Illustrated Flora of East Texas

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Special recognition for Lorine Gibson who shared our passion for the plants of East Texas

Photo courtesy of David H. Gibson

"I shall know life is simply lots of beginnings and endings with love that glues it together."

—Lorine Dieu Crenshaw Gibson, February 25, 1990

Lorine Dieu Crenshaw Gibson was a conservationist at heart and was devoted to and compassionate about plants, whether in the wild in East Texas or in her beautiful garden at home in Dallas. She was one of the early supporters of the Flora of East Texas Project and we are appreciative of her support and encouragement. Upon her untimely death, her family requested that memorials be given to help underwrite the flora that Lorine had been so excited about. Subsequently, her family has generously supported the flora and made a critical major gift that completed the funding necessary for publication.

We would like to recognize and express our appreciation to the following individuals who contributed in Lorine's memory. Their support has resulted in a scholarly publication that will be a lasting legacy for Lorine and her fellow Texans.

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Austin College Center for Environmental Studies

and the

Botanical Research Institute of Texas

to produce illustrated floristic treatments

designed to be useful to both botanical specialists

and a more general audience.

"Deep East Texas is an old, quiet land. Ancient trees, winding roads, moss and vines offer a sense of timelessness. A mysterious and almost mystical beauty prevails....Over and over I sense this...land is about trees....I felt the power of tall pines and saw the exotic sculptures of cypress trees draped in Spanish moss. Somehow...[the] trees [felt] imbued with a special magic."

David H. Gibson, 1993

To

Elray S. Nixon

for his contributions to

East Texas botany

Elray S. Nixon

Elray Nixon was born in Escalante, Utah, on February 5, 1931. He and his wife, Tillie, married in 1957, and they had three daughters and one son. Dr. Nixon received his B.S. degree from Brigham Young University in 1957, his M.S., also from Brigham Young, in 1961, and his Ph.D. from the University of Texas at Austin in 1963. After a brief stint as Professor of Biology at Chadron State College in northwest Nebraska (1963–65), he took up residence in the Biology Department at Stephen F. Austin State University (SFASU) in Nacogdoches, Texas, in 1965. He remained there for nearly thirty years until his retirement in 1993. During that time, Dr. Nixon provided botanical training to hundreds of students as a full-time teaching professor. As a constant researcher, he also published numerous articles and scientific papers and received many grants. In addition, he authored three books: *Trees, Shrubs and Woody Vines of East Texas*, 1985, second edition, 2000 (fully illustrated by Bruce Cunningham); *Plant Characteristics, Aids to Plant Identification*, with Suzanne Anderson, 1989; and *Ferns and Herbaceous Flowering Plants of East Texas*, with John G. Kell, 1993. Not the least of his accomplishments, in addition to his teaching duties, was the tireless effort he put into the inception and growth of the SFASU herbarium. Though it serves as a historic account of the flora of the region, through diligent exchange with other herbaria it is also very diverse. It is one of the largest herbaria in East Texas and is an important resource for both practical and scientific purposes. During his tenure at SFASU, the herbarium grew from a few to more than 75,000 specimens, most of which he collected himself. He taught classes at both the undergraduate and graduate level, developed and introduced several new courses, and directed many graduate students in their research. A number of the approximately 20 graduate students that he directed published their thesis research in scientific journals and continue to contribute to Texas botany. As a dedicated ecologist/taxonomist, he spent many hours in the field collecting specimens and research data resulting in numerous publications. Many of these were on the ecology and composition of woody species associations in East Texas. He also served the scientific community as president of the Texas Academy of Science and was named an Honorary Life Fellow in 1984 in recognition of outstanding service. He received other awards including Regent's Professor for Research for the 1986-87 academic year in recognition of research accomplishments at SFASU, the 1992 Harold Beatty Award from the Texas Organization for Endangered Species, and the Charles Weddle Memorial Award for Life Time Achievement in the field of Texas native plants from the Native Plant Society of Texas, 1992, and was awarded a certificate of appreciation from the United States Department of Agriculture (Forest Service) in recognition of his pioneering work in botany and plant ecology throughout East Texas, which will be a lasting contribution to the National Forests of Texas. During his tenure at SFASU he received eight faculty research grants to study plant succession and floristic ecology. He also received grants from the U.S. Army Corps of Engineers as project director and principal researcher for vegetational studies of the Sabine and Trinity river watersheds. It is with special thanks and appreciation that we dedicate this book to Elray Nixon, a selfless, indefatigable icon of East Texas botany. Dr. Nixon is currently enjoying retirement in Las Vegas, Nevada, and Escalante, Utah, with his wife, Tillie.

PHOTO COURTESY OF ELRAY S. NIXON

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Hymenocallis liriosme

Abstract

The *Illustrated Flora of East Texas* is a three-volume work treating all native and naturalized vascular plant species known to occur in East Texas. The flora includes 3,402 species, more than two-thirds of the species known for the entire state, and 3,660 taxa (species, subspecies, and varieties) overall. This diversity represents more than one out of every six species known in the U.S.A. and Canada combined. Volume One, which treats ferns and similar plants, gymnosperms, and monocotyledons, covers 1,060 species and 1,131 taxa. An introduction gives an overview of East Texas and includes discussions of the vegetation, geology, soils, climate, presettlement and early settlement conditions, floristic origins, conservation, and botanical history. The taxonomic treatments include family and generic synopses, keys and descriptions, derivations of scientific names, notes on toxic/poisonous and useful plants, and references to supporting literature. Line drawing illustrations are provided for all species, distribution maps for almost all species, and color photographs for nearly 200. The appendices address topics such as phylogeny, cladistics, nomenclature, endemic species, species of conservation concern, suggested native ornamentals, commercially important timber trees, and botanically related internet addresses.

Resumen

La *Flora Ilustrada del Este de Texas* es un trabajo en tres volúmenes que incluye todas las especies de plantas vasculares nativas y naturalizadas que se conocen en el Este de Texas. La flora incluye 3.402 especies, más de dos tercios de las especies conocidas en el estado entero, y 3.660 taxa (especies, subespecies, y variedades) en conjunto. Esta diversidad representa más de una de cada seis especies conocidas en U.S.A. y Canadá conjuntamente. El Volumen Uno, que trata los helechos y plantas similares, gimnospermas y monocotiledóneas, cubre 1.060 especies y 1.131 taxa. La introducción da una visión de conjunto del Este de Texas e incluye discusiones de la vegetación, geología, suelos, clima, condiciones de preasentamiento y asentamiento temprano, orígenes florísticos, conservación e historia botánica. Los tratamientos taxonómicos incluyen sinopsis de familias y géneros, claves y descripciones, etimología de los nombres científicos, notas sobre las plantas tóxicas/venenosas y útiles, y las referencias bibliográficas que lo apoyan. Se aportan dibujos de todas las especies, mapas de distribución de casi todas ellas, y fotografía en color de unas 200. Los apéndices tratan temas tales como filogenia, cladística, nomenclatura, especies endémicas, especies que necesitan conservación, especies nativas que se sugieren como ornamentales, árboles madereros comercialmente importantes, y direcciones de internet relacionadas con la botánica.

ILLUSTRATED FLORA OF EAST TEXAS

OVERVIEW OF THE FLORA

The *Illustrated Flora of East Texas* is a floristic treatment of all native and naturalized vascular plant species known to occur in East Texas. It includes 3,402 species, more than two-thirds of the approximately 5,100 species known for Texas, and a total of 3,660 taxa (species, subspecies, and varieties) overall. This diversity represents more than one out of every six species known in the U.S. and Canada combined (18,000 species—Thorne 1993d). Representatives of 202 families and 1,079 genera are included. Volume One, which treats ferns and similar plants, gymnosperms, and monocotyledons, covers 1,060 species and 1,131 taxa. The flora is a continuation of the Illustrated Texas Floras series, of which *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999) was the first publication. The *Illustrated Flora of East Texas* follows in the tradition of a number of floristic works for the area including Elray Nixon and J.G. Kell's *Ferns and Herbaceous Flowering Plants of East Texas* (1993), Nixon's *Trees, Shrubs, & Woody Vines of East Texas* (1985, 2000), Lloyd Shinners' *Spring Flora of the Dallas-Fort Worth Area Texas* (1958a), and Monique Reed's *Manual of the Dicot Flora of Brazos and Surrounding Counties* (1997).

A number of features have been incorporated to make the flora more useful to non-specialists. Line drawings are provided for all species, making it the first fully illustrated flora for East Texas. Color photographs are provided for nearly 200 taxa. County distribution maps are also included for almost all species. An introduction covering general aspects of the vegetation, geology, soils, climate, presettlement and early settlement conditions, floristic origins, conservation, and botanical history has been included to provide background and context. The taxonomic treatments include brief synopses of each family and genus, derivations of generic names and specific epithets, characters helpful in family recognition in the field, notes on useful and toxic plants (ethnobotanical information), and references to supporting literature. Finally, appendices are provided on a variety of topics, including evolutionary relationships (phylogeny) at the family level, cladistics (a current controversy/approach in taxonomy), changes in scientific names, illustration sources, collecting herbarium specimens, endemics, species of conservation concern, conservation organizations, books for the study of native plants, suggested native ornamentals, sources for native plants, native plants important to wildlife, lepidopteran (butterfly and moth) host plant information, commercially important timber trees, and botanically related internet resources. When possible and practical, we have attempted to conform to the suggestions in Schmid's (1997) article on ways to make floras more user-friendly.

GEOGRAPHIC AREA COVERED

East Texas (Fig. 1) is an area of roughly 62,600 square miles (162,200 square kilometers, 40 million acres, or 16.2 million hectares) or about the size of Georgia. This 87 county region stretches from the border of Texas with Arkansas and Louisiana west to the western margin of the Blackland Prairie, and from the Red River border with Oklahoma south nearly to San Antonio. Vegetational areas include the Pineywoods, the Post Oak Savannah, the Blackland Prairie, and the Red River Area (Fig. 2).

How does one define the limits of a region like East Texas for a floristic work such as this? One simple method would be to simply limit the flora to the Pineywoods (vegetational area 1 of Correll and Johnston (1970) and Hatch et al. (1990)—Fig 3). Another approach would be to cover both the Pineywoods and the floristically related Post Oak Savannah (vegetational areas 1 and 3). Unfortunately, the vegetational areas of Texas do not make for easily drawn lines on maps (see Figs. 4, 5). Portions of the Post Oak Savannah and the Blackland Prairie are extensively intermingled, and parts of the Blackland Prairie extend into the Pineywoods. Further, as pointed out by MacRoberts et al. (2002c), "the east Texas flora clearly extends into those counties just east of Austin and San Antonio." Therefore, it was decided that in order to make this work as useful as possible, three major vegetational areas, the Pineywoods, the Post Oak Savannah, and the Blackland Prairie, would be included. In addition, the area adjacent to the Red River (typically classified as part of the Post Oak Savannah), which we designate as the Red River Area (Fig. 2), was covered. Coastal Texas (the Gulf Prairies and Marshes vegetational area) was excluded because the tremendous number of

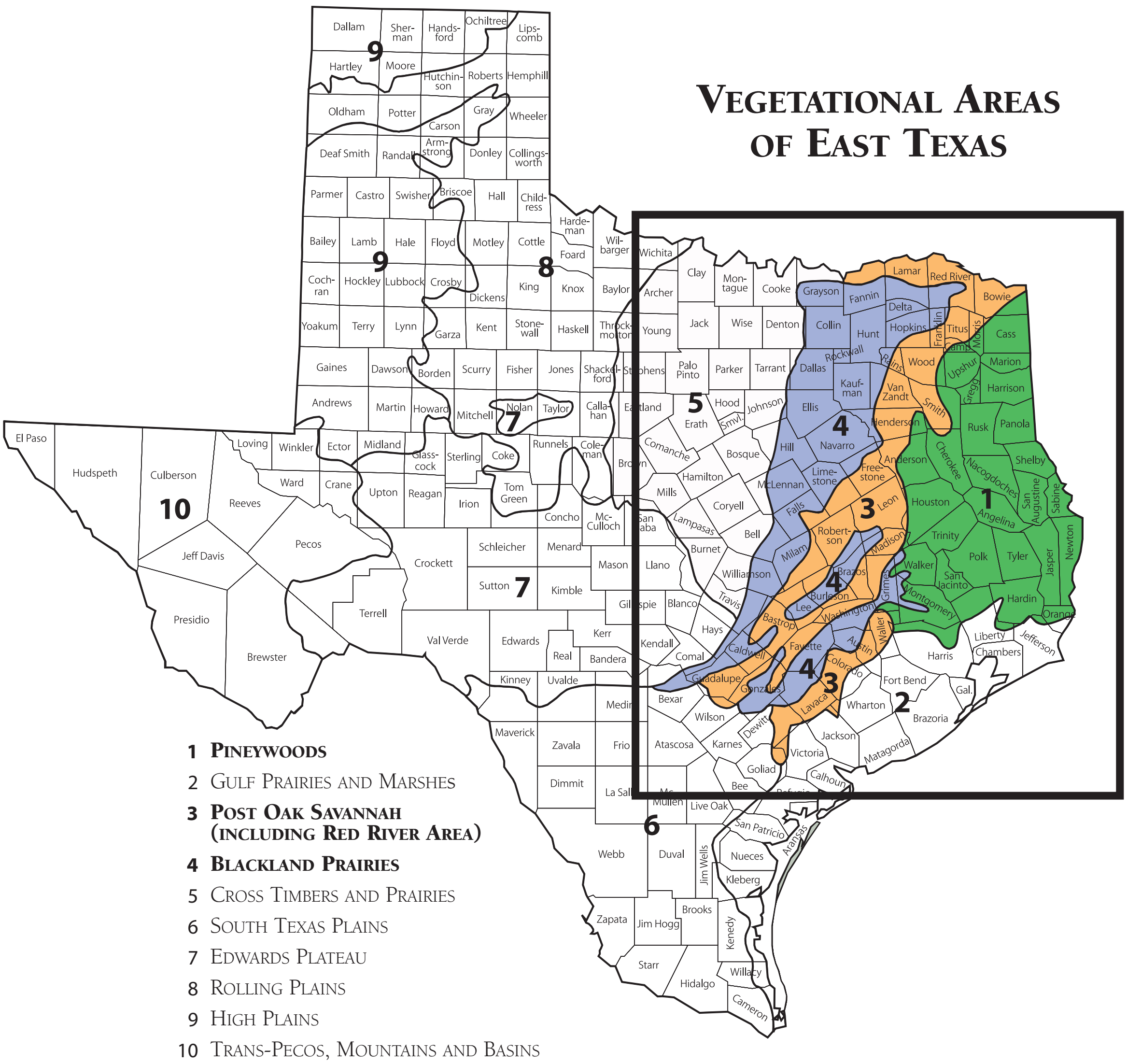
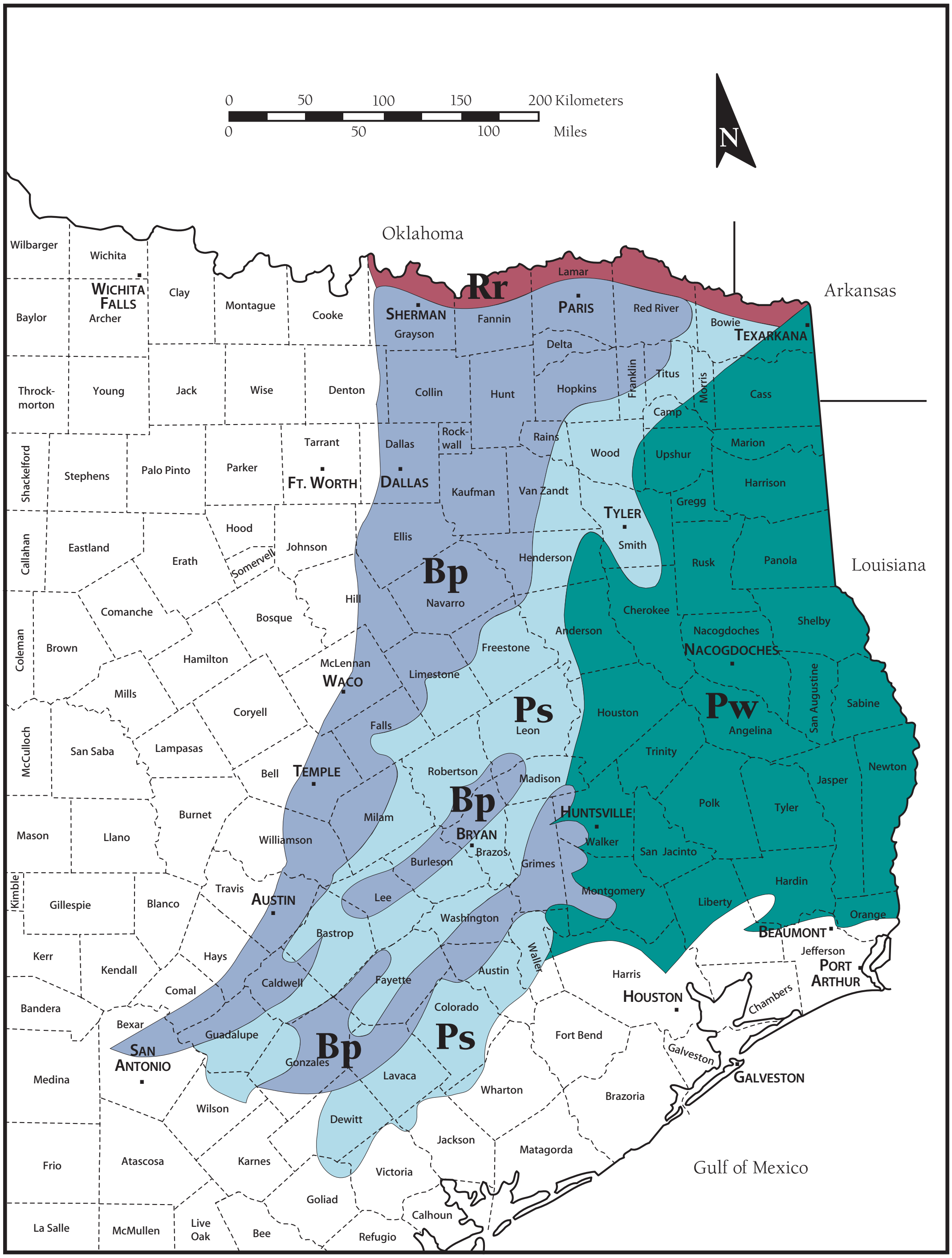


FIG. 1/ VEGETATIONAL AREAS OF EAST TEXAS IN RELATION TO THE REST OF THE STATE. FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE; REPRODUCTION OF THIS IMAGE DOES NOT REQUIRE COPYRIGHT PERMISSION.



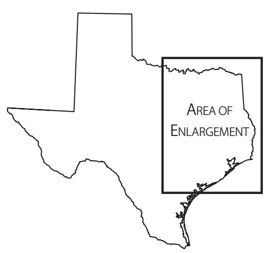


Fig. 2/ Vegetational areas of East Texas. Figure produced by BRIT/Austin College; reproduction of this image does not require copyright permission.

salt marsh and coastal species found there were beyond the scope of this project and because that area is closely tied to the flora of South Texas. Also, that area is a separate center of endemism needing detailed study (Sorrie & Weakley 2001; MacRoberts et al. 2002c). Thus, for the purposes of this work, East Texas corresponds roughly with vegetational areas 1 (Pineywoods), 3 (Post Oak Savannah), and 4 (Blackland Prairie) of Correll and Johnston (1970) and Hatch et al. (1990) (Fig. 3). Interestingly, this is almost exactly the portion of Texas that is included in the West Gulf Coastal Plain phytogeographic region by MacRoberts et al. (2002c) (see page 215). An alphabetical list of the counties wholly or partially included can be found in Table 1. It should be kept in mind that the vegetation maps presented (Figs. 1–5) portray varying interpretations of what is thought to have been present prior to the time of European settlement. However, in some cases it is extremely difficult to determine with certainty the original vegetation of an area. Further, humans have extensively modified the original vegetation, and modern day conditions are quite different (Fig. 6). For example, virtually all of the Blackland Prairie has been converted to agricultural uses, and there are now extensive areas of grass vegetation (pasture) as well as pine plantations that have replaced large areas of the original pine-hardwood vegetation of the Pineywoods.

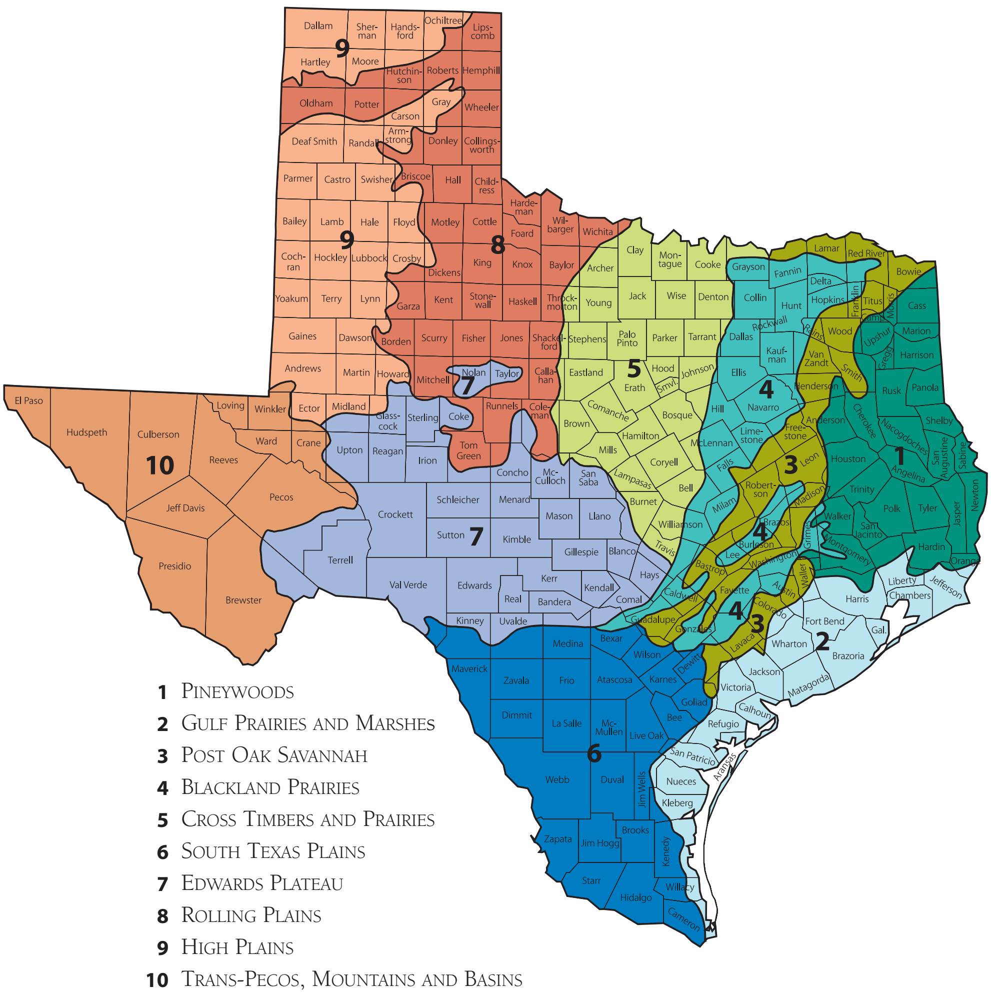


FIG. 3/ MAP OF VEGETATIONAL AREAS OF TEXAS MODIFIED FROM *MANUAL OF THE VASCULAR PLANTS OF TEXAS* (CORRELL & JOHNSTON 1970) AND *CHECKLIST OF THE VASCULAR PLANTS OF TEXAS* (HATCH ET AL. 1990). NEARLY IDENTICAL MAPS HAVE BEEN USED IN NUMEROUS WORKS ON TEXAS, INCLUDING GOULD (1962). FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE; REPRODUCTION OF THIS IMAGE DOES NOT REQUIRE COPYRIGHT PERMISSION.

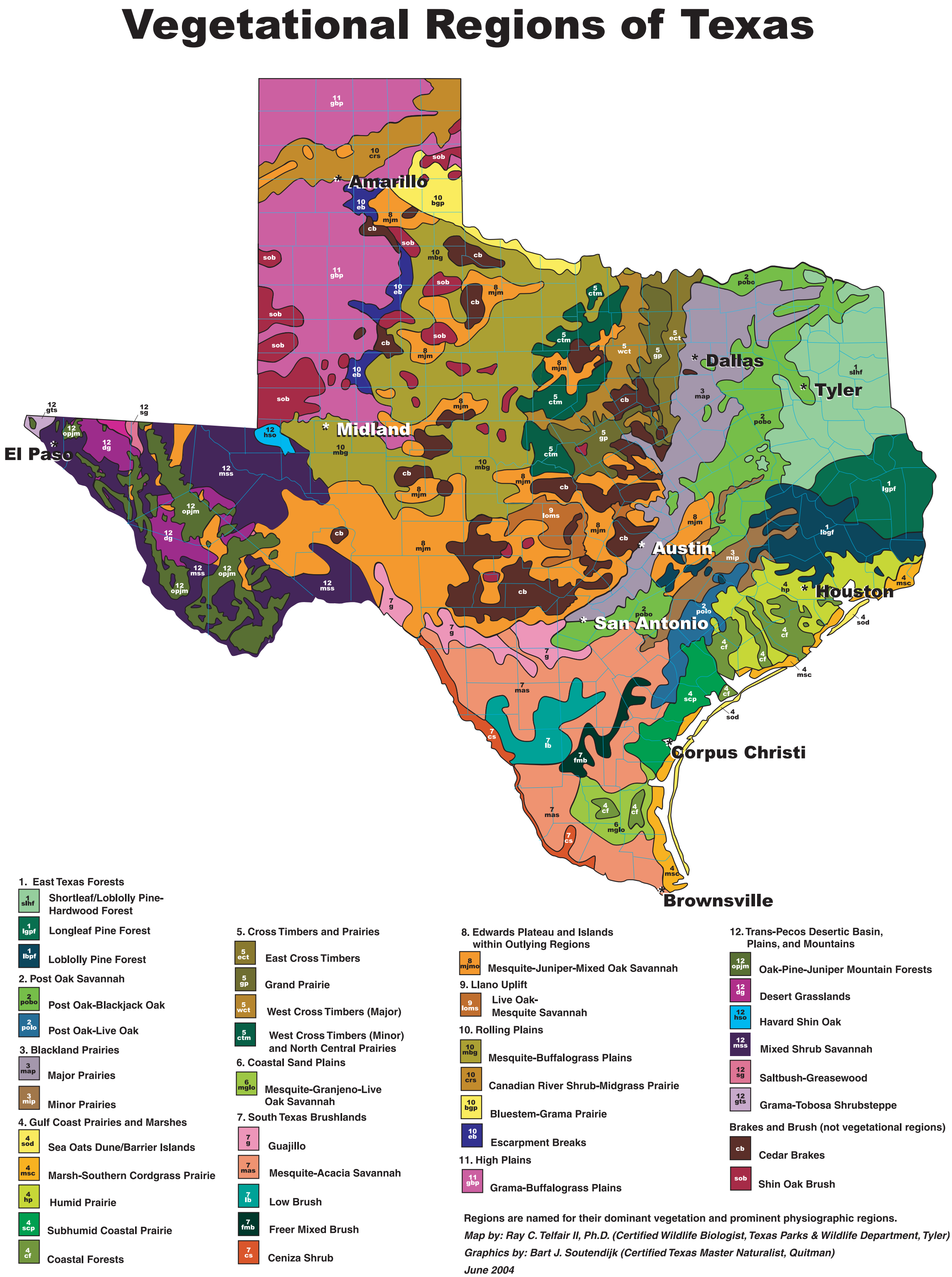


FIG. 4/ VEGETATIONAL REGIONS OF TEXAS. MAP BY RAY C. TELFAIR II, USED WITH PERMISSION (© 2004). ORIGINALLY PUBLISHED IN TELFAIR (1983), UPDATED IN TELFAIR (1999), FURTHER UPDATED AND HERE PUBLISHED IN COLOR FOR THE FIRST TIME.

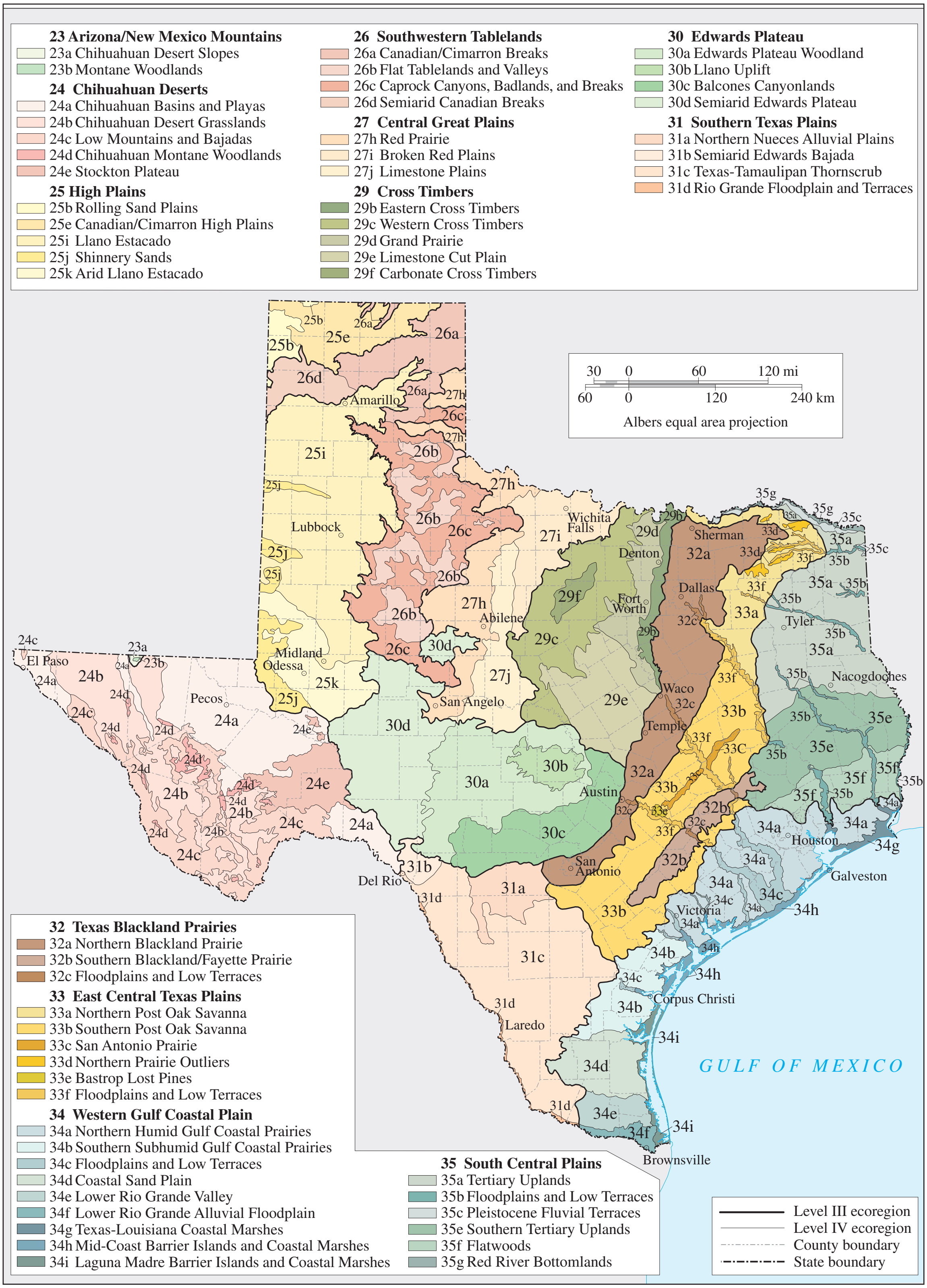


FIG. 5/ MAP OF THE ECOREGIONS OF TEXAS (GRIFFITH ET AL. 2004). USED WITH PERMISSION OF THE ENVIRONMENTAL PROTECTION AGENCY.

FIG. 6/ VEGETATION/COVER TYPES OF TEXAS 2000. USED WITH PERMISSION OF THE BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS AT AUSTIN.

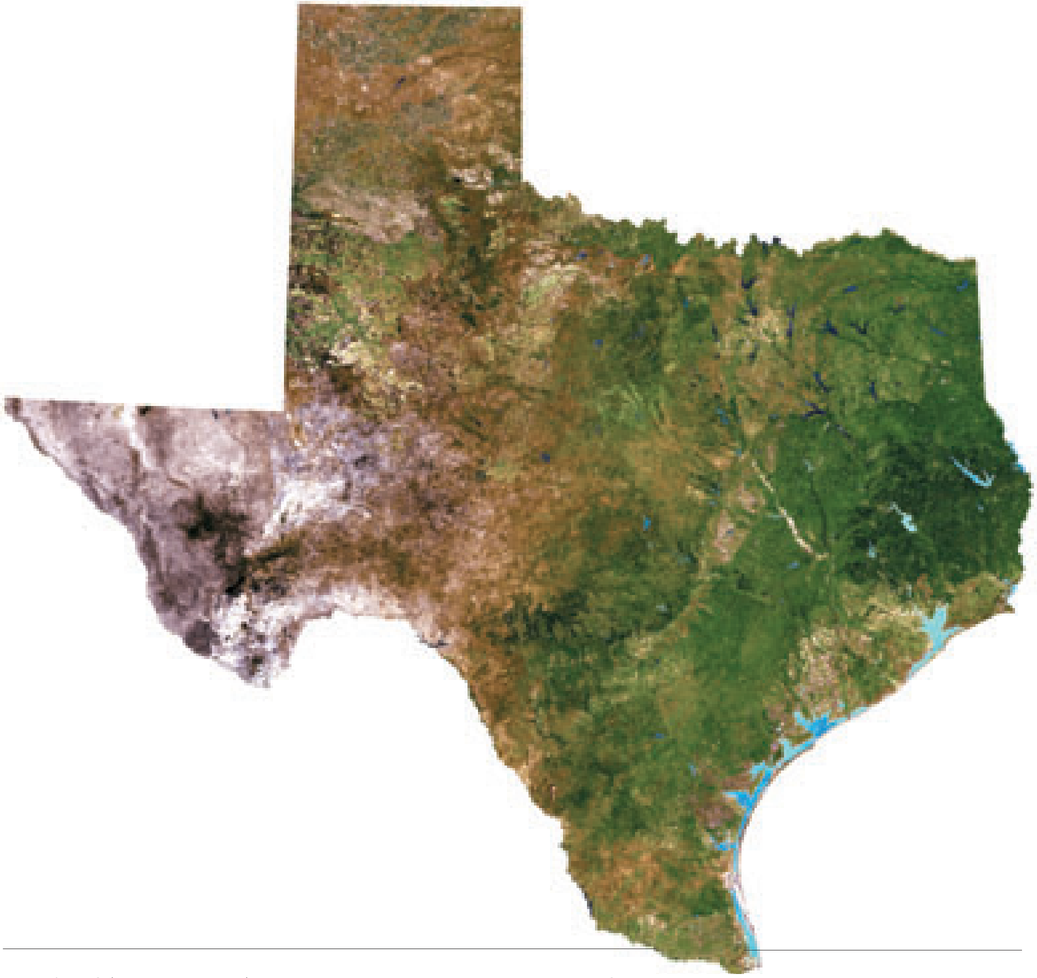
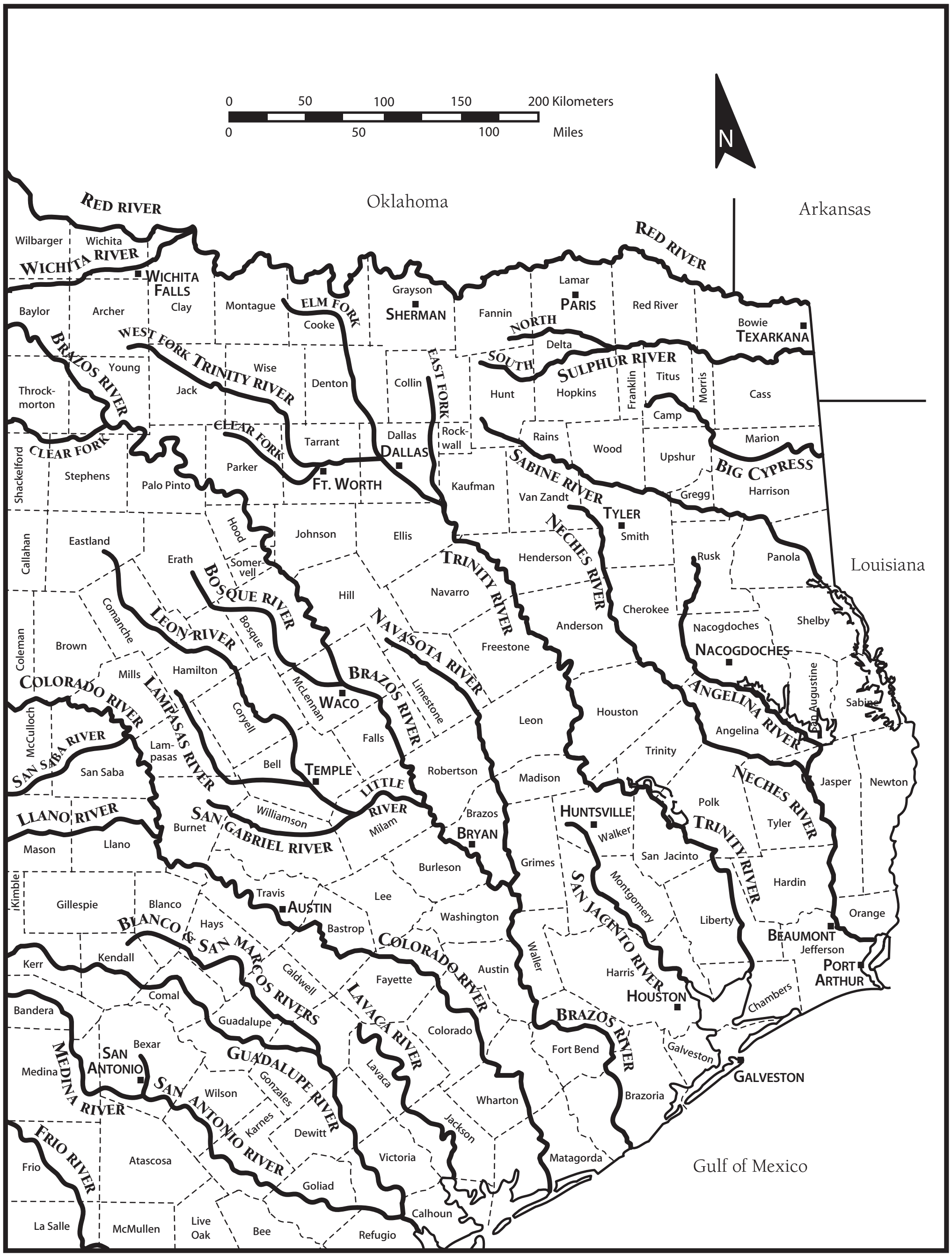


FIG. 7/ WiFS (WIDE FIELD SENSOR) SATELLITE IMAGE OF TEXAS. IMAGERY COURTESY OF SPACE IMAGING.

