment-596-9029/.

Boyer, W. D. 1985. *Longleaf Pine.* Accessed 06 06, 2015. http://www.na.fs.fed.us/spfo/pubs/silvics_manual/Volume_1/pinus/palustris.htm.

Brandeis, Thomas J., et. all. 2014. *Forests of East Texas, 2014.* Resource Bulletin update FS-60, Knoxville: Southern Research Station, USDA Forest Service.

Brister, Evelyn, Elizabeth Hane, Karl Korfmacher. 2011. "Visualizing Plant Community Change Using Historical Records." *International Journal of Applied Geospatial Research, v.2* 1-18.

Cholke, Sam. 2015. *dnainfo: Chicago.* 3 23. Accessed 12 6, 2016. https://www.dnainfo.com/chicago/20150323/hyde-park/olmsteds-historic-wooded-island-looks-clear-cut-but-its-part-of-plan.

Code, U.S. 1897. *16 U.S. Code § 473 - Revocation, modification, or vacation of oorders or proclamations establishing national forests.* Washington: U.S. Congress.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. *Ecological Systems of* *the United States: A Working Classification of U.S. Terrestrial Systems.* Classification Report, Arlignton: NatureServe.

Cox, Mike and Brett Holmes. 2012. *Texas Parks and Wildlife.* 5 23. Accessed 6 8, 2016. http://tpwd.texas.gov/newsmedia/releases/print.phtml?req=20120523a.

Cruikshank, J. W. and I.F. Eldredge. 1939. *Forest Resources of Southeastern Texas.* Progress report, Washington: U.S. Government Printing Office.

D'Costa, Krystal. 2015. "A Story of Wood." *Scientific American.* June 4. Accessed Sept 29, 2016. http://www.scientificamerican.com/.

Eldredge, I.F. 1938. *Forest Resource of Northeast Texas.* Progress Report, New Orleans: Southern Forest Experiment Station.

Elliott, Lee. 2014. *Draft Descriptions of Systems, Mapping Subsystems, and Vegetation Types for Texas.* Austin: Texas Parks and Wildlife Department, January 14.

Elliott, Lee F., et. al. 2014. *Ecological Mapping Systems of Texas: Summary Report.* Summary Report, Austin: Texas Parks and Wildlife Department.

EPA. 16. *United States Environmenal Protection Agency - Ecoregions of North America.* 11 12. Accessed 9 2, 2017. https://www.epa.gov/eco-research/ecoregions-north-america.

Fedkiw, John. 1998. "National Forest and the Performace of the Organic Act of 1897." *Forest History Today* 12-17.

Goldstein, Michael I., Wilkins, R. Neal, and Lacher, Thomas E. Jr. 2005. "Spatiotemporal Responses of Reptiles and Amphibians to Timber Harvest Treatments." *Journal of Wildlife Management* 69(2):525-539.

Gould, F. W., Hoffman, G.O., and Rechenthin, C.A. 2011. "Gould Ecoregions of Texas." *Vegetational area of Texas.* Austin: Texas Parks and Wildlife, January 27.

Green Facts. 2016. *Green Facts: Facts on Health and the Environment.* 11 30. http://www.greenfacts.org/en/ecosystems/millennium-assessment-2/4-factors-changes.htm.

Griffith, G.E., Bryce, S.A., Omernik, J.M., Comstock, J.A., Rogers, A.C., Harrison, B.,. 2004. *Ecoregions of Texas (color poster with map, descriptive text, and photographs).* Map Poster, Reston: U.S. Geological Survey.

Jackson Park Advisory Counsel. 2014. *Jackson Park Advisory Counsel.* Accessed 12 6, 2016. http://www.jacksonparkadvisorycouncil.org/history-2/.

Joyce, Matt. 2015. "Boggy Slough conservation effort conters forest fragmentation; The Temple Foundation's plans for historic Boggy Slough porperty." *Texas Highways.* January 1. Accessed 12 1, 2016. http://www.texashighways.com/history/item/7716-boggy-slough-conservation-effort-counters-forest-fragmentation.

Leipnik, Mark R., et al. 1997. "Geographic Information System Based Analysis of Current and Historical Vegetation Composition in East Texas." *The Texas Journal of Science, v 39 (supplement)* 13-20.

Lentz, Seth D Breeding and Sallie Starr. 2012. *Handbook of Texas Online.* June 12. Accessed November 16, 2016. http://www.tshaonline.org/handbook/online/articles/roc01.

Little, E. L., Jr. 1971. *Atlas of United States Trees, volume 1. Conifers and important hardwoods.* Msc. Publication, Washington: U.S. Department of Agriculture, Forest Service, Msc. Publ. No. 1146. 9p + maps.

MacCleery, Douglas W. 2011. *American Forest, A History of Resiliency and Recover.* Issue Series, Durham: The Forest History Society.

Maxwell, Robert S. 2010. *Handbook of Texas Online.* June 15. Accessed 06 06, 2016. http://www.tshaonline.org/handbook/online/articles/drl02. .

McMahan, Craig A., Roy G. Frye, Kirby L Brown. 1984. *The Vegetation Types of Texas, Including Cropland: An Illustrated Synopsis to Accompany the Map.* PWD Bulletin 7000-120, Austin: Texas Parks and Wildlife.

Michael I. Goldstein, et al. 2005. "Spatiotemporal Responses of Reptiles and Amphibians to Timber Harvest Treatments." *Journal of Wildlife Management* 525-539.

Miles, P.D. 2010. *Forest Inventory EVALIDator web-application version.* 03 22. Accessed 03 10, 2012. http://fiatools.fs.fed.us/Evalidator4/tmattribute.jsp.

Muhn, James. 1992. *The Forest History Society.* Accessed 2 28, 2017. http://www.foresthistory.org/Publications/Books/Origins_National_Forests/sec17.htm.

Muir, John. 1868. "July 1867 - February 1868, The "thousand mile walk" from Kentucky to Florida and Cuba." *Holt-Atherton Special Collections.* 10 30. Accessed 11 30, 2016. http://digitalcollections.pacific.edu/cdm/compoundobject/collection/muirjournals/id/115/rec/1.

Nagendra, Harini, et al. 2004. "From pattern to process: landscape fragmentation and the analysis of land use/ land cover change." *Agriculture, Ecosystems & Environment* 111-115.

Nixon, Elray S., R. Larry Willet and Paul W. Cox. 1977. "Woody Vetgetation of a Virgin Forest in an Eastern Texas River Bottom." *Castanea, Vol. 42 No. 3* 227-236.

Nowak, D. J. 2013. "Carbon storage and sequestration by trees in urban and community areas of the United States." *Environmental Pollution: 178* 229-236.

Nowak, D.J. 2012. "Tree and impervious cover in the United States." *Elsevier: Landscape and Urban Planning 107* 21-30.

NRC. 1999. *Global Environmental Change: Research Pathways for the next Decade.* Washington, DC: (National Research Council, Board on Sustainable Development, Policy Division, Committee on Global Change Research) National Academy Press.

Oswalt, Sonja N., editor. 2014. *U.S. Forest Resrouc Facts and Historical Trends.* Brochure, Knoxville: USDA Forest Service, Forest Inventory and Analysis Program.

Prasad, A.M. and L.R. Iverson. 2003. *Little's range and FIA importance value database for 135 eastern US tree species.* Accessed 11 30, 2016. http://www.fs.fed.us/ne/delaware/4153/global/littlefia/index.html.

Rose, Julie K. 1996. *A History of the Fair.* Accessed 12 6, 2016. http://xroads.virginia.edu/~MA96/WCE/history.html.

Rudis, Victor A., Carraway, Burl, Sheffield, Ramnond M. 2003. *East Texas Forests.* Resource Bulletin, SRS-137, Asheville: U.S. Department of Agriculture Forest Service, Southern Research Station.

Schafale, Michael P. and P.A. Harcombe. 1983. "Presettlement Vegetation of Hardin County, Texas." *American Midland Naturalist, vol 109, no. 2* 355-366.

Service, U.S. Forest. 2016. *Forest Inventory and Analysis National Program.* 10 20. Accessed 11 30, 2016. http://www.fia.fs.fed.us/.

2014. *Southern Forests for the Future.* Accessed 06 06, 2015. http://www.seesouthernforests.org/case-studies/longleaf-pine-forests-and-savannas.

TAMU Forest Service. 2014. *Trees of Texas.* 1 1. Accessed 10 3, 2016. http://texastreeid.tamu.edu/content/texasEcoRegions/Pineywoods/.

Texas Conservation Alliance. 2016. "Texas Conservation Alliance." *Texas Conservation Alliance.* Accessed 12 1, 2016. http://www.tcatexas.org/?portfolio=importance-of-bottomland-hardwood-forests.

Texas Parks and Wildlife Department. 2014. *Ecological Mapping Systems of Texas: Summary Report.* Summary Report, Austin: Texas Parks and Wildlife.

Texas Society of American Foresters. 2006. *Texas Society of American Foresters.* Accessed 03 02, 2015. http://www.safnet.org/statesocieties/fileuploads/Highlights.pdf.

The Longleaf Alliance. 2016. *The Longleaf Alliance.* Accessed 10 30, 2016. http://www.longleafalliance.org/.

The Nature Conservancy. 2016. *Texas Longleaf Pine.* September 15. Accessed September 15, 2016. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/texas/explore/plants-longleaf-pine.xml.

The Obama Foundation. 2016. *Obama Foundation.* Accessed 12 6, 2016. https://www.barackobamafoundation.org/the-center.