Likewise, there are now widespread areas of cedar brakes (*Juniperus* spp.) and other thickets that have developed after fire suppression was imposed.The square miles/kilometers considered to be in each of the three major vegetational areas, the Pineywoods (24,400 square miles/63,200 square kilometers), the Post Oak Savannah including the Red River Area (20,600 square miles/53,400 square kilometers), and the Blackland Prairie (17,600 square miles/45,600 square kilometers) were calculated using detailed map data from Glenn Griffith (pers. comm.; see also Fig. 5).

Some correspondence to the vegetational areas outlined here can even be seen in modern satellite maps (Fig. 7). For example, a band corresponding to the Blackland Prairie can approximately be recognized.

In virtually any geographic region, the "typical" habitat is modified by microclimates and migration corridors provided by major rivers (Figs. 8, 9), any unusual levels of precipitation, and any specialized geologic features. These modifiers allow the occurrence of species not otherwise typical of that particular region. While these species may be neither abundant nor widespread, they are important biogeographically, in some cases providing important information about the botanical history of an area. If the occurrence of such a species is at the margin of its range, it may serve as an ecological indicator, possibly providing information in the future on important issues such as climate change or habitat alteration. The East Texas flora has many such examples. Numerous predominantly eastern species are limited in East Texas to the very eastern portion of the Pineywoods where precipitation levels average nearly 60 inches (152.4 cm) per year. In some cases plants are confined to only one or two counties (e.g., Jasper and Newton). An analogous situation occurs



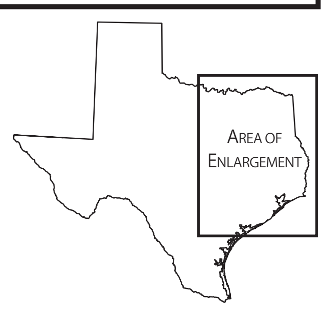


Fig. 8/ Major rivers of East Texas. Figure produced by BRIT/Austin College; reproduction of this image does not require copyright permission.

where numerous plants typical of the Edwards Plateau extend into the western edge of East Texas (e.g., on outcrops of the Oakville Sandstone in Burleson, Fayette, and Grimes counties). Other range extensions are known where species extend east from western Texas along such rivers as the Red or Comal. Yet other species, more typical of southern or southwestern Texas, reach only the extreme southwestern margins of East Texas. Finally, some predominantly coastal species extend inland into areas of the Big Thicket, or even farther in special cases (e.g., inland salt marsh near Grand Saline in Van Zandt Co.).

River basins	Texas length (miles)	Texas area (sq mi)	Number of major reservoirs*	Conservation storage (acre ft)*	Storage (acre ft/sq mi)
Brazos	840	42,800	19	3,322,880	75
Canadian	200	12,700	2	560,900	44
Colorado	600	39,893	11	3,803,900	95
Guadalupe	250	6,070	2	420,000	70
Lavaca	74	2,309	1	157,900	68
Neches	416	10,011	4	3,455,500	345
Nueces	315	16,950	2	931,640	60
Red	680	30,823	7	4,593,460	149
Rio Grande	1,250	48,259	3	3,772,000	78
Sabine	360	7,426	2	6,041,300	814
San Jacinto	70	5,600	2	570,400	102
Trinity	550	17,696	14	6,969,710	388

*Data from Texas Water Development Board.

FIG. 9/ RIVER BASIN MAP OF TEXAS. USED WITH PERMISSION OF THE BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS AT AUSTIN.

The generalized vegetation map of East Texas (Fig. 2) is a modification of maps in Tharp (1926), Gould (1957b), Gould (1962), Correll and Johnston (1970), Mahler (1988), Hatch et al. (1990), and Diggs et al. (1999). The western edge of the Blackland Prairie is defined to the south by the Balcones Escarpment and to the north by the beginning of the East Cross Timbers. To the east, the Blackland Prairie and the Post Oak Savannah intermingle extensively, usually with prairie vegetation on clay soils and savannah vegetation on sandy soils. To the east of the Post Oak Savannah is the Pineywoods vegetational area, a region of pine, mixed pine-deciduous, and deciduous forests occupying the wettest portion of East Texas. The northern boundary of East Texas is the Red River border with Oklahoma. The area adjacent to the Red River is designated as the Red River Area, a vegetationally distinct, narrow strip of land near the Red River, with sandy soils supporting numerous plants more typically found farther east. The eastern boundary of the Pineywoods, and East Texas as a whole, is the state line between Texas and Arkansas to the north and Louisiana to the south. To the south, East Texas extends to the beginning of the Gulf Prairies and Marshes and the South Texas Plains vegetational areas. Components of both those areas extend north into the region treated in this study.

Information Helpful in Using the Flora

Plants Treated

All known native and naturalized vascular plant species occurring in East Texas (Fig. 2; Table 1) are treated taxonomically in the flora. For a species to be included, voucher specimens must have been seen, a reliable literature citation found, or in a few cases, plants observed in the field. If a taxon was included based on a literature citation, the citation is given in the text. A significant number of species were included based on mapped locations in the recently published *Atlas of the Vascular Plants of Texas* by Turner et al. (2003), which is based on specimens at TEX, or in a few instances, on other sources checked by Turner and his colleagues. A few other species were included based on a listing for vegetational areas 1 (Pineywoods), 3 (Post Oak Savannah), or 4 (Blackland Prairie) by Hatch et al. (1990). In a few instances, species were included based on field observations by individuals. These are listed in the treatments as “pers. obs.” (personal observation, which denotes observation by one of the authors) or “pers. comm.” (personal communication, which indicates an individual’s observation communicated to the authors; such individuals are listed in the literature cited with a one or two line biography).

Plants growing in East Texas can be divided into five categories (native, naturalized, persisting, waif, and cultivated), following Nesom (2000). **Native** plants are those naturally occurring in the area before Anglo-European settlement. For the purposes of this work, a **naturalized** species is simply a non-native that is reproducing in the area without human assistance. Nesom’s (2000) more detailed definition of naturalized species is as follows: “Plants of non-native species accidentally or deliberately introduced into the flora, now reproducing and maintaining viable populations from year to year (more than just one or a few seasons), and dispersing without deliberate human assistance beyond the population or populations of original establishment.” The term “escaped”, included here within the definition of naturalized, is used by various authors. It often is used to imply that the species in question is represented in the wild by only a few individuals or occurs only in a limited area. A limited number of **persisting** but apparently non-reproducing taxa (e.g., *Iris germanica*—garden iris), have been included because they are likely to be encountered and because they can be difficult to distinguish from native or naturalized species. While not truly naturalized (“not reproducing or at least not spreading beyond the original planting”), these long-persistent plants can remain at old home sites, roadsides, etc. for many decades without human assistance, even after all evidence of associated human presence is gone (Nesom 2000). Also, a few **waifs** (“non-native species growing outside of cultivation but not maintaining a viable population for more than one or a few seasons”—Nesom 2000) have

TABLE 1. Alphabetical list of counties wholly or partially in East Texas (also see Fig. 2).

Alphabetical List of Counties

Wholly or Partially in East Texas

Anderson	Denton	Hays	Marion	San Augustine
Angelina	DeWitt	Henderson	McLennan	San Jacinto
Austin	Ellis	Hill	Milam	Shelby
Bastrop	Falls	Hopkins	Montgomery	Smith
Bell	Fannin	Houston	Morris	Titus
Bexar	Fayette	Hunt	Nacogdoches	Travis
Bowie	Franklin	Jackson	Navarro	Trinity
Brazos	Freestone	Jasper	Newton	Tyler
Burleson	Goliad	Jefferson	Orange	Upshur
Caldwell	Gonzales	Kaufman	Panola	Van Zandt
Camp	Grayson	Lamar	Polk	Victoria
Cass	Gregg	Lavaca	Rains	Walker
Cherokee	Grimes	Lee	Red River	Waller
Collin	Guadalupe	Leon	Robertson	Washington
Colorado	Hardin	Liberty	Rockwall	Wharton
Comal	Harris	Limestone	Rusk	Williamson
Dallas	Harrison	Madison	Sabine	Wilson
Delta				Wood

been included, particularly if they occur repeatedly. Again, while not actually naturalized, such species can be found in various habitats and can be hard to distinguish from plants that are either native or truly naturalized.

Additionally, a few taxa in areas immediately adjacent to the boundaries of East Texas (typically in adjacent parts of a partially treated county) have been included to avoid confusion, to improve clarity, or for general interest. For example, a number of Edwards Plateau plants are included that occur only a few miles outside the southwestern boundaries of East Texas in such counties as Bell, Bexar, Comal, Hays, Travis, and Williamson. In particular, because Travis County is one of the most important centers of botanical activity in the state, and because of the existence of a highly accurate plant list for that county (Carr 2002a), we have attempted to include all plants known to occur in Travis County. In some instances, plants in areas immediately outside East Texas (e.g., in an adjacent county of Louisiana) are listed as notes. Such plants, with their scientific names in italics but not in bold face, are listed after all the alphabetically arranged species of a genus and are not illustrated. If such plants are in a genus not treated in the flora, they are included in the family synopsis.

No attempt has been made to include the hundreds of **cultivated** (plants deliberately planted, actively maintained, and grown for specific uses), non-native crop, landscape, and greenhouse plants which are grown in East Texas but which are not naturalized in the area. Information on cultivated plants can be found in such works as Bailey (1949), Shinners (1958), Bailey and Bailey (1976), Huxley et al. (1992), Sperry (1991), Garrett (1994, 1996, 2002), Brickell and Zuk (1997), and Arnold (2002).

The East Texas flora has about 67–70% of the 4,834–5,042 species of native and naturalized vascular plants recognized as occurring in Texas by Hatch et al. (1990) and Turner et al. (2003) and about 70% of the 5,256 taxa mapped by Turner et al. (2003). Since non-naturalized, cultivated plants are not included in this flora, a direct comparison is not possible with another recent checklist of Texas plants (Jones et al. 1997), which lists 6,871 taxa including cultivated plants.

Arrangement of Taxa and General Methods

Families are listed alphabetically within the divisions Psilophyta, Lycopodiophyta, Equisetophyta, Polypodiophyta, Pinophyta, Gnetophyta, and Magnoliophyta. All East Texas members of the first six of these divisions are treated in this volume. The flowering plants (Magnoliophyta) make up the vast majority of East Texas species; within this group, families within class Monocotyledonae (monocots) are treated in this volume, while families in class Dicotyledonae (dicots) will be treated in volumes 2 and 3. Each family treatment includes a taxonomic description of the East Texas members, a brief synopsis (indicated by the symbol and with such information as number of genera and species), a short section on family recognition in the field, and references, if appropriate. If the type genus (genus after which the family is named) of a family is not treated in the flora, a brief synopsis of the type genus and the derivation of its name are given at the end of the family synopsis. When only one genus of a family is represented in the flora, the family and generic descriptions are combined. Appendix 3 is a phylogenetic classification of all treated families, modified from that proposed by the Angiosperm Phylogeny Group (2003), while Appendix 2 is a phylogenetic classification modified from those of Cronquist (1981, 1988), Lellinger (1985), and Hickman (1993).

Genera are treated alphabetically within families and species alphabetically within genera. Each genus treatment includes a taxonomic description of the East Texas species, a brief synopsis (indicated by the symbol), derivation of the generic name, and references, if appropriate. When only one species of a genus is represented in the flora, the generic and specific descriptions are combined. For each genus of Poaceae, the synopsis is followed (in parentheses) by the subfamily and tribe; these follow *Flora of North America North of Mexico* volumes 24 (Flora of North America Editorial Committee ined.) and 25 (Flora of North America Editorial Committee 2003) and the Grass Phylogeny Working Group (2001). References for both families and genera are intended to provide an entry point into the more detailed taxonomic literature and should not be viewed as inclusive. Additional references can be found in Kent (1967), Hatch et al. (1990), Taylor and Taylor (1994), Jones et al. (1997), and Diggs et al. (1999), and online at Royal Botanic Gardens, Kew (2003) and New York Botanical Garden (2003).

For each taxon treated at the rank of species, subspecies, or variety, all or most of the following are provided if appropriate: 1) scientific name (**in bold type**) including authority; 2) derivation of the specific or infraspecific epithet (in parentheses); 3) common name(s) if available (in SMALL CAPITAL letters); 4) taxonomic description; 5) habitat; 6) range within Texas including notes on endemism; 7) range within the U.S. and Canada; 8) phenology (period of flowering); 9) area of origin if not native to East Texas; 10) taxonomic synonyms (in *italics* in brackets, [ ] ; 11) notes on toxic/poisonous nature (indicated by the symbol ☠) or other short notes of ethnobotanical or taxonomic interest; notes on species of conservation concern (indicated by the symbol ⚠); notes on noxious or harmful or potentially harmful exotic plants (indicated by the symbol ⊘); 12) an indicator, the symbol , for taxa introduced to the United States; 13) the symbol /500 followed by a page number for those species (a total of nearly 200) for which a color photograph is provided; and 14) the symbol /500 followed by a page number for those species with an entry in the Commercially Important Timber Trees Appendix (Appendix 21). A line drawing illustration is provided for each species (and in some cases for infraspecific taxa), and a county distribution map (from Turner et al. 2003 with modifications or for *Carex* from S.D. Jones) is included for almost all species. The illustrations and maps are separately grouped on full pages and are as close to the description of a species as possible, typically within a few pages. All color photographs of species are grouped together near the beginning of the book.

Descriptions

Because of space limitations due to the inclusion of illustrations and maps, descriptions are as brief as possible while still allowing accurate identification. Characters described for a taxon at a higher rank (e.g., family) are usually not repeated for included taxa (e.g., genera). Characters useful in identification or helpful in confirming the identity of a plant have been stressed. Information given in the keys is often not repeated in the descriptions. When only one species of a genus occurs in East Texas, the generic and specific descriptions are combined. Therefore, the species descriptions in such cases are generally more ample than for other species. Descriptions were written for East Texas taxa and may not apply to taxa from other parts of the world; this is sometimes emphasized in the descriptions by the qualifiers "ours" or "East Texas species" to denote species within the East Texas area.

Keys

Keys are tools or shortcuts by which unknown plants can be identified. They provide a choice between alternative statements about plant characteristics, for instance:

1. Petals red; leaf blades pubescent on lower surface.
   2. Petals < 1 cm long; leaf blades entire __________ **Species a**
   2. Petals > 2 cm long; leaf blades toothed __________ **Species b**
1. Petals white; leaf blades glabrous on lower surface.
   3. Plant a shrub; leaf blades with acute apex __________ **Species c**
   3. Plant a tree; leaf blades with obtuse apex __________ **Species d**

The first choice (here lines beginning with the number 1) is followed by another choice indented under it (here lines beginning with the number 2) and so on, until the identity of a plant is determined. In other words, after a choice has been made between the two alternatives of a pair (= couplet), the user goes to the next more indented couplet where another choice is presented. The keys provided in this work all have successive choices indented for ease of use and are strictly dichotomous; that is, the user must decide between only two choices at a time. It should be kept in mind that plant species are variable, and sometimes an individual plant does not perfectly fit either of the two choices. In such instances, the choice that *best* fits the specimen in hand should be chosen.

The keys have been written to be as parallel as practical. In other words, when a character is given for one choice, it is also given for the other choice. However, in some cases, clarity, practicality, or the avoidance of ambiguity prevents absolute parallelism. Occasionally, a taxon, particularly a highly variable one, is keyed in more than one way to enhance ease of use and clarity. When possible, several characters are used for each choice in the keys; optimally both reproductive and vegetative characters are given. Where appropriate, easily observable characters are emphasized and these are often listed first in the couplets. However, in some cases obscure or highly technical characters have to be used since they are essential in separating the species being studied. This is particularly true in the Cyperaceae (sedge family), Poaceae (grass family), or Eriocaulaceae (pipewort family), where technical characters (sometimes microscopic) are the only ones separating species. Sometimes, the plants falling under one alternative are variable or exhibit two character states; in order to emphasize this situation, the OR given between these two states is sometimes capitalized, for instance:

1. Leaves usually 30 cm or more long OR, if shorter, with a hard spiny tip.
1. Leaves 10–30 cm long, without a hard spiny tip.

While not preferred, such characters can still be helpful in identification.

Keys to genera and species were specifically written for the plants of East Texas and are not intended to be inclusive of plants occurring in other parts of the world. In volume 1, a key to ferns and similar plants (pteridophytes), a key to gymnosperms, and a key to the families of monocots are provided. The General Key to All Families (to be published in volumes 2 and 3) is modified from a key to families generously provided by the Oklahoma Flora Editorial Committee (Tyrl et al. 1994 and updated versions). While numerous couplets have been added to cover additional plants that occur in East Texas, no couplets have been deleted from the Oklahoma family key. Therefore, a few families/taxa occurring in Oklahoma but not in East Texas are included in the key. This was done so that the family key would be of maximum benefit to Oklahoma users as well as those in Texas. Such families are indicated in the *General Key to All Families* by a note in brackets, e.g., [Family in OK, not in East TX]. In a number of instances, it is possible to key to the correct family even if a particular, easily confused dichotomy is misinterpreted. For such cases, explanatory notes are given in brackets in the key. In volumes 2 and 3, in addition to the General Key to All Families, several supplemental keys will be added for some groups. These include a key to aquatic plants and a key to woody vines.

Sources of Information

In addition to original observations and measurements, material for the keys and descriptions has been obtained from a variety of sources listed in the literature cited. Of particular assistance were the following works: *Manual of the Vascular Plants of Texas* (Correll & Johnston 1970); *Grasses of Texas* (Gould 1975b); *Flora of the Great Plains* (Great Plains Flora Association 1986); *Flora of North America North of Mexico, Vol. 2, Pteridophytes and Gymnosperms* (Flora of North America Editorial Committee 1993); *Flora of North America North of Mexico, Vol. 3, Magnoliophyta: Magnoliidae and Hamamelidae* (Flora of North America Editorial Committee 1997); *Flora of North America North of Mexico, Vol. 22, Magnoliophyta: Alismatidae, Arecidae, Commelinidae (in part), and Zingiberidae* (Flora of North America Editorial Committee 2000); *Flora of North America North of Mexico, Vol. 26, Magnoliophyta: Liliidae: Liliales and Orchidales* (Flora of North America Editorial Committee 2002a); *Flora of North America North of Mexico, Vol. 23 Magnoliophyta: Commelinidae (in part): Cyperales* (Flora of North America Editorial Committee 2002b); *Flora of North America North of Mexico, Vol. 25 Magnoliophyta: Commelinidae (in part): Poales, part 2* (Barkworth et al. 2003); *Flora of North America North of Mexico, Vol. 24 Magnoliophyta: Commelinidae (in part): Poales, part 1* (Barkworth et al. ined.); *Manual of the Vascular Flora of the Carolinas* (Radford et al. 1968); *Grasses of Louisiana* (Allen 1992b); *Flora of Missouri* (Steyermark 1963); and *Steyermark's Flora of Missouri* (Yatskievych 1999).

Information for the family synopses was obtained from *The Plant Book* (Mabberley 1987, 1997); *Flowering Plants of the World* (Heywood 1993); *Guide to Flowering Plant Families* (Zomlefer 1994); *Vascular Plant Taxonomy* (Walters & Keil 1995); and *Contemporary Plant Systematics, 2nd ed.* (Woodland 1997). Material for the brief FAMILY RECOGNITION IN THE FIELD section given for each family was obtained from Smith (1977), Davis and Cullen (1979), Baumgardt (1982), Jones and Luchsinger (1986), and Heywood (1993). Generic synopses were modified from Mabberley (1987, 1997). In the interest of space, citations for synopses and family recognition are given in general only for material from sources other than these.

Derivations (etymology) of generic names and specific and infraspecific epithets were obtained or modified from a variety of sources including *Plant Names Scientific and Popular* (Lyons 1900); *The Standard Cyclopedia of Horticulture* (Bailey 1922); *How Plants Get Their Names* (Bailey 1933); *Gray's Manual of Botany* (Fernald 1950a); *Composition of Scientific Words* (Brown 1956); *Dictionary of Word Roots and Combining Forms* (Borror 1960); *A Gardener's Book of Plant Names* (Smith 1963); *Flora of West Virginia* (Strausbaugh & Core 1978); *Dictionary of Plant Names* (Coombes 1985); *Weeds and Words: The Etymology of the*

Scientific Names of Weeds and Crops (Zimdahl 1989); *The New Royal Horticultural Society Dictionary of Gardening* (Huxley et al. 1992); *Botanical Latin* (Stearn 1992); and *Plants and Their Names* (Hyam & Pankhurst 1995).

References of particular importance for the Introduction to East Texas included the classic *Geography and Geology of the Black and Grand Prairies, Texas* (Hill 1901); *A Field Guide to the Blackland Prairie of Texas, From Frontier to Heartland in One Long Century* (Hayward & Yelderman 1991); *The Texas Blackland Prairie, Land, History, and Culture* (Sharpless & Yelderman 1993); *The Big Thicket Forest of Eastern Texas: A Brief Historical Botanical and Ecological Report* (McLeod 1972); *Big Thicket Plant Ecology: An Introduction* (Watson 1975); *Land of Bears and Honey: A Natural History of East Texas* (Truett & Lay 1984); *Roadside Geology of Texas* (Spearing 1991); *Backwoodsmen: Stockmen and Hunters Along a Big Thicket River Valley* (Sitton 1995); *The Big Thicket: An Ecological Reevaluation* (Gunter 1993); and many others.

Nomenclature

Nomenclature, including authorities, largely follows *A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland* (Kartesz 1999), unless specifically indicated otherwise. A significant exception is that nomenclature for ferns and other pteridophytes, gymnosperms, and selected angiosperms follows the recent treatments in *Flora of North America* (Flora of North America Editorial Committee 1993, 1997, 2000, 2002a, 2002b, 2003, ined.). Further, in a number of cases indicated in the treatments, nomenclature follows recent taxonomic works or the *Vascular Plants of Texas* (Jones et al. 1997). While the decision as to which source or sources to follow for nomenclature was not an easy one, in our minds the advantages of a standard source outweighed the advantages of other possible choices. Thus, only in instances where more recent works have been followed or where we believe biological reality or clarity is compromised by nomenclature do we differ from Kartesz. Unless other varieties or subspecies are specifically mentioned in the text, the type variety or subspecies is assumed.

Following the rules of the *International Code of Botanical Nomenclature* (Greuter et al. 2000), the scientific name of each species (or variety or subspecies) is followed by the authority, i.e., the author(s) who originally published that name. If the name has been transferred to a different genus or rank, the name of the original author is placed in parentheses, followed by the name of the author(s) who made the transfer. For example, *Erythraea calycosa* Buckley was originally named by Samuel B. Buckley. Later, Merritt L. Fernald transferred the species to the genus *Centaurium*, with the correct citation becoming *Centaurium calycosum* (Buckley) Fernald. In some cases, the word “ex” inserted between the names of authors (e.g., *Hydrolea ovata* Nutt. ex Choisy) indicates that an author (such as Choisy) published a new species (or variety or subspecies) based on a name attributed to but not validly published by another author (in this case Nuttall). Abbreviations for authorities of scientific names follow Brummitt and Powell (1992), which is now widely considered the standard for such abbreviations.

Nomenclatural change is inevitable as more is learned about various plant groups (see Appendix 7). These changes, especially when involving well known species, can be particularly irritating to professional and amateur botanists, as well as to others wanting to know correct scientific names. In order to avoid confusion regarding name changes, limited synonymy is provided. In particular, some superseded names used in Mahler (1988), Correll and Johnston (1970), and Hatch et al. (1990) are listed as synonyms. Other synonyms are given to help clarify nomenclature or for general interest. However, no attempt is made to give complete synonymy. For detailed synonymy for Texas plants see Jones et al. (1997) and Kartesz (1999). For a discussion of the current controversy involving botanical nomenclature and for information on our general approach see Appendix 6 or Diggs and Lipscomb (2002).

Pronunciation of scientific names is somewhat arbitrary. As Hoshizaki and Moran (2001) indicated, "No one knows exactly how Latin was pronounced, and even in the heyday of the Roman Empire several dialects were probably spoken in different regions. So who's to say who's right? The best advice is to pronounce the names as the people around you do. When someone presumes to correct your pronunciation, a knowing smile is the appropriate response." Based on personal experience, we know that professional botanists trained at different institutions in the U.S. often pronounce scientific names quite differently. Pronunciation of scientific names outside the U.S. varies even more. While some pronunciations are standard, or at least widely accepted, it is our belief that encouraging individuals to use scientific names (even if pronounced creatively) is always more important than some unattainable desire for consistency.

Common names are included in the treatments and in the index, enabling the identification of plants for which little other information is available. These names have been obtained from a variety of literature sources (particularly Reid 1951, Hatch et al. 1990, and Kartesz 1999); none have been manufactured for this publication. Caution is advised for the use of common names—often the same plant has many common names, and even worse, sometimes a number of very different plants may share the same common name.

Geographic Distributions

County distribution maps are given for nearly all species. Most are from or slightly modified (e.g., based on additional collections and different taxonomic interpretations) from those in the *Atlas of the Vascular Plants of Texas* (Turner et al. 2003). Maps for the genus *Carex* (Cyperaceae) were provided by Stanley D. Jones. For a number of species not included in Turner et al. (2003), maps are based on herbarium specimens from a variety of Texas herbaria. In a few instances where a species is reported in the scientific literature only for a vegetational area (e.g., Pineywoods) or for which no specific county record is known, no map is provided. Likewise, for a few species added after map pages for the flora were completed, no county distribution map is given. The maps are grouped together on full pages and are as close to the description of a species as possible, typically within a few pages. In addition, for some taxa with limited known geographic distributions within East Texas, individual counties from which voucher specimens have been collected are cited in the text using standard herbarium abbreviations (following Holmgren et al. 2004) for the institutions where the specimens are deposited (see section on Abbreviations and Symbols later in this introduction). Many of these citations refer to the BRIT herbarium (Botanical Research Institute of Texas, including SMU and VDB), the second largest herbarium in the state. Specimens in the private collections of G. Diggs and R. O'Kennon that are being processed for deposit at BRIT are also cited as BRIT. Specimens from other herbaria, particularly ASTC (Stephen F. Austin State University), BAYLU (Baylor University), SBSC (Spring Branch Science Center—Houston), SHST (Sam Houston State University), TAES (S.M. Tracy Herbarium, Texas A&M University), TAMU (Biology Department Herbarium, Texas A&M University), and TEX (University of Texas at Austin—the largest herbarium in Texas), are also frequently cited. Records supplied by Jack Stanford of Howard Payne University are indicated by the herbarium abbreviation HPC, and collections by Stanley Jones of the Botanical Research Center Herbarium are indicated by BRCH.

A more general distribution within Texas usually follows the counties listed; examples include: "Pineywoods and Post Oak Savannah," "Blackland Prairie s and w to w Texas," and "nearly throughout TX." Following the Texas distribution, the distribution of each species in North America north of Mexico is given. These ranges generally follow Kartesz (1999), unless more accurate data was available in specific cases (e.g., from *Flora of North America* volumes).

Many plants listed as endemic to Texas in Correll and Johnston (1970) have since been found in immediately adjacent areas. Therefore, for current information on endemics we are following Carr (2002b, 2002c) of the Nature Conservancy of Texas, who generously contributed his data on Texas endemics. This information is given in the descriptions following a plant's Texas distribution and is also summarized in Appendix 11. In order to make Texas endemics easily recognizable in the text, the symbol is placed at the end of such species' taxonomic treatments. Relatively few plants are endemic to East Texas; these are indicated by the symbol in front of the scientific name.

For plants whose place of origin is outside the continental United States, the symbol is placed at the end of the species' taxonomic treatment. A symbol to allow such introduced species to be recognizable at a glance seemed a useful inclusion (Schmid 1997). However, the question of defining "introduced" proved more difficult. For example, all species native to the U.S. somewhere outside of East Texas could have been considered introduced; similarly, introduced species could have been defined as all species not native to the state of Texas. Ultimately, we decided to use symbolic representation only for species not native to the United States. However, all species not native to East Texas have their area of origin indicated in the descriptions.

Information on Toxic/Poisonous Plants

Notes on toxic/poisonous properties (indicated by the symbol) are given in the synopses and at the end of the treatments of various taxa. This information has been obtained from a variety of cited sources, particularly the authoritative *Toxic Plants of North America* by Burrows and Tyrl (2001). Note, however, that a lack of information about toxicity does not indicate that a plant is safe, and no plant material should be eaten unless one is sure of its edibility. Indeed, most plants have not been tested for toxicity and all should be considered potentially dangerous unless known otherwise. Though technically a poison is a substance that has properties harmful or fatal to an organism, and a toxin (a more specific term) is any of various poisonous substances that are specific products of the metabolic activities of living organisms (Gove 1993), the terms have been used synonymously in the text. Most toxins are probably defensive compounds that evolved to protect the plant from herbivore, bacterial, or fungal attack. While there are no general rules on precisely predicting plant toxicity, there are rules of thumb among botanists about certain plants that are more likely to be toxic—e.g., avoid eating unknowns in the carrot family (Apiaceae, which contains some of the most toxic species known), the potato family (Solanaceae, also referred to as the deadly nightshade family and the source of numerous toxic alkaloids), the buttercup family (Ranunculaceae, with many species containing alkaloids or other toxins such as glycosides or saponins), the aroid family (Araceae, with raphides—bundles of microscopic, needle-like calcium oxalate crystals—and various toxins), the death-camas family (Melanthiaceae, with highly toxic *Veratrum* alkaloids), and anything with milky or colored latex or sap (e.g., members of the Asclepiadaceae—milkweed family, the Apocynaceae—dogbane family, or the genus *Euphorbia*, the spurges).

In case of poisoning by plant material or any other source, the **Texas Poison Center Network** can be reached at **1-800-222-1222**. This number connects you with the nearest poison control center anywhere in the U.S., 24 hours a day, seven days a week. Poison control centers can also be reached indirectly via the emergency number **9-1-1**. Information can also be found at the web sites of the American Association of Poison Control Centers at **http://www.1-800-222-1222.info/** or **http://www.aapcc.org/**.

Information on Plants of Conservation Concern, including Endangered and Threatened Taxa

A list of East Texas species of pteriodophytes, gymnosperms, and monocots considered to be of conservation concern can be found in Appendix 12. In addition, material about the conservation status of these species can be found in the taxonomic treatments.

Information on plants of conservation concern has been derived from a number of sources. This was necessary since the Texas Natural Heritage Program was abolished in 1995 (Diamond et al. 1998), apparently as part of a larger political attempt to weaken activities associated with protecting endangered species. Sources of information include the Texas Organization for Endangered Species (TOES 1993), the Nature Conservancy of Texas (Carr 2001, 2002d), and a combined group from Texas Parks and Wildlife Department and the Nature Conservancy (Poole et al. 2002). In addition to plants listed by these organizations, we have designated a number of additional species to be of conservation concern in Texas, based on our knowledge of their extremely limited occurrence in the state (these species are noted in Appendix 12 by the abbreviation IFET—Illustrated Flora of East Texas). Species in all of these categories are signified by having the symbol ⚠ placed at the end of their taxonomic treatments.

Taxa listed by the Texas Organization for Endangered Species (TOES 1993) are further indicated by having (TOES 1993: Roman numeral) at the end of their treatment. The Roman numeral signifies the category as indicated by TOES:

Category I:
Endangered Species—legally protected.

Category II:
Threatened Species—legally protected.
Likely to become endangered

Category III:
Texas Endangered—listed species.
Endangered in Texas portion of range

Category IV:
Texas Threatened—listed species.
Likely to become endangered in Texas portion of range

Category V:
Watch List—listed species.
Either with low population numbers or restricted range in Texas

Those taxa of conservation concern listed by Carr 2001, Poole et al. 2002, and Carr 2002d, are further indicated in the text as RARE 2001, RARE 2002a, and RARE 2002b respectively, followed by the designations given below:

Global Rank

G1 = fewer than 6 occurrences known globally; critically imperiled, especially vulnerable to extinction

G2 = 6–20 occurrences known globally; imperiled and very vulnerable to extinction throughout its range

G3 = 21–100 occurrences known globally; either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g., a single state or physiographic region), or having other factors making it vulnerable to extinction throughout its range

G4 = more than 100 occurrences known, apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery
G5 = demonstrably secure globally, though it may be quite rare in parts of its range
GH = of historical occurrence throughout its range, i.e., formerly part of the established biota, with expectation that it may be rediscovered

State Rank

S1 = fewer than 6 occurrences known in Texas; critically imperiled in Texas; especially vulnerable to extirpation from the state
S2 = 6–20 known occurrences in Texas; imperiled in the state because of rarity; very vulnerable to extirpation from the state
S3 = 21–100 known occurrences in Texas; either rare or uncommon in the state
S4 = more than 100 occurrences in Texas; apparently secure in the state, though it may be quite rare in some areas of the state
S5 = demonstrably secure in Texas
SH = historical in Texas, not verified within the past 50 years but suspected to be extant
SR = reported from Texas in literature but not verified via specimens or field observations
SX = presumed extirpated from Texas

A global or state rank followed by "Q" indicates that the taxonomic status of the plant is a matter of conjecture. A rank followed by "?" indicates that the rank is not certain. A "T" subrank following a global rank denotes the rank for subspecific taxa. Two G or S ranks together (G2G3, S1S2, etc.) indicate that the plant is borderline between the ranks. All state and most global ranks are assigned by the Texas Conservation Data Center (2003).

Other designations are provided as follows (from Poole et al. 2002):

Federal Legal Status (according to the United States Fish & Wildlife Service):

LE = federally listed as an endangered plant
LT = federally listed as a threatened plant
PE = proposed to become listed as endangered
PT = proposed to become listed as threatened
C1 = category 1 candidate for listing as threatened or endangered
SOC = species of concern
3B = no longer considered taxonomically valid
3C = no longer under federal review for listing; either more abundant or widespread than was previously thought
DL = de-listed

State Legal Status (according to the Texas Parks & Wildlife Department)

E = listed as a state endangered plant
T = listed as a state threatened plant

Information on Illustrations and Photographs

The more than approximately 1,000 line-drawing illustrations in volume 1 and the estimated more than 2,000 to be published in volumes 2 and 3 have been obtained from a variety of sources in the botanical literature dating back to the 1500s (e.g., Fuchs 1542). We thank the appropriate individuals or organizations for allowing their use. Thirty-one illustrations are published in volume 1 for the first time. Twenty-eight of these were produced by Linny Heagy, two by Robert George, and one by Anne Hollingworth for all those East Texas species either not previously illustrated or for which suitable illustrations could not be found. Further, a number of illustrations are published here for only the second time, having been presented previously in *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999). These include drawings of Cyperaceae done by Brenda Mahler and Jessica Procter (as part of B. Lipscomb's research on that family) and a number of drawings done decades ago by the late Eula Whitehouse, David Wagnon, Pat Mueller, and unknown SMU students. These illustrations, preserved in the archives at BRIT, were made for Lloyd Shinners, whose untimely death prevented publication of his planned *Flora of North Central Texas*. Finally, Linny Heagy produced 226 original drawings for the *Illustrated Flora of North Central Texas*.

Beneath each illustration is the scientific name of the plant represented. The name is followed by a code in brackets indicating the source of the illustration. A list of illustration sources with codes is given in Appendix 1. Because all species are illustrated, reference to illustrations is not made in the text. Illustrations are located as close to the taxonomic descriptions as possible and in general are located after the taxonomic descriptions.

The 194 color photographs are arranged alphabetically by genus and are grouped together in plates. Following the common name of each species and the page number of its description, a three letter code is given to designate the photographer (listed here alphabetically): [PMB] = Paul Martin Brown, [GHB*] = George H. Bruso, [WLC] = Scooter Cheatham, [BRC]=Ben R. Cox, [JAC]=J. Andrew Crosthwaite, [GMD] = George M. Diggs, [NGF*] = Norman G. Flaigg, [HAG] = Heinz A. Gaylord, [RJG] = Robert J. George, [SGJ] = Stanley & Gretchen Jones, [ELK] = Eric L. Keith, [JAL] = Joe A. Liggio, [CLL*] = Campbell & Lynn Loughmiller, [RJO] = Robert J. O'Kennon, [SLO] = Steve L. Orzell, [JWS*] = Julia W. Sanders, [JVK] = James Van Kley, [AFV*] = Albert F.W. Vick, Jr., and [WCW] = W. C. Weatherby. Codes followed by an asterisk indicate that the photographs are used courtesy of the Lady Bird Johnson Wildflower Center. The symbol /100 at the end of a species description indicates a color photograph is provided on that page number. As in the text, species not native to the U.S. are denoted by the symbol .

In order to provide a service for fellow educators, scientists, and interested individuals, the use of figures 1, 2, 3, 8, 41, 63, 68, 76, 176, 177, 178, and 183 does not require copyright permission.

INFORMATION ON THE GLOSSARY

The Glossary is reprinted from Diggs et al. (1999). It is modified from those of Shinners (1958) and Mahler (1988), with additional entries obtained or modified from a variety of sources including Lawrence (1951), Featherly (1954), Correll (1956), Gleason and Cronquist (1963, 1991), Radford et al. (1968), Correll and Johnston (1970), Gould (1975b), Lewis and Elvin-Lewis (1977), Benson (1979), Schmutz and Hamilton (1979), Fuller and McClintock (1986), Jones and Luchsinger (1986), Schofield (1986), Gandhi and Thomas (1989), Blackwell (1990), Isely (1990), Harris and Harris (1994), Spjut (1994), and Hickey and King (1997). The glossary is rather extensive and includes a number of terms not otherwise found in the book. This was done so that when using this work in conjunction with other taxonomic treatments, the meaning of obscure terms can be readily found.