Thompson, I., Mackey, B., McNulty, S., Mosseler, A. 2009. *Forest Resilience, Biodiversity, and Climate Change: A Synthesis of the Biodiversity/Resilience/Stability Relationship in Forest Ecosysytems.* Technical Series no. 43, 67 pages, Montreal: Secretariat of the Convention on Biological Diversity.

TPWD. 2012. *Texas Conservation Action Plan 2012 – 2016: East Central Texas Plains Handbook.* Handbook, Austin: Editor, Wendy Connally, Texas Conservation Action Plan Coordinator.

TPWD. 2012. *Texas Conservation Action Plan 2012-2016: Western Gulf Coastal Plain Handbook.* Handbook, Austin: Texas Parks and Wildlife Department.

—. 2016. *Texas Parks and Wildlife.* 1 1. Accessed Oct 3, 2016. https://tpwd.texas.gov/education/hunter-education/online-course/wildlife-conservation/texas-ecoregions.

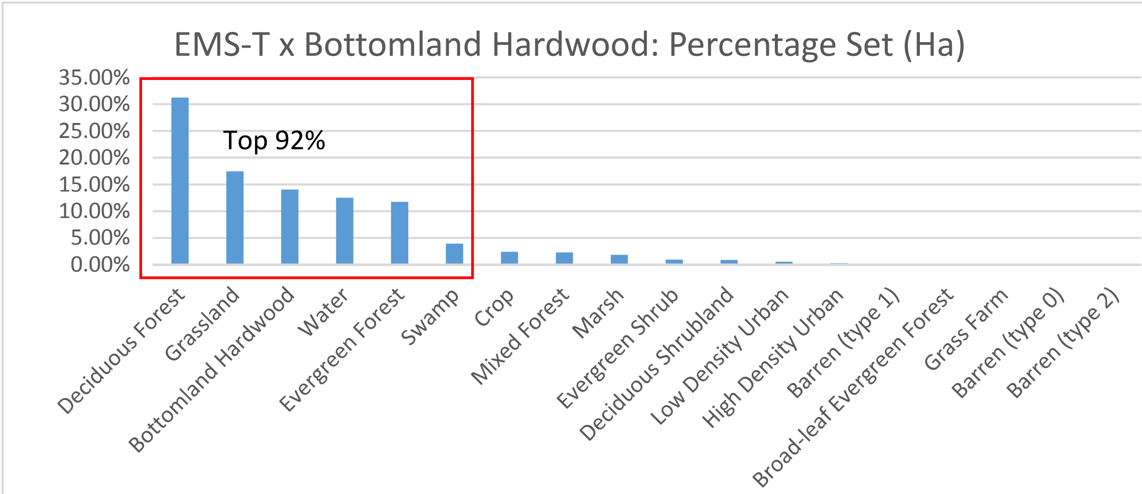
U.S. Census Bureau. 2016. *United States Census Bureau.* 12 6. Accessed 12 6, 2016. http://www.census.gov/.

W. B. Conkey Company. 1893. *The Official Directory of the World's Columbian Exposition.* Chicago: W. B. Conkey Company.

Wikipedia, Contributors. 2016. *History of Texas Forests.* May 31. Accessed June 6, 2016. https://en.wikipedia.org/wiki/History_of_Texas_forests.

APPENDIX A

Detailed Analysis, EMS-T x Bottomland Hardwood



The digitized boundary for Bottomland Hardwoods contains 841,936 hectares. Current day composition of these areas are 31% Deciduous Forest, 18% Grassland, 14% Bottomland Hardwood, 13% Water, 12% Evergreen Forest, and 4% Swamp. This accounts for 92% of its ecological composition as described by Land Use/Land Cover value. The sections below describe ecological composition for each of these contributing classifications.

The “Deciduous Forest” classification, LULC value 5, is composed of 27% Pineywoods: Upland Hardwood Forest, 18% Pineywoods: Bottomland Temporarily Flooded Hardwood Forest, 12% Pineywoods: Small Stream and Riparian Temporarily Flooded Hardwood Forest, and 11% Pineywoods: Bottomland Seasonally Flooded Hardwood Forest. These total to 68% of the total ecological composition.

The “Grassland” classification, LULC value 15, is composed of 41% Pineywoods: Disturbance or Tame Grassland and 16% Post Oak Savanna: Savanna Grassland, and 15%

Pineywoods Small Stream and Riparian Wet Prairie. These account for 72% of its ecological make up.

The "Bottomland Hardwood" classification, LULC 35, is composed of 76% Pineywoods: Bottomland Seasonally Flooded Hardwood Forest and 16% Pineywoods: Small Stream and Riparian Seasonally Flooded Hardwood Forest. These account for 92% of its ecological make up.

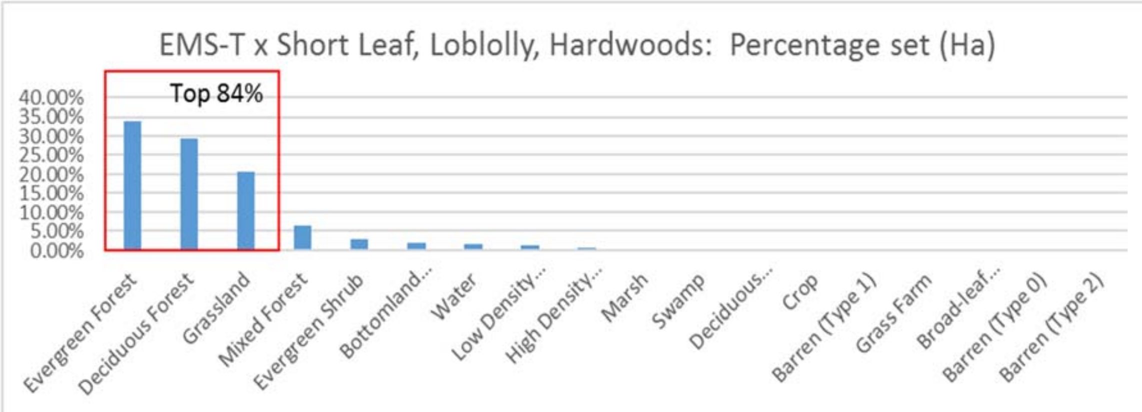
The "Water" classification, LULC value 21, is composed of 100% of Open Water.

The "Evergreen Forest" classification, LULC value 19, is composed of 47% Pineywoods: Pine Forest or Plantation and 37% Pine Plantation > 3 meters tall. These account for 84% of the total ecological composition.

The "Swamp" classification, LULC value 33, is composed of 81% Pineywoods: Bottomland Baldcypress Swamp and 11% Pineywoods: Small Stream and Riparian Bladcypress Swamp. This accounts for 92% of the total ecological composition.

APPENDIX B

Detailed Analysis, EMS-T x Short Leaf, Loblolly, Hardwoods



The digitized boundary for Eldredge/Cruikshank's "Short Leaf, Loblolly, Hardwoods" classification contains 3,975,983 hectares. Current day composition of these areas are 34% Evergreen Forest, 29% Deciduous Forest, and 21% Grassland. This accounts for the top 84% of its ecological composition as described by Land Use/Land Cover value. The sections below describe the ecological composition for each of these contributing classifications.

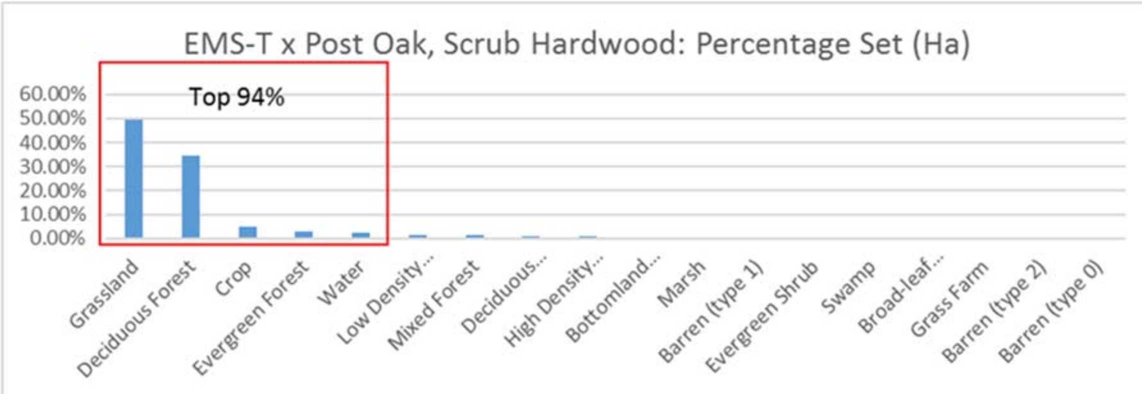
The "Evergreen Forest" classification, LULC value 19, is composed of 53% Pineywoods: Pineforest or Plantation and 34% Pine Plantation > 3 meters tall. This accounts for 87% of all areas identified within the Eldredge/Cruikshank classification.

The "Deciduous Forest" classification, LULC value 5, is composed of 55% Pineywoods: Upland Hardwood Forest and 16% Pineywoods: Northern Mesic Hardwood Forest. Together this represents 71% of the "Deciduous Forest" classification.

The "Grassland" classification, LULC value 15, is composed of 76% Pineywoods: Disturbance or Tame Grassland and 12% Pineywoods: Small Stream and Riparian Wet Prairie. Together this represents 88% of the "Grassland" classification.

APPENDIX C

<u>Detailed Analysis, EMS-T x Post Oak, Scrub Hardwoods</u>



The digitized boundary for Eldredge/Cruikshank's Post Oak, Scrub Hardwood classification contains 3,504,954 hectares. Current day composition of these areas are 49% Grassland, 35% Deciduous Forest, 5% Crop, 3% Evergreen Forest, and 2% Water. This accounts for 94% of its ecological composition as described by Land Use/Land Cover value. The sections below describe ecological composition for each of these contributing classifications.