INFORMATION ON REFERENCES AND LITERATURE CITED

The Literature Cited section contains bibliographic citations for all sources mentioned, including those listed immediately following family and generic synopses (e.g., REFERENCES: Wood 1958; Kral 1998). While an attempt was made to be as thorough as possible, the magnitude of the botanical literature makes complete coverage impossible. Therefore, the references given are intended to provide an entry point into the more detailed taxonomic literature and should not be viewed as inclusive. Abbreviations for periodicals follow *Botanico-Periodicum-Huntianum* (B-P-H) (Lawrence et al. 1968) and *Botanico-Periodicum-Huntianum/Supplementum* (B-P-H/S) (Bridson & Smith 1991). For each individual person cited in the text as having personally communicated unpublished information to the authors (indicated by the abbreviation "pers. comm."), a short biographical entry is given in the Literature Cited section.

Abbreviations and Symbols

ABBREVIATIONS/SYMBOLS	MEANING
	family or generic synopsis
	endemic to East Texas
	endemic to Texas
	introduced species, subspecies, or variety (not native to the U.S.)
⚠	species, subspecies, or variety of conservation concern (e.g., endangered, threatened)
☠	toxic/poisonous plant
⊘	noxious or harmful or potentially harmful exotic plant
/100	color photograph provided; page number follows symbol
/100	commercially important timber trees appendix provided; page number follows symbol
<	less than
≤	less than or equal to
>	more than
≥	more than or equal to
±	more or less
+	or more (e.g., small tree 2–5+ m tall)
×	times or to indicate hybridization
auct.	Latin: *auctorum*, author
ASTC	herbarium abbreviation for Stephen F. Austin State University, Nacogdoches, TX
BAYLU	herbarium abbreviation for Baylor University Herbarium, Waco, TX
BCNWR	herbarium abbreviation for Balcones Canyonlands National Wildlife Refuge
B.P.	before present
BRCH	herbarium abbreviation for Botanical Research Center Herbarium, Bryan, TX
BRIT	herbarium abbreviation for Botanical Research Institute of Texas, Fort Worth
c	central
ca.	Latin: *circa*, about
cm	centimeter
COA	herbarium abbreviation for City of Austin's Office of Environmental Resource Management
comb. nov.	Latin: *combinatio nova*, new combination of name and epithet

ABBREVIATIONS/SYMBOLS	MEANING
diam.	diameter
dm	decimeter
DUKE	herbarium abbreviation for Duke University, Durham, NC
DUR	herbarium abbreviation for Southeastern Oklahoma State University, Durant, OK; currently housed at the Botanical Research Institute of Texas, Fort Worth
e	east
e.g.	Latin: *exempli gratia*, for example
ex.	used when an author publishes a new species (or variety or subspecies) based on a name attributed to but not validly published by another author–see preceding section on nomenclature for detailed explanation
f.	Latin: *filius*, son; e.g., L. f. indicates the younger Linnaeus
HPC	herbarium abbreviation for Howard Payne University, Brownwood, TX
i.e.	Latin: *id est,* that is
ined.	Latin: *ineditus*, unpublished
m	meter
MICH	herbarium abbreviation for the University of Michigan, Ann Arbor
mm	millimeter
mya	million years ago
n	north
$n =$	haploid chromosome number
$2n =$	diploid chromosome number
NY	herbarium abbreviation for the New York Botanical Garden, Bronx
nom. illeg.	Latin: *nomen illegitimum*, illegitimate name
of authors, not	used to indicate a name was used in the sense of certain authors, but not in the sense of the author making the combination; technically written as: auct. non
OCLA	herbarium abbreviation for the University of Science and Arts of Oklahoma, Chickasha
ours	used in descriptions to emphasize character states of East TX species that may be different in other geographic areas
p.p.	Latin: *pro parte*, in part
pers. comm.	personal communication of information to the authors
pers. obs.	personal observation by one of the authors
RARE	used to highlight the designation of species of conservation concern by Carr 2001, Carr 2002d, and Poole et al. 2002.

ABBREVIATIONS/SYMBOLS	MEANING
s	south
sensu	in sense of; used to indicate that a name is used in the sense of one author, not another
sensu lato	in the broad sense, e.g., if a genus is broadly treated to include many species
sensu stricto	in the strict sense, e.g., if a genus is narrowly treated to include few species
SBSC	herbarium abbreviation for Spring Branch Science Center, Spring Branch Independent School District, Houston
SHST	herbarium abbreviation for Sam Houston State University, Huntsville, TX
SMU	herbarium abbreviation for Southern Methodist University Herbarium, now part of the Botanical Research Institute of Texas (BRIT), Fort Worth
s.n.	Latin: *sine numero*, without number
sp.	species
spp.	species (plural)
subsp.	subspecies
TAES	herbarium abbreviation for S. M. Tracy Herbarium, Department of Rangeland Ecology & Management, Texas A&M University, College Station
TAMU	herbarium abbreviation for Biology Department Herbarium, Texas A&M University, College Station
TEX	herbarium abbreviation for University of Texas at Austin (including LL—Lundell Herbarium and RUNYON—Robert Runyon Herbarium)
TOES: (roman numeral)	Texas Organization for Endangered Species (category/status)
Univ.	university
UTTYLER	unofficial herbarium abbreviation for University of Texas at Tyler
VDB	herbarium abbreviation for Vanderbilt University Herbarium, currently housed at the Botanical Research Institute of Texas, Fort Worth
var.	variety
w	west

Ranges for measurements, e.g., (10–)12–23(–30) mm long, should be interpreted as "typically 12 to 23 mm long, rarely as little as 10 mm long, rarely as much as 30 mm long"

States are abbreviated using standard, two letter, United States Postal code abbreviations (e.g., TX = Texas, OK = Oklahoma, LA = Louisiana, AR = Arkansas)

Summary Data on the Flora

AND COMPARISON WITH OTHER FLORAS

Summary of the Flora of East Texas*

	Ferns & Similar Plants	Gymnosperms	Monocotyledons	Dicotyledons	Angiosperms	Total
Families	19	3	46	134	180	202
Genera	39	4	252	784	1036	1079
Species	73	9	978	2342	3320	3402
Additional Infraspecific taxa	1	0	70	187	257	258

*Dicot and total angiosperm data and totals are tentative pending completion of volumes two and three.

Comparison with Other Floras

	East Tx	TX[1]	NCTEX[2]	OK[3]	AR[4]	LA[5]	KS[6]	WV[7]	NC&SC[8]	CA[9]
Genera	1079	1328	854	850	942	1010	801	693	951	1222
Species	3402	5042	2223	2549	2877	3249	2111	2155	3360	5862
Native Species	2783		1829		2427	2423	1667		2913	4739
Introduced Spp.	619		394		760	826	435		747	1023
Total Taxa	3660	5256	2376	2844	3187		2228			
Area (in 1000s of square miles)	62.6	269	40	70	53	52	82	24	86	164

East Texas:

ca. 67 % of the species in Texas (in 23 % the land area)
133 % as many species as Oklahoma (in 89 % the land area)
82 % native species (18 % introduced from outside the United States)
163 Texas endemics and 26 East Texas endemics
115 taxa of conservation concern (Vol. I only)

Number of genera and species of Poaceae (Largest East Texas family)	117	410
Number of genera and species of Asteraceae	127	398
Number of genera and species of Cyperaceae	16	248
Number of genera and species of Fabaceae	62	240
Number of species of *Carex* (Largest East Texas genus, Cyperaceae)		80

[1]Turner et al. 2003; [2]Diggs et al. 1999; [3]Taylor & Taylor 1994; [4]Arkansas Vascular Plant Manual Committee 2002; [5]Thomas & Allen 1993–1998; [6]C. Freeman, pers.comm.; [7]Strausbaugh & Core 1978; [8]Radford et al. 1968; [9]Hickman 1993.

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Elray Nixon, to whom this volume is dedicated, the late Lloyd Shinners, and William (Bill) Mahler deserve special recognition for their contributions to an understanding of the flora of East Texas. For information about Nixon, see the dedication in the front of this book; for a list of his publications, see Appendix 24. For a biography of Shinners, see Ginsburg (2002); for a synopsis of Shinners' life, see Mahler (1971b); for a guide to his botanical contributions, see Flook (1973). This East Texas flora is published as a volume of *Sida, Botanical Miscellany*, which was founded by Wm. F. Mahler and Barney L. Lipscomb in 1987 in association with the botanical journal *Sida, Contributions to Botany*, begun by Shinners in 1962.

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Individuals who found errors in *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999) are thanked for their efforts. Since there is significant overlap in species between that volume and this one, many of the errors found have been corrected here. Also, because of overlap between the two floras, all individuals assisting with the North Central Texas flora are thanked again here.

Additional individuals who contributed to *Shinners' Manual of the North Central Texas Flora* (Mahler 1988), a partial precursor of the present volume, should also be recognized. These include Geyata Ajilvsgi, Gerald Arp, Barry Comeaux, Charlotte Daugirda, Victor Engel, Kathie Parker, Andrea McFadden, Jane Molpus, Ann Nurre, Tami Sanger, Harriet Schools, and numerous students who have used earlier versions of either Shinners' or Mahler's works.

This project is part of the ongoing collaboration between the Austin College Center for Environmental Studies and the Botanical Research Institute of Texas. Without the support of both institutions it would not have been possible. Thanks to Austin College; Oscar Page, President; Michael Imhoff, Vice President for Academic Affairs; Peter Schulze, Director of the Center for Environmental Studies; and the Austin College Board of Trustees and Robert J. Wright, its Chairman. We are also grateful to the Botanical Research Institute of Texas; S.H. Sohmer, Director; and the BRIT Board of Trustees; David Niven, its previous Chairman; and Tim McKinney, its current Chairman. We also wish to express our thanks to the founding organizations of BRIT: Dallas Arboretum and Botanical Gardens, Inc.; Fort Worth Botanical Society; Fort Worth Garden Club; Fort Worth Park and Recreation Department; Southern Methodist University; and Texas Garden Club, Inc.

Financial support for this work has come from a number of sources—these are listed on the contributors' pages near the beginning of the book. Without their generosity this project would not have been possible.

We would like to thank those individuals who gave us our taxonomic training, including Gary Breckon, Mickey Cooper, Gustav Hall, Stephan Hatch, Hugh Iltis, Marshall Johnston, Robert Kowal, William Mahler, James Manhart, Michael Nee, James Phipps, Benny Simpson, Edwin Smith, John Thomson, Donna Ware, Hugh Wilson, Barton Warnock, and Robert Ziegler.

Finally, thanks to our parents, Helen and Minor Diggs, Jack and Christa Lipscomb, Robert and Elizabeth O'Kennon, and Maurice and Louise Dubrule, as well as George Diggs' partner, Kerry Brock, and Monique Reed's husband, David Reed.

Authors' Note

In a work such as this, it is inevitable that omissions and errors, both large and small, escape attention. Because of the possibility of future editions, we would appreciate corrections, suggestions, or additions from individuals using the book. Also, as part of the Illustrated Texas Floras Project (a collaborative effort between the Austin College Center for Environmental Studies and BRIT), we are currently working on Volumes 2 and 3 (Dicots) of the *Illustrated Flora of East Texas*. Corrections or suggestions can thus be incorporated in those volumes. In addition, there is the possibility of illustrated floras for other regions of Texas, such as the Edwards Plateau or Plains Country. For all of these projects, corrections and suggestions regarding the present volume would be very helpful. Such information can be sent to:

George M. Diggs, Jr	Barney L. Lipscomb	Monique D. Reed	Robert J. O'Kennon
gdiggs@austincollege.edu	barney@brit.org	monique@mail.bio.tamu.edu	okennon@brit.org

Also, we hope that this book will spur additional interest in, and collecting of, plants in East Texas. Plant specimens, particularly county, regional, or state records would be much appreciated and can be deposited at a number of herbaria in the state (see Appendix 9 for contact information) including:

Botanical Research Institute of Texas Herbarium (BRIT)
509 Pecan Street, Fort Worth, TX 76102-4060
Phone: 817/332-4441; www.brit.org

Such specimens will be important scientific contributions, will have permanent protection, and will be important resources for the future (Prather et al. 2004a, 2004b). Records of dicot collections will be included in Volumes 2 and 3 (Dicots) of the *Illustrated Flora of East Texas*, currently in preparation. Information on proper collecting techniques can be found in Appendix 8.

Introduction to East Texas

Overview

East Texas is an area of approximately 62,600 square miles (162,200 square kilometers), delimited on the east by the state border, on the north by the Red River, and extending west and south to Dallas, Austin, and nearly to San Antonio and Houston. While a small region compared to Texas as a whole (approximately 269,000 square miles = 697,000 square km), it is about the size of Georgia. It includes the Pineywoods, Post Oak Savannah, Blackland Prairie, and the Red River Area (Fig. 2). The flora includes 3,402 species, slightly more than two-thirds of the total for all of Texas (Hatch et al. 1990; Turner et al. 2003), and 3,660 taxa (species, subspecies, and varieties) overall. This biological diversity is the result of numerous factors, including the region's geologic and climatic variation and its location on the ecotone or transition zone between the eastern deciduous forests and the central North American grasslands. Further, this biological crossroads is influenced by its proximity to the southwestern deserts, the southeastern swamps, and the nearly tropical areas of southern Texas. East Texas is thus a mixing ground for plants, with the result being high species richness. For the past two centuries, humans have had, and are continuing to have, a tremendous impact on the plants and animals of the region. Presettlement and early settlement conditions were radically different from those found today, and environmental change continues to accelerate. Given current trends, the present generation may be the last with the opportunity to preserve even small remnants of the once extensive natural ecosystems of the area.

General Geology of East Texas

The geology of East Texas is a fascinating story which has unfolded over millions of years. It is also a story that is key to understanding the plant life of the area, as well as the mineral wealth (e.g., oil and gas) so important to this part of the state. The geological history of the region is much more interesting and complex than the gently rolling to flat topography of most of East Texas would suggest. It is a subtle tale that can be read in stream beds, road cuts, or other areas where the soil is removed and small areas of the underlying bedrock are exposed. In only a few places can rocks be seen at the surface (e.g., Daingerfield State Park in Morris County; Boykin Springs in Angelina County—Fig. 10). In general, the easily erodible rocks and relatively heavy rainfall have combined to create a thick soil layer obscuring the interesting geology beneath. During the Pennsylvanian Period (325–286 million years ago [mya]) (Fig. 11), what is now East Texas was under an ocean on the southern edge of a North American continent shaped very differently than it is today. Later, as a result of plate tectonic movements, North America collided with Africa and South America to become part of the supercontinent Pangaea. The outcome of this collision was the uplift and formation of an extensive mountain system including the Appalachians, Wichitas, and Ouachitas. The ancient Ouachita Mountains formed approximately 300 million years ago in a line roughly following the western edge of the current Blackland Prairie, from near Sherman and Dallas, south along the Balcones Escarpment to Austin and beyond (Fig. 12). This ancient Ouachita mountain belt also continued to the northeast; the eroded Ouachitas seen today in southeastern Oklahoma and southwestern Arkansas are remnants of this once much more extensive range. To the west of the ancient Ouachita Mountains, crustal areas sagged and low basins formed. Shallow inland seas invaded these low areas, and during the Pennsylvanian, and later the Permian (286–248 mya), western Texas served as a collection basin for the sediments that eroded from the Ouachita Mountains east of the basin. These thick sediments harbor oil-bearing layers, so

FIG. 10/ ROCK OUTCROP NEAR BOYKIN SPRINGS, ANGELINA NATIONAL FOREST, ANGELINA CO. (PHOTO BY GMD).

important to the Texas economy, and are also the source of the strikingly bright red, iron oxide-rich (hematite) Permian layers that easily erode and give the modern Red River its name. The salinity of the Red River and thus of Lake Texoma is also the result of erosion from salt-rich Permian-age evaporation flats, through which the river passes on its course east from the Texas Panhandle. Over tens of millions of years the Ouachita Mountains gradually eroded, until today all that is left over most of Texas are their roots, deeply buried under thousands of feet of younger sediments (Spearing 1991).

During the Triassic (248–213 mya) and Jurassic (213–145 mya) periods and continuing into the Cretaceous Period (145–65 mya), Pangaea eventually split into a southern portion (Gondwana) and a northern portion (Laurasia) and then into separate continents. The western part of the East Texas region once again became very active geologically, with the ancient zone of weakness where the Ouachitas had originally formed serving as the site of continental rifting or breakup between North and South America. It was here, where the continents pulled apart and the crust sagged, that huge shallow seas, eventually retreating to become the present-day Gulf of Mexico, began to form. Relatively early in this process, during the Jurassic Period, the Gulf was shallow and not well-connected to the ocean, and sometimes it virtually dried up, leaving vast salt flats. The result over long periods of time was the deposition of tremendously thick layers of salt known now as the Louann Salt. Eventually, as sedimentation continued and more and more material was laid down over the salt, the tremendous pressure of the overlying younger sediments (from the Cretaceous and Tertiary) caused the salt layers to become distorted. Acting under pressure, almost like toothpaste being squeezed out of a tube, the salt formed upward thrusting columns and spires, which in some areas broke through the covering sediments to reach to or near the surface in the form of isolated domes of salt (e.g., near Palestine in Anderson County and Grand Saline in Van Zandt County; in the latter case, the salt is currently mined) (Jackson & Seni 1984a; Spearing 1991) (Fig. 13). These salt domes are ecologically significant because of the effect they have on plant and animal life. Coastal salt marsh plants, for example,

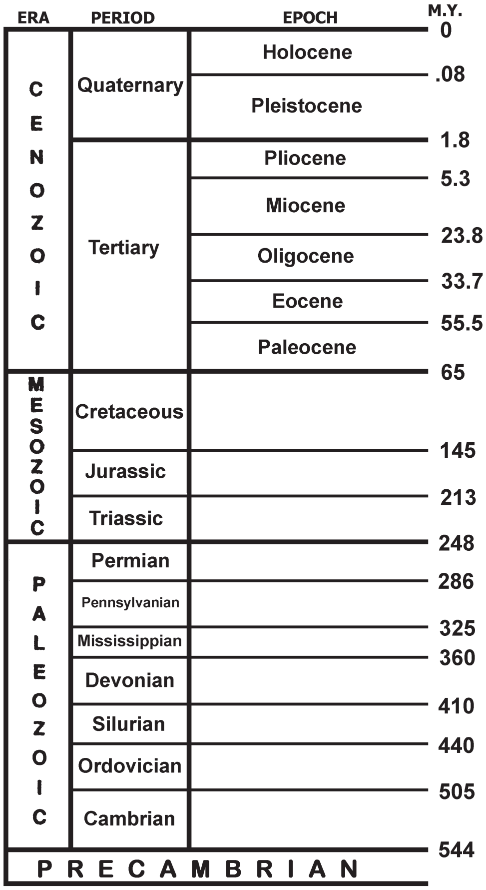


FIG. 11/ GEOLOGIC TIME SCALE (DATES, IN MILLIONS OF YEARS, BASED ON U.S. GEOLOGIC SURVEY 2002).

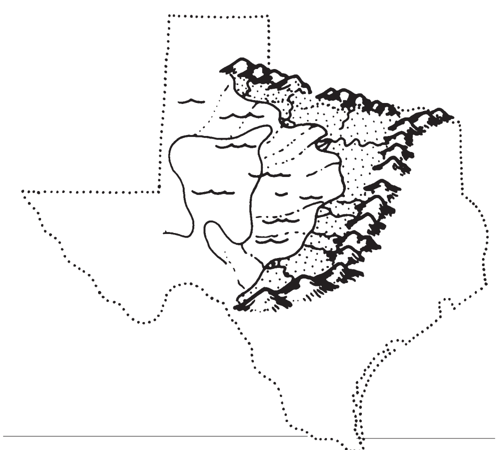


FIG. 12/ ANCIENT OUACHITA MOUNTAINS (PART OF THE APPALACHIAN-OUACHITA-MARATHON MOUNTAIN SYSTEM). THIS RANGE ROSE APPROXIMATELY 300 MILLION YEARS AGO AS A RESULT OF A PLATE TECTONIC COLLISION (ADAPTED FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

can be found hundreds of miles inland when salt from a dome reaches the surface and forms an inland salt marsh (e.g., *Bolboschoenus robustus* of the Cyperaceae at Grand Saline) (Fig. 14). In addition, in a few cases the salt domes push the overlying strata more than 200 feet above the surrounding landscape (e.g., at Davis Hill State Park in Liberty County), exposing sedimentary layers, such as the calcareous Fleming Formation, that are unusual for the area. This can result in unexpected plant distributions (e.g., the rare Texas occurrence of the calciphilic [= calcium-loving] shadow witch orchid, *Ponthieva racemosa*, at Davis Hill—Liggio 2002). Economically, salt domes (Fig. 15) are very important because rich deposits of oil often collected around them from nearby oil-bearing layers—e.g., at Spindletop, the first gusher that in 1901 ushered in the Texas oil boom (Sanders 2000).

As large-scale geologic changes (e.g., plate movements, changes in sea level) continued into the Cretaceous and the Gulf widened, virtually all of Texas was frequently covered by advancing and retreating shallow seas (Fig. 16). In fact, the seas reached to the Big Bend area and at times even stretched from the Gulf of Mexico north to the Arctic Ocean. An example, the Western Interior Seaway, extended north-south the complete length of the continent across what is now the central United States and Canada. Thick layers of sediment continued to be deposited into these seas during much of the Cretaceous, the material coming in part from erosion of the Rocky Mountains rising to the west. As a result of the varying water depths and other conditions, a number of different layers of Cretaceous sediments were laid down across the state, with some of these being mostly sand, some limestone, and some containing abundant fossils (Spearing 1991). According to Hill (1901),

> In general the sands are near-shore deposits, such as are seen to-day on most ocean beaches. The finer sands were carried a little further

seaward than the coarse material. The clays are the lighter débris of the land, which were laid down a little farther from the land border; and so on through the various gradations to the chalky limestones, which largely represent oceanic sediments deposited in relatively purer waters farthest away from the land. The limestones are not all chalky. Some are agglomerates of shells of animals which inhabited the sandy or muddy bottoms; others are old beach wash. The vast numbers of sea shells occurring upon the mountains and prairies of Texas have not been transported, as some people believe. Save that they have been subjected to general regional uplift whereby the sea bottom was converted into land, they are now in the exact locality where they lived and flourished, and the clays and limestones in which they were buried were once the muds of the old ocean bottom.

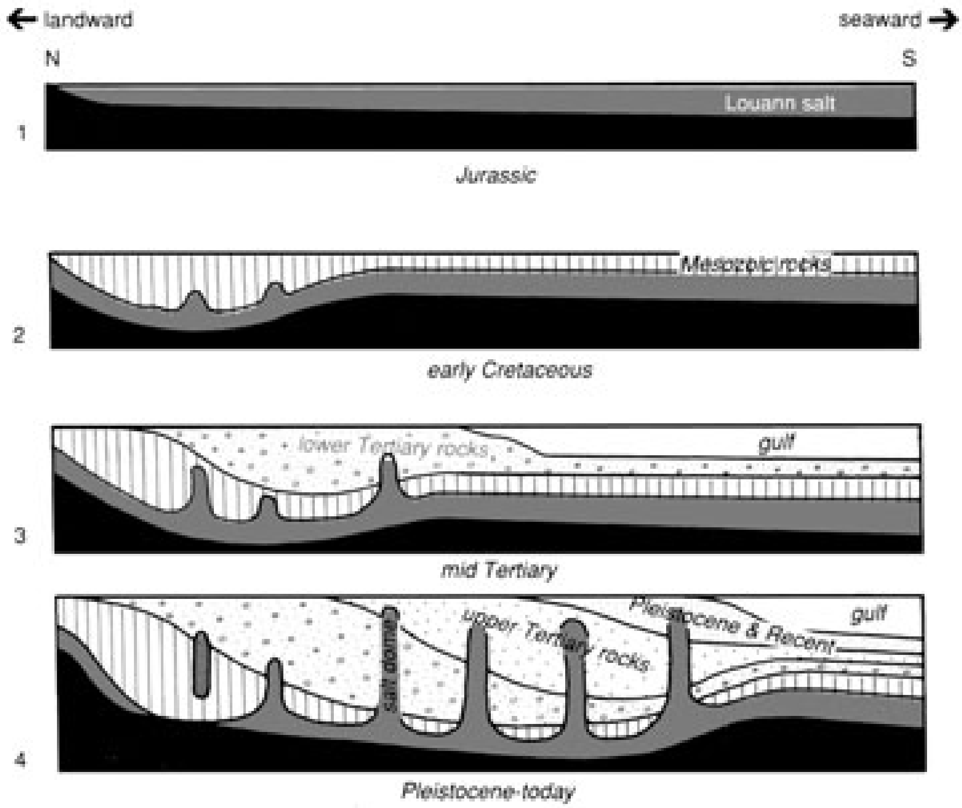


FIG. 13/ HISTORY OF DEVELOPMENT OF GULF OF MEXICO AND SEDIMENT WEDGES. NOTE THE FORMATION OF SALT DOMES EXTENDING INTO THE SEDIMENTS ABOVE (FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

Such sedimentation is the source of a relatively fine-grained, white, Upper Cretaceous limestone deposited about 90 to 85 mya that is exposed near the western edge of East Texas and known as the Austin Chalk (Hayward & Yelderman 1991). This layer is the bedrock from which the soil of much of the Blackland Prairie formed. The remainder of the main body of the Blackland Prairie is underlain by slightly younger Cretaceous sediments ranging in age from 79 to 68 million years old (Hayward & Yelderman 1991).

With the exception of Upper Cretaceous sediments such as those underlying the Blackland Prairie, most of East Texas is underlain by deposits of Tertiary age (65–1.8 mya), with the majority being laid down during the Eocene Epoch (55.5 to 33.7 mya) (Figs. 17, 18). Throughout much of the Tertiary, the Gulf continued to subside, and clay, silt, sand,

FIG. 14/ INLAND SALT MARSH NEAR GRAND SALINE, VAN ZANDT CO. WHITE CRUSTY SALT DEPOSITS CAN BE SEEN AT TIMES OF LOW WATER LEVEL (PHOTO BY GMD).

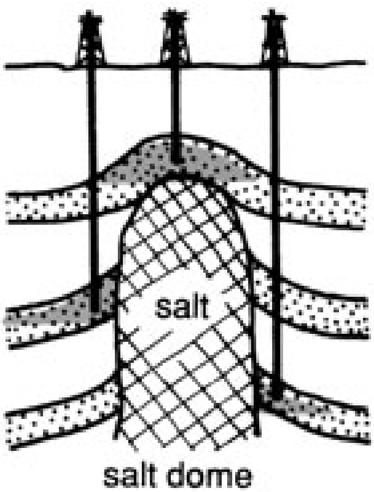


FIG. 15/ OIL DEPOSITS IN ASSOCIATION WITH SALT DOME (ADAPTED FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

and gravel from the west continued to pour in, forming a massive stack of sediments. These inclined sedimentary layers are thought to have added nearly 250 miles to the coastline of the North American continent and to total nearly 50,000 feet in thickness. During the Tertiary, sea levels rose and fell and shallow seas repeatedly covered and then retreated from much of the state. As a result, the conditions under which the sediments now underlying East Texas were deposited also showed a great deal of variation (Seldon 1979; Spearing 1991). As pointed out by Sellards et al. (1932), during the Tertiary there was

> ...a continuous and relentless struggle between the encroaching waters of the Gulf and heavily loaded, large streams. The sea endeavored to advance over the land, and the rivers constantly tried to build seaward a newly deposited land in the form of a deltaic plain. In some epochs the water forces prevailed, in others the land-building processes predominated.

As Maxwell (1970) explained, there was a

> ...rhythmic alternating succession between marine and continental deposition. In most places massive sandstones are either delta deposits or were laid down by streams on a land surface. The fossiliferous clays are mostly shallow-water marine beds. The glauconitic clay and sandy clay beds were deposited during a change in the position of the shoreline, and the lignite beds were formed in swamps or lagoons on a low continental area above the shoreline.

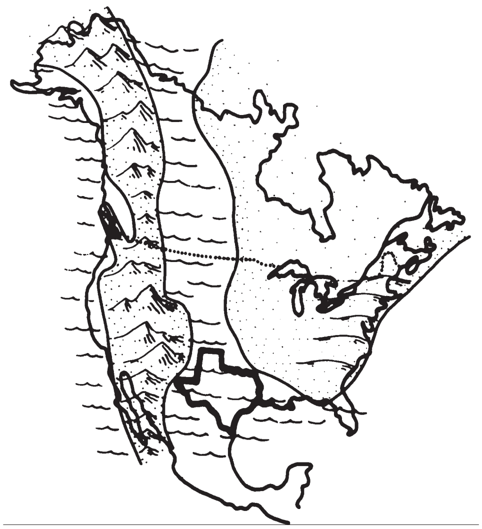


FIG. 16/ FIGURE SHOWING AN EXAMPLE OF HOW TEXAS WAS COVERED BY AN INLAND SEA AT VARIOUS TIMES DURING THE CRETACEOUS (ADAPTED FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

The result is a complex intergrading and interbedding of Tertiary sediments, some representing off-shore marine layers (with fossil shells), some coastal mud flats, others sandy or gravelly coastal beach or delta deposits, and still others materials laid down in the swampy or marshy areas between the meanders of coastal plain rivers. Numerous layers were deposited over the area, the type of layer depending on water depth, distance from shore, and other factors. Often an alternation can be seen between material dominated by calcareous clay deposited under shallow water marine conditions and layers dominated by sand deposited on land. The following sequence, exposed in East Texas, is an example of such an alternation of geologic formations: Sparta (sand—S), Weches (calcareous clay—CC), Queen City (S), Reklaw (CC), Carrizo (S) (Sellards et al. 1932; Bridges & Orzell 1989a). These sedimentary processes continue today as modern rivers (e.g., Colorado, Brazos, Sabine) dump their clay, silt, sand, and gravel near, at, or off the Texas coast. (Sellards et al. 1932; Spearing 1991). However, a significant amount of the sediment moving down Texas rivers is today being trapped in man-made reservoirs. This results in the filling of the reservoirs and the eventual end of their usefulness, as well as the erosion of Gulf Coast beaches as lost sediments are not replaced.

Eventually, pressure, heat, and time consolidated the sediments, in some cases producing rather hard sandstones. However, a variety of other materials also formed, including glauconite (a green-colored hydrous iron potassium silicate clay), iron ore (e.g., in the Weches formation), and lignite (a low grade coal). Later, changes in sea level and tectonic movements caused these sedimentary rocks, which now underlie East Texas, to be thrust above sea level. Erosion then removed material, in some places exposing older layers, and shaped the surface into its modern form—other than sedimentation, erosion is the most important geologic factor shaping the landscape of East Texas. In fact, all of East Texas is an erosional landscape, with sediments slightly more resistant to erosion occupying higher points in the landscape and more easily eroded layers occupying lower positions.

As one drives from west to east across East Texas, progressively younger wedges of sediment are exposed at the surface, "arranged like a tipped stack of books" (Spearing 1991) or a stack of cards, with the youngest layers found near the present-day Gulf Coast (Figs. 19, 20). These sedimentary layers are more or less parallel to the coast (see Figs. 17, 18), giving stark visual evidence of their history—layer after layer laid down over tens of millions of years, little by little increasing the size of the North American continent. In fact, probably the best short-hand description of the geology of East Texas is given by Spearing (1991) who said the story "is one of tremendous sedimentation and progressive construction of the southern continental margin of North America. . . ." The one significant exception to this pattern is the area associated with the Sabine Uplift in the northeastern part of East Texas in the vicinity of Harrison, Panola, Sabine, and Shelby counties (Collins et al. 1980) (Figs. 17, 21). This structural feature represents an area of regional uplift resulting in slightly older sediments being exposed at the surface. As a result, some geologic layers which are

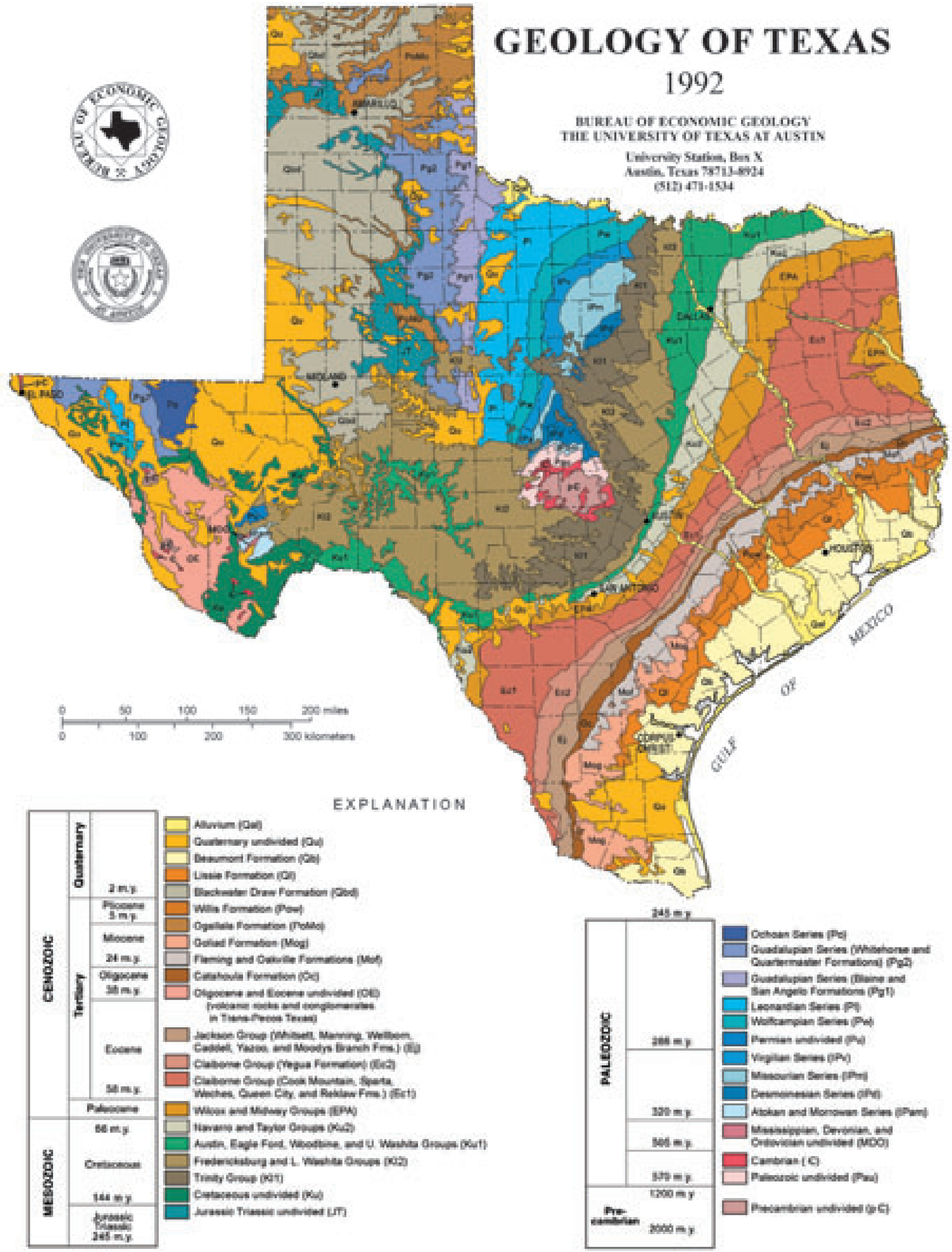


FIG. 17/ GEOLOGIC MAP OF TEXAS. USED WITH PERMISSION OF THE BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS AT AUSTIN.

exposed to the west crop out again at the surface on the Sabine Uplift (e.g., Carrizo Formation). In general, however, there is a striking progression of younger sediments towards the coast.

Some of the Tertiary sediments are rich in organic materials from the abundant plant life in the ancient swamps. These are particularly important economically because their hydrocarbon compounds (modified by heat and pressure) are the source of significant amounts of modern day oil, gas, and low-grade coal (lignite). Oil and gas are widely associated with East Texas, sometimes to the detriment of the environment because of the destructive techniques used to extract them. Lignite, however, is less well known in East Texas. Probably best described as somewhere between hard peat and soft coal, lignite represents the carbonized remains of plants that once flourished in the densely vegetated swamps near the coast. Examples include Eocene age (about 50 million years old) lignite mined near Winfield west of Mt. Pleasant and near Longview west of Marshall. Such lignite is used as fuel for power plants that generate electricity (Spearing 1991).

While predominantly sand, the Tertiary layers of East Texas show significant variation (e.g., local areas of clay, shale, silt, marl, limestone, gravel, iron-rich layers, glauconite, lignite, oil and gas-bearing strata, or some sandy layers particularly hard and thus more resistant to erosion, etc.), which greatly affects modern day landscapes and economies. For example, according to Spearing (1991), "Rolling countryside speaks of alternating sandy and shaly sequences of rocks, where the sands form ridges and soft shales erode to form valleys." The color of the layers also varies considerably, with some strikingly red due to the presence of oxidized iron. In fact, in limited areas (e.g., Cass and Morris counties), iron ore was mined from the Weches Formation beginning in the mid-nineteenth century (Brown et al. 1969) and was used during the Civil War in the manufacture of guns and other metal objects (Maxwell 1970).