The "Grassland classification, LULC value 15, is composed of 47% Post Oak Savanna: Savanna Grassland, 12% Pineywoods: disturbance or Tame Grassland, 11% Central Texas: Floodplain Herbaceous Vegetation, and 10% Blackland Prairie: Disturbance or Tame Grassland. This accounts for 80% or its ecological composition.

The "Deciduous Forest" classification, LULC value 5, is composed of 44% Post Oak Savanna: Post Oak Motte and Woodland, 15% Central Texas: Floodplain Hardwood Forest, 12% Pineywoods: Upland Hardwood Forest, 6% Pineywoods: Northern Mesic Hardwood Forest, and 5% Pineywoods: Small Stream and Riparian Temporarily Flooded Hardwood Forest. These account for 82% of its ecological make up.

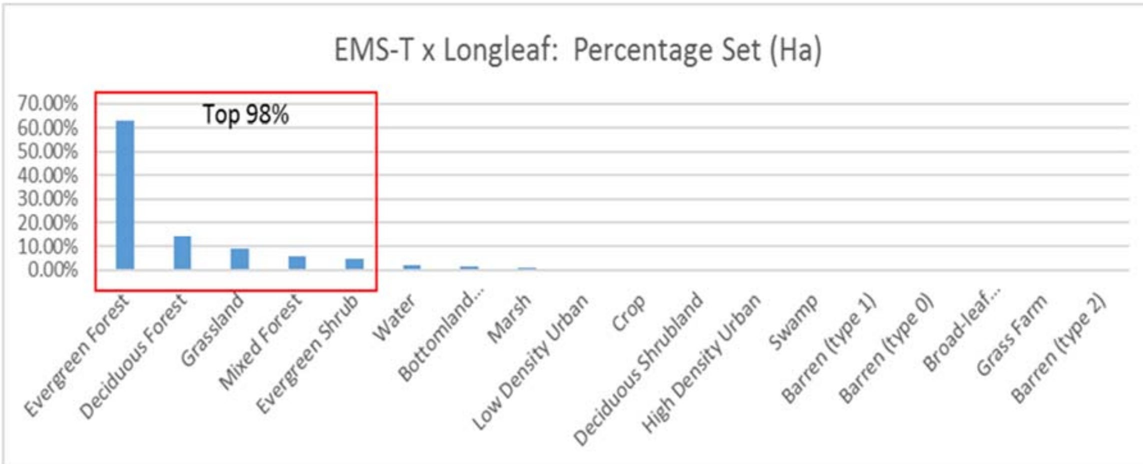
The “Crop” classification, LULC value 9, is composed of 95% row crops.

The “Evergreen Forest” classification, LULC value 19 is composed of 53% Pineywoods: Pine Forest or Plantation, 21% Native Invasive: Juniper Woodland, and 18% Pine Plantation > 3 meters tall. These account for 92% of its ecological make up.

The “Water” classification, LULC value 21, is 99% open water.

APPENDIX D

Detailed Analysis, EMS-T x Longleaf



The digitized boundary for Eldredge/Cruikshank's Longleaf classification contains 611,534 hectares. Current day composition of these areas are 63% Evergreen Forest, 15% Deciduous Forest, 9% Grassland, 6% Mixed Forest, and 5% Evergreen Shrub. This accounts for 98% of its ecological composition as described by Land Use/Land Cover value. The sections below describe the ecological composition for each of these contributing classifications.

The "Evergreen Forest" classification, LULC 19, is composed of 41% Pineywoods: Pine forest or Plantation, 34% Pine Plantation > 3 meters tall, 12% Pineywoods: Sandhill Pine Woodland, 8% Pineywoods: Dry Pine Forest or Plantation, 6% Pineywoods: Longleaf or Loblolly Pine Flatwoods or Plantation, and .07% Longleaf Pine Woodland. These account for 99.06% of its ecological composition.

The "Deciduous Forest" classification, LULC 5, is composed of 62% Pineywoods: Upland Hardwood Forest, 11% Pineywoods: Small Stream and Riparian Temporarily Flooded Hardwood Forest, 10% Pineywoods: Hardwood Flatwoods, and 10%.

Pineywoods: Southern Mesic Hardwood Forest. This accounts for 93% of its ecological composition.

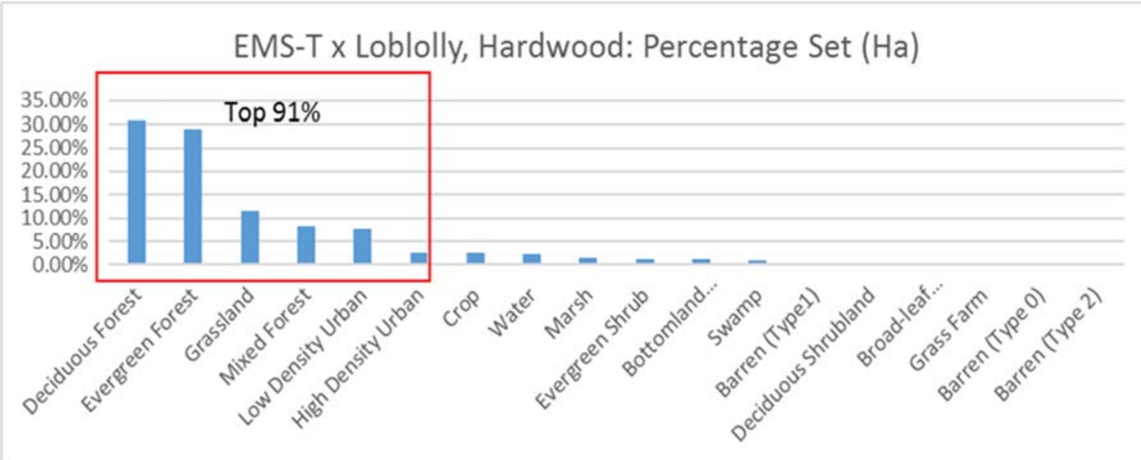
The “Grassland” classification, LULC value 15, is composed of 86% Pineywoods: Disturbance or Tame Grassland and 7% Pineywoods: Small Stream and Riparian Wet Prairie. This accounts for 93% of its ecological composition.

The “Mixed Forest” classification, LULC value 31, is composed of 59% Pineywoods: Pine - Hardwood Forest or Plantation, 14% Pineywoods: Southern Mesic Pine - Hardwood Forest, 12% Pineywoods: Small Stream, and 6% Riparian Temporarily Flooded Mixed Forest Pineywoods: Longleaf or Loblolly Pine - Hardwood Flatwoods or Plantation. This accounts for 91% of its ecological composition.

The “Evergreen Shrub” classification, LULC value 11, is composed of 96% Pine Plantation 1 to 3 meters tall.

APPENDIX E

Detailed Analysis, EMS-T x Loblolly, Hardwood



The digitized boundary for Eldredge/Cruikshank's Loblolly Hardwood classification contains 741,294 hectares (Figures 23 and 24). Current day composition of these areas are 31% Deciduous Forest, 29% Evergreen Forest 12% Grassland, 8% Mixed Forest, 8% Low Density Urban, and 3% High Density Urban. This accounts for 91% of its ecological composition as described by Land Use/Land Cover value. The sections below describe the ecological composition for each of these contributing classifications.

The "Deciduous Forest" classification, LULC value 5, is composed of 39% Pineywoods: Upland Hardwood Forest, 19% Pineywoods: Hardwood Flatwoods, 12% Non-Native Invasive: Chinese Tallow Forest, Woodland, or Shrubland, 10% Native Invasive: Deciduous Woodland, and 8% Pineywoods: Small Stream and Riparian Temporarily Flooded Hardwood Forest. These account for 88% of the ecological composition.

The "Evergreen Forest" classification, LULC value 19, is composed of 40% Pineywoods: Pine Forest or Plantation, 37% Pine Plantation > 3 meters tall, and 23%

Pineywoods: Longleaf or Loblolly Pine Flatwoods or Plantation. This accounts for 99.9% of its ecological composition.

The “Grassland” classification, LULC value 15, is composed of 62% Pineywoods: Disturbance or Tame Grassland and 28% Gulf Coast: Coastal Prairie. This accounts for 90% of its ecological composition.

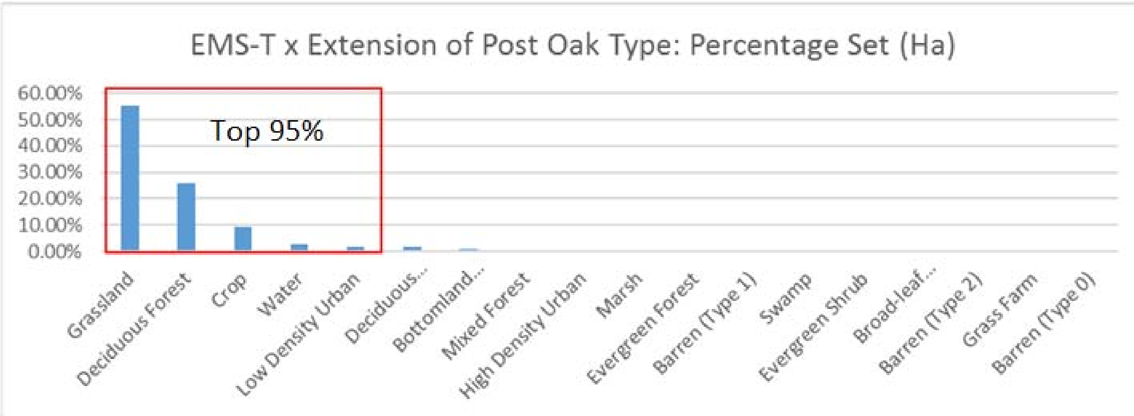
The “Mixed Forest” classification, LULC value 31, is composed of 43% Pineywoods: Pine - Hardwood Forest or Plantation, 23% Pineywoods: Longleaf or Loblolly Pine - Hardwood Flatwoods or Plantation, 12% Chenier Plain: Mixed Live Oak - Deciduous Hardwood Fringe Forest, 8% Post Oak Savanna: Post Oak - Redcedar Motte and Woodland, and 7% Pineywoods: Small Stream and Riparian Temporarily Flooded Mixed Forest. This accounts for 93% of its ecological composition.