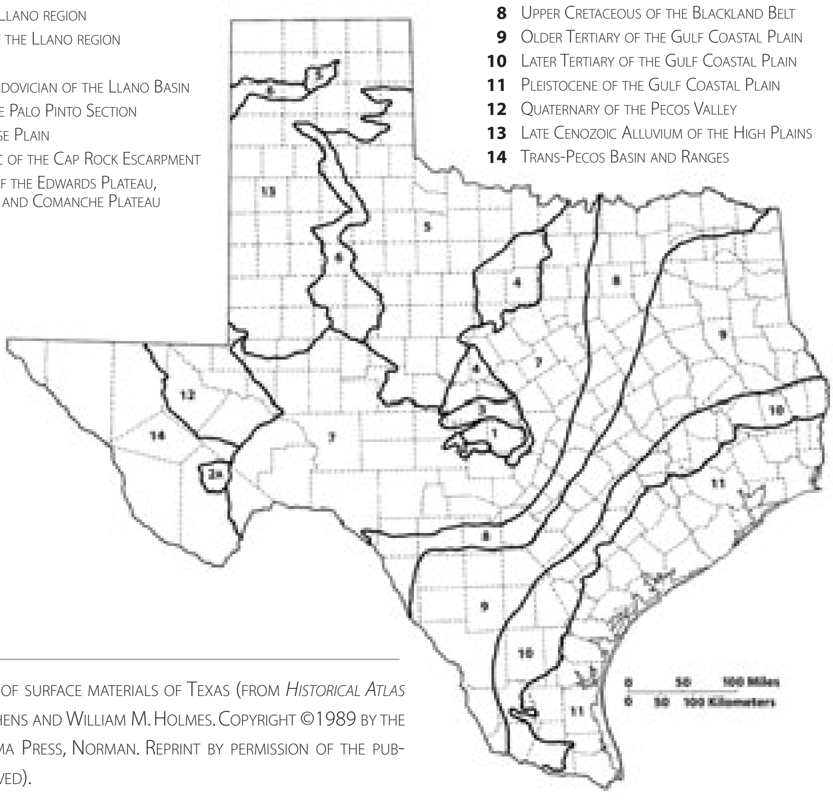


Fig. 18/ Geologic age of surface materials of Texas (from *Historical Atlas of Texas*, by A. Ray Stephens and William M. Holmes. Copyright ©1989 by the University of Oklahoma Press, Norman. Reprint by permission of the publisher. All rights reserved).

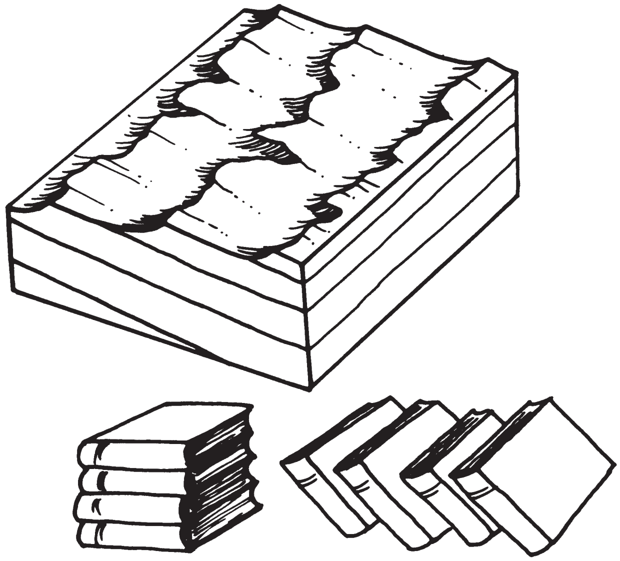


FIG. 19/ ILLUSTRATION SHOWING HOW FROM WEST TO EAST ACROSS EAST TEXAS, PROGRESSIVELY YOUNGER WEDGES OF SEDIMENT ARE NOW EXPOSED AT THE SURFACE, "ARRANGED LIKE A TIPPED STACK OF BOOKS," WITH THE YOUNGEST FOUND NEAR THE PRESENT-DAY GULF COAST (ADAPTED FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

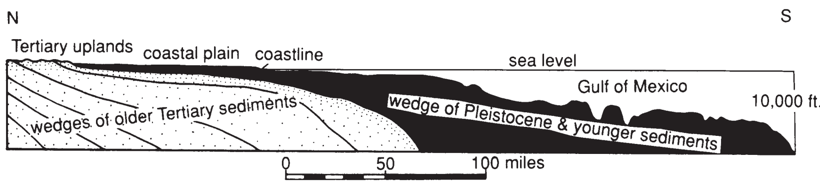


FIG. 20/ CROSS SECTION OF THE GULF COAST, SHOWING YOUNGEST, POST-TERTIARY (PLEISTOCENE AND HOLOCENE) SEDIMENTS CLOSEST TO AND UNDER THE GULF (ADAPTED FROM *ROADSIDE GEOLOGY OF TEXAS*, DARWIN SPEARING, 1991, ©MOUNTAIN PRESS PUBLISHING COMPANY, MISSOULA, MT).

In the very southeastern part of East Texas closest to the coast (e.g., southern part of the Big Thicket around and north of Beaumont), even younger, post-Tertiary sediments are found at the surface (Fig. 20). These are Pleistocene (Ice Age) sediments (e.g., Lissie and Beaumont) deposited during interglacial periods between approximately 1.8 million and 8,000 years ago. They are nearly flat and represent the modern Gulf Coastal Plain. Also during the Pleistocene, and even more recently during the Holocene (8,000 years ago to the present), sands were deposited along the streams of East Texas. Some of these sands were moved by the vast quantities of water from melting Ice Age glaciers. Large deposits of such sand can be seen along some drainages, with sub-fossils (e.g., bison skulls) sometimes still found as the flood plain sands shift or are removed for human purposes (Bullard 1931; Sellards et al. 1932; Shuler 1935, 1937; Albritton 1942; Renfro et al. 1973; McGowen et al. 1991; Spearing 1991).

In order to fit the geology of East Texas into the broader picture of the state as a whole, a brief description of the areas to the west can be helpful. Directly to the west of most of East Texas lie the Cross Timbers and Prairies and Edwards Plateau, both underlain primarily by Cretaceous materials. As one moves progressively west from the Gulf through these regions, the rocks become older and older, a continuation of the same trend seen in East

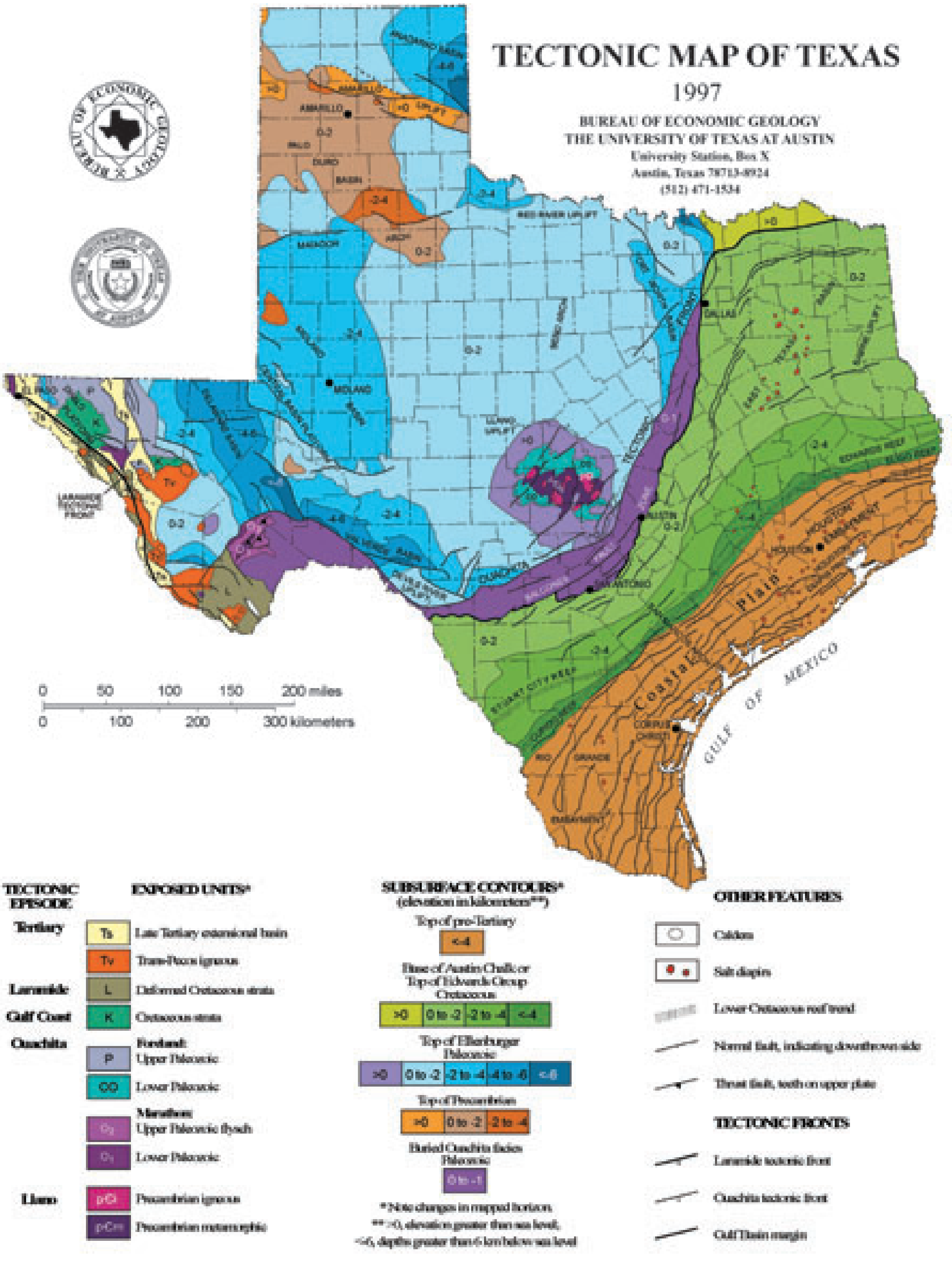
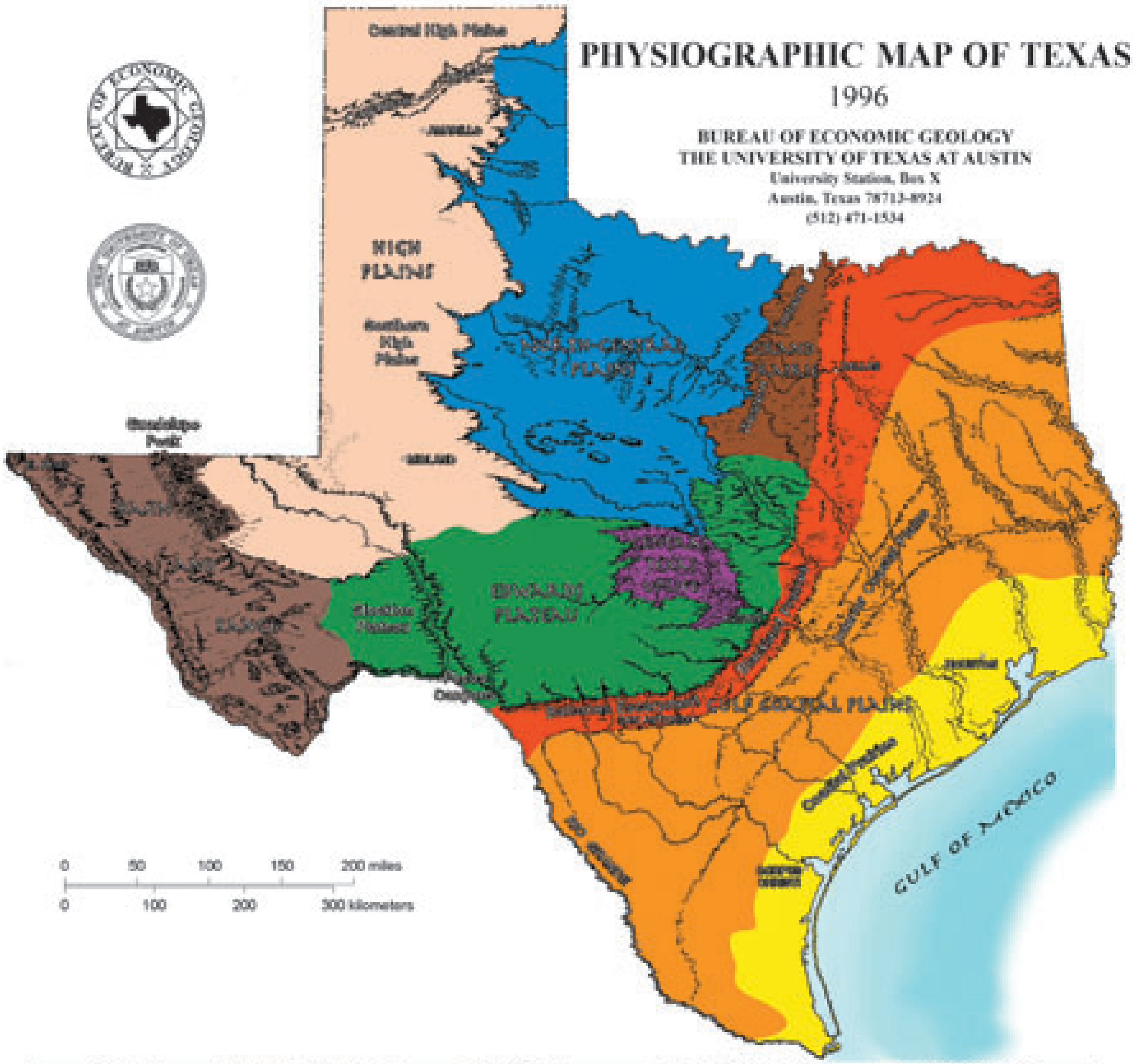


FIG. 21/ TECTONIC MAP OF TEXAS. USED WITH PERMISSION OF THE BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS AT AUSTIN.



PROVINCE	MAX. ELEV. (ft)	MIN. ELEV. (ft)	TOPOGRAPHY	GEOLOGIC STRUCTURE	BEDROCK TYPES
Gulf Coastal Plains					
Coastal Prairies	300	0	Nearly flat prairie, <1 ft/mi to Gulf	Nearly flat strata	Deltaic sands and muds
Interior Coastal Plains	800	300	Parallel ridges (questas) and valleys	Beds tilted toward Gulf	Unconsolidated sands and muds
Blackland Prairies	1000	450	Low rolling terrain	Beds tilted south and east	Chalks and marls
Grand Prairie	1250	450	Low stairstep hills west; plains east	Strata dip east	Calcareous east; sandy west
Edwards Plateau					
Principal	3000	450	Flat upper surface with box canyons	Beds dip south; normal faulted	Limestones and dolomites
Pecos Canyons	2000	1200	Steep-walled canyons		Limestones and dolomites
Stockton Plateau	4200	1700	Mesa-formed terrain; highs to west	Unfaulted, near-horizontal beds	Carbonates and alluvial sediments
Central Texas Uplift	2000	800	Knobby plain; surrounded by questas	Centripetal dips, strongly faulted	Granites; metamorphics; sediments
North-Central Plains	3000	900	Low north-south ridges (questas)	West dip; minor faults	Limestones; sandstones; shales
High Plains					
Central	4750	2900	Flat prairies slope east and south	Slight dips east and south	Eolian silts and fine sands
Canadian Breaks	3800	2350	Highly dissected; local solution valleys		
Southern	3800	2200	Flat, many playas; local dune fields		
Basin and Range	8750	1700	North-south mountains and basins	Some complex folding and faulting	Igneous; metamorphics; sediments

FIG. 22/ PHYSIOGRAPHIC MAP OF TEXAS. USED WITH PERMISSION OF THE BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS AT AUSTIN.

Texas. In fact, if one were to travel from the modern day Texas Gulf Coast west across much of the state, it would be a trip crossing older and older sediments deposited during the past 145 million years. Further west, to the west of the Cross Timbers and Prairies, lies the vast area known as the Rolling Plains, underlain by the famous and even older Permian Red Beds. This region, at least in part, is sometimes referred to as the Red Plains because of the obviously red color of iron oxides in the Permian strata. The western edge of much of the southern part of East Texas is marked by the Balcones Escarpment, a striking feature of the Texas landscape. According to Spearing (1991), "The Spanish explorer, Bernardo de Miranda, in 1756 named the escarpment 'Los Balcones', meaning 'balconies', which describes quite well the stair-step, balcony-like topography rising above the plains." The displacement occurred ca. 10 million years ago along the zone of weakness associated with the ancient Ouachita mountains (Fig. 21). The escarpment is most obvious from Waco south through Austin and San Antonio. As one moves from east to west across this escarpment, higher and higher benches or "steps" are encountered until the older Lower Cretaceous rocks of the Edwards Plateau are reached—about 2,000 feet above sea level (Figs. 22, 23). In one isolated region to the southwest of East Texas is a rugged area, variously known as the Burnet Country, Central Mineral Region, or Llano Basin, which includes granite and other very old Precambrian and Paleozoic outcrops. Here, ancient material has been exposed by the extensive erosion of overlying Cretaceous sediments. This is one of relatively few places in the state where materials of igneous origin can be easily viewed (e.g., Enchanted Rock) (Spearing 1991).

Fig. 23/ Physiographic regions of Texas (from *Historical Atlas of Texas*, by A. Ray Stephens and William M. Holmes. Copyright ©1989, by the University of Oklahoma Press, Norman. Reprint by permission of the publisher. All rights reserved.

Several unusual geologic features seen in East Texas deserve special mention. First, while virtually all surface rocks exposed in East Texas are sedimentary in origin, there is one minor, but interesting exception—Pilot Knob in Travis County. This small (about 2 miles in diameter), slightly elevated (180 feet above the surrounding terrain) feature southeast of Austin served during early settlement times as a landmark for travelers of the old Dallas-San Antonio stage route (Young et al. 1982). Geologically, it represents the remnants of a volcano that exploded from beneath the sea during the Cretaceous Period about 80 million years ago. Lava, volcanic ash, and other igneous material erupted through the limestone that was being deposited and formed an explosion crater. Today, these igneous rocks can be found at the surface. Because they are more resistant to erosion than the surrounding limestones and marls, the result is a geologically interesting, if less than spectacular, knob of land standing above the nearby landscape (Trippet & Garner 1976; Spearing 1991).

Another interesting type of geologic feature that is widespread but very limited in size is the series of salt domes scattered through East Texas (discussed briefly previously; also see Fig. 21). These domes are not only economically (e.g., oil, gas, salt, sulfur) and ecologically important (providing specialized microhabitats), but are also the cause of several very unusual, isolated areas of Cretaceous rocks reaching the surface in East Texas. In the vast area of the state east of the Blackland Prairie, Tertiary and Quaternary (including Pleistocene and Holocene) sediments are seen nearly exclusively. However, several very small areas of Cretaceous rock have been pushed to the surface by rising columns of salt—an excellent example is the salt dome near Palestine in Anderson County (Spearing 1991). Disturbingly, some of the East Texas salt domes were considered in the past as possible repositories for radioactive wastes (see Kreitler et al. 1980; Jackson & Seni 1984b).

A third geologic phenomenon worth mentioning is the Cretaceous–Tertiary (K-T) boundary, a zone of contact between older Cretaceous and younger Tertiary rocks, dated at approximately 65 million years ago (the German word for Cretaceous begins with a K). The boundary is found at the surface in a line snaking from northeast to southwest across East Texas where the appropriate sedimentary rocks have been exposed by erosion so that one can see material deposited from the end of the Cretaceous Period to the Early Tertiary Period.

This has long been a particularly fascinating boundary for biologists because it represents the time of one of the best known "great dyings" or mass extinctions—the simultaneous extinction of huge numbers of the earth's species. The boundary is also of great interest to geologists because its sediments display a highly unusual accumulation of iridium (Ir), an element generally not found in significant quantities in rocks at the earth's surface but one which is much more abundant in certain asteroids/meteorites. At widely scattered locations across the planet (e.g., Denmark, Italy, New Zealand, North Pacific, South Atlantic, and East Texas), the same tell-tale anomalous iridium concentration can be found (in some cases about 200 times greater than background levels). Based on this and many other types of evidence, it now seems clear that a massive extraterrestrial object rich in iridium struck the earth about 65 million years ago. Recent research suggests that the object (an asteroid about 10 km/6 miles in diameter) hit the northern edge of the Yucatan peninsula of Mexico, creating a huge crater with a diameter of about 180 km. This crater, now deeply buried under sediments, is named Chicxulub (from Mayan, tail of the devil). Debris from this collision was scattered around the world, resulting in widespread unusual deposits at the K-T boundary. Even here in East Texas, additional clues can be found for this temporally distant event. Shocked quartz (quartz grains with striations that form under sudden intense pressure), thought to have been thrown out from the impact site, has been found near the Brazos River (in Falls County), as has evidence of an unusual layer of sandstone apparently deposited by a tsunami (= giant tidal wave) caused by the impact. This sandstone, which is immediately below the iridium anomaly, contains a chaotic mix of sand jumbled with pieces of fossilized wood, shell fragments, fish teeth, and chunks of lime-rich mudstone—the kind of mixture expected to be laid down at an inland site inundated by a giant tidal wave.

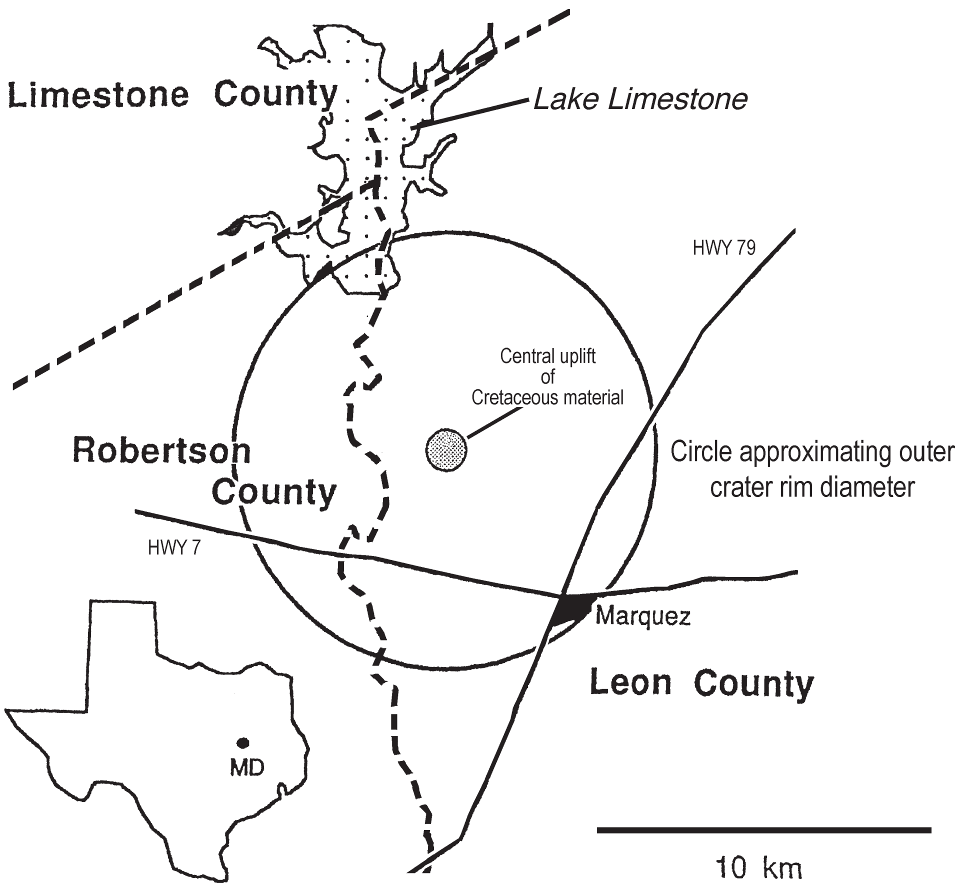


FIG. 24/ LOCATION OF THE MARQUEZ DOME IMPACT STRUCTURE IN LEON CO. AND ADJACENT ROBERTSON CO. THE CENTRAL UPLIFT IS MARKED AS THE SMALL SHADED CIRCLE WITH THE LARGER CIRCLE APPROXIMATING THE CRATER RIM DIAMETER. (ADAPTED FROM BUCHANAN ET AL. 1998 AND WONG ET AL. 2001; USED WITH PERMISSION OF METEORITICS & PLANETARY SCIENCE).

The consequences of such a tremendous impact (a force estimated at 10,000 times the world's nuclear arsenal) would have included vast amounts of debris thrown into the atmosphere causing temporary darkening and cooling of the earth, ecosystem disruption, and widespread extinction. The mysterious mass extinction of the dinosaurs, ammonites, and many other creatures approximately 65 million years ago thus seems to be explained at least in part. Some scientists, however, believe that extensive volcanism contributed to the mass extinction. It is estimated that 44% of the genera and 70% of the species of marine plankton became extinct as a result of the impact and its aftermath. The extinction was selective, however, with certain marine groups and large terrestrial organisms being especially hard hit (Alvarez et al. 1980, 1984; Bohor et al. 1984; Alvarez 1986; Bourgeois et al. 1988; Swisher et al. 1992; Krogh et al. 1993; Hildebrand et al. 1995; Dingus & Rowe 1998, a balanced overview; Graham 1999, a concise summary; Hildebrand 2002). A striking point regarding the extraterrestrial impact-mass extinction connection is that our awareness of this phenomenon is quite recent—dating only from the seminal 1980 Alvarez et al. paper. While still controversial, this discovery is a major conceptual breakthrough about geological processes on earth and their effects on the planet's living organisms.

Finally, while such major impact events may be relatively rare, we have evidence of at least one smaller impact which occurred in East Texas. Local farmers and ranchers (e.g., family of J.A. [Jack] Lincecum, J.B. Lincecum, pers. comm.) in Leon county near Marquez have long known that there was something strange about the geology of their area (Fig. 24). A surface outcrop of disturbed Upper Cretaceous limestone rocks, unlike those anywhere nearby, occurs in an area otherwise characterized by much younger Paleocene sandstone. Some geologists thought the structure, known as the Marquez Dome, was another example of the salt domes found widely scattered in East Texas (e.g., Spearing 1991). Recently, however, based on a variety of evidence, including core samples (petroleum industry well-log data), gravity anomaly data, seismic reflection data, surface geology, faults, and steeply sloping strata, geologists have more satisfactorily explained this unusual geologic feature as an impact crater. It is thus one of fewer than 200 such craters known worldwide (Perkins 2002b). Approximately 58 million years ago near the Paleocene-Eocene boundary, when the region was a near-shore environment, an extraterrestrial object (e.g., a meteorite) slammed into the soft unconsolidated sediments, producing a 13 km diameter impact crater. Subsequently buried by sediments and later partially uncovered by erosion, the only present-day surface exposure of the crater is an uplifted area at its center—a 1.2 km diameter outcrop of blocks of Cretaceous Pecan Gap limestone (Taylor Group) in a sand and clay matrix. The presence of this anomalous limestone at the surface represents at least a 1,120 m vertical uplift of the Cretaceous rocks, and is an indication of the tremendous energy released during the impact (Gibson & Sharpton 1989; Gibson 1990; McHone & Sorkhabi 1994; Buchanan et al. 1998; Wong et al. 2001).

SOILS AND SOIL-RELATED GEOLOGY OF EAST TEXAS

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INTRODUCTION AND SOIL FORMATION

Soils of East Texas vary dramatically, ranging from loose, drought prone sands to rich Blackland Prairie soils to the flooded soils of swamps and bogs. These different soils have profound impacts on vegetation, in some cases being the determining factor in plant distribution and abundance. The varied soils have formed as a result of a complex series of interactions involving the effects of parent material, time, climate, plant and animal life, and topography (Dolezel et al. 1988). Key processes include erosion, weathering, leaching of soluble bases, accumulation of organic matter in surface layers, and the downward movement of clay particles. It is obvious that many of these factors are interrelated. For example, time has relatively little effect on soil development in very dry areas such as deserts. In East Texas, however, with annual rainfall of 28 to nearly 60 inches (71 to 152 cm), subtropical temperatures, and an abundance of plant and animal life, there has been significant soil development. One of the most important factors in determining the type of soil that develops in a given area is parent material. In East Texas there are three major categories of parent material: 1) the alluvial fills of flood plains, 2) the Pleistocene Age mounded terraces, and 3) extensive areas of older marine and fluvial (= associated with a river or stream) sediments. The varying makeup of these parent materials and their complex distributions across East Texas have resulted in numerous different soil types arranged in an extremely complex pattern. During the process of soil development, different layers (called horizons) form, resulting in characteristic soil profiles (= cross-section of a soil including all horizons). Such differences are the basis for soil classification.

Soil Order Definitions

As botanists have a classification system for plants, soil scientists have developed a similar organizational system by which to classify the diversity seen in soils. This classification system has several broad categories called orders. Most soils occurring in East Texas can be classified to one of the following six orders: Alfisols, Entisols, Inceptisols, Mollisols, Ultisols or Vertisols. There are minor areas of two other orders, Histosols and Spodosols, in extreme southeastern Texas.

The names of these soil orders end with "sol" (from Latin: *solum*, soil), and they are defined as follows, based on *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (Soil Survey Staff 1999).

Alfisols—have well-developed horizons, are somewhat weathered, and may have a relatively high concentration of base minerals such as calcium. The derivation of the name comes from the word "pedalfer," an old term used in soil science (the root alf- is an artificial syllable). Alfisols are typically slightly acid to neutral forest soils that have relatively high natural fertility. They are similar in development to Ultisols (e.g., they have a subsoil with appreciably more clay than the surface layer) but are less weathered and have more base minerals. In the Pineywoods area of East Texas, Alfisols occur on stream terraces, the Yegua Formation, most of the Jackson Group, the Fleming Formation, and the flatwoods part of the Lissie and Beaumont formations. As rainfall decreases to the west (i.e., resulting in less weathering), starting at about the Trinity River, Alfisols tend to be the dominant soils on much of the Post Oak Savannah and also occur in limited areas of the Blackland Prairie.

Entisols—are soils defined as having little or no soil profile/horizon development, and they are typically of recent origin. The root of the word Entisol is a meaningless syllable coming from the word "recent" (Soil Survey Staff 1975). Most East Texas Entisols occur in the bottomlands of rivers and smaller streams. New material is deposited on the surface during each flood sequence, thereby preventing profile development. The only other East Texas variation of this soil order occurs in the deep sandy upland soils of the Carrizo Formation that do not have enough fine particles to develop a subsurface layer.

Histosols—(from Greek: *histos*, tissue), which are rare in Texas, are defined as soils that have large amounts of organic material (at least 20–30% organic matter by weight). They are generally wet and are often referred to as peats and mucks. They typically "form in settings where restricted drainage inhibits the decomposition of plant and animal remains, allowing these organic materials to accumulate over time" (McDaniel 2004).

Inceptisols—derive their name from the Latin, *inceptum*, beginning. While like Entisols in exhibiting minimal horizon development, Inceptisols show the beginnings of the process and do display some profile characteristics. However, they lack the well-developed subsurface layers that are characteristic of Alfisols and Ultisols. In East Texas they occur primarily in river and larger stream bottomlands.

Mollisols—(soft and dark, from Latin: *mollis*, soft) are soils that have developed under deep-rooted prairie vegetation. They have a dark gray to black surface layer (more than 10 inches [25 cm] thick) resulting from the long-term addition of organic materials derived mainly from plant roots. Shrink-swell phenomena and cracking, while still occurring on Mollisols, are less pronounced than on Vertisols. Mollisols mainly occur in the Beaumont Formation and the Blackland Prairie. They are scarce in the Pineywoods, with isolated areas in the Weches and Fleming formations.

Spodosols—(from Greek: *spodos*, wood ashes) are rare in Texas, occurring primarily on the Lissie Formation and on the Pleistocene to possibly Holocene age terraces (often associated with the Beaumont Formation) sometimes referred to as the Deweyville (Arnow no date).

These are low fertility, acidic, forest soils, which form in areas of sandy parent material. They are highly leached and defined by a dark colored subsurface layer (humus complexed with aluminum and sometimes iron) underlying a bleached layer of light-colored sand.

ULTISOLS—are deeply weathered, somewhat infertile, acidic soils that form in areas of relatively high precipitation and subtropical temperatures, and thus substantial weathering. In fact, they are considered the most weathered of all midlatitude soils, hence the derivation of their name (Latin: *ultimus*, ultimate) (Steila 1993). They are common on geologically old landscapes in warm climates where soil weathering processes such as the leaching of clays and other minerals out of the topsoil by abundant rainfall have occurred over a long period of time. Due to both chemical and physical weathering, Ultisols tend to be deep and leached of most soluble bases such as calcium, resulting in their acidic nature and low fertility (lower than Alfisols). Extensive weathering also results in a highly developed soil profile and a subsurface horizon enriched in clay. Under good drainage conditions, Ultisols are frequently reddish or yellowish in color due to the oxidation of iron and manganese compounds (e.g., Fe-Mn oxides). They are the dominant soil order on the Wilcox, Reklaw, Queen City, and Sparta formations generally north of Nacogdoches and Crockett, as well as the Willis Formation north of Jasper and Woodville, and they support much of the forest vegetation in those areas. While capable of supporting productive forest, Ultisols are not well-suited for continuous agriculture without the input of commercial fertilizers (McDaniel 2002).

VERTISOLS—(self-swallowing or churning, from Latin: *verto*, turn upward) are high shrink/swell soils that are clayey throughout and that crack to the surface when dry. Because of the shrinking and swelling characteristic of Vertisols and the resulting continuous cycle of overturning or self-plowing (Steila 1993), they generally have less well-developed horizons than many other soil orders. The microtopographical features known as gilgai are usually present (see page 63 for details). Soils that crack to the surface have such a profound effect on the vegetation and land use that this governs their classification. Vertisols occur mainly on the Cook Mt., Manning, Fleming, and Beaumont Formations and on the Blackland Prairie.

Primary Soil Characteristics Affecting Plant Communities

There are several primary soil characteristics which affect plant communities: soil texture, available water-holding capacity, soil reaction (pH), fragipans (compacted layers below the soil surface), and surface slope or gradient. Of particular importance in determining the properties of a soil is its texture, resulting from the proportion of mineral particles in three different size categories. The smallest soils particles are referred to as clay (particle size of 0.0001 to 0.002 mm), somewhat larger particles as silt (0.002 to 0.05 mm), and the largest as sand (0.05 to 2 mm). Soil texture and available water-holding capacity are related. Clayey soils, with their greater surface area, hold more water than sandy soils. As the clay content increases the water-holding capacity increases. However, when the clay content of a soil exceeds 30 to 35 percent, the available water-holding capacity does not necessarily increase (and may in fact decrease). This is because clay particles have such a strong attachment to soil moisture that it is not available to plant roots. In contrast to clay soils, some upland sandy soils are so excessively drained that even in areas of high rainfall, plants living on these soils are adapted to quite dry conditions. Highly acidic (low pH) soils can also greatly affect vegetation by limiting nutrients, including nitrogen. In such cases, plants adapted to low nutrient conditions (e.g., carnivorous plants) are sometimes common. In soils with a high pH (alkaline), iron becomes less available, causing some plants (especially pines) to become chlorotic (= yellow or bleached due to the loss of chlorophyll or failure of chlorophyll synthesis). Although other factors are important, possibly the greatest natural influences on pine tree growth and density may be the available water in a soil and the soil acidity.

Because of the sedimentary nature of East Texas parent materials, and because of the typically shallow slope of many of the strata, very thin layers of one material (e.g., sand) can sometimes overlay a different type (e.g., clay). Thus, a superficial examination of the surface material may not be sufficient to determine what is actually influencing the plant cover at a particular location. An excellent example can be found in some areas of the Post Oak Savannah, where various arrangements of sand and clay layers result in a complex mosaic of woodland/savannah and prairie vegetation.

Soil surfaces with a nearly level gradient, clayey texture, and compacted or impermeable layers can become supersaturated or have standing water over the soil surface. This can result in characteristic plant communities (e.g., wet pine savannahs). Another example can be seen in certain small seepage areas, commonly referred to (depending on type and classification system) as "Wet Herbaceous Seeps" (see page 96), "hanging bogs," "hillside bogs," "acid seeps," "muck bogs," or "possum haw bogs." These occur where a layer of permeable sand at the surface is underlain by a relatively impermeable clay or sandstone. Water percolating downward through the sand encounters the impermeable layer and moves laterally, sometimes forming small areas at the surface that are saturated with water—and which are typically highly acidic and nutrient-poor. Unusual plant assemblages occur in these habitats and include a number of rare species (e.g., *Palhinhaea cernua*, nodding club-moss—MacRoberts & MacRoberts 1995b). Species typically present in Wet Herbaceous Seeps include carnivorous plants (*Drosera* spp., *Pinguicula pumila*, *Sarracenia alata*), *Xyris* spp. (yellow-eyed-grass), Eriocaulaceae (pipeworts), orchids (e.g., *Pogonia ophioglossoides*), club-mosses (Lycopodiaceae), and cinnamon and royal ferns (*Osmunda cinnamomea, O. regalis*) (Bezanson 2000). Fire suppression, resulting in the encroachment of woody vegetation, is a serious threat to the long-term survival of many of these communities (Keith & Carrie 2002).

Soils of East Texas Bottomlands

The Entisols and Inceptisols typical of bottomlands receive new sediments during each flood occurrence and vary greatly in texture, acidity, wetness, and drainage. Colors range from gray to red depending on the state of iron oxidation. Highly oxidized iron is reddish to yellowish in color, while reduced iron is generally gray. Texture and relative productivity of these soils is strongly determined by the source of the deposited sediment. In the smaller streams where the slope gradient is higher (i.e., more rapid water flow), only the coarser material is deposited. This gives rise to better-drained, loamy soils. As streams get larger and the slope gradient decreases, they become relatively more sluggish, especially during floods. This allows the finer clayey particles to be deposited. The resulting soils are generally more clayey and wetter. The soils in the bottomlands of smaller streams, where the soils are better drained, support a predominance of pines. In the central and northern parts of East Texas, the large stream bottomland soils are generally poorly or very poorly drained and support vegetation often referred to as "bottomland hardwoods." In the southern part of East Texas, the extremely poor drainage results in many swamps and isolated marshes. The swamps may have a predominance of *Taxodium distichum* (bald-cypress), *Nyssa aquatica* (water tupelo), or *Acer rubrum* (red maple).

Soils of East Texas Stream Terraces

Stream terrace soils are mostly Alfisols and occur as nearly level to gently sloping benches or plains adjacent to larger streams throughout East Texas. Landscapes of the terraces may be three-tiered and are generally accepted to be older alluvial depositions that have been modified by wind. Poorly drained depressions, flats, and mounds may occur in sequence. Such a landscape, ranging from poorly drained depressions to well-drained mounds, tends to give rise to varied plant communities. The wetter depressions are covered with hardwoods while pines dominate the loamy mounds.

Soils of the Pineywoods Uplands

Uplands cover large areas of East Texas east of the Trinity River. Ultisols are the most dominant soil order on the Wilcox, Reklaw, Queen City, Sparta, and Willis formations and on significant portions of the Carrizo Formation; they occur as gently sloping interstream divides to steeply sloping side slopes above drainage ways. Soil types occurring in the Carrizo, Queen City, Sparta and Willis formations generally have sandy surface layers over reddish to yellowish loamy subsurface layers. Soils developing in the Wilcox and Reklaw formations are typically loamy over more clayey subsurface layers. *Pinus taeda* (loblolly pine) and *Pinus echinata* (shortleaf pine), with a scattering of *Quercus* spp. (oaks) dominate most of the canopy. However, on the Willis and adjacent formations, *Pinus palustris* (longleaf pine) predominates. Where the Carrizo overlays the relatively impermeable Wilcox, there are large flowing springs which support a diverse vegetative cover.