The “Low Density Urban” classification, LULC value 25, is composed 100% of Urban Low Intensity.

The “High Density Urban” Classification, LULC value 23, is composed of 100% Urban High Intensity.

APPENDIX F

Detailed Analysis, EMS-T x Extension of the Post Oak Type



The digitized boundary for Eldredge/Cruikshank's Extension of Post Oak Type classification contains 377,030 hectares (Figures 25 and 26). Current day composition of these areas are 55% Grassland, 26% Deciduous Forest, 9% Crop, 3% Water, and 2% Low Density Urban. This accounts for 95% of its ecological composition as described by Land Use/Land Cover value. The sections below describe the ecological composition for each of these contributing classifications.

The "Grasslands" classification, LULC value 15, contains 36% Blackland Prairie: Disturbance or Tame Grassland, 29% Post Oak Savanna: Savanna Grassland, 6% Red River: Floodplain Wet Prairie, and 5% Red River: Floodplain Herbaceous Wetland. This accounts for 76% of its ecological composition.

The "Deciduous Forest" classification, LULC value 5, contains 38% Post Oak Savanna: Post Oak Motte and Woodland, and 28% Native Invasive: Deciduous Woodland, 12% Red River: Floodplain Hardwood Forest. This account for 78% of its ecological composition.

The “Crop” classification, LULC value 9, contains 88% row crops, 3% Blackland Prairie: Disturbance or Tame Grassland, and 3% Post Oak Savanna: Savanna Grassland. This accounts for 94% of its ecological composition.

The “Water” Classification, LULC value 21, contains 95% open water.

The “Low Density Urban” classification, LULC value 25, contains 94% Urban Low Intensity.

VITA

David Ray Hoffpauir

Sr. GIS Programmer/Analyst I, Office of Research and Sponsored Programs (ORSP), Sam Houston State University, Huntsville, TX. Current position since June, 2012.

Duties include:

- Geographic analysis and mapping in association with various University initiatives organized through the Office of Research and Sponsored Programs and the SHSU Applied Geospatial Research Center (A/G SRC)

Programmer/Analyst I, Law Enforcement Management Institute of Texas (LEMIT), College of Criminal Justice, Sam Houston State University, Huntsville, TX. September, 2005 to June 2012.

Programmer/Analyst I, Texas Research Institute for Environmental Studies (TRIES), Sam Houston State University, Huntsville, TX. September 1994-September 2005.

EDUCATION

Master of Science, Applied Geography. Sam Houston State University-Currently enrolled. Major emphasis in Geographic Information Systems. **Projected graduation**, May 2017.

Graduate Geographic Information Systems Certificate. Sam Houston State University. Completion of Graduate Certificate requirements. Awarded March 2013.

Master of Arts, Technology. Sam Houston State University-1994. Major emphasis in Computer Aided Design (CAD) and Geographic Information Systems. Graduate Minor in Education

Bachelor of Science, Industrial Technology. Sam Houston State University-1989. Major emphasis in design and development with minors in Art and English

Graduate Fellowship, Texas Regional Institute for Environmental Studies, Sam Houston State University, Spring and Summer Semesters, 1994

APPOINTMENTS, AWARDS, AND ACHIEVEMENTS (2010 – Present)

- **20-Year Service Award, Sam Houston State University, 2014.**

- **David Cameron/ IACP Environmental Crime of the Year Award, 2012.** Presented by the International Association of Chiefs of Police (IACP) to the Collaborative Task Force investigating the Houston Police Department's illegal hazardous waste dumping case of March, 2012. Awarded, October 2012
- **Chief of Police Commendation**, City of Houston. Citation for assistance to the Environmental Crimes Unit during investigation of their largest ever illegal hazardous waste dumping case, March, 2012
- Collaterally assigned to the Sam Houston State University, Critical Incident Management Team as the **Planning Section Chief,** 2010
- **Planning Committee** member for the Southeast Texas Applied Forensic Science Facility, 2008-2011
- **Research Committee** member for the Southeast Texas Applied Forensic Science Facility, 2009-2011
- Liaison for SHSU agreement with **Houston Galveston Area Council of Governments (HGAC) Geographic Information Development Committee**, 2005 to present

PUBLICATIONS AND PRESENTATIONS (2010 – Present)

Hoffpauir, David R., *Geographic analysis of current and historical vegetation of East Texas*. Thesis, Master of Science (Applied Geography), Sam Houston State University, Huntsville, Texas, May, 2017.

Hill, J.M., David Hoffpauir, and Ashar Neyez. *"Innovative University Administration GIS Applications: Texas Supreme Court Requests, Academic Program Development, Economic Reach, and Fundraising."* Texas GIS Forum, Austin, Texas, October 2016.

David R. Hoffpauir, *GIS in Environmental Investigations*. Sam Houston State University, Online course in association with the Law Enforcement Management Institute of Texas (LEMIT), September, 2016.

GIS/mapping support – Philip Matich, Godwin, William and Fisher, Mark. *Long-term trends in fish community composition across coastal bays and lakes in the Lavaca-Colorado Estuary.* Canadian Journal of Zoology/ NRC Research Press, September 2016.

McDonald, Danny, David R. Hoffpauir, and Jerry Cook. *Red Imported Fire Ant Survey Yields Seven New Texas County Records and Documents Further Spread of Solenopsis invicta, Buren (Hymenopetera: Formicidae)*. Southwestern Entomologist, July 2016.

Hill, J.M., A. Scarbrough, and David R. Hoffpauir. *Innovative Public Health Care GIS Applications*. Medicine-Humanities-Social Sciences Round Table Symposium, Sam Houston State University, March 2016.

Hill, J.M., A. Scarbrough, David R. Hoffpauir, and W. Panupong. *"Innovative Public Health Care Applications."* Texas GIS Forum, Austin, Texas, October 2015.

Hill, J.M., A. Scarbrough, David R. Hoffpauir, and W. Panupong. *Asset Mapping, Gap Analysis, and Visualization to Improve Health Care Decision Making.* First Annual International Conference on Health Care, San Jose, Costa Rica, September 2015.

Dilliard, Kaitlin, Joan Bytheway, Phd., and David Hoffpauir. *Study of Two Faces: Preliminary Study on the Use of a 3d Scanner in Determining Asymmetry in the Craniofacial Bones*. Presented at the Texas Association of Biological Anthropology, Sam Houston State University, November, 2014.

Messer, Ross, Jack Hill, David Hoffpauir, Jerry Cook, Autumn Smith-Herron, Brian Piper. *Texas Parks and Wildlife's Ecological Mapping Systems Classification & Mapping Project Data Applied to Invasive and Rare Species*. Texas GIS Forum, October, 2014.

GIS/ Mapping Support- Morgan, A. R., Smith-Herron, A. J., & Cook, J. L. (2013). *Rapid Spread of Balclutha rubrostriata (Hemiptera: Cicadellidae) in Texas and Southwestern Louisiana, USA with Notes on its Associated Host Plants. Florida Entomologist*, *96*(2), 477-481.

GIS/ Mapping Support- Anderson, Sidney M., Riccardo A. Fiorillo, Tamara J. Cook, and William I. Lutterschmidt. *Helminth Parasites of Two Species of Lepomis (Osteichthyes: Centrarchidae) From and Urban Watershed and Their Potential Use in Environmental Monitoring*, Georgia Journal of Science, 2013.

GIS/ Mapping Support- Martin, Samantha L. and William I. Lutterschmidt. *A Checklist to the Common Cyprinid and Centrarchid Fishes of the Bull and Upatoi Creeks Watershed of Georgian with a Brief Glimpse of Correlative Urban Influences and Land Use.* Southeastern Naturalist, 2013.

David R. Hoffpauir. *Geographic Selection Methodology for Placement of Invasive Emerald Ash Borer Trap Locations in Texas.* Poster presentation, Institute for the Study of Invasive Species (ISIS), May 2013.

Rakozy, Lila, Sandra Rogers, and David R. Hoffpauir *Use of Ground Penetrating Radar (GPR) to Detect Lost Graves in the Historically Black Section of Oakwood Cemetery, Huntsville, Texas.* , May, 2013.

Nobles, Matt R., David R. Hoffpauir, and Jack M. Hill *Houston-Area Environmental Crime Incident Data: Description and Needs Assessment.* Submitted to the Houston Police Department Major Offenders Division, Environmental Investigations Unit, July 2012.

Smith, Autumn J. and David R. Hoffpauir *Evaluation of Parasitic Diseases of the Eurasian Collared-Dove and the Ecological Impacts on Native Dove Species.* Presented at the Texas Invasive Species Plant and Pest Conference, 2011.

Webb, David W. and David R. Hoffpauir - *Critical Incident Management and Geographically–based Systems.* **International Journal of Applied Geospatial Research (IJAGR), An Official Publication of the Information Resources Management Association,** 2010.