Alfisols occur in a number of upland areas and tend to be dominant on the Yegua formation, most of the Jackson Group, the Fleming formation, and the flatwoods part of the Lissie and Beaumont formations. There are soils on the Yegua formation and part of the Jackson Group and the flatwoods part of the Lissie formation that have unique characteristics and properties. These soils do not have a high pH but are high in salts (i.e., calcium sulfate [gypsum]) that do not raise the pH appreciably. This condition, coupled with a nearly level topography and a degree of wetness, supports a large population of prairie crayfish which keep the soil profile churned.

There is also a belt of Alfisols in the Weches Formation. They are typically very red soils high in oxidized iron. In areas where calcareous marine shells occur near the soil surface, hardwoods are dominant and unique plant communities may exist. In some areas on the Weches, isolated pockets of prairie vegetation may occur.

Vertisols and Alfisols with vertic properties (soils that crack open/turn) occur in the Beaumont, Fleming, and Cook Mountain formations, and in the Manning Formation of the Jackson Group. The shrink-swell properties of these soils cause pines to undergo extreme stress as the clayey soil exerts pressure on the roots. Pines growing under such stress do not compete well with other species and result in poor quality timber products (in part because the trunks often become crooked). On a related topic, many red-cockaded woodpecker colonies are located in these stressed trees. As a result of the negative soil effects on pines, oaks may be dominant in these areas.

Some soils in the Beaumont formation have developed under deep rooted prairie vegetation and are dark gray to black in color to depths of 10 inches (25 cm) or more due to the accumulation of organic material. These are classified as Mollisols.

Soils of the Post Oak Savannah Uplands

The soils of the Post Oak Savannah uplands are typically sandy or loamy. They are generally old, with highly developed horizons, and are typically moderately acid to neutral in reaction. Exceptions include limited areas of calcareous deposits which have developed more basic soils (Brown et al. 1969) and restricted sites with unusual mineral or rock deposits (e.g., glauconite, iron ore, lignite). In general, the soils of the Post Oak Savannah "developed under moderately high rainfall (30 to 45 inches/year) and deciduous and coniferous forests" (Brown et al. 1969). One soil order, Alfisols, dominates the sandy and loamy Post Oak Savannah. Alfisols can form under a number of conditions, but characteristically develop under forests. Because of their often brownish color and the fact that they often develop under broad-leaf trees, they are sometimes referred to as brown forest soils (Woodward 1996). The brown color derives from the relatively high humus content, which is the result of the breakdown of leaves and their incorporation into the upper soil horizons (Woodward 1996). As a result of their relatively high fertility, until the invention of the steel plow in the 1800s allowed the breaking of the prairie sod and the cultivation of its rich Mollisols and Vertisols, the Alfisols were considered the most fertile, easily worked, and easily cleared of northern hemisphere temperate zone soils (Woodward 1996).

Soil-Related Geology of the Pineywoods and Post Oak Savannah

While there are almost innumerable soil types that occur in the Pineywoods and Post Oak Savannah and their detailed discussion is beyond the scope of this book, a number of the geologic layers reaching the surface develop soils that have special characteristics which profoundly influence the vegetation. Brief mention will be made of a few of these special circumstances, with the underlying geologic strata of the Holocene, Pleistocene, and Tertiary listed from youngest to oldest. Geologists divide the various strata they find into categories called groups and subdivide these groups into formations. In the discussion below, while we generally focus on formations, in several cases these subdivisions do not warrant detailed treatment and the group is discussed as a whole (i.e., Jackson, Wilcox, and Midway groups). Figure 17 provides further information on the various strata found in East Texas.

Holocene Age Alluvial Fills—These occur in stream bottomlands that flood during periods of high intensity rainfall. Sediments eroded from uplands are deposited in such bottomlands during floods. Sand particles, which are heavier than silt or clay, are deposited first in the upper reaches of streams where the gradient is steeper. Clay-sized particles are deposited in the larger streams where the water flow is much slower. “The alluvial surfaces are continuous with and graded to alluvial surfaces downstream” (Arnow 1988). Soils of the alluvial flood plains may have profiles with layers of various textures, as the sediments of the different layers are dependent upon the deposited material. Generally, the smaller streams have soils with a loamy texture and the larger streams have a clayey-textured profile. Entisols occur mainly on the smaller streams and Inceptisols on the larger stream flood plains.

Quaternary (Pleistocene Age) Stream Terraces and Eolian (= wind-borne) **Deposits—**Various areas adjacent to large streams in East Texas are the result of terraces or eolian deposits of Quaternary Period (Pleistocene Epoch) age. A number of different terrace levels may occur within one general area. Soils of the stream terraces have a loamy soil profile that is high in very fine sand and silt, particles of sizes that can be moved by wind. Most of these soils are Alfisols, have a high available water capacity, and are relatively fertile. They are easy to cultivate and have a variety of plant communities. Mounded soils also occur in these areas. The mounds are known as “pimple mounds” or “mima mounds” and range from the coast in the vicinity of Corpus Christi into East Texas as far north as the Red River. These mounds, thought by many to be wind-deposited, are widely known north to Minnesota, east into Louisiana and west to Colorado, California, Washington, and Oregon. For the most part, the mound material seems to be Pleistocene or Early Holocene in age, regardless of the age of the geologic substrate underlying the mounds. The mounds vary from 1 m (3.28 feet) to more typically 6 m (20 feet) to 15 m (50 feet) in diameter and are rarely more than 1.5 m (5 feet) in height (Arnow 1988). Since the slightly higher mounds are relatively better drained than immediately adjacent areas, they significantly increase the number of plant species which can grow in their vicinity. See further discussion of mima mound formation on page 65.

Pleistocene and Tertiary Sedimentary Marine and Fluvial Deposited Geologic Groups and Formations

Beaumont Formation—This is a Pleistocene formation of usually calcareous clays interbedded with more or less continuous lenses of sand (Smeins et al. 1982). It represents levee, delta, and interdelta deposits associated with shifting Ice Age rivers (Sellards et al. 1932). The Beaumont weathers into rich dark soils that are crossed by low, meandering ridges of sand (Solis 1981). While clay predominates, because of the mixture of components in the parent material, soils ranging from sandy to clayey are derived from the Beaumont, with extensive areas of clay soils in depressions and flats (Sellards et al. 1932). The black clay soils are sometimes referred to as “gumbo” and are noted for trapping surface water—some have been converted for rice cultivation (Block 2002). As most of this formation originally had a cover of grass, the soils are black or dark gray, reflecting high levels of organic matter. The predominantly clayey soils are Vertisols which crack to the surface when dry. The soil surface has the microtopographic features known as "gilgai," which trap water during periods of intense rainfall. Limited areas have a thin loamy surface layer or mounds of wind-deposited sediments or even a surface of sandy material. In general, the Beaumont underlies "a flat, featureless, treeless coastal plain extending in a belt about 40 miles wide about 10 to 15 miles from the coast. . . . " (Sellards et al. 1932). However, on the poorly drained Beaumont flats between rivers on the southern edge of East Texas (parts of Hardin, Harris, Jasper, Liberty, Newton, and Orange counties), extensive flatwoods wetlands with pines, hardwoods, and often abundant palmetto occur (Moulton & Jacob no date; Watson 1975). Some of these areas are classified as Wetland Longleaf Pine Savannahs by Bridges and Orzell (1989b) or Wet Pine Savannahs by Van Kley (see page 97). Also, in extreme southeastern Texas (on the southern margin of East Texas) and on extensive areas near the coast just south of East Texas, both the Beaumont and the next layer, the Lissie, in places support Coastal Prairie with prairie "potholes." These are unique microtopographic depressions that form important areas of wetlands. These unusual features, which often occur in combination with mima mounds (see page 65) and intermound flats, are rapidly being destroyed by land leveling for agriculture and by urbanization (e.g., the area around Houston). "This complex pattern, formed thousands of years ago by ancient rivers and bayous, and modified through time by climatic (especially wind) and biotic forces, is an irreplaceable geological legacy. Once these complexes are gone, there is no replacing them" (Moulton & Jacob no date). Because of moisture differences associated with microtopographical change, plant diversity in the area of these complexes can be quite high. In areas of Wetland Longleaf Pine Savannahs, longleaf pines are sometimes confined mostly to mima mounds or other relatively drier areas. A number of additional physiographic features, including meander belts and barrier bars, are well-preserved and easily recognized in the Beaumont Formation (Garner 1967).

LISSIE FORMATION—(including Montgomery and Bently)—Like the Beaumont, the Lissie, a slightly older layer located further inland, is a Pleistocene age formation. It is composed of thick beds of sand with lenses of gravel and some clays, sandy clays, and silt (Sellards et al. 1932; Solis 1981; Smeins et al. 1982). The Lissie represents continental and delta deposits laid down by floodwaters during glacial times. It outcrops "in a belt about 30 miles wide parallel to the present coastal plain about 50 miles from the coast" (Sellards et al. 1932). Topographically, the Lissie generally forms a nearly featureless plain (Sellards et al. 1932). However, mima mounds (see page 65) can be present, adding to habitat diversity (Bridges & Orzell 1989b). Soils of the Lissie Formation are mainly Alfisols with a scattering of Ultisols. These soils have a loamy to sandy surface layer over a loamy subsoil. Extensive areas are dissected by wet to ponded lows that are covered with water during most of the cool season. Alfisols occupy the depressions, drainage ways, and some of the lower mounds, while Ultisols occur on some of the slightly higher ridges. Depending on hydrologic and soil conditions, the Lissie supports quite different vegetation types. In frequently inundated flood plains with calcareous clay soils there are extensive flatwoods wetlands sometimes referred to as "the Flatwoods" (Moulton & Jacob no date; Watson 1975). Some of these flatwoods wetlands are classified as longleaf pine savannah/wet pine savannah/pine savannah wetlands and have floristic ties with bog habitats (Watson 1975; Bridges & Orzell 1989b). Closer to the coast, the Lissie underlies extensive areas of Coastal Prairie. As pointed out by Watson (1975), small-scale but vegetationally quite important topographic/soil differences can be seen in the Lissie—only slightly higher but well-drained sandy ridges (e.g. old levees) support the xerophytic vegetation known as arid or xeric sandylands, while quite nearby hydrophytic vegetation is found in swales underlain by more calcareous, clay-rich, poorly drained soils—such variation is well known from the Village Creek area of Hardin County (Watson 1975; also see page 165).

Willis Formation—The Pliocene age Willis Formation is composed of continental quartzose reddish sand and gravels (petrified wood can be present) which form well-drained soils. Soils of the Willis Formation are mainly Ultisols with a droughty, coarse sandy surface layer more than 51 cm (20 inches) thick. The Willis sands are somewhat coarser than those of the overlying Lissie. One portion has the particles cemented by iron oxide, which makes it somewhat erosion-resistant and hence ridge-forming (Garner 1967; Solis 1981; Liggio 2002). The result can be sandy ridges and large areas of gravelly soils. Such ridges of residual Willis sands often support upland longleaf pine savannah (Bridges & Orzell 1989b). An example can be seen in the Upland Island Wilderness Area of southern Angelina County, where longleaf pines dominate the canopy. This area is hilly and relatively open with various grasses dominating the ground cover. In the Big Thicket, the Willis also underlies extensive areas of beech-magnolia-loblolly forest. In places where the Willis is underlain by an impermeable layer, seepage areas supporting a bog community can be found—e.g., the Willis-Catahoula contact (Bridges & Orzell 1989a). In the Big Thicket, the dividing line between the "Upper Thicket" and the "Lower Thicket," sometimes referred to as the Hockley Scarp, is the contact between the Willis and the Lissie formations (Watson 1975). While quite important in the southern part of the Pineywoods, the Willis in Texas has a rather limited surface outcrop—in general, it occurs only east of the Colorado River (Sellards et al. 1932). In the southwestern area of its outcrop (e.g., Colorado and Austin counties), the Willis supports areas of Post Oak Savannah.

Goliad Formation—The Goliad Formation, laid down during Miocene times, is composed largely of sandstone cemented with calcium carbonate. This formation barely enters East Texas, occurring only in the southwest part of the area in DeWitt, Lavaca, and Colorado counties (Sellards et al. 1932). Because of the relatively hard sandstone, the Goliad forms ledges, ridges, valleys, and cuestas (in contrast to the nearly featureless topography which develops from such formations as the Lissie). The ledges have been used as building stone—a possible explanation of why early missions were built at Goliad (Maxwell 1970). In general, in its limited occurrence in East Texas, the sandy soils derived from the Goliad support Post Oak Savannah vegetation.

Fleming Formation—(previously sometimes referred to as the Lagarto)—Of upper Miocene age, the Fleming Formation represents stream deposits on a low coastal plain merging seaward with delta deposits (Sellards et al. 1932). It "is composed of gray to light brown calcareous clay and silt, calcium carbonate concretions, and fine to medium-grained calcite-cemented sandstone" (Liggio 2002). It is similar to the adjacent Oakville but has a greater proportion of clay (Sellards et al. 1932). The Fleming outcrops from Newton County west across East Texas to Grimes County and then south. Its average width at the surface is approximately 15 miles (24 km) (Sellards et al. 1932). Botanically, the Fleming is of significance because the soils developed from it are calcareous (and thus basic) unlike most (but not all) soils in the Pineywoods and Post Oak Savannah. Many of these soils are Vertisols or vertic Alfisols. As a result, a number of calciphilic plants occur on the Fleming. An example is the occurrence of the shadow witch orchid, *Ponthieva racemosa*, at a unique outcropping of the Fleming on a salt dome (Davis Hill) in Liberty County (Liggio 2002). At other Fleming outcrops (e.g., Jasper, Newton, Tyler counties) unusual occurrences of calciphilic plants are also known (Bridges & Orzell 1989a; J. Liggio, pers. comm.)—e.g., *Acer leucoderme* (chalk maple) on calcareous clays in Tyler County. Bridges and Orzell (1989a) noted that it "is significant that our *Acer leucoderme* sites had little or no *Magnolia grandiflora* or *Pinus taeda*, two of the major canopy species of southeast Texas mesic ravine forests and a richer flora of infrequent mesic vernal herbs than most such forests." Some of the interesting herbs mentioned by Bridges and Orzell (1989a) include *Erythronium rostratum* (yellow trout-lily), *Phegopteris hexagonoptera* (broad beech fern), *Platanthera integra* (yellow fringeless orchid), *Sanguinaria canadensis* (blood-root), *Thaspium trifoliatum* (purple meadow-parsnip), and *Uvularia perfoliata* (perfoliate bellwort).

Because of the high clay content, in some parts of the Pineywoods small prairies develop on the Fleming (e.g., Windham Prairie in Polk County—Brown et al. 2002b). Further, in areas of lower rainfall to the west of the Pineywoods, the Fleming supports extensive grassland vegetation (Sellards et al. 1932)—e.g., it underlies much of the Fayette Prairie (Smeins & Diamond 1983).

OAKVILLE FORMATION—The Miocene Oakville, a continentally deposited layer of limey sandstone, is found in limited areas of East Texas, particularly in the central Post Oak Savannah (e.g., northeast of the town of Navasota in Grimes County, near Kountze Bayou in Burleson County, and Monument Hill and Kreische Brewery State Historic Sites in Fayette County). It also lies beneath a small portion of the Fayette Prairie (Smeins & Diamond 1983). Because the sandstone tends to be more resistant to erosion than most adjacent sediments, the Oakville often occurs as low ridges or hills (e.g., Monument Hill). It outcrops in a northeast to southwest band about eight miles (12.8 km) wide across East Texas (Sellards et al. 1932) and for much of its length is covered with soil. However, where hardened sandstone reaches the surface, a rich and unusual flora has developed. There, on soil-less or nearly soil-less areas, many plants are found that are more typical of the Edwards Plateau hundreds of miles to the west (e.g., *Diospyros texana*—Texas persimmon) (Reed et al. 2002). Further, one of the two known locations of the East Texas endemic Navasota false foxglove (*Agalinis navasotensis*) is from such an Oakville site in Grimes County (Canne-Hilliker & Dubrule 1993).

CATAHOULA FORMATION—This Oligocene formation is made up of "thick, light-gray, fine- to medium-grained quartz sand and interbedded light-olive-gray mud. The sand is locally indurated and tuffaceous" (Jackson & Garner 1982). The formation was in general laid down under continental conditions and, in addition to other materials, contains significant amounts of volcanic ash and tuff, at least some of which probably came from southwest Texas (Sellards et al. 1932). In places, the resulting sandstone and siltstone can be quite consolidated (Bridges & Orzell 1989b). The surface outcrop of this formation in East Texas varies from about four to six miles (6.4 to 9.6 km) in width (Sellards et al. 1932). Soils of the Catahoula Formation are mainly Alfisols with a loamy surface layer over a dense plastic clay subsoil. In some areas where the Catahoula sandstone outcrops, "sandstone barrens" characterized by shallow soils

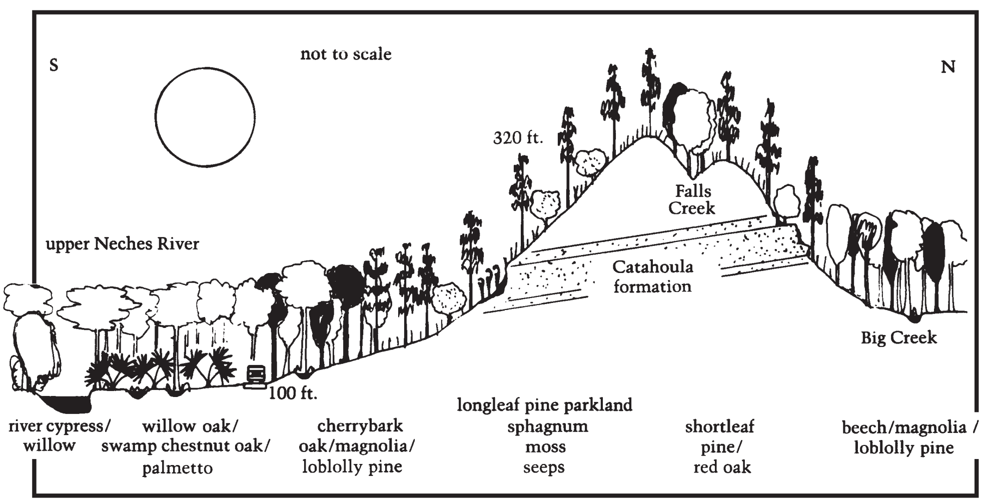


FIG. 25/ CROSS SECTION OF THE UPLAND ISLAND WILDERNESS AREA SHOWING THE CATAHOULA FORMATION (OLIGOCENE IN AGE) AND THE TOPOGRAPHICAL TRANSITION FROM A MAJOR RIVER (THE NECHES), THROUGH FLOODPLAIN, TO SLOPE AND DRY HILLTOP WITH LONGLEAF PINES (THE "UPLAND ISLAND") (FROM *REALMS OF BEAUTY: THE WILDERNESS AREAS OF EAST TEXAS* BY EDWARD C. FRITZ, PHOTOGRAPHS BY JESS ALFORD. COPYRIGHT © 1986. BY PERMISSION OF THE AUTHOR AND THE UNIVERSITY OF TEXAS PRESS).

and xeric conditions develop. Interestingly, even though the thin soil is extremely dry during the summer or droughts, it can be saturated during wetter months—the result is a mixture of xeric adapted plants and those adapted to temporarily or seasonally saturated soils—e.g., *Crassula aquatica* (water pygmyweed), *Drosera brevifolia* (annual sundew), and *Saxifraga texana* (Texas saxifrage) (Bridges & Orzell 1989b). In general, woody plant growth is sparse and the outcrops are typically dominated by low, prairie-like, predominantly herbaceous vegetation often interspersed with areas of stunted deciduous woodland (Bridges & Orzell 1989b). The herbaceous layer includes such species as *Bigelowia nuttallii* (Nuttall's rayless goldenrod), *Schizachyrium scoparium* (little bluestem), and *Selaginella arenicola* subsp. *riddellii* (Riddell's spikemoss) (Bezanson 2000). Marietta and Nixon (1984) described such a "prairie-like community" from the Catahoula of Jasper County and suggested that the natural "prairie-like openings in the forests of east Texas appear to be a result of edaphic factors associated with the Catahoula Formation, and typically are associated with a very shallow and very slowly permeable upland soil…." When overlain by porous materials (e.g., Willis), water moving laterally over the impenetrable Catahoula can appear at the surface as seeps supporting communities referred to as "hillside seepage bogs," "hillside bogs," "hanging bogs" (Watson 1975; Bridges & Orzell 1989a, 1989b; Peacock 1994; MacRoberts & MacRoberts 2001) or Wet Herbaceous Seeps (see page 96). In other areas where the Catahoula is highly weathered, leaving a soil primarily of residual sand, it supports upland longleaf pine savannahs (Bridges & Orzell 1989b). The Catahoula underlies portions of both the Post Oak Savannah and Pineywoods and can be seen in such locations as the Upland Island Wilderness Area (Fritz 1993) where its outcrops contribute to the rich habitat diversity (Ward 1986) (Fig. 25).

JACKSON GROUP—The upper Eocene Jackson Group deposits are the result of an ancient delta system, representing shallow water, near shore deposits as well as continental and beach deposits (Sellards et al. 1932; Kaiser et al. 1980). They are made up of sands, clays, and lignite, and also include significant amounts of volcanic ash originating from volcanoes to the west (Sellards et al. 1932). The Jackson Group outcrops in East Texas in a belt averaging five miles (8 km) in width (Sellards et al. 1932). Soils of the Jackson Group range from clayey to loamy or sandy. Most are Alfisols except for a band of Vertisols in the Manning Formation. In general, depending on location, they support Post Oak Savannah or Pineywoods vegetation.

CLAIBORNE GROUP—(including the Yegua, Cook Mountain, Sparta, Weches, Queen City, Reklaw, and Carrizo formations)

YEGUA FORMATION—This formation was laid down during the Eocene, generally under nonmarine river and delta conditions—it is "essentially a piedmont, coastal, alluvial fan built up by the coalescing of stream levees and deltas" (Sellards et al. 1932). It consists of light-brown, fine-grained quartz sands interbedded with brown muds (Jackson & Garner 1982). In general, the Yegua, which outcrops as a typically forested, gently rolling, sandy band averaging 12 miles (19.2 km) wide (Sellards et al. 1932), supports parts of the Post Oak Savannah and Pineywoods. Soils of the Yegua Formation are Alfisols that are typically gray in color with a loamy surface over a loamy to clayey subsoil, which in turn lies over a rather impervious somewhat consolidated mudstone. This causes a slow permeability of water through the soil. These conditions, along with salts in the lower soil profile, support a large population of crayfish. To the east where rainfall is heavier, calcium and magnesium are leached out and the soils derived from the Yegua can be described as lateritic, acidic, and infertile (Jackson & Garner 1982). Economically, the Yegua is important because it is one of three main lignite-bearing layers in Texas (the others are Wilcox and Jackson groups) (Kaiser et al. 1980).

COOK MOUNTAIN FORMATION—Laid down under marine conditions during the Eocene, the Cook Mountain Formation is an approximately 30 m thick layer "of fossiliferous marine muds and poorly indurated mudstones with minor interbeds of sand and limestone" (Smeins

FIG. 26/ CLOSEUP OF WECHES FORMATION OUTCROP SHOWING CALCAREOUS MARINE FOSSILS. SAN AUGUSTINE CO. (PHOTO BY RJG).

& Diamond 1983; Miller & Smeins 1988). Soils of the Cook Mountain Formation are Vertisols or vertic Alfisols. These soils are very clayey. The clay, known as "montmorillonite" or "smectite," has a high shrink/swell ratio and exerts immense pressure on the roots of all vegetation. This condition is extremely stressful to pines. The soils derived from the Cook Mountain support prairie vegetation (Jackson & Garner 1982) and underlie the southwestern tip of the Fayette Prairie and part of the San Antonio Prairie (Smeins & Diamond 1983). Further east, where moisture is more abundant and the soils more leached, the Cook Mountain supports vegetation characteristic of the Pineywoods.

SPARTA FORMATION—This Eocene layer of primarily loose, unconsolidated, fine to coarse, light-colored quartz sand (with some fragments of fossil wood) is a continental deposit laid down approximately 50 million years ago as the Gulf of Mexico transgressed inland (Sellards et al. 1932; Maxwell 1970; Goodwin 2002; C. Miller Drilling 2001). The sandy soils derived from the Sparta underlie portions of the Post Oak Savannah and Pineywoods. High, dry habitats on the porous soils of the Sparta are similar to those found on the Carrizo (see below) and Queen City formations, and are typically Ultisols with a sandy surface layer over a loamy subsoil. They are characterized by such species as *Quercus stellata* (post oak), *Q. incana* (bluejack or sandjack oak), *Yucca louisianensis* (Louisiana yucca), *Pinus echinata* (shortleaf pine), and *Schizachyrium scoparium* (little bluestem).

WECHES FORMATION—The Middle Eocene, shallow marine-deposited Weches Formation is characterized by the mineral glauconite (a green-colored iron potassium silicate related to micas and clays), as well as glauconitic clays, calcareous marls, rich marine fossil deposits (Fig. 26), and mudstone (Sellards et al. 1932; George 1988; George & Nixon 1990). In some areas, where the soluble ingredients of the glauconite have leached out and iron has concentrated, iron-bearing limonite (iron-stone) is found. This ore was mined in the nineteenth century—e.g., near Jefferson in Marion County and near Rusk in Cherokee County

(Sellards et al. 1932; Brown et al. 1969). The average width of the outcrop of the Weches is two to five miles (3.2 to 8 km) (Sellards et al. 1932). Surface exposures usually occur on slopes (due to erosion) and are typically small, ranging from only 5 to 20 m wide and usually not more than 100 m in length (George & Nixon 1990). Where freshly exposed, the glauconitic strata have an olive green cast, but upon weathering become reddish brown (Fig. 27) (George & Nixon 1990). Soils of the Weches Formation range from shallow and rocky (which apparently limits voody vegetation) on the steeper slopes to deep on the flatter slopes (generally less than 5 to 8 percent), are characterized by a basic pH, and have a layer of glauconitic clay. They are typically Alfisols with a distinctive red clayey subsoil. Outcrops of the Weches are often waterlogged during the spring because of the clay stratum, since "downwardly percolating water reaching the impermeable clay layer moves laterally until it exits on hillsides where the outcrops occur" (George 1988). However, due to their shallowness, Weches outcrop soils can become quite dry in summer and fall (George & Nixon 1990). The basic pH (7.1–8.2) is in striking contrast to that of the mostly acidic soils of East Texas (pH 4.4–6.2) and is probably of major importance in determining the unusual plant community occupying the outcrops.

The unique conditions provided by the Weches Formation result in the development of "Glauconite shale glades" (Bezanson 2000), also known as Weches outcrop communities (Fig. 28). These are usually small, isolated, natural opening or glade communities typically having sparse woody growth and an unusual herbaceous assemblage, including two endemics: Texas golden glade cress (*Leavenworthia aurea* var. *texana*) (Mahler 1987; Poole et al. 2002) and the federally endangered white bladderpod (*Lesquerella pallida*) (George & Nixon 1990). Interest in this habitat increased dramatically when *Lesquerella pallida*, now recognized as endemic to Weches outcrops, was rediscovered in 1981 after having not been seen since its initial collection in the 1830s (Nixon et al. 1983; George & Nixon 1990). This species is currently known from only seven localities, all in San Augustine County (Texas Parks and Wildlife 1999). A number of other species (e.g., *Liatris mucronata*, *Paronychia virginica*, *Petalostemum pulcherrimum*) found on Weches outcrops are disjunct from much further west in Texas. Similarities exist between the Weches outcrop communities and those of the "cedar glades" well known in the southeastern U.S. and adjacent areas (see e.g., Baskin & Baskin 1985, 2000; George & Nixon 1990). Another interesting phenomenon is the occurrence of the somewhat calciphilic *Thaspium barbinode* (Apiaceae), whose only known Texas location is in Houston County on sand over the Weches. The nearest other locations of this species are in the Ouachita Mountains of McCurtain County, Oklahoma, and in deep ravines west of the Ouachita River in Caldwell Parish, Louisiana—disjunctions of approximately 300 km (186 miles) (Bridges & Orzell 1989a).

The Weches can also significantly affect local topography (and thus vegetation). For example, where erosion-resistant ironstone layers occur they cap hills and escarpments—maximum local elevations are found in Anderson and Cherokee counties (Fogg & Kreitler 1982). The result can be "a picturesque, rugged topography of steep, high, flat-topped hills dissected by deep V-shaped valleys" (Sellards et al. 1932). In areas without ironstone, the topography can merely be rolling. Outcrops of the Weches are sometimes mined for road material, gravel, or the fertilizer/soil additive greensand (though it is of low quality for this use), while others are overgrazed or destroyed by various types of development. Unfortunately, the unusual plant community on the Weches currently has virtually no protection in Texas.

Queen City Formation—The Eocene Queen City Formation represents delta deposits and marginal marine sand shoals (Kreitler et al. 1980) and "consists mostly of thick bedded to massive cross-bedded very fine to fine quartz sand that is interbedded with silt and clay. Stringers of lignite and clay are present in the upper portions of the formation and layers of shale are found deeper in the formation" (C. Miller Drilling 2001). Where porous sands of

Fig. 27/ Weches Formation outcrop with reddish brown coloration due to weathering. San Augustine Co. (Photo by RJG).

Fig. 28/ Weches Formation outcrop and Weches outcrop (Glauconite shale glade) community with researcher Robert George (George 1988; Nixon & George 1990). (Photo by Elray Nixon).

the Queen City are underlain by impermeable clay, seepage bogs can result (e.g., Van Zandt County—Kral 1955). The Queen City produces a gently rolling topography and occupies a relatively large surface area in East Texas (Sellards et al. 1932). Soils of the Queen City Formation are typically Ultisols with a sandy surface layer over a loamy subsoil. To the west they underlie parts of the Post Oak Savannah, and in the more moist areas to the east they support extensive portions of the Pineywoods.

REKLAW FORMATION—The Eocene marine-deposited Reklaw Formation consists of a layer of dark silty shale over a layer of dark gray to green, very fine glauconitic silty sand and contains some lignite (Sellards et al. 1932; C. Miller Drilling 2001). Soils of the Reklaw Formation are Ultisols with a loamy surface layer over a reddish clayey subsoil. Though they support some Post Oak Savannah, the red somewhat clayey (sandy clay) soils derived from the Reklaw are "less forested" than adjacent areas developed from the Carrizo and Queen City formations. The Reklaw has sometimes been described as "a red prairie belt between two broad, oak-forested ridges" (Sellards et al. 1932). A second belt of the Reklaw is found on the edge of the Sabine Uplift and underlies portions of the Pineywoods.

CARRIZO FORMATION—The Eocene Carrizo Formation is composed of continental alluvial plain sand deposits, is generally grayish yellow in color (weathering light brown), and is loose, permeable, and friable in nature (McBryde 1933; Kreitler et al. 1980). The surface outcrop, which occurs entirely within Texas, varies from about three to twelve miles (4.8 to 19.2 km) in width (Sellards et al. 1932; McBryde 1933) and extends in a southwest to north-east line from the Bexar-Guadalupe County line in the very southwestern portion of East Texas to Cass County in the extreme northwest. It then trends south to northern Sabine County (see page 217 for additional discussion) (Sorrie & Weakley 2001). Soils of the Carrizo Formation are mainly Entisols and Ultisols. Some of these soils are so sandy that a finer-textured subsoil cannot develop within 2 meters (80 inches) of the surface (they are thus Entisols). Other areas develop a subsoil layer of slightly finer texture than the thick sandy surface and are classified as Ultisols (see page 47 for additional discussion). These loose, coarse to fine sandy soils underlie a significant portion of the Post Oak Savannah (McBryde 1933; MacRoberts et al. 2002b) and small areas of the Pineywoods. The most characteristic vegetation type developed on the Carrizo Formation is xeric sandylands (MacRoberts et al. 2002b), also known as Dry Uplands on Deep Coarse Sands (see page 92). This vegetation type is characterized by such tree species as *Quercus incana* (bluejack or sandjack oak), *Q. margarettiae* (sand post oak), *Q. stellata* (post oak), and *Carya texana* (black hickory), as well as a variety of typical herbaceous/understory species, including *Aristida desmantha* (curly threeawn), *Asimina parviflora* (small-flower pawpaw), *Brazoria truncata* (rattlesnake flower), *Cyperus grayoides* (Mohlenbrock's sedge), *Polanisia erosa* (large clammyweed), *Selaginella arenicola* subsp. *riddellii* (Riddell's spike-moss), and *Yucca louisianensis* (Louisiana yucca) (MacRoberts et al. 2002b). In the Pineywoods, *Pinus palustris* (longleaf pine) can be important in the overstory. Fire and periodic drought appear to be important factors in maintaining this xeric sandylands community typically found on the Carrizo Formation (MacRoberts et al. 2002b).

Another interesting type of vegetation that is found in part on the Carrizo Formation is the disjunct "Lost Pines" area of Bastrop County. This area of pine-oak woodland, somewhat similar to the xeric sandylands, is unusual in being dominated by loblolly pines isolated approximately 100 miles (162 km) west of the main body of East Texas pines (Maxwell 1970; Texas Parks and Wildlife 2002b; Taber & Fleenor 2003). The infiltration of water into the porous sandy soils of the Carrizo and nearby sandy and gravelly layers (e.g., Quaternary gravels) has allowed the survival of the pines "which would otherwise not be successful in this area of Central Texas" (Riskind & Moreland 1973).

The Carrizo sands are an important local center of endemism in the West Gulf Coastal

Plain, with 10 taxa (e.g., *Crataegus nananixonii*, *Hymenopappus carrizoanus*, *Monarda viridissima*, and *Rhododon ciliatus*) confined to the area and two more nearly so (Sorrie & Weakley 2001). In the words of Sorrie and Weakley (2001), "Such areas of porous sandy soils have functioned as edaphic islands and have generated considerable diversification." The endemics present have apparently evolved to deal with the excessively well-drained and droughty soils, which are prone "to frequent water deficits and nutrient limitations" (MacRoberts et al. 2002c).

Because of the movement of water through the sandy, porous Carrizo Formation, bogs and other wetlands are distributed along a line corresponding to surface exposures of the Carrizo. This line of wetlands runs roughly southwest from Henderson County to Palmetto State Park in Gonzales County (Bullard 1936; Rowell 1949; Kral 1955; Bradsby et al. 2000). Examples include several bogs near Flynn in Leon County, Mill Creek and Southworth bogs in Robertson County, and Patschke, Boriak, and Wall bogs in Milam County. MacRoberts et al. (2002b) reported on floristics of the xeric sandylands community that occurs on the Carrizo sands in the Post Oak Savannah and discussed the association of this community with seepage areas, "muck bogs," "possum haw bogs," and other wetlands—basically, the adjacent xeric sandylands are the water source for the wetlands. "The deep sands act as a reservoir or sponge holding water that feeds adjacent seeps and springs that are the headwaters for the area's wetlands and ultimately the streams and rivers. These upslope soils are porous and drain readily; rainwater percolates through the sand and moves down a gradient created by underlying impermeable or slowly permeable clays. Eventually, water seeps laterally out of the hillside" (MacRoberts et al. 2002b). Other sandstone formations (e.g., Queen City, Sparta) can result in similar vegetational expressions (Kral 1955; Bridges & Orzell 1989a; Bezanson 2000).

WILCOX GROUP—The Paleocene age Wilcox Group is comprised of medium to fine quartz sands (approximately 50% of the total) with other layers of shale and lignite, and in large part represents deposition on an ancient alluvial plain. Boulder-like concretions are present in some areas. This is one of the most important lignite (coal)-bearing geologic units in Texas, and in some places the lignite beds can reach nearly 25 feet (8 m) in thickness (Sellards et al. 1932; Fogg & Kreitler 1982; Tewalt et al. 1982). Some workers divide the Wilcox into separate formations (e.g., Calvert Bluff, Simsboro, Hooper—Kaiser et al. 1980); for the purposes of this work, we are considering it a single unit. It is the principal source of ground water across northeast Texas (C. Miller Drilling 2001). This and the adjacent Carrizo Formation form an aquifer system referred to as the Carrizo-Wilcox, one of Texas' major aquifer complexes (Kreitler et al. 1980; Bradsby et al. 2000). According to Fogg and Kreitler (1982), "Ground water constitutes about 40 percent of the total water used in East Texas, and most of this water is pumped from the Wilcox and Carrizo aquifers." Soils of the Wilcox Group are mainly Ultisols. They have a sandy to loamy surface layer over a clayey subsoil and support large portions of the Post Oak Savannah. In addition, where it outcrops near the surface in the area of the Sabine Uplift adjacent to the Louisiana border (e.g., Panola and Shelby counties), the Wilcox also underlies a significant part of the Pineywoods.

MIDWAY GROUP—The Paleocene age Midway Group, the oldest of the Tertiary strata in East Texas, consists of marine-deposited calcareous clay and silty clay and some limestone and glauconitic sand (Sellards et al. 1932; Fogg & Kreitler 1982; C. Miller Drilling 2001). Sedimentary concretions up to four feet (1.2 m) in diameter are sometimes found. The Midway is divided by some workers (e.g., Sellards et al. 1932) into the Kincaid and Wills Point, but it is here treated as a unit. The clay loam and sandy loam soils developed from the Midway Group support the easternmost margin of the Blackland Prairie and the transition to the Post Oak Savannah.

FIG. 29/ PHOTOGRAPH SHOWING STRIKING CONTRAST BETWEEN THE EXTREMELY DARK "BLACK WAXY" SOIL TYPICAL OF THE BLACKLAND PRAIRIE AND A PIECE OF THE NEARLY WHITE UNDERLYING AUSTIN CHALK BEDROCK FROM WHICH IT DEVELOPED. THE PHOTOGRAPH WAS TAKEN DURING TRENCHING ON THE AUSTIN COLLEGE CAMPUS, SHERMAN, TX (PHOTO BY GMD).

SOILS OF THE BLACKLAND PRAIRIE

Most soils of the Blackland Prairie are derived from lime-rich Upper Cretaceous rocks which weather to form soils with substantial levels of clay. Outlying segments of the Blackland Prairie (Fayette and San Antonio prairies) have soils developed from younger Tertiary age deposits. While the majority of Tertiary deposits in East Texas are sandy in nature (e.g., those supporting the Pineywoods and Post Oak Savannah), those underlying prairie areas (e.g., the Fleming, Oakville Sandstone, and Cook Mountain formations) in general have a relatively high clay content and in some cases even develop soils displaying the gilgai microtopography so typical of certain high clay soils (Launchbaugh 1955; Smeins & Diamond 1983; Miller & Smeins 1988; also see page 63). Further, small isolated areas of prairie vegetation can be found where clay lenses occur in other geologic strata outcropping to the west (Cross Timbers) and east (Post Oak Savannah and Pineywoods) of the Blackland Prairie. Thus, clay appears crucial in the development and maintenance of the grassland vegetation characteristic of the Blackland Prairie (see pages 111–115 for a detailed discussion of this concept). In general, all soils of the Blackland Prairie "have in common a very slowly permeable, clayey subsoil. These subsoils, coupled with a generally flat topography, make most Texas prairies poorly drained" (Diamond & Smeins 1985). In some cases, clay is abundant throughout all soil horizons (e.g., the shrink-swell soils discussed below), while in others there is a clay-loam or loam surface layer—all, however, have significant amounts of clay (Godfrey et al. 1973).

The distinctive "black waxy" soils of the main belt of the Blackland Prairie are derived from rock layers which are sometimes strikingly white in color (e.g., Austin Chalk). Through the process of weathering there is a dramatic change in color (Fig. 29). The main soil-forming process for the soils of the Blackland Prairie is known as melanization, which is a darkening of the soil caused by the addition of organic matter. As the profuse roots of grasses and other prairie plants penetrate the soil and eventually decay, dark, stable compounds (i.e., humus) are left—these compounds coat the mineral particles and result in the characteristic, dramatically dark soil (Sims 1988; Sims & Risser 2000). In the words of Hill (1901),

> The Black Prairie owes its name to the deep regolith of black calcareous clay soils which cover it. When wet these assume an excessively plastic and tenacious character, which is locally called "black waxy." These soils are the residue of the underlying marls and chalks, or local surficial deposits derived from them, and hence are rich in lime. Complicated chemical changes, probably due to humic acid acting upon vegetable roots, are believed to cause the black color. The region is exceedingly productive, and nearly every foot of its area is susceptible to high cultivation. In fact, the prairies are the richest and largest body of agricultural land in Texas, constituting a practically continuous area of soil extending from Red River to the Comal.…

More specifically, the Blackland Prairie (also referred to as the Blacklands) has three dominant soil orders: Vertisols, Mollisols, and Alfisols (Fig. 30). The Vertisols develop primarily on the main belt of the Blacklands, mainly on the Eagle Ford shale and rocks of the Taylor Group. In addition, they can be found in portions of the outlying Fayette and San Antonio prairies (Launchbaugh 1955; Smeins & Diamond 1983; Miller & Smeins 1988). These Vertisols are characterized by abundant smectitic (shrink-swell) clays with the ability to adsorb large amounts of water (and thus swell) (Hallmark 1993). With wetting and drying, these soils often undergo dramatic changes in volume, which can result in significant soil movements. Swelling and shrinking cause cracks up to 50 centimeters or more deep and as much as 10 centimeters wide at the surface (Hallmark 1993). Stories of golf balls or even baseballs or other objects disappearing in deep cracks are not uncommon from long-time residents of Blackland soil areas. Soil movements can have dramatic effects on human construction, resulting in uneven or cracked roadways, shifting buildings, and cracked foundations (Hallmark 1993). Only the most elaborately protected houses on many Vertisols are free from at least some cracks or other soil stability problems. These smectitic clay soils are also quite sticky and difficult to manage agriculturally, being easily compacted by farm machinery when wet and forming large clods when plowed dry. Because they can be effectively tilled only within a narrow moisture range, they gained the nickname "nooner soils"—too wet to plow before noon and too dry after noon (Hallmark 1993). This stickiness, as well as the soil's slipperiness, results from lubricating films of water between the innumerable, minute, flat, plate-shaped clay particles (Foth 1990).

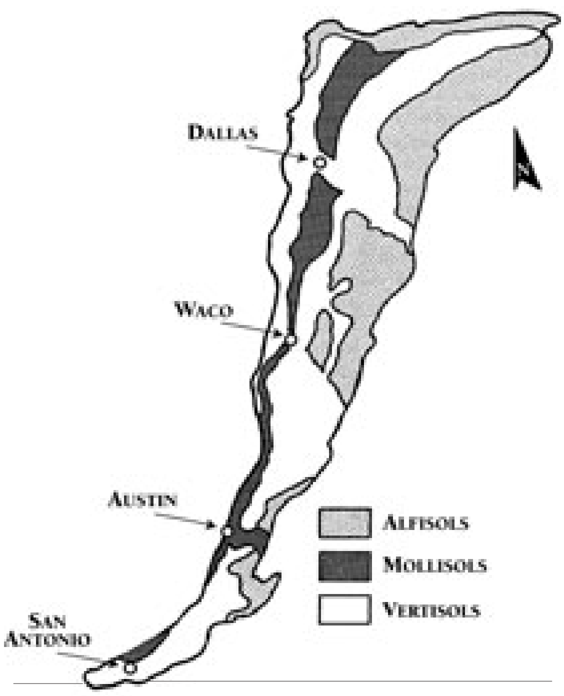


FIG. 30/ DOMINANT SOIL ORDERS OF THE MAIN BELT OF THE BLACKLAND PRAIRIE (FROM HALLMARK 1993, IN M.R. SHARPLESS AND J.C. YELDERMAN, EDS. THE TEXAS BLACKLAND PRAIRIE: LAND, HISTORY, AND CULTURE; WITH PERMISSION OF BAYLOR UNIV. ©1993).

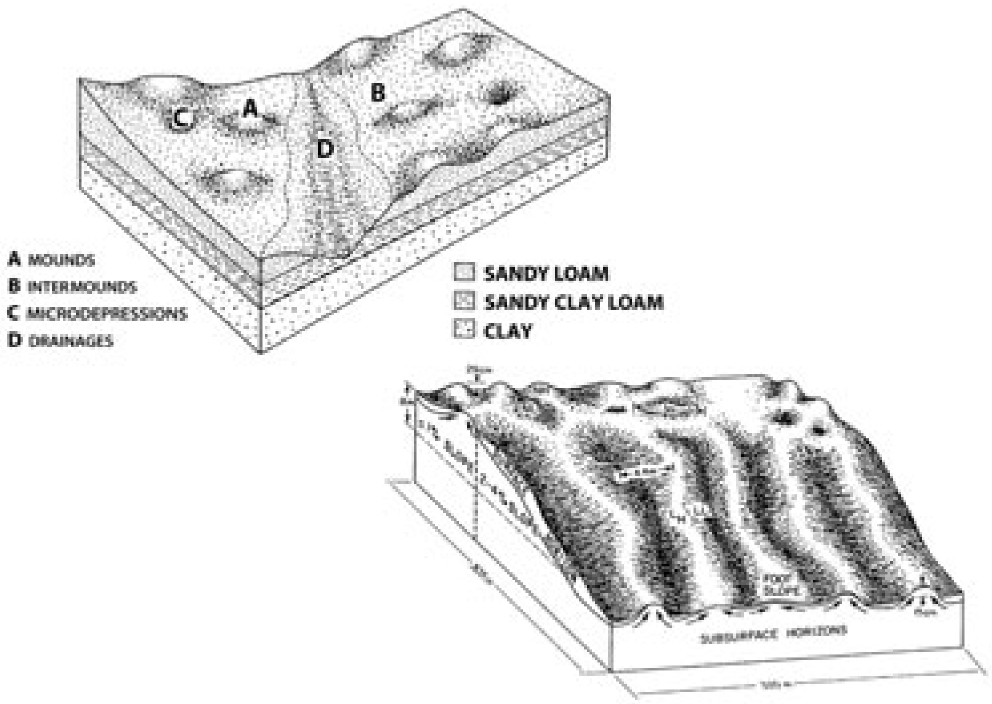


FIG. 31/ DIAGRAMS OF MIMA MOUNDS AND GILGAI. **TOP—**MICROHABITAT VARIATION IN TEXAS TALLGRASS PRAIRIE SHOWING TYPICAL MIMA MOUNDS ON ALFISOL SOILS. **BOTTOM—**MICROHABITAT VARIATION IN TEXAS TALLGRASS PRAIRIE SHOWING TYPICAL GILGAI MICRORELIEF ON VERTISOL SOILS. NH = NORMAL HIGH; NL = NORMAL LOW; LH = LATERAL HIGH; LL = LATERAL LOW. (FROM DIAMOND & SMEINS 1993, IN M.R. SHARPLESS AND J.C. YELDERMAN, EDS. THE TEXAS BLACKLAND PRAIRIE: LAND, HISTORY, AND CULTURE; WITH PERMISSION OF BAYLOR UNIV. ©1993).

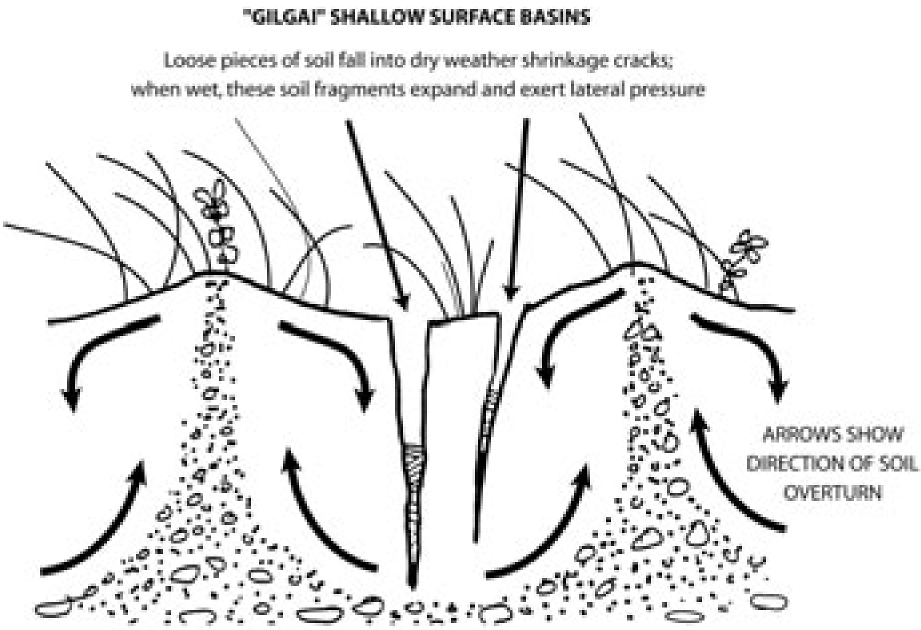


FIG. 32/ DIAGRAM SHOWING GILGAI FORMATION (ADAPTED FROM HAYWARD & YELDERMAN 1991). THE TERM "GILGAI" DESCRIBES A PECULIAR FORM OF SURFACE CONFIGURATION IN WHICH THE LANDSCAPE IS COVERED BY A VAST NUMBER OF SMALL DEPRESSIONS, TEN TO TWENTY FEET ACROSS, AND AS MUCH AS A FOOT-AND-A-HALF DEEP. IN WET SEASONS THESE FILLED WITH WATER, MAKING THE EARLY SETTLEMENT PRAIRIE ALMOST IMPASSABLE. THEY FORMED BECAUSE OF OVERTURN THROUGHOUT THE FULL DEPTH OF THE HIGHLY EXPANSIVE "BLACK WAXY" SOILS OF THE BLACKLANDS.

The smectitic clays also result in both slickensides and gilgai, two phenomena often seen in Vertisols. Slickensides are planes of weakness in the soil caused by movements associated with shrinkage and swelling. These can lead to rather large-scale slippage or failure of soil blocks, which can be problematic in construction (Hallmark 1993). According to Hallmark (1993), the collapse of the walls of construction trenches, caused by slickenside slippage, results in Texas workers being crushed to death in trenches almost every year. Gilgai are the microhigh, microlow topography or relief features found on essentially all Vertisols (Diamond & Smeins 1993). On flat areas in the prairie landscape, gilgai typically form circular, almost tub-like depressions, called "hog wallows" by early settlers. These range from about three to six meters across and up to about one-half meter deep (Hayward & Yelderman 1991). On slopes, gilgai take the form of microridges and trough-like microvalleys up to about 20 centimeters deep which run perpendicular to the contour of the slope (Miller & Smeins 1988; Diamond & Smeins 1993) (Fig. 31). Both gilgai and the great soil depth of this region are the result of the constant churning and overturning of the shrink-swell, clay-based soils. When these soils shrink during dry weather and large cracks form, loose pieces of soil fall deep into the cracks. Upon wetting, these pieces swell and exert lateral pressure on adjacent soil particles. Soil below is pushed outward and eventually upward, resulting in depressions rimmed by slightly raised areas (Hayward & Yelderman 1991) (Fig. 32). Gilgai are thus formed and the soil is slowly but continually churned in a cycle of overturning or self-plowing (Steila 1993), a type of pedoturbation (soil-mixing).

On the native Blackland Prairie, soil erosion was low because of the dense tall grass community and also because of the water-trapping capacity of gilgai. Temporary water storage in the numerous gilgai depressions has been estimated at one-half acre-foot of water per acre of flat prairie. As much as six inches of rain could be temporarily trapped in these structures before runoff began (Hayward & Yelderman 1991). This would have greatly reduced runoff and allowed significant infiltration, particularly important considering that clay soils are often rather impermeable. In fact, early accounts refer to clear runoff and clear streams on the Blacklands (Hayward & Yelderman 1991), in stark contrast to present-day conditions. For example, McClintock (1930) in 1846 described the San Gabriel in the Blackland Prairie north of Austin as "so transparent are its waters that fish, and even small pebles [sic] can be disserned [sic] at a depth of ten feet." However, because thousands of gilgai covered the prairies and created pools of standing water during wet weather, the prairies were at times virtually impassable for early settlers (Hayward & Yelderman 1991). Under present agricultural conditions, with no plant cover during much of the year and with the suppression of gilgai formation by plowing, erosion rates in the Blacklands are high. Thompson (1993) noted that the Blacklands have one of the highest rates of soil loss on cropland of any major area in Texas—from tens to hundreds of times higher than under the original native prairie vegetation (Hayward & Yelderman 1991). Richardson (1993) cited annual erosion figures of 15 tons per acre (t/a) for a cultivated Blackland area, compared with only 0.2 t/a for a native grass meadow, a 70-fold difference. Such a loss is clearly not sustainable indefinitely and it raises important questions about current agricultural practices.

Even though gilgai were one of the most evident surface features on the original Blackland Prairie, because they are destroyed by plowing, they are rarely observed today. Excellent examples of these "hog wallows," however, can still be seen at the Nature Conservancy's Clymer Meadow preserve in Hunt County, the Matthews-Cartwright-Roberts Prairie in Kaufman County, and Austin College's Garnett Prairie in Grayson County, as well as on other scattered prairie remnants (Fig. 33). It should be noted that due to the continuing soil movement associated with Vertisols, gilgai can reform if soils are left undisturbed for decades.

Mollisols are found on the Blackland Prairie on rocks of the Austin Group. These areas have high calcium carbonate levels and consolidated parent rocks. Because bedrock is usually just below the surface, root growth and soil water storage are restricted. Typically, Mollisols

FIG. 33/ PHOTOGRAPH OF GILGAI ON SLOPE (SHOWING MICROVALLEY AND MICRORIDGE EFFECT) ON VERTISOL IN NORTHERN GRAYSON CO., TX (PHOTO BY GMD).

FIG. 34/ PHOTOGRAPH OF MIMA MOUND ON ALFISOL IN NORTHERN GRAYSON CO., TX (PHOTO BY GMD).

are less useful for agriculture than are Vertisols, and at present they tend to be used as pastures or home sites. Shrink-swell phenomena, while still occurring on Mollisols, are less problematic than on Vertisols (Diamond & Smeins 1993; Hallmark 1993). Mollisols are more common to the west of East Texas on the Grand Prairie (made up of the Fort Worth Prairie and Lampasas Cut Plain). The soils of that region are often developed on layers of relatively hard limestone, and the area has sometimes been called the "hard lime rock region" (Hill 1901). Laws (1962) and Brawand (1984) have studied the characteristics of soils formed from the Austin Chalk in the Dallas area.

Alfisols, which develop principally on bedrocks which are higher in sand and lower in calcium carbonate, are found in the Blacklands mainly on the eastern and northern margins of the main belt of the Blackland Prairie (Hallmark 1993) (Fig. 30), on the western margin of the Fayette Prairie, and in places on the San Antonio Prairie. These soils, which develop under forests as well as prairies, are less fertile than either Vertisols or Mollisols (Hallmark 1993). Mima mounds (also called pimple mounds or prairie mounds), another microtopographical feature (Fig. 31), were once found on many Alfisols within the Blackland Prairie region and can still be observed on certain unplowed prairie remnants (e.g., northern Grayson County (Fig. 34) and the Nature Conservancy's Tridens Prairie in Lamar County). Mima mounds are circular, saucer-shaped hills ranging from about 1 to 15 meters in diameter and up to approximately 1.5 meters in height. While numerous hypotheses have been proposed, the specific cause of these structures is not known with certainty and they are possibly of multiple origins (Collins et al. 1975; Diamond & Smeins 1993). Though wind (erosion/deposition) appears to be a widely accepted explanation, other possibilities are that the mounds formed by wave action, are the products of past drainage patterns (e.g., runoff erosion combined with vegetation anchoring soil in place), are formed by fossorial (= burrowing) rodents (such as pocket gophers), or are the result of seismic activity (Diamond & Smeins 1985; Cox & Hunt 1990; Sletten et al. 1994; Ganse 2003). What is known is that some process operating in the past (but not presently in the area) is responsible for mima mound formation—this seems clear since, once destroyed, mima mounds do not reform under current conditions (unlike gilgai which will reestablish). Both gilgai and mima mounds increase microhabitat diversity and thus contribute to vegetational differences over small distances. The overall biological diversity of the prairie is therefore greatly increased by this variation in microtopography (Miller & Smeins 1988; Diamond & Smeins 1993). Due to the variation in vegetation associated with the different microhabitats produced by both gilgai and mima mounds, these features are often easily discernible in the field at certain seasons of the year (Figs. 33, 34). Sometimes a particularly conspicuous species will be quite obviously associated with a microtopographical high or low (e.g., *Helianthus mollis*, ashy sunflower, on mima mounds) and allow these areas to be spotted from long distances.

Climate and Weather of East Texas

East Texas, like the state as a whole, is a region of dramatic climate transition. The striking vegetational change from the swampy tropical-like forests of Caddo Lake and the Big Thicket on the eastern margin of East Texas to the grasslands of the Blackland Prairie just to the west is a vivid reflection of this climatic transition (Stahle & Cleaveland 1995). The climate of East Texas is considered subtropical (Jordan et al. 1984; Yelderman 1993; Norwine et al. 1995; Peterson 1995), but a wide range of extremes can be found. Detailed climatic information about one East Texas site, Nacogdoches, can be found in Chang et al. (1996). Like the rest of the state, East Texas can be referred to climatically as a "land of contrasts" (Bomar 1995). This results in part from two major competing factors which dominate the climate of Texas—frontal systems from the north and west, and moist air moving inland from the Gulf of Mexico. As these influences interact, dramatic weather often results (North et al. 1995b). There is ample reason why locals say, "If you don't like the weather, just wait a few minutes."

"Blue northers," cold fronts swinging down from the north and accompanied by rapid drops in temperature of dozens of degrees, are common (Bomar 1995). An example was the "frigid blast of bitterly cold Arctic air" that in January of 1973 "knifed through Texas and far into the Gulf of Mexico, leaving a blanket of snow as deep as nearly a half foot in the piney woods of East Texas" (Bomar 1995).

One of the most important factors causing such extremes is East Texas' geographic position. The North American continent is uniquely shaped—like a giant funnel or inverted wedge with a 6,500 km (4,040 mile) wide base in the sub-Arctic. From there it narrows to the south eventually ending in the tiny Isthmus of Panama. The central part of the continent has two north-south mountain ranges, the eastern Appalachians and the western Rockies, which act like the sides of a funnel. An old saying is that "there ain't nothin' between Texas and the North Pole but an old barbed-wire fence and it's down most of the time" (Girhard 2003). During winter, super-chilled Arctic air from the vast northern part of the continent can surge uninhibited far to the south, to East Texas and beyond (e.g., "blue northers" can even reach Guatemala, causing freezing temperatures and damage to plants in mountainous areas of the tropics—G. Diggs, pers. obs.). This phenomenon is sometimes referred to as a "climatic trumpet," presumably because it magnifies or amplifies seasonality and long-term climate—the exaggerated seasons and weather extremes of North America are thus a function of geography (Flannery 2001). Conversely, warm air from the Gulf of Mexico can move far to the north during summer. An important consequence of the unimpeded movement of these air masses is that for much of the eastern U.S., including southern areas like East Texas, temperatures during the coldest month often approach freezing or below, while summers are virtually tropical. Such conditions are perfect for deciduous forests, and it is no accident that in presettlement times a vast deciduous forest spread all across the eastern U.S. as far west as East Texas (Flannery 2001).

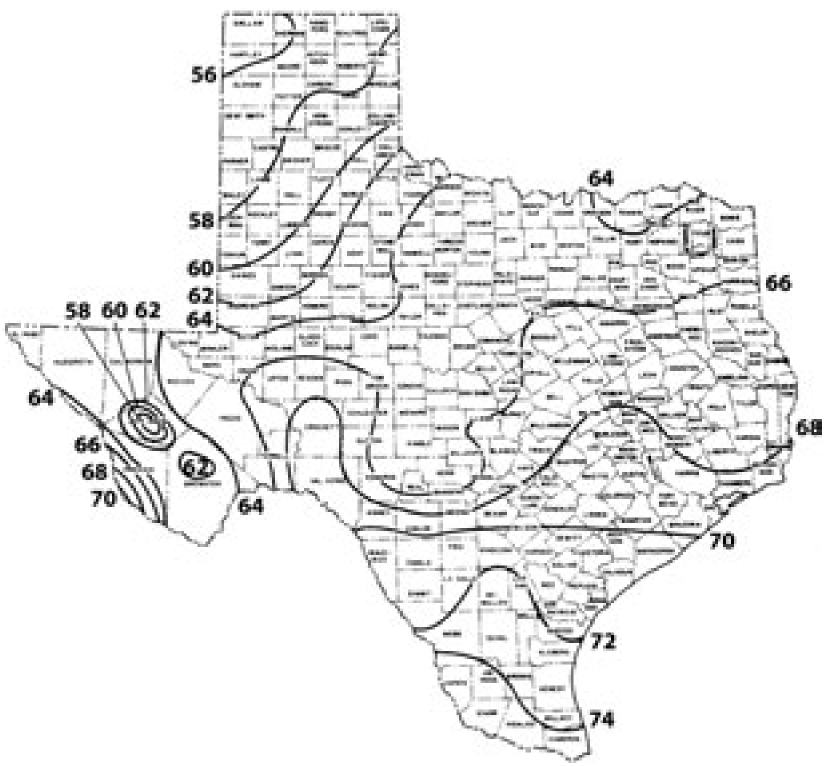


FIG. 35/ MEAN ANNUAL TEMPERATURE (°F) FOR TEXAS (ADAPTED FROM GRIFFITHS & ORTON [1968] BY HATCH ET AL. [1990]).

Mean annual temperature in East Texas varies from nearly 70° F (21° C) in the south (Bexar, DeWitt, and Wilson counties) to about 64° F (18° C) in the north (along the Red River) (Griffiths & Orton 1968) (Fig. 35), but temperatures of 0° F (-18° C) and 110° F (43° C) are occasionally seen in winter and summer respectively, with even more extreme readings rarely observed. The highest East Texas temperature reading, 118° F (48° C), was recorded for McKinney in Collin County in 1936 (Bomar 1995). Some parts of East Texas and adjacent areas have recently experienced their hottest temperatures ever—an example is the all-time record of 112° F (44.4° C) set in College Station on September 4, 2000 (National Weather Service 2000). Other September 2000 records include Austin at 112° F, San Antonio at 111° F (43.8° C), and Houston at 109° F (42.7° C) (National Weather Service 2000, 2003c). Dallas-Fort Worth, at the western margin of the area, apparently has the East Texas record for number of days with a temperature of 100° F (38° C) or above, experiencing 69 such days in the heat wave of 1980 (D. Finfrock, pers. comm.). The coldest temperatures recorded in East Texas include -13° F (-25° C) (Paris) and -8° F (-22° C) (Tyler), both in the unusually cold winter of 1899 (Bomar 1995). In fact, virtually all of East Texas, even the southernmost parts, has experienced temperatures as low as 5° F (-15° C)—for example, during the historic cold waves of 1889 and 1989 (Bomar 1995). The mean length of the frost-free period in the area is given in Figure 36.

Native vegetation has therefore evolved with, and is adapted to, such recurrent extremes. A good example of the different effects of extreme weather on native versus introduced plants occurred in December of 1983. During that prolonged, intense cold spell, introduced landscape plants in the northwestern parts of East Texas suffered extensive damage, while most native plants were not adversely affected. However, even native plants can be damaged under exceptional circumstances. An example is the phenomenon known as false spring. As discussed by Stahle (1990) and Stahle and Cleaveland (1995), a false spring episode includes

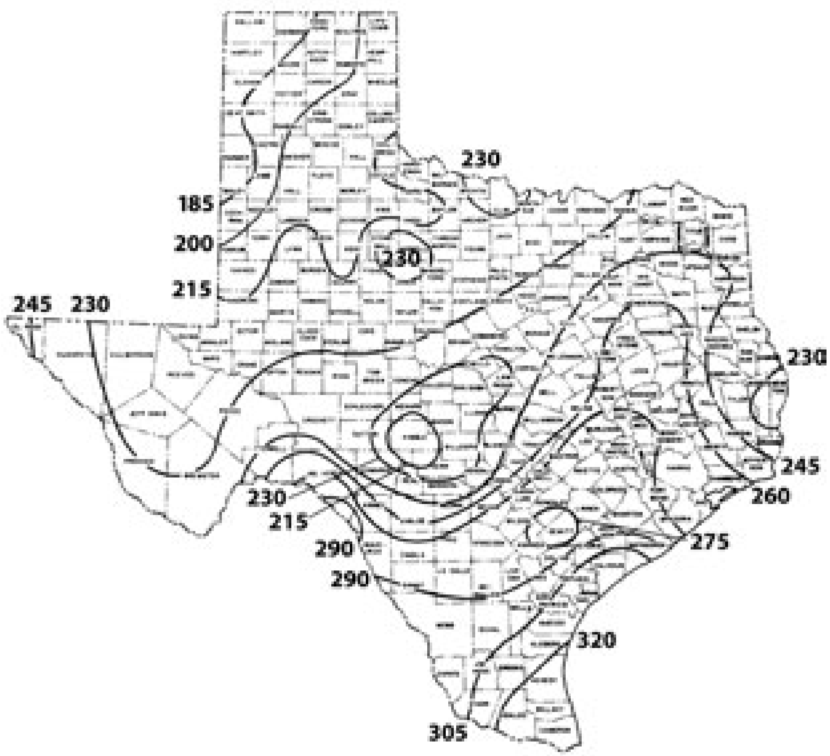


FIG. 36/ MEAN LENGTH (IN DAYS) OF FROST-FREE PERIOD FOR TEXAS (ADAPTED FROM GRIFFITHS & ORTON [1968] BY HATCH ET AL. [1990]).

late winter warmth followed by the movement of polar or arctic air into southern regions. A good example was the unseasonably late freeze on the night of 11–12 April 1997. Following a period of relatively warm weather, temperatures dropped to substantially below freezing over a large part of the northwestern part of East Texas and adjacent North Central Texas. For example, a low of 22° F (-55° C) was recorded for a native habitat (Garnett Preserve) in Montague County (H. Garnett, pers. comm.). The result was substantial damage to the young foliage of many native species and in some cases nearly complete defoliation. Some of the natives significantly damaged in Grayson County include *Berchemia scandens* (supple-jack), *Cercis canadensis* (redbud), *Diospyros virginiana* (common persimmon), *Fraxinus americana* (white ash), *Gleditsia triacanthos* (common honey-locust), *Morus rubra* (red mulberry), *Platanus occidentalis* (sycamore), *Quercus macrocarpa* (bur oak), *Quercus marilandica* (black-jack oak), *Quercus muehlenbergii* (chestnut oak), *Quercus shumardii* (Shumard's red oak), *Quercus stellata* (post oak), and *Rhus glabra* (smooth sumac). Effects on native oaks at Hagerman National Wildlife Area (Grayson County) were serious enough that leaf damage was still obvious at a glance in late May (G. Diggs, pers. obs.). The intense subfreezing temperatures cause widespread damage to cultivated crops as well as native plant species which have begun spring growth prematurely triggered by the unusually mild winter temperatures. Forty-four major false spring episodes have been documented in Texas between 1650 and 1980 (Stahle 1990; Stahle & Cleaveland 1995). Such historical events can be studied because frost-damaged cambial tissues leave a permanent record in the annual growth rings of trees, and these can be dated dendrochronologically (i.e., via tree-ring dating) to the exact year of their formation. These distinctively damaged annual rings, known as "frost rings" have been studied in post oak and white oak trees and "can be microscopically identified by specific anatomical features only associated with freeze damage" (Stahle &

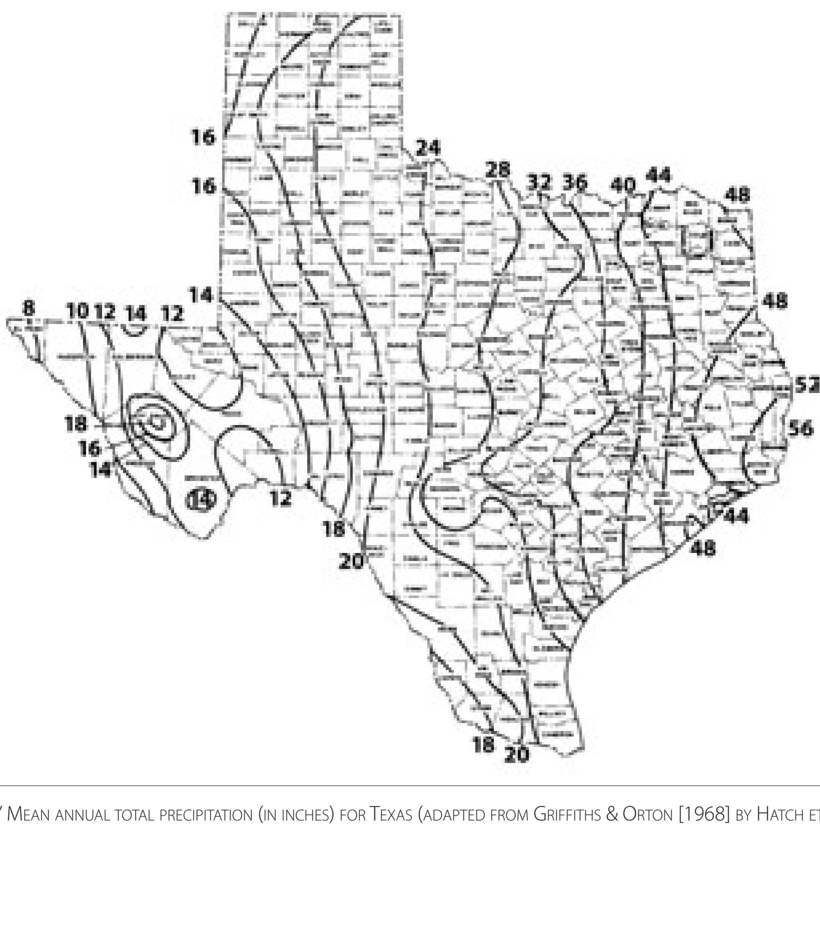
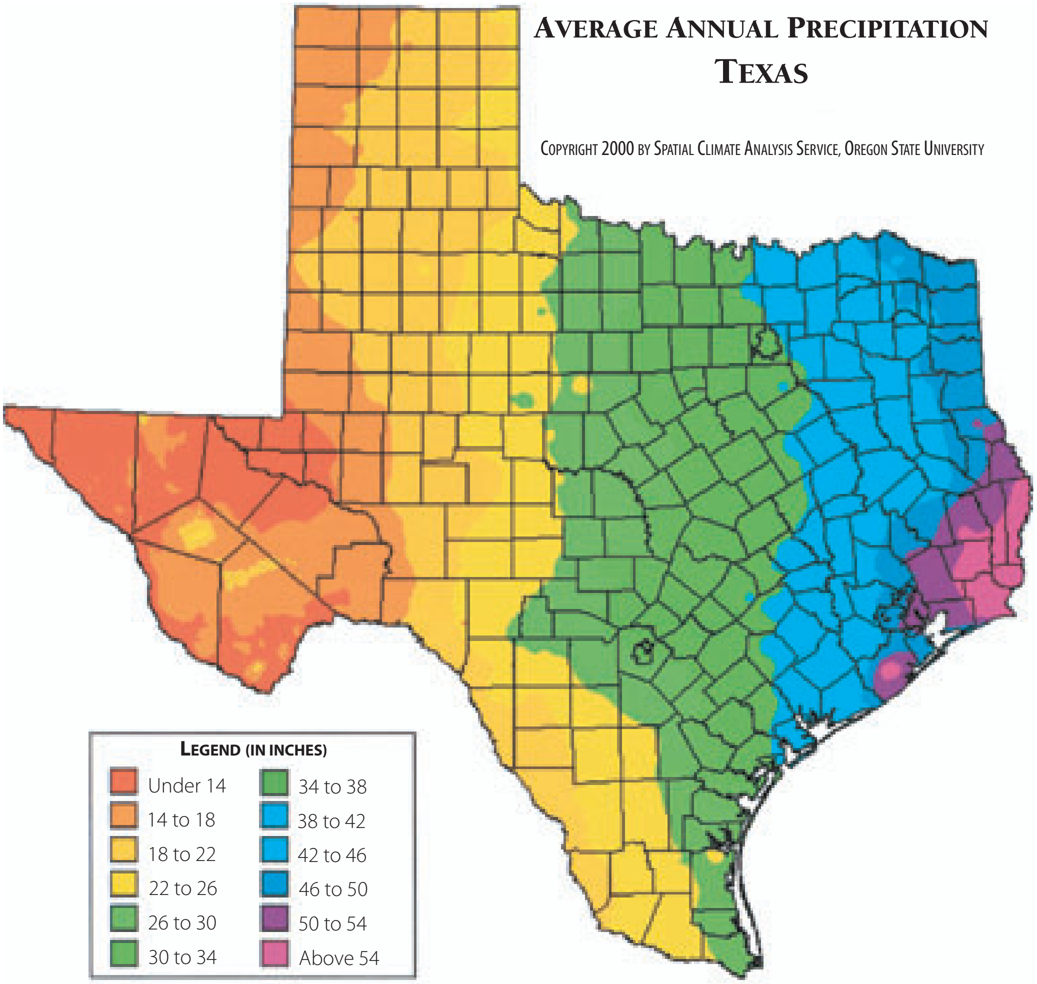


FIG. 37/ MEAN ANNUAL TOTAL PRECIPITATION (IN INCHES) FOR TEXAS (ADAPTED FROM GRIFFITHS & ORTON [1968] BY HATCH ET AL. [1990]).



This is a map of annual precipitation averaged over the period 1961-1990. Station observations were collected from the NOAA Cooperative and USDA-NRCS SnoTel networks, plus other state and local networks. The PRISM modeling system was used to create the gridded estimates from which this map was made. The size of each grid pixel is approximately 4 x 4 km. Support was provided by the NRCS Water and Climate Center.

For information on the PRISM modeling system, visit the SCAS web site at:
http://ocs.orst.edu/prism
The latest PRISM digital data sets created by the SCAS can be obtained fro the Climate Source at:
http://climatesource.com

FIG. 38/ MAP OF ANNUAL PRECIPITATION (IN INCHES) AVERAGED OVER THE PERIOD 1961–1990. USED WITH PERMISSION OF SPATIAL CLIMATE ANALYSIS SERVICE, OREGON STATE UNIV. ©1993.

Cleaveland 1995). While there has been a notable decline in the frequency and intensity of false spring episodes in Texas in the last 100 years, the cause of this decrease is not clear (Stahle & Cleaveland 1995).

There is a steep east-west precipitation gradient across East Texas. Mean annual precipitation is inversely related to longitude, ranging from about 58.93 inches (150 cm) in the southeastern corner of the area in Orange County (Bomar 1995) to about 28 inches (71 cm) in the southwesternmost portion of the area in Bexar County (Griffiths & Orton 1968) (Figs. 37, 38). In general, mean annual precipitation decreases about one inch for each 15 miles from east to west (Bomar 1983). Thus, there is a rainfall difference of more than 30 inches (76 cm) between the southeastern and southwestern boundaries of East Texas (Griffiths & Orton 1968; Bomar 1995). This huge difference is in large part due to the influence of the warm moist air from the Gulf of Mexico (Bomar 1995). In fact, proximity to the Gulf is the most important factor causing regional differences in climate in Texas (North et al. 1995b). The eastern part of East Texas typically has rainfall distributed relatively evenly throughout the year. However, the western part of East Texas, like much of the state as a whole, often has wet springs and falls but dry summers. Unfortunately, this western portion can also receive too much rain in a short time (Sharpless & Yelderman 1993). Severe storms and some of the largest rainfalls in the United States have occurred there. According to Hayward et al. (1992), all the point rainfall records for North America are held within a belt 50 miles east and west of a line from Dallas through Waco, Austin, and San Antonio. The town of Thrall, in Williamson County on the eastern edge of the Blacklands, had one of the United States' largest rainfalls on 9–10 September 1921, when 38.2 inches (97 cm) fell in 24 hours (Jordan 1984; Yelderman 1993), with an astonishing 32 of the inches (81 cm) in a 12 hour period (Bomar 1995). The yearly precipitation record for Texas, 109.38 inches (277.8 cm), is also in East Texas. It occurred in 1873 at Clarksville in Red River County, near the extreme northeastern tip of the Blackland Prairie (Bomar 1983). For short periods of time, rainfall rates of 11 inches (28 cm) per hour have been recorded in the state (Bomar 1995), though these rates have not been sustained for an entire hour. Such extreme rainfall events are generally the result of either very slowly moving thunderstorms or hurricanes, and some have caused devastating floods in parts of East Texas.

While hurricanes obviously have more of an impact on coastal areas (e.g., the "West India Hurricane" of 1900 that killed an estimated 5,000–8,000 people in Galveston), all of East Texas can be influenced by the heavy precipitation and flooding caused by these powerful storms (Bomar 1995). For example, serious flooding resulted in September 1963 when Hurricane Cindy dumped huge amounts of rain along the coast and in the southern part of East Texas—Deweyville (Newton County) in the Sabine River Valley received nearly 24 inches of rain from that storm (Bomar 1995).

The southwesternmost portion of East Texas, at the edge of the Balcones Escarpment, is particularly susceptible to flood damage. Thunderstorms and intense rainfall occur when moisture-laden air moving inland from the Gulf cools as it suddenly rises at the increased elevation of the Balcones Escarpment (Trippet & Garner 1976). According to Bomar (1995), "no portion of Texas—and, for that matter, the entire United States—is as prone to be afflicted by flash floods" as the vicinity of the Balcones Escarpment. In addition to the higher terrain leading to increased rainfall, the topography of the Edwards Plateau and Balcones Escarpment (e.g., broad uplands cut by narrow deep canyons) exacerbates flooding by funneling the heavy runoff into narrow river and stream corridors. The area of Travis County around Austin is a prime example, having suffered a number of devastating flash floods, including those of 1960, 1974, 1975, and 1981 (Bomar 1995).

The southeastern part of East Texas also experiences serious flooding. An example was the extensive damage associated with the massive rainstorm of June 12–13, 1973, which "dumped 10–15 inches of rain centered in the vicinities of Houston, Liberty, and Conroe"

(Bomar 1995). Houston and nearby areas have unfortunately experienced more recent inundations, including those resulting from Tropical Storm Allison. This storm, which stalled over the Houston area for five days in June of 2001, produced as much as 37 inches (94 cm) of rain and caused devastating flooding. The results included 22 fatalities in Texas and approximately $5 billion in damages, making it the costliest tropical storm in U.S. history (National Weather Service 2003a, 2003b).

It should be noted that flooding in urban areas such as Houston is exacerbated by human-caused changes in hydrology (e.g., paving over large areas, and thus dramatically increasing runoff), while natural vegetation in many flood-prone areas (e.g., parts of the Big Thicket) absorbs water, reduces flood damage, is well-adapted to recurrent flooding and inundation, and is seldom permanently affected. In addition, Houston may possibly influence its own rainfall patterns. The "urban heat island" effect has long been known (e.g., Howard 1833; Streutker 2003). Caused by heat generation associated with human activities and the greater absorption of heat by asphalt, concrete, and buildings than by natural landscapes, cities are often warmer than surrounding areas. On hot summer days, urban air can be 2–10°F (1.1–5.6°C) hotter than the nearby countryside (Environmental Protection Agency 2003). However, it has recently been suggested that major cities, with their large amounts of rising hot air and turbulence caused by tall buildings, may actually generate convective clouds, thunderstorms, and rainfall locally. This appears particularly likely when there is a nearby source of moist air (e.g., the Gulf of Mexico) (NASA 2000; Goddard Space Flight Center 2003; Kluger 2003; Shepherd & Burian 2003). There is also an issue with ground subsidence along the Texas Gulf Coast. The excessive pumping of groundwater, combined with the increased weight from city development, has lowered the elevation of major coastal cities like Houston, leading to a heightened potential for increasingly damaging floods (D. Finfrock, pers. comm.; Neighbors 2003). Houston's repeated bouts with natural disasters thus seem to be at least partly the result of a number of either predictable or human-caused problems—a large population living in a low-lying, naturally flood-prone coastal area, continuing hydrologic modifications making flooding ever more likely, ground subsidence, and human-induced weather changes.

In a different part of East Texas, the incredibly sticky "black waxy" soil of the Blackland Prairie is particularly problematic during wet weather. Personal accounts (e.g., Mosely in Yelderman 1993) described how under wet conditions the dirt roads were virtually impassable and families actually went hungry until the ground dried enough for people to get to town to obtain food. Drought, on the other hand, is a bigger problem in the western part of East Texas, with the lack of water probably always being a limiting factor for humans as well as plants and animals. The relatively impermeable clay soils, the lack of dependable shallow water-bearing layers, and the scarcity and transitory nature of surface streams made the early Blacklands a particularly inhospitable environment. This difficulty was noted in the early explorer accounts, such as the one by D.P. Smythe (1852) who described a trip across the Blacklands:

> The soil improves now at every step becoming more level, and uniformly of a dark rich color, but the water is very bad and scarce, drying up entirely during the heat of the summer.… During the forenoon of today we must have traveled some twenty miles without passing over a spot of thin soil; being chiefly the black stiff 'hog wallow' prairie, rolling just enough to drain itself, but entirely destitute of water during the summer.…

Josiah Gregg, another early explorer who traveled in the area in 1841–1842, indicated that in addition to droughts, the lack of springs or dependable water was "one of the greatest defects of this country" (Fulton 1941).

Even today, the concentration of rainfall in spring and fall, coupled with hot dry summers, makes the water problem acute on the Blackland Prairie (Yelderman 1993). Currently, access to deep aquifers, such as the Trinity, and surface storage in large reservoirs (e.g., Cedar Creek Reservoir, Lake Lavon, Lake Lewisville, Lake Ray Hubbard, Lake Tawakoni, Lake Texoma), provide water for this water-poor western part of East Texas (Hayward & Yelderman 1991). However, Simpson (1993) has emphasized that, "Texas has been a water-deficit state since the dawn of recorded history" and that, "The problem will only be exaggerated as population growth expands." Today, many cities and water-supply corporations in Texas are actively seeking access to more water, and some cities, such as San Antonio, have a serious water supply problem (Simpson 1993). At present, even the relatively water-rich eastern parts of East Texas are involved in controversies over this critical resource. Examples are recent (2002) efforts by the City of Marshall (Harrison County) to divert large amounts of water from Caddo Lake (with potentially devastating ecological and economic consequences) and plans to dam the Sulphur River to supply the Dallas area's ever-increasing water needs. Other examples include plans and proposals to dam various East Texas streams to create reservoirs, in many cases to send water to drier areas to the west. Unfortunately, the result of such impoundments is the destruction of increasingly rare bottomland forest habitat with its high biological diversity (U.S. Fish and Wildlife Service 1985). The recurrent water difficulties seen locally are a reminder of the overall scarcity of water in the southwestern United States.

Major thunderstorms and accompanying tornadoes have long been a problem in the region. At least the western part of East Texas, like much of the central U.S., is in the infamous "tornado alley," a region of high tornado frequency (Perkins 2002a; Edwards 2003). Like the temperature extremes seen in the region, the frequent tornadoes are at least partly caused by the atmospheric instability resulting from the effects of the "climatic trumpet." The unimpeded movement and clash of warm moist (tropical maritime) Gulf air from the south and cold air from the far north contribute to the formation of thunderstorms (including especially powerful ones called supercells that are characterized by rotation) and tornadoes over the Great Plains and adjacent areas. While tornado formation is not fully understood (Edwards 2003), a number of other factors, including dry air masses moving into the area from the Rocky Mountains to the west and Mexico to the southwest, are thought to be involved. The dry air can produce a "cap" above the warm, moist Gulf air near the surface. As the day progresses, more and more energy is trapped below the cap. Occasionally, enough energy accumulates in one area to punch through the cap, and an explosive thunderstorm or supercell forms. The result of this unique set of conditions—warm moist air from the south, cold air from the north, and dry air moving in from the west and southwest—is that nowhere else in the world has as many tornadoes as the central United States. In fact, some authorities estimate that up to 90% of the world's tornadoes occur in North America (Flannery 2001). The two most devastating Texas tornadoes were those in Goliad in the southeastern part of East Texas in 1902 (114 fatalities) and Waco on the western margin of East Texas in 1953 (again 114 fatalities) (Bomar 1995). More recent destructive tornadoes (e.g., Paris 1982 (Bomar 1983), Jarrell in Williamson County 1997) and hail storms (e.g., car-bumper-deep hail in Rusk County in May 1976 (Bomar 1995), grapefruit-size hail in Fort Worth just west of East Texas in May 1995) are present-day reminders of the ongoing power of extreme weather events. The lightning accompanying thunderstorms can also have important effects. Lightning-started fires were probably frequent in presettlement times (Komarek 1966) and were undoubtedly significant in maintaining various fire-dependent plant communities in East Texas, including the Blackland Prairie and Arenic Longleaf Pine Uplands.

A more unusual type of atmospheric event, dust storms, also affects Texas, including the eastern part of the state. Removal of the prairie sod cover from west Texas soils for agricultural purposes, coupled with drought and high winds, results in large amounts of soil particles being lifted into the air and transported long distances. While the problem is much worse in western Texas, occasionally the sky in various parts of East Texas can have a strange,

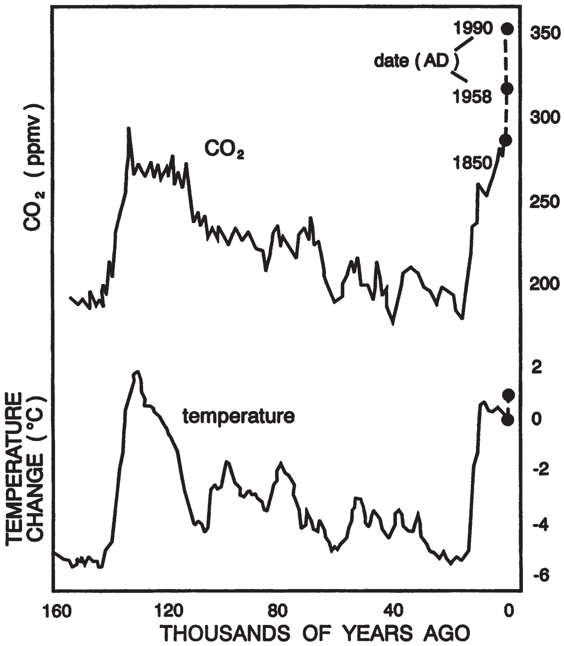


FIG. 39/ CO_2 AND TEMPERATURE RECORDS FOR THE PAST 160,000 YEARS, FROM ANTARCTIC ICE CORES AND RECENT ATMOSPHERIC MEASUREMENTS. REPRINTED FROM HANSEN ET AL. 1993, NATIONAL GEOGRAPHIC SOCIETY, ©1993.

almost orange color—the next day there will be a coating of dust on cars and other objects. An example is the "mammoth dust storm of January 25–26, 1965, which limited visibilities to one or two miles in such disparate locations as El Paso, San Angelo, Dallas, San Antonio, and Houston" (Bomar 1995). While irritating to the residents of East Texas, the loss of topsoil and its ecological and agricultural implications are serious issues for the western part of the state.

Pollen, plant macrofossils, packrat middens, and other types of evidence demonstrate that the climate of Texas has changed substantially over the past 15,000 years since the end of the last glacial period. At 15,000 years ago, the mean annual air temperature was 5° C (9° F) less than at present, and there was a more widespread forest mosaic over most of Texas, with boreal species such as *Picea glauca* (white spruce) in specialized microhabitats (Bryant 1977; Stahle & Cleaveland 1995). Certain present-day plant distributions, such as the rare western occurrence of plants normally found predominantly in eastern Texas, may thus reflect these past climatic conditions (see page 209). While past long-term climate change is well-documented, attention has focused recently on the possibility of future climate change in Texas due to human-induced modifications of the atmosphere (e.g., increased CO_2 concentrations) and the resulting increased greenhouse effect and global warming (see e.g., Norwine et al. 1995; North et al. 1995a). While considerable controversy exists over details, there is solid evidence that global atmospheric CO_2 concentrations have increased by about 31% since pre-industrial times and that this trend can be attributed primarily to human activities (e.g., fossil fuel use, land-use changes, and agriculture) (Houghton et al. 1995, 2001). In addition, over the past 160,000 years there has been a strong correlation between global atmospheric CO_2 concentrations and average global temperatures (Fig. 39) (Graham 1999). However, there is controversy over whether CO_2 concentrations can be characterized as the cause of these previous temperature changes.

Since at least 1995, scientific consensus has existed that there is "…a discernible human influence on climate" (Houghton et al. 1995). More recently, Houghton et al. (2001) have indicated that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." Further, Houghton et al. (2001) note that the increase in temperature during the twentieth century is probably the largest to have occurred during the past 1,000 years, and that taken together, a number of trends "illustrate a collective picture of a warming world." However, while the data clearly show a global warming trend, there is still uncertainty about the actual cause—some authorities believe the observed warming is at least partly the result of natural climatic fluctuations rather than human activities (e.g., Grossman 2001; Lindzen 2001).

FIG. 40/ CROSS SECTION OF STEM OF *PINUS TAEDA* (LOBLOLLY PINE) FROM GRAYSON CO. SHOWING TREE RINGS (PHOTO BY W.C. WEATHERBY).

Plants can contribute to an understanding of climate change in several ways. First, dendrochronology, the study of tree rings (Fig. 40), can provide information on past climate and thus a reference point for present and future studies (Stahle & Cleaveland 1992). Extensive tree-ring chronologies based on remnant old growth *Taxodium distichum* (bald-cypress) stands have provided accurate climatic reconstructions for the past 1,000 years for a number of areas in the southeastern United States, including Big Cypress (Bienville Parish) in northwestern Louisiana immediately adjacent to East Texas (Stahle et al. 1988; Stahle & Cleaveland 1992, 1995). In North Carolina, living bald-cypress trees up to 1,700 years old have been used to build a climate record extending back to A.D. 372 (Stahle et al. 1988). These ancient bald-cypresses are the oldest living trees in eastern North America (Graham 1999). Unfortunately, almost all old growth bald-cypresses in Texas have been destroyed by lumbering. However, in one location, Peach Tree Bottom along the Neches River in Jasper County, there is a cut-over area of bald-cypress where old cull trees were left when logging occurred. The oldest datable tree from this stand began growing in 1499 (D. Stahle, pers. comm.) and is thus more than 500 years old. Even older trees are present but are so damaged by heart rot that they are not useful for dating (D. Stahle, pers. comm.). Cook et al. (1996), using both living trees and dead (subfossil) logs, obtained a bald-cypress tree-ring chronology from this area covering the period 1255–1993, making it the longest tree-ring record produced in Texas. Stahle and Cleaveland (1995) noted that tree-ring chronologies developed from bald-cypress trees and subfossil logs might eventually provide paleoclimatic data for the eastern half of Texas covering the past 2000 years. However, at present, the northwest Louisiana data provide the best available estimate of the climate of East Texas over the past millennium. On a shorter time scale, well-documented chronologies based on remnant populations of *Quercus stellata* (post oak) have yielded detailed information on the East Texas climate for the past 300+ years (Stahle & Hehr 1984; Stahle et al. 1985; Stahle & Cleaveland 1988, 1993, 1995; D. Stahle, pers. comm.). Examples include tree-ring data from numerous trees in the 250 to nearly 350 year range sampled at such East Texas sites as Brazos River in Milam Co., Capote Knob in Guadalupe Co., Coleto Creek in Goliad Co., Ecleto Creek in Guadalupe Co., Pecan Bayou in Red River Co., and Yegua Creek in Burleson Co. (Stahle et al. 1985; National Oceanic and Atmospheric Administration 2002; D. Stahle, pers. comm.). The oldest living post oak known in East Texas, dating from 1658, is from the Yegua Creek site. David Stahle (pers. comm.) also noted that many of the oldest trees are hollow and thus impossible to accurately date. He believes that some of these veteran Texas post oaks may reach 500 to 600 years old. Interestingly, the tree-ring data show a connection between the Texas climate and the El Niño/Southern Oscillation (ENSO), which impacts climate globally (Stahle & Cleaveland 1993, 1995).

Changes in phytogeography (plant distributions) can also reflect climate change. An example is shown by the long-term McWilliams study (1995) of the distribution of *Tillandsia recurvata* (ball-moss, Bromeliaceae). This species has expanded its geographical range in Texas over the last 80 years, with much of the expansion occurring since the 1940s (note that White et al. [1998a] questioned this interpretation). McWilliams suggested that even slight changes in temperature or moisture conditions can have significant implications for the survival of plants at the margins of their ranges. The loss from Texas of species currently limited to the mesic conditions of deep East Texas and the northward shift of southerly species could both be expected based on climate models which predict increased temperature (and thus evapotranspiration) and decreased regional precipitation and soil moisture (Houghton et al. 1990; Packard & Cook 1995; Schmandt 1995). Since many species (e.g., a number of forest trees) reach their southwestern range limits in East Texas, and since changes associated with shifts in global climate will most likely occur first at such range limits, East Texas will be an excellent area in which to study climate change-induced responses in plant communities (Harcombe et al. 1998). Climate change will almost certainly affect biological diversity in Texas. In the words of Packard and Cook (1995), "it is certain that the assemblages of native plants and animals that we know today would change in distribution and/or composition as a result of global warming." This is a troubling thought when it is considered that "an increase in temperature is indicated for the entire midwestern U.S., with reduced precipitation and drier soil conditions for the Texas area" (Ward & Valdes 1995).

While the magnitude and long-term effects of human-induced climate change are still much debated and difficult to predict, to quote Stahle and Cleaveland (1995),

> It is sobering to recall that the 'consensus' estimate for global temperature change by the middle of the 21st century due to a doubling of atmospheric CO_2 is +1.5° C (IPCC 1990). This would represent some 30% of the glacial to postglacial temperature rise that took place in Texas over at least 5000 years…if such warming were sustained indefinitely then the ecosystem changes that could result in Texas are not pleasant to contemplate.

Forests define East Texas, and to a great extent they always have.

— Mark Barringer, 2002

The Pineywoods

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Occurrence of the Pineywoods

The Pineywoods vegetational area (Figs. 41, 42) forms the eastern edge of Texas. It occupies an area of about 63,200 square kilometers (6.3 million hectares or 24,400 square miles), about 9% of Texas, and extends roughly from Bowie County in the north to Orange and Hardin counties in the south. Upshur, Smith, Anderson, Houston, Walker, and Montgomery counties (north to south) form the approximate western boundary (Hatch et. al 1990), much of which corresponds with the 98 cm (40 inches) mean annual precipitation line (Larkin & Bomar 1983). Topographically, the area ranges from nearly flat to gently rolling or hilly and varies in elevation from about 150 m (500 feet) above sea level in the north and west to only slightly above sea level at the southern margin in the lower part of the Big Thicket. The Pineywoods represents the western terminus of the pine and deciduous forests of the southeastern coastal plain, which extends from Virginia to Texas (Christensen 2000; Delcourt & Delcourt 2000). Floristically and ecologically, the area has more in common with Louisiana and other southeastern states than it does with the remainder of Texas. Braun (1950) divided the southeastern coastal plain into an oak-pine forest region, which in East Texas mainly occurs to the north of Nacogdoches County and to the west of the Trinity River, and the southeastern evergreen forest which occupies the remaining southeastern portion of the Pineywoods. The ecological classification system used by the U.S. Forest Service (Keys et al. 1995; Turner et al. 1999) likewise divides the Pineywoods into two Provinces: the Southeastern Mixed Forest Province and the Outer Coastal Plain Mixed Forest Province. A chief difference is that longleaf pine (*Pinus palustris*) dominated many uplands on the Outer Coastal Plain Mixed Forest Province prior to European settlement, whereas the region to the north and west was outside of this range and its upland presettlement forests consisted of a mixture of shortleaf pine (*P. echinata*) and deciduous hardwoods (Cruikshank & Eldredge 1939; Evans 1997). MacRoberts et al. (2003a) provide a similar delineation. Human activity over the past two centuries has radically altered the region's vegetation, and many formerly extensive natural ecosystem types are rare on the modern landscape. Many of the best remnants are threatened by human activity and time is running out to preserve them. Within the Pineywoods are two long-famous areas, the Caddo Lake ecosystem in the northeast and the Big Thicket in the southeast—both of these are discussed in more detail beginning on page 149 and page 156, respectively.

Geology of the Pineywoods

At the beginning of the Tertiary Period (65 million years ago), the area now occupied by the Pineywoods was covered by a shallow sea, an expanded Gulf of Mexico (Spearing 1991). The Gulf gradually retreated southeastward, and eastern Texas was built up as a series of east-west oriented bands of sedimentary deposits (Dumble 1918). As one travels from the northern Pineywoods southward toward the Gulf of Mexico, surface layers become progressively younger and the landscape shows progressively less topographic relief (Bernard & LeBlanc 1965).

These deposits are variously of marine and continental origin, the result of multiple advances and retreats of the Gulf over the ages (Sellards et al. 1932). The northern portion is mainly of Eocene age (54–38 million years old) and is composed largely of sands

Fig. 41/ Generalized map of the Pineywoods vegetational area. Figure produced by BRIT/Austin College; reproduction of this image does not require copyright permission.

and clays that originated variously as erosion from the highlands to the north, as littoral (beach and shallow water) deposits, or as marine sediments (Bureau of Economic Geology 1975, 1979, 1993; Turner 1999). From north to south (oldest to youngest), the major Eocene geologic groups are the Midway, Wilcox, Claiborne (including the Yegua, Cook Mountain, Sparta, Weches, Queen City, Reklaw, and Carrizo formations), and Jackson. The uplands surrounding Caddo Lake, a unique bald-cypress (*Taxodium distichum*) swamp ecosystem, and most of the Angelina, Davy Crockett, and Sabine national forests lie within these geologic groups. Topography is generally rolling, and while exposed bedrock is

FIG. 42/ ARENIC LONGLEAF PINE UPLANDS FROM ANGELINA NATIONAL FOREST, ANGELINA CO. (PHOTO BY JVK).

largely absent, ironstone concretions are locally common. To the south of the Eocene sediments, underlying the extreme southern part of the Angelina and Sabine national forests, are various Oligocene (38–25 million years ago) deposits ranging from sands to clays. They include the sandstone, mudstone, and clay Catahoula formation, which supports several unique plant communities. Topography on the Oligocene sediments is generally rolling to gently rolling (Bureau of Economic Geology 1993; Turner 1999).

Continuing southward, the Miocene (25–5 million years ago) and Pliocene (5–2 million years ago) Fleming and Willis formations underlie the Sam Houston National Forest and the northern portions of the Big Thicket National Preserve. Deposits are mainly sands with some silts and clays. The sandy and gravelly Willis Formation is the southernmost of these layers, and its topography undergoes a transition from gently rolling in the north to nearly flat in the south (Bureau of Economic Geology 1992; Turner 1999). The southernmost portion of the Pineywoods, including much of the Big Thicket National Preserve, occurs on the Pleistocene Lissie and Beaumont formations (Bureau of Economic Geology 1992; Turner 1999). Many of these deposits are of river-borne gravels and sands deposited by meltwaters from the continental ice sheets to the north. Topography is nearly flat in this area, which is transitional to the Gulf Prairies and Marshes to the south.

River floodplains are a prominent feature of the Pineywoods landscape. They are broad and consist of Pleistocene and Recent (Holocene) sandy, silt, and clay alluvial deposits. East Texas rivers are slow-moving, meander extensively, and tend to be muddy. As a result of the region's abundant rainfall, they frequently overflow their banks and inundate their floodplains. From northeast to southwest, the major rivers flowing through the Pineywoods include Big and Little Cypress Bayou, the Sabine River, Attoyac Bayou, the Angelina River, the Neches River, the lower Trinity River, and the San Jacinto River. Major water bodies include Wright Patman Lake, Caddo Lake, Lake Livingston, Lake O' the Pines, Sam Rayburn Reservoir, and Toledo Bend Reservoir. With the exception of Caddo Lake, which originally formed naturally (Barrett 1995; Van Kley & Hine 1998), all East Texas lakes (except for oxbow lakes) are artificial impoundments.

Soils of the Pineywoods

A variety of soil types exists in the Pineywoods (see page 49)—excessively well-drained soils of dry sandy uplands and flooded soils of river swamps may occur in close proximity on the same landscape. Most upland soils have light-brown to reddish sandy loam, loam, or clay loam topsoils, with clay content usually somewhat higher in the subsoil than in the topsoil. They are usually medium acid to very strongly acid and are relatively low in available nutrients as the result of leaching caused by the region's abundant rainfall. Soils are usually more than 1 m (3.3 ft) deep and rock outcrops are uncommon, although locally, ironstone hardpans and outcrops of sandstone, glauconite, and other sedimentary rocks occur (Dolezel 1975, 1980, 1988; Neitsch 1982; McEwen et al. 1987).

On uplands, the Ultisol and to a lesser extent Alfisol soil orders dominate, although Vertisols and Entisols (Psamments = a very sandy subtype of Entisols) occur locally (Buol 1973; Dolezel 1975, 1980, 1988; Christensen 2000). The broad river floodplains, a prominent feature of most Pineywoods landscapes, consist of alluvial (flood-deposited) soils belonging to the Entisol and Inceptisol orders (Buol 1973; Christensen 2000). In Nacogdoches County, the heart of the Pineywoods, widespread upland loam and clay-textured soils include the Nacogdoches, Sacul, Trawick, and Woodtell series. Common upland sandy soils include the Lilbert, Darco, Tenaha, and Tonkawa series, while on river floodplains the Mantachie and Marietta soils dominate (Dolezel 1980).

Climate of the Pineywoods

Eastern Texas has a subtropical climate characterized by hot, humid summers and mild winters with occasional periods of frost, but usually with negligible snowfall (Larkin & Bomar 1983). Periods of freezing temperatures are usually of short duration and commonly associated with "Blue Northers," cold fronts from the north accompanied by dramatic temperature drops and temperatures to as low as -17ºC (0ºF) (Bomar 1983). The average number of frost days per year is 16 and 23 for Jefferson (Beaumont County) and Liberty (Liberty County), respectively (Marks & Harcombe 1981). These frosts are an important factor excluding many subtropical species from the region despite its otherwise year-round warm climate.

Average yearly temperatures range from 19.5º C (67º F) in the south to 17.8 C (64º F) in the north near the Arkansas border. Mean July and August high temperatures are 34º C (93–94º F), although high temperatures of 35–38º C (upper 90s F) are not uncommon (Larkin & Bomar 1983). Average low temperatures are 21.7º C (70–71º F) for these months. While daily highs are cooler than for Central Texas, high humidity ensures that summer days in the Pineywoods are uncomfortably "hot and muggy" for most people. However, for much of the year (October–April) temperatures are pleasant. Even in January, the coldest month of the year, mean high temperatures range from 15.6º C (60º F) in the south to 11.1º C (52º F) in the north (Larkin & Bomar 1983). Average January lows range from -1.1º C (30º F) near the Arkansas border to 3.9º C (39º F) in Hardin County in the southern Pineywoods (Larkin & Bomar 1983).

Average rainfall ranges from 152 cm (nearly 60 inches) along the southeastern border with Louisiana to about 98 cm (40 inches) at the western edge of the Pineywoods (for example at Crockett and at the Van Zandt County line on Interstate 20). Precipitation is evenly distributed throughout the year and significant rains fall even during the hottest summer months (Larkin & Bomar 1983). However, summer droughts, such as those of 1999 and 2000, cause severe stresses, especially to non-native and non-adapted plants. Nonetheless, a relatively humid climate has enabled forest vegetation to develop in the Pineywoods. Thunderstorms often accompany precipitation, especially in summer. They are often severe, and lightning from these storms ignited many of the frequent fires that burned through the pine-dominated uplands characteristic of the presettlement landscape (Komarek 1974; Frost 1993).

Climate extremes, especially droughts and low temperatures are likely more important than average conditions for excluding non-adapted species from the Pineywoods and maintaining natural vegetation patterns on the landscape. For example, *Ilex opaca* (American holly), a native broad-leaved evergreen characteristic of mesic sites, has become common in recent years on a variety of upland sites. Following the severe summer drought of 2000, it was possible to observe a "kill line" on many hill slopes above which this species had died on the higher and drier topographic positions and below which it had survived on more mesic sites (J. Van Kley, pers. obs.).

Human activities involving fossil fuel use and forest clearing have contributed to a 31% increase in atmospheric CO_2, since the industrial revolution. Global warming, changes in precipitation patterns, and more irregular weather patterns are among the predicted results (Houghton et al. 1995, 2001). Balancing on the eastern edge of a dramatic precipitation gradient, the Pineywoods are potentially vulnerable to even small climatic shifts. Increased transpiration resulting from warmer temperatures, more frequent summer droughts, and/or reduced rainfall could cause an eastward shift in the forest boundary and the replacement of Pineywoods forests with scrubland. Many Pineywoods trees (e.g., *Quercus alba* [white oak], *Liquidambar styraciflua* [sweetgum], *Acer rubrum* [red maple], and *Fagus grandifolia* [American beech]) are temperate species at the southwestern (hot, dry) corner of their ranges. Vegetation will be important in monitoring effects of any climate changes, and baseline vegetation data are critical if we are to document any long-term changes.

Presettlement, Early Settlement, and More Recent Conditions in the Pineywoods

As in modern times, the landscape of the presettlement and early settlement Pineywoods was a mosaic of different vegetation types, each responding to local patterns of soils, topography, and disturbance. Native Americans, primarily various Caddo tribes in the north and central parts of East Texas and the Atakapas to the south (Newcomb 1961; Smith 1995; La Vere 1998, 2004), had long inhabited and modified localized areas (e.g., cultivated fields in river bottoms), but in general the region was a vast area of forest and woodland (Phelan 1976; McWilliams & Lord 1988). Pines dominated in some areas, hardwoods in others, and mixed forests in still others. However, even prairies were present in some areas with special soil conditions.

The earliest known non-natives to enter the Texas Pineywoods were members of the Spanish Moscoso Expedition led by Luis de Moscoso Alvarado, who replaced Hernando De Soto upon his death. The expedition entered East Texas in 1542 and continued west perhaps as far as the Brazos River (Bruseth 1996). One of the earliest descriptions of the Pineywoods was of an area in the vicinity of modern Houston County—this was Don Domingo de Terán's 1691 account (from Weniger 1984b):

> On the 3rd, our royal standard and camp continued the march toward the north, a quarter northeast from the aforesaid bank [of the Trinity River], penetrating through a dense wood and over a rough country.…We marched this day five leagues. On the 4th our general muster was held and our royal standard and camp moved forward in search of the Texas or Teija.…We made this day five leagues through the same kind of dense woods and through a rough country.…The whole country is wooded to a distance of about twenty-five leagues from this spot.

Somewhat later, more detailed descriptions of parts of the Pineywoods were provided by Amos A. Parker (1968) who traveled through the area in 1834. Of the area just east of the Sabine River, Parker noted:

> After we passed the river bottom, we came to gentle swells, of red clayey soil, covered with oak, hickory, &c. called oak openings. Sometimes we passed a small prairie…

Near Nacogdoches, Parker (1968) described a pine forest as follows:

> ...the trees straight and tall, but standing so far apart, that a carriage might go almost any where among them. The grass grew beneath them, and we could see a great distance as we passed along.

While the Pineywoods are now often thought of as closed forest, this description by Parker agrees with the conclusions of various workers who suggest that some of the presettlement areas of longleaf pine were perhaps better described as open forests or savannahs with a grass-dominated understory (Watson 1975; Harcombe et al. 1993). Because of the frequent fire during presettlement times, many areas would have had much more open vegetation than at present. Josiah Gregg, in 1841 (Fulton 1941), gave a still more detailed picture of part of the early Pineywoods vegetation:

> Came near 40 m. today and stayed in a new little village called Angelina, on east side (or S.E.) of Angelina R. a branch of the Neches. The road passed today principally over a poor pine country (mostly long leaf) intermixt a little with oaks, gums, dogwood, etc. About 10 m. back however from village passed a few miles of very pretty land, timbered with beech, bay, etc.... Today the greatest portion of the day's travel was through a beautiful looking undulating country, timbered with white oak, black oak... some black and sweet gum, bay, holly, beech, sassafras, pignut hickory... chinkapin, dogwood, ironwood, cypress on branches....

Oran M. Roberts (later a governor of Texas), also in the 1840s, described part of the Pineywoods as follows (in Truett & Lay 1984):

> Immediately above and north of the level Gulf prairie, in southeastern Texas, lies a body of longleaf pine, over one hundred miles in width, on the Sabine River from about Sabine Town [east of present-day Hemphill] down that stream, thence west, diminishing in width for about one hundred miles. This lies just below the old San Antonio road as it passes through eastern Texas, where it is in the shape of high, rolling ridges or undulating plains, and becomes more and more level as you go southward, until it reaches the level Gulf prairie, which it joins.... There is other timber than pine upon, and adjoining, the numerous streams of this region. The timber grows rapidly, with long, slender, pliant branches, and is intermixed with evergreens and vines,—especially the Muscadine vine,—indicating the prevalence of a great deal of moisture. The numerous and never-failing streams furnish water-power to saw up the pine, cypress and other trees, into lumber.

He went on to say,

> There is about the middle of this pine region, a very fertile belt, which may be denominated the Magnolia belt, about twenty miles wide running westwardly from the Sabine River.... It is not an unbroken strip, but is run into by the pine at different places, so as to make it irregular in form. It is overgrown with a magnificent forest of mammoth white-oaks, beech, sugartree, elm, water-oak and magnolia, with innumerable evergreens and vines, presenting, even upon the ridges, the appearance of a rich bottom adjoining a river.

It is believed that East Texas once contained 5,000 square miles of longleaf pine forest (Bray 1901b; Oberholser 1974). Even in 1905, Bailey was able to say, "The long-leaf pine (*Pinus palustris*) occupies the southeastern part of the state, and where untouched by ax or fire forms miles of dense forest of the cleanest, most uniform and symmetrical body of pine to be found on the continent...." The importance of longleaf pine can be seen in Harper's (1920) description of the area around Kountze (Hardin County): "as in nearby parts of Louisiana, *Pinus palustris* is practically the only tree on the uplands there." Some of the longleaf pines were huge, with trees 100 to 150 or even 200 feet tall and 4 to 5 feet or more in diameter (Bollaert 1843; McWilliams and Lord 1988; Maxwell 1996b). Specific examples (Fig. 43) can be seen in the following quote from Block (1995):

> In April, 1927, a huge long leaf log, 61-inches in diameter and sixty feet long, was cut at New Blox log camp in Jasper County, and it required three 8-wheel log wagons to transport it. About 1900,

FIG. 43/ LONGLEAF PINE LOG, 61 INCHES IN DIAMETER, CUT IN JASPER CO. IN 1927. PHOTO COURTESY TEXAS FORESTY MUSEUM, LUFKIN.

> Mexican shingle makers in Nacogdoches County cut a long leaf pine log and counted 283 growth rings in it. The tree was already a sapling whenever the Pilgrims celebrated their first Thanksgiving. About 1905, a huge short leaf pine tree on the W.R. Pickering timberlands in Shelby County was 33 feet in circumference.

Other species could also be huge—present-day record-holding trees give some impression of what the original forest must have looked like (e.g., a 165 ft. (50 m) tall *Quercus pagoda* (cherry-bark oak), a 150 ft. (46 m) *Quercus lyrata* (overcup oak), a 146 ft. (44.5 m) *Quercus nigra* (water oak), a 139 ft. (42 m) *Carya texana* (black hickory), *Fagus grandifolia* (American beech) with diameter breast height (dbh) of approximately 1 meter, *Liquidambar styraciflua* (sweetgum) with dbh up to 60 inches (152 cm), and a *Quercus michauxii* (swamp chestnut oak) with dbh of 5.5 feet (168 cm)—Nixon et al. 1980b; Schafale & Harcombe 1983; Fritz 1993; Texas Forest Service 1998; J. Van Kley, pers. obs.

However, other areas were quite different, and it should be noted that the forests were not all tall or impressive. Frederick Law Olmsted (1857) described the area near the western edge of the Pineywoods in Houston County, as "a very poor country, clay or sand soil, bearing short oaks and black-jack." Similarly Stephen F. Austin (1821) described part of the Pineywoods as follows:

> The general face of the country from within 5 miles of the Sabine to Nacogdoches is gently rolling and very much resembles the Barrens of Kentucky, except that the growth of timber is larger and not so bushy—Black jack and Black Hickory, Mulbery [sic], is the principal timber, but it [is] all too low and scruby [sic] for Rails, or building, except on the Creeks where the timber is very good and lofty....

Likewise, Mirabeau B. Lamar, who traveled through the region from the Sabine to Nacogdoches in 1835, noted the area as "very badly timbered" and had nearly all "scrubby growth" except on the watercourses (Parker 1980). Such early descriptions emphasize the variation in vegetation that was apparently present in the presettlement forests.

While the Pineywoods were originally mostly forest, it should be stressed that reports by early settlers and travelers confirm the existence of numerous small prairies in the old growth Pineywoods. In the words of William A. McClintock (in his journal published in 1930) who passed through the area in 1836,

> Crossed the Nechis [sic] this morning by swiming [sic]. Some beautiful glade prairie (low bottom prairie) dotted here and there with groves of pine, oak, and hickory. Nothing in woodland scenery can surpass in beauty and symmetry many of these groves.

Weniger (1984b) noted that before 1860, prairies were reported from most East Texas counties, including most of the Pineywoods. According to Truett and Lay (1984), names given by early settlers to at least 46 places in the forested area of East Texas also reflect the presence of prairies—e.g., Mustang Prairie at Crockett, Tarkington Prairie in Liberty County, and Shawnee Prairie in Angelina County. Likewise, Jordan (1973) mapped dozens of areas in the Pineywoods which were described in 19th century accounts as being prairie or had the term prairie included in their place names. A specific example is the account of Gideon Lincecum who in 1835 traveled from San Augustine to Liberty on the lower Trinity—after crossing the Angelina River he found "pine barrens interspersed with prairies." Another early Texas traveler, Gustav Dresel (1954), crossed the Neches River south of Zavalla in 1839 and described the area as follows:

> Having left the forests of the Neches River behind, we came into a fertile prairie where the most excellent grass sprouted from black earth and the most diverse flowers grew exuberantly in between. Here and there the wide plain was broken by groups of trees.

Near the Neches, Parker (1968—from his 1834 travels) noted that, "We now passed through ten miles of pine woods; then prairies of a mile or so in extent, and post-oak openings." According to Sitton and Conrad (1998),

> The great East Texas forest was thinner and more open to the north and west, where small prairies occasionally broke its expanse, especially in the "Redlands" around Nacogdoches. East and south of Nacogdoches toward the Sabine, rainfall increased, the forest grew thicker and more luxuriant, and the "openings" gradually disappeared.

Mary Austin Holley (1836), who was a cousin of Stephen F. Austin, also reported prairies in the "eastern section of Texas," noting that it was "heavily timbered with pine, oak, ash, cedar, cypress, and other forest trees…occasionally variegated by small prairies

FIG. 44/ LARGE OLD GROWTH *PINUS PALUSTRIS* (LONGLEAF PINE), 2 MILES NW OF WILLARD, TRINITY CO. PHOTO COURTESY TEXAS FORESTRY MUSEUM, LUFKIN.

FIG. 45/ HARDWOOD BOTTOMLAND FOREST IN EAST TEXAS. PHOTO COURTESY STEPHEN F. AUSTIN STATE UNIV., FOREST HISTORY COLLECTIONS, THOMPSON PHOTO ALBUMS.

containing from one hundred to one thousand acres." While small prairies were thus probably common in the original Pineywoods, forests dominated vast stretches, with the trees in many areas being large, impressive, and economically valuable.

The potential for lumber in the vast presettlement forest of the Pineywoods was nearly unbelievable (Figs. 44, 45). According to Maxwell and Baker (1983),

> To the visitor first entering the region the towering pine forest was almost overpowering. Travelers often described the magnificent pines (probably longleaf) soaring 100 to 150 feet in the air with bases 4 or 5 feet in diameter. The forest floor under the great longleaf trees was clean, and the forest was described as parklike. Here the combination of sandy soil and woods fires had eliminated most competing growth, and the traveler walked or rode through the forest without difficulty.

Because there was such a large quantity of wood, early small-scale lumbering efforts had relatively little impact. Water and steam-powered lumber mills began to appear by the 1820s, but their small size limited the effect on East Texas forests. Not until late in the 1800s were large-scale mills introduced (Maxwell 1982; Maxwell & Baker 1983). However, the advent of these more modern mills and the development of an extensive network of railroads (Fig. 46) in the late 1800s led to a dramatic expansion of lumbering. Of all human activities in the Pineywoods, none has had such a profound impact on the original vegetation as lumbering. The situation in Texas was not an isolated phenomenon: "The development of the 19th Century lumber empires in Texas paralleled a pattern repeated throughout the South. Mill operators purchased large tracts of timberland, built a mill and supporting 'company town' and constructed spur tracks into the woods off the main railways to provide access to the virgin timber" (McWilliams & Lord 1988). Because of the extensive use of railroads and the dependence on steam-powered equipment, this type of logging has sometimes been referred to as "railroad-steamlogging" (Fickle 2002). The years 1880 to 1930 were the "Bonanza Era" of lumbering in East Texas, with more than 600 mills operating at one time (Maxwell & Baker 1983). Figures 47 and 48 give a visual impression of that era.

FIG. 46/ LOG TRAINS IN THE PINEYWOODS. PHOTO COURTESY STEPHEN F. AUSTIN STATE UNIV., FOREST HISTORY COLLECTIONS.

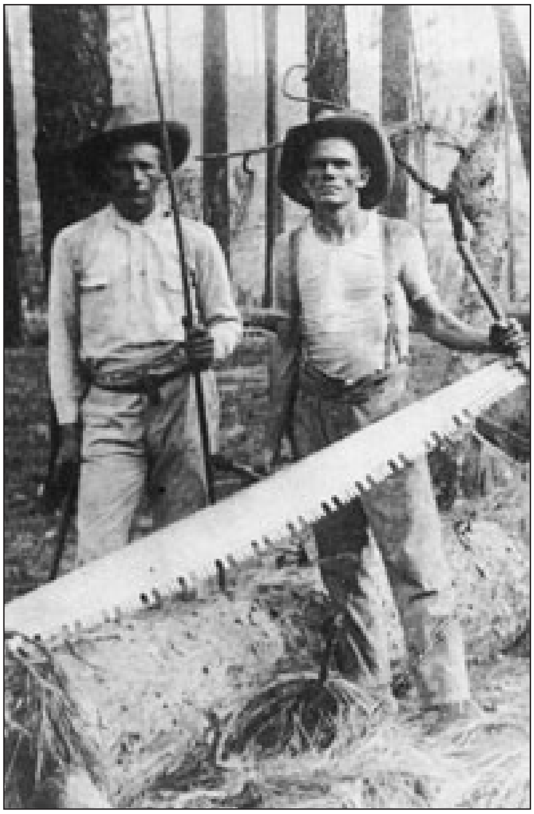


FIG. 47/ TIMBER CUTTERS, KNOWN AS "FLATHEADS," WITH CROSSCUT SAW. PHOTO COURTESY TEXAS FORESTRY MUSEUM, LUFKIN.

Prior to 1901, lumbering was Texas' largest manufacturing enterprise, was the state's largest employer, and was first among Texas industries in generating income. It held second place, after oil, in these categories until 1930 (Maxwell & Baker 1983). There were numerous company towns and company stores, with workers often paid in "merchandise checks" or tokens that could only be used in the company stores; well known examples include Diboll in Angelina County, Silsbee in Hardin County, Kirbyville in Jasper County, and Wiergate in Newton County (Maxwell 1964; Sitton & Conrad 1998). As pointed out by Maxwell and Baker (1983),

> The company-town system has been denounced as vicious and pernicious, enslaving and degrading to the workers and their families. It was all these and became more so as years and decades passed without any change in the social, economic, or political control of the community.... Yet many lumber owners were genuinely

FIG. 48/ LOADING CREW AT WORK ON LOG RAMP, WITH RAILROAD CAR PARTLY LOADED. PHOTO COURTESY TEXAS FORESTRY MUSEUM, LUFKIN.

> concerned about the well-being of their employees and consistently worked to improve working and living conditions. Three generations of Carters, two generations of Kurths and Hendersons, and three generations of Temples disproved the stereotype that sawmill employer-employee relations were all exploitation and hostility.

Relationships between the companies and their employees varied widely, ranging from employee loyalty to serious disputes. Attempts to organize labor were aggressively thwarted. One extreme example was the Central Coal and Coke Company ("4-C") which had a large mill near Ratcliff in Houston County: "The company also had an arbitrary policy with its employees. In an effort to force them to trade entirely at the company commissary, the manager had a high fence erected separating the company properties from the older town of Ratcliff. Much hostility was generated against the company, which suffered many annoyances, spite fires, bombings, and petty reprisals" (Maxwell & Baker 1983). Further, there was an "alarming number of serious accidents" associated with lumbering resulting in the "maiming or death of hundreds of workers annually" (Maxwell 1964).

FIG. 49/ W. GOODRICH JONES (1860–1950). PHOTO COURTESY STEPHEN F. AUSTIN STATE UNIV., FOREST HISTORY COLLECTIONS.

Even before 1900, far-sighted individuals like W. Goodrich Jones (1860-1950; "father of Texas forestry") (Fig. 49) understood that the timber industry policies were not sustainable. Jones made repeated trips through the Pineywoods and wrote on the conditions and future of Texas forestry. The result was a blueprint for those wanting to conserve the forests and develop a sustained-yield approach. He criticized the incredible waste of the early logging operations and predicted that the East Texas forests would disappear within twenty-five years. Clearly ahead of his time, he stressed reforestation and a planned-cutting program that would allow the forest resource to be used indefinitely. Jones eventually organized the Texas Forestry Association (later renamed the Texas Forest Service) in 1914 and was instrumental in the establishment of a state department of forestry (Maxwell 1974, 1996a).

Unfortunately most of Jones' recommendations were not widely followed. For example, the first large-scale attempt to reforest clearcut land by direct seeding was not carried out until 1925 (Courtenay 1984). As Jones predicted, by the end of the 1920s the forests that initially seemed inexhaustible were rapidly disappearing, and it was estimated that of the 14 to 18 million acres of forest that once covered East Texas, fewer than 1 million acres were left (Maxwell & Baker 1983). By the early 1930s so much lumber had been cut that the result was the elimination of most old growth forests and a serious depletion in the forest resources of the area—for example, by 1935, "barely thirty square miles" of old growth longleaf pine forests remained (Mohlenbrock 1992). Thus ended an era in Texas history. In just five decades, the vast virgin forests of East Texas had been destroyed, representing an unprecedented period of environmental devastation sometimes referred to as the "Great Cutover" (MacRoberts & MacRoberts 2001).

Various environmental problems, in addition to destruction of forests, accompanied the lumber boom and its aftermath. Lay (2002), for example, discussed water pollution associated with the advent of early paper mills:

> E.L. Kurth, a second generation 'timber baron,' built East Texas' first paper mill at Lufkin. The effluent drained into Peach Creek, later renamed Paper Mill Creek, and the Angelina River. From 1940, when paper production began, through the fall of 1944, game wardens and their supervisor from Austin talked to the mill superintendent about state water pollution laws. Promised ponds for settling out some waste were never built.
>
> Finally Tucker of the Texas Game, Fish and Oyster Commission wrote a letter to Kurth stating that he would ask a court to stop pollution unless some action was taken. Tucker was under pressure from fishermen who had employed a lawyer in Nacogdoches after witnessing heavy losses of fish. Damage reached to the coast. Waste fibre clogged nets. Caustic chemicals caused cotton and linen lines and nets to waste away. Some camp owners along the river had to quit using their places.
>
> Pointing to the jobs he had created, Kurth asked for help in Austin, and Tucker lost his job about six months later. The mill operated with little change until the 1970s when the Environmental Protection Agency forced some air and water protections.

Unfortunately, not only the environment, but also the economy and numerous individuals suffered the consequences of short-sighted and self-serving practices: "At the end of the era most of the large operators moved on, leaving great problems for conservationists and the government to cope with regarding both human and natural resources" (Maxwell & Baker 1983). One positive step during this period was that the federal government purchased more than 600,000 acres (243,000 hectares) of cutover land and in 1936 President Roosevelt officially proclaimed the Texas national forests (Maxwell & Baker 1983; Maxwell 1996b). In addition, reforestation efforts were mounted by the Civilian Conservation Corps (CCC) during the 1930s (Watson 1975).

Since that time there have been many changes in the Pineywoods, but the lumber industry has remained an essential part of the economy. Enlightened conservation attitudes became more widespread and reforestation and sustained-yield strategies were widely adopted—as a result, lumber production increased dramatically. In recent decades, management of East Texas forests has intensified and monocultures of genetically superior loblolly pines have become the norm (McWilliams & Lord 1988). The replacement of vast areas of high diversity forests with such monocultures has sometimes been referred to as "coniferization." While effective in terms of wood production, it is controversial ecologically because of the resulting tremendous decrease in biodiversity. Instead of high diversity forests supporting numerous plant and animal species, such monocultures are in essence "biological deserts" (Ajilvsgi 1979), with little potential to support the rich variety of wildlife previously found in the area (Truett & Lay 1984).

In 2001 and 2002, a dramatic change occurred in the region when two of the major timber companies, International Paper and Louisiana-Pacific announced their pullout from Texas—together they are selling over a million acres in East Texas, much of it near the Big Thicket National Preserve (Johnston & Roberts 2002). Current efforts are underway to obtain for conservation some of the vast acreages now changing hands. It is clear that there will never again be a conservation opportunity of the magnitude that now presents itself.

Presettlement Vegetation Types of the Pineywoods

Although modern equivalents exist for many presettlement plant communities (Harcombe et al. 1993), there have been dramatic changes in both their structure and abundance. Widespread logging has assured that, unlike historic forests which had an uneven-aged structure (= with trees of various ages) with some trees more than 400 years old (Mohr 1897; Schwarz 1907; Chapman 1909), most modern forests are immature, even-aged stands with few trees more than 80 years old. Dramatic changes also resulted from the virtual elimination of fire as an ecological force over most of the landscape and the consequent replacement of longleaf pine-dominated woodlands by mixed forests of loblolly pine and broad-leaved deciduous hardwoods (Frost 1993). In addition, large areas have been cleared for ranching and agriculture, reservoirs have covered many acres of former river floodplains, and more and more areas are becoming urbanized.

Despite the importance of understanding historic vegetation for both science and conservation, only a few published studies quantitatively estimating presettlement vegetation exist for the Pineywoods and adjacent areas (Evans 1997). Much of what is known has been either reconstructed from witness tree data (Delcourt 1976; Schafale & Harcombe 1983), derived from early published descriptions in combination with detailed knowledge of existing relationships between vegetation, soils, and physiography (Brown 1944; Marks & Harcombe 1981; Harcombe et al. 1993; Van Kley & Hine 1998; Van Kley 1999a, 1999b), or reconstructed from early timber company surveys (Evans 1997). The following accounts are largely adapted from the description of Pineywoods and western Louisiana historical vegetation in the Ecological Classification System of Turner et al. (1999).

LONGLEAF PINE COMMUNITIES—Texas longleaf pine woodlands represented the western edge of "an unbroken forest of the same general character" which extended eastward to Virginia (Bray 1906; Frost 1993). Early data from uncut forests (Mohr 1897; Schwartz 1907; Chapman 1909) reveal mostly uneven-aged stands with the oldest and largest trees 400 or more years old and up to about 98 cm (40 inches) (rarely to about 60 inches—Block 1995) in diameter at breast height (dbh). Bailey (1905) described Texas longleaf pine as "miles of dense forest of the cleanest, most uniform and symmetrical body of timber to be found on the continent." Often occurring in pure stands, longleaf pine dominated most upland areas in the southern and eastern Pineywoods but diminished to the west and north. Wet longleaf pine savannahs with a ground layer of grasses, sedges, and specialized wetland plants occurred on the poorly-drained, nearly level topography along the southern (Big Thicket) edge of the region. Longleaf pine woodlands with a diverse ground layer of grasses, composites, and legumes (Bridges & Orzell 1989a) were prevalent to the north on drier, more topographically variable uplands where, as today, communities similar to wet pine savannahs (Herbaceous Seeps or "bogs") occurred as isolated inclusions in areas of groundwater seepage. Low-intensity surface fires ignited by lightning strikes and, during the last 12,000 years, also set by Native Americans burned the grasses and fallen pine needles every 2 to 8 years and maintained a grassy, open woodland by destroying competing woody plants (Heyward 1939; Grelen & Duvall 1966; Komarek 1968; Christensen 1981). These fires were more common in the spring and summer when thunderstorms are more frequent (Christensen 1981) and, once ignited, could burn for days across large areas of uplands. Longleaf pine, which has adaptations enabling both adults and seedlings to survive fire (Platt et al. 1988), would then dominate on such sites. These were clearly pyrogenic (= resulting from fire; fire dependent) communities and the critical role of fire in their maintenance is now widely recognized (e.g., Christensen 1981). Following the logging era of 1880–1930 and the virtual elimination of fire during the twentieth century, mixed second growth stands of loblolly pine and deciduous hardwoods developed. Today, longleaf pine is dominant on only about 1.5% of its former range (Frost 1993; Outcalt 1997; Estill & Cruzan 2001).

SHORTLEAF PINE COMMUNITIES—Uplands in the northern and western Pineywoods were largely dominated by mixed stands of shortleaf pine and a variety of dry-site oaks and hickories. Mohr (1897) described how longleaf pine forests "toward their northern limit…gradually pass into a mixed growth of deciduous trees and shortleaf pine." Gow (1905) referred to these shortleaf pine-oak-hickory forests as "high hammocks" and indicated that their "appearance differs totally from (longleaf) pine uplands," being "characterized by dense thickets of shortleaf pine seedlings, often stunted by shade of hardwoods under which they grow." The oldest and largest trees in these mixed-age stands were more than 200 years old and 86 cm (35 inches) or more dbh, (Turner et al. 1999). Most virgin shortleaf pine in the region had been cut by the early 1900s (Bray 1906; Foster et al. 1917). While fires periodically burned through these forests, their frequency, estimated at 10 fires per century, was typically lower than for the longleaf pine communities to the south (Landers 1991). Following logging, loblolly pine replaced shortleaf pine over much of the landscape, at least in part as a result of a lack of fire.

Upland Hardwood Communities—Historical evidence suggests that deciduous hardwoods were also present on many upland landscapes (Harcombe et al. 1993; Evans 1997). Upland hardwoods were particularly important in a distinctive geographic and ecological region known historically as the "redlands" or "oak-uplands" (Roberts 1893; Gow 1905; Johnson 1931). Much of this limited area (between Nacogdoches and Lufkin) was cultivated long ago because of the fertility of its clay loam and loam soils (Roberts 1881; Johnson 1931), obliterating most evidence of original vegetation. However, several authors recorded a scrubby deciduous hardwood forest of oaks (*Quercus* spp.—southern red oak, post oak, and blackjack oak), hickory (*Carya* spp.), elm (*Ulmus* spp.), and other tree species (Austin 1821; Roberts 1881).

Mixed Deciduous Hardwoods–Loblolly Pine Forests—Mixed forests of deciduous hardwoods and loblolly pine occurred most commonly on river bluffs (Mohr 1884), lower slopes, steep ravines, tributary stream bottoms, and "topographic islands and peninsulas" (Harper 1911; Delcourt 1976). In these areas, fires spreading from adjacent uplands were limited by having to burn downhill away from their fuel source, cross streams, or burn through moist areas with wet soils (Christensen 1981; Wharton et al. 1982). This allowed fire-sensitive tree seedlings and other forest plants to survive. Loblolly pine typically did not occur in pure stands, but rather grew with a diverse mixture of deciduous hardwood and shrub species, including *Quercus alba* (white oak), *Q. falcata* (southern red oak), *Liquidambar styraciflua* (sweetgum), *Nyssa sylvatica* (black-gum), *Q. nigra* (water oak), *Prunus serotina* (black cherry), *Fagus grandifolia* (American beech), *Magnolia grandiflora* (southern magnolia), and *Ilex opaca* (American holly). Stands were predominantly uneven-aged, with the oldest and largest loblolly pines more than 150 years old and larger than 147 cm (60 inches) dbh and the oldest/largest hardwoods probably near 300 years old and approaching 123 cm (50 inches) dbh (Louisiana Natural Heritage Program 1985–1999). Delcourt and Delcourt (1977) suggested that much of the southeastern U.S. was once dominated by "climax" forests of American beech and southern magnolia, though historical evidence points to a largely pine-dominated landscape (Frost 1993). The best existing examples of American beech communities are primarily from areas topographically isolated from uplands, such as steep slopes and stream bottoms, where they occur with loblolly pine and other deciduous species; this is also likely where they were important historically.

Mohr (1897) and Bray (1906) indicated that mixed hardwood-loblolly pine forests, rather than shortleaf pine or longleaf pine communities, occurred historically on uplands in the extreme southwestern portion of the Pineywoods in San Jacinto, Montgomery, and Walker counties—an area which includes much of the present-day Sam Houston National Forest. These forests were described as quite dense, "a jungle of hardwood with some loblolly" (Zon 1904), which made overland travel difficult (Parks & Cory 1936). White oak was conspicuous in local forests, growing to diameters of 176–206 cm (6–7 feet) (South Western Immigration Company 1881).

Bottomland Forests—The fires that were so critical for structuring upland vegetation rarely burned into the floodplains of the Pineywoods' numerous streams and rivers. In such floodplains, forests dominated by fire-sensitive but flood-tolerant species developed. Cruikshank and Eldredge (1939) mapped large areas of bottomland forest in the Pineywoods region, where loblolly pine and moderately flood-tolerant deciduous hardwoods such as *Quercus alba* (white oak), *Q. nigra* (water oak), *Liquidambar styraciflua* (sweetgum), *Fagus grandifolia*

(American beech), and *Magnolia grandiflora* (southern magnolia) occupied the bottoms of small and medium-sized tributary streams. Downstream, on the wetter floodplains of larger rivers, "bottomland hardwood" dominant species included *Quercus phellos* (willow oak), *Q. laurifolia* (laurel oak), and *Quercus lyrata* (overcup oak), while *Taxodium distichum* (baldcypress), *Nyssa aquatica* (water tupelo), and *Planera aquatica* (water elm) were important in swamps and backwaters. Many modern floodplains that have not been cleared for agriculture or impounded as reservoirs have forests that appear to retain much of their natural composition and structure, and relatively intact present examples provide clues to historical forest vegetation (Mundorff 1998; Van Kley & Hine 1998).

OTHER VEGETATION TYPES—A number of minor historic community types, most of which have modern counterparts (see below), existed as inclusions within larger forest-dominated landscapes. Schafale and Harcombe (1983) deduced a forested seep or baygall community with *Magnolia virginiana* (sweetbay magnolia), *Nyssa biflora* (swamp tupelo), *Ilex opaca* (American holly), and *Persea borbonia* (redbay) in Hardin County. There is evidence for the existence of a variety of prairies, barrens, glades, bogs (Herbaceous Seeps), and other small, non-forested openings that resulted from unusual local soil properties (Chapman 1909; Jordan 1973; MacRoberts & MacRoberts 1997b, 2004d). Many of these were calcareous prairies on clay soils (Evans & Nesom 1997; MacRoberts & MacRoberts 1997b, 1997c, 2004d) or openings associated with the Catahoula geologic formation (Marietta & Nixon 1984). "The presence of saline prairies" has been indicated by General Land Office records in Angelina County. Loughbridge (1880) described a several hundred acre "saline" from Van Zandt County, as well as smaller examples in Smith County. Soil properties, burrowing crayfish, and possibly fire probably maintained these openings.

CURRENT VEGETATION OF THE PINEYWOODS

Modern Pineywoods vegetation is a mosaic of vegetation patches, each responding to combinations of ecological factors such as disturbance and land use history, soil properties, geology, soil moisture, flooding regime, and topographic position. Despite limited topographic relief and the superficially uniform appearance of some landscapes, rich variability in these factors provides the Pineywoods with an array of recognizable ecosystem types—combinations of plant communities, soil conditions, and topography.

Despite being historically neglected by major vegetation researchers in the Southeast, the Pineywoods has a rich tradition of quantitative, plot-based vegetation study. Earlier work mostly consisted of small-scale analyses of a single location or community type. Much of this early work was directed by E.S. Nixon, who retired from Stephen F. Austin State University in 1993 (e.g., Chambless & Nixon 1975; Nixon & Raines 1976; Nixon et al. 1977; Marietta 1979; Nixon et al. 1980b; Marietta & Nixon 1983; Marietta & Nixon 1984; Nixon & Ward 1986; George & Nixon 1990; Ward & Nixon 1992; see Appendix 24). More recently, larger landscape-wide data sets have been developed that enable quantitative description and comparison of vegetation from many plant communities across much of the landscape. Marks and Harcombe (1981) and Harcombe et al. (1993) compiled a large data set based on woody species and described natural community types for the Big Thicket region in the southern Pineywoods. Recent work at Stephen F. Austin State University (e.g., Evans 1997; Dehnisch 1998; Mundorf 1998; Van Kley & Hine 1998; Turner 1999; Turner et al. 1999; Van Kley 1999a, 1999b; Blackwelder 2000; Quine 2000) has yielded enough plot-based vegetation data to enable us to describe vegetation and associated environmental factors for most Pineywoods ecosystems, using quantitative data from sample plots rather than merely relying on intuitive descriptions of vegetation as was done in the past.

The main source for the following descriptions of Pineywoods vegetation is an analysis of nearly 400 plots of natural and semi-natural vegetation that were established between

1994 and 2000 throughout the four National Forests in Texas and the Kisatchie National Forest in nearby Louisiana, largely as part of an effort to classify the National Forest lands into ecological units based on soils, topography, and potential natural vegetation (Turner et al. 1999). Multivariate statistical methods, including ordination (DCA—Detrended Correspondence Analysis (Hill & Gauch 1980; McCune & Medford 1997), cluster analysis (TWINSPAN, Hill 1979), and regression, were used to identify groups of sample plots with similar species composition and to correlate differences in species composition among plots with differences in measured soil and environmental variables. An ordination diagram resulting from one part of this analysis (Fig. 50) shows the relative position, on the basis of ground layer (herbs and seedlings) species composition, of 370 sample plots from the four National Forests and other public lands from the Texas Pineywoods and from nearby Kisatchie National Forest in climatically similar western Louisiana. Points plotted on the graph represent the sample plots. Those near each other have a similar vegetative composition while distant plots are dissimilar. Classification of the plots on the ordination diagram into the vegetation types shown was mainly accomplished with TWINSPAN cluster analysis.

On any given site the observed natural plant community corresponded most strongly to a small number of environmental factors. These included topographic position (whether a site is located on an upland, lower slope, small stream, or river floodplain), soil nutrient levels (especially calcium and magnesium), soil texture (particularly among upland sites), fire regime (wherever prescribed burning was practiced), and among wet sites, the flooding

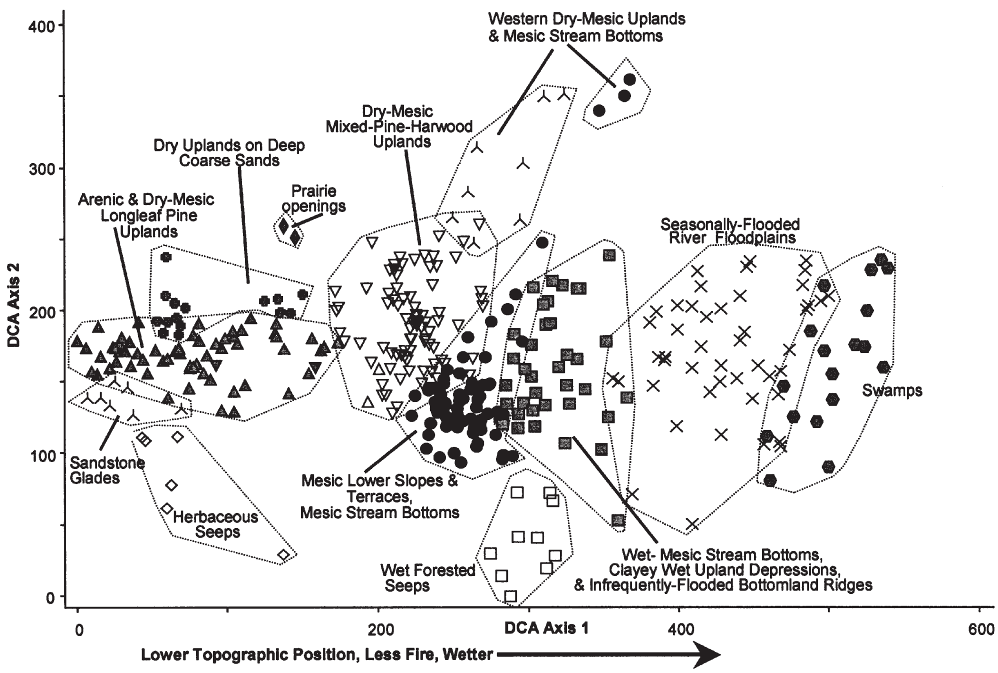


FIG. 50/ A DCA ORDINATION DIAGRAM (SEE TEXT FOR EXPLANATION) FOR 370 PLOTS BASED ON GROUND LAYER SPECIES COMPOSITION FROM THE TEXAS PINEYWOODS AND WESTERN LOUISIANA. POLYGONS SHOW A CLASSIFICATION OF THE PLOTS INTO VEGETATION TYPES LARGELY DERIVED FROM TWINSPAN CLASSIFICATIONS OF SEVERAL INDEPENDENT, SMALLER, LOCAL DATA SETS PRIOR TO THEIR BEING COMBINED FOR THE ORDINATION ANALYSIS (BY J.E. VAN KLEY).

regime (Evans 1997; Dehnisch 1998; Mundorf 1998; Van Kley & Hine 1998; Turner 1999; Van Kley 1999a, 1999b; and Turner et al. 1999). Species lists and environmental characters summarized for the sample plots in each of the analysis-derived vegetation types provided the majority of the information used to describe the specific Pineywoods ecological types presented below. Other sources are referenced. Figure 51 shows typical relationships between soils, topography and natural vegetation for selected ecosystem types on the Pineywoods landscape.

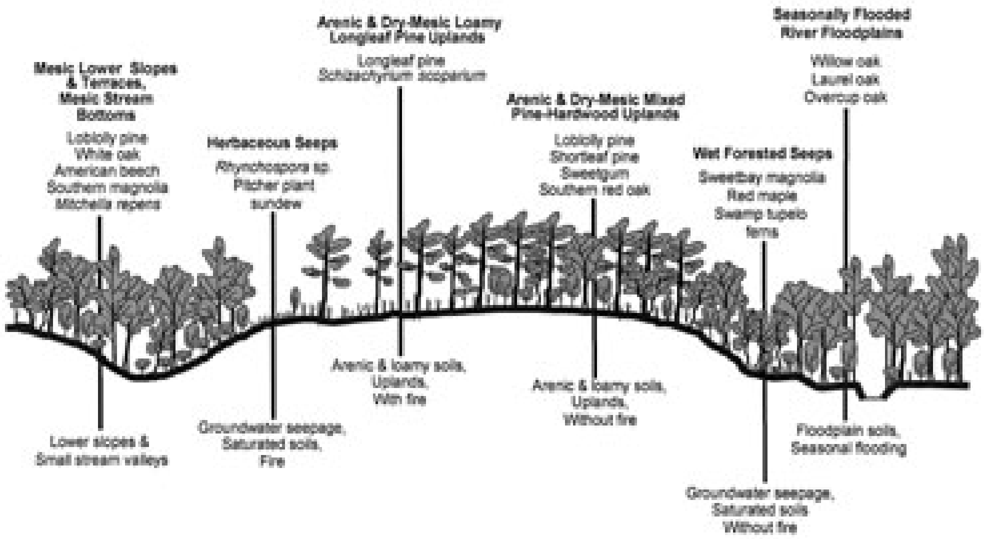


FIG. 51/ RELATIONSHIPS BETWEEN SOILS, TOPOGRAPHY, AND NATURAL VEGETATION FOR SELECTED EAST TEXAS PINEYWOODS ECOLOGICAL TYPES (BY J.E. VAN KLEY).

DRY UPLANDS ON DEEP COARSE SANDS (XERIC SANDYLANDS)—Sometimes called "sandylands," these areas are equivalent to the "xeric sandylands" of MacRoberts et al. (2002b), the "grossarenic dry uplands" of Turner et al. (1999), the "sandhill pine forests" of Marks and Harcombe (1981), and the "Oak-Farkleberry Sandylands" of Ajilvsgi (1979). These sites are characterized by deep coarse sands, upland or ridge-top topographic positions, and an open canopy of small, stunted trees. The excessively well-drained sandy soils are rapidly permeable and have a limited ability to hold moisture, so rainfall percolates downward quickly; hence they become droughty during even short rainless periods. Even in the absence of fire, soil conditions tend to maintain an open forest canopy on many sites. Common tree species include *Quercus incana* (bluejack oak), *Q. margaretta* (sand post oak), *Q. marilandica* (blackjack oak), *Carya texana* (black hickory), *Pinus palustris* (longleaf pine–chiefly in the southeastern Pineywoods), and *Pinus echinata* (shortleaf pine). *Schizachyrium scoparium* (little bluestem) and *Pityopsis graminifolia* (narrow-leaf silk-grass) may contribute to the often sparse ground cover. *Yucca louisianensis* (Louisiana yucca), *Tragia urticifolia* (nettle-leaf noseburn), *Cnidoscolus texanus* (Texas bull-nettle), and *Opuntia stricta* (erect prickly-pear) are typical indicators of these sites. This community is the droughtiest of all types seen in the Pineywoods and is rare on most landscapes. Good examples occur on the Carrizo Formation north of Nacogdoches in the Tonkawa Springs area, as well as in the San Augustine Sandhills and Matlock Hills areas of the central Sabine National Forest. Examples are also known from the Big Thicket (Ajilvsgi 1979).

ARENIC DRY UPLANDS—"Arenic" is a soil term describing a deep sand layer occurring atop a loamy subsoil. In addition to the increased moisture-holding capacity of the loamy subsoil, the sand may be finer grained or contain more silt and clay than that of Dry Uplands on Deep Coarse Sands; hence Arenic Dry Uplands are not as droughty. Relatively common on many Pineywoods landscapes, they correspond in part to Nixon's (2000) broad "dry upland" category. We recognize two distinctive natural plant communities on this ecological type, depending on whether a site has burned regularly and whether it is within the geographic range of longleaf pine.

FIG. 52/ ARENIC MIXED PINE-HARDWOOD UPLANDS FROM ANGELINA NATIONAL FOREST, ANGELINA CO. (PHOTO BY JVK).

ARENIC MIXED PINE-HARDWOOD UPLANDS—These are somewhat open- to closed-canopy forests consisting of a variety of tree species, including *Pinus echinata* (shortleaf pine), *Quercus incana* (bluejack oak), *Q. stellata* (post oak), *Q. marilandica* (blackjack oak), *Q. falcata* (southern red oak), *Carya texana* (black hickory), *Sassafras albidum* (sassafras), and *Nyssa sylvatica* (black-gum). *Pinus taeda* (loblolly pine) may also be present, but it is often not as abundant as on less droughty sites. *Rhus copallina* (flame-leaf sumac), *Rhus aromatica* (fragrant sumac), and *Vaccinium arboreum* (farkleberry) are common shrubs. Bracken fern (*Pteridium aquilinum*) may be abundant. A variety of wide-ranging, common taxa such as *Rubus* spp. (blackberry), *Smilax* spp. (greenbrier), and *Lespedeza virginica* (slender lespedeza) may also occur. Species more common on drier sites, *Yucca louisianensis* (yucca), *Cnidoscolus texanus* (Texas bull-nettle), *Tragia urticifolia* (nettle-leaf nose-burn), and *Opuntia stricta* (erect prickly-pear), are often present—especially in more open patches (Figs. 52, 53). Formerly, these communities were limited to areas outside the range of longleaf pine and to locations where wildfires were infrequent as a result of topographic features. They have increased on modern landscapes at the expense of longleaf pine-dominated communities.

ARENIC LONGLEAF PINE UPLANDS—*Pinus palustris* (longleaf pine) dominates these areas, forming nearly pure stands. The rather open canopy allows enough light to reach the ground to support a species-rich, prairie-like ground layer of grasses, composites, and other sun-loving species (Fig. 42 on page 78). *Schizachyrium scoparium* (little bluestem) may be dominant. Because of the importance of the dominant species, this community has sometimes been referred to as "Longleaf Pine-Bluestem Range" (Watson 1975). It also corresponds in part with the "longleaf bluestem uplands" of Ajilvsgi (1979). Other important species include

FIG. 53/ ARENIC LONGLEAF PINE UPLANDS ON THE NATURE CONSERVANCY'S ROY E. LARSEN SANDYLAND SANCTUARY, HARDIN CO. NOTE THE LOOSE SANDY SOIL. (PHOTO BY GMD).

FIG. 54/ DRY-MESIC MIXED PINE-HARDWOOD UPLANDS FROM SABINE NATIONAL FOREST, SAN AUGUSTINE CO. (PHOTO BY JVK).

Pityopsis graminifolia (narrow-leaf silk-grass), *Solidago odora* (anise-scented goldenrod), *Tephrosia virginica* (goat's-rue), and various species of *Panicum* (panic grasses). Also present are indicators of dry sandy sites, including *Pteridium aquilinum* (bracken fern), *Tragia urticifolia* (nose-burn), *Cnidoscolus texanus* (Texas bull-nettle), *Stylisma pickeringii* (Pickering's dawn-flower), and *Berlandiera pumila* (soft greeneyes). Recurring fires keep shrubs sparse and maintain the grassy ground layer. With the exception of longleaf pine, whose seedlings are adapted to surviving fire, trees have difficulty becoming established in regularly burned stands. Rare on modern landscapes, these communities persist mainly on public lands in areas with prescribed burning programs. Good examples are found in the southern Angelina National Forest.

Loamy Dry-Mesic Uplands—This ecological type has sandy loam or loam surface soils with loam or clay loam more than 30 cm below the surface. Consequently, these soils hold more moisture than Arenic Dry Uplands. They represent the least-droughty examples of the "dry uplands" of Nixon (2000), and the "dry upland forests and savannas" of Harcombe et al. (1993). On most Pineywoods landscapes they are the most widespread upland ecological type. As with Arenic Dry Uplands, we recognize two natural plant communities, mixed pine-hardwood forests and longleaf pine woodlands, depending on whether stands have had a history of regular fire and are within the range of longleaf pine.

Dry-Mesic Mixed Pine-Hardwood Uplands—On these uplands (Fig. 54), *Pinus taeda* (loblolly pine) is abundant, even dominant, but usually occurs with a mixture of broad-leaved deciduous trees, including *Liquidambar styraciflua* (sweetgum), *Quercus falcata* (southern red oak), *Q. stellata* (post oak), *Ulmus alata* (winged elm), and *Carya* spp. (hickory). Shortleaf pine (*Pinus echinata*) may also be present, especially on sites of more natural quality, although human activities and lack of fire have favored loblolly pine and have reduced the occurrence of shortleaf pine even in the northern and western Pineywoods where it was always an important component of Dry-Mesic Uplands. The shrub-layer may be dense and includes *Callicarpa americana* (American beauty-berry), *Ilex vomitoria* (yaupon), and *Cornus florida* (flowering dogwood). Woody vines, especially *Smilax* spp. (greenbrier) and *Vitis aestivalis* (summer grape) are common. A variety of species with a wide ecological range, including among others, *Chasmanthium sessiliflorum* (narrow-leaved wood-oats), *Toxicodendron radicans* (poison ivy), and *Parthenocissus quinquefolia* (Virginia creeper) dominate the ground layer. These mixed forest communities have increased markedly on the post-settlement landscape at the expense of longleaf pine woodlands.

Dry-Mesic Longleaf Pine Uplands—These stands, which correspond in part with the "longleaf bluestem uplands" of Ajilvsgi (1979), are typically open-canopied *Pinus palustris* (longleaf pine) woodlands, often with scattered individuals of *Quercus marilandica* (blackjack oak). The sparse canopy allows enough light to reach the ground to support a dense, prairie-like ground layer of grasses, composites, and other sun-loving species. *Schizachyrium scoparium* (little bluestem) usually dominates the ground layer. Other important species include *Pityopsis graminifolia* (narrow-leaf silk-grass), *Solidago odora* (anise-scented goldenrod), *Tephrosia virginica* (goat's-rue), *Panicum virgatum* (switch grass), and *Dichanthelium* (rosette grass) species. Frequent fire controls shrubs such as *Rhus copallina* (flame-leaf sumac), *Ilex vomitoria* (yaupon), and *Liquidambar styraciflua* (sweetgum) saplings, which rapidly invade unburned sites. While longleaf pine seedlings are capable of surviving fire, regular fire prevents seedlings of most other species from becoming established. In the absence of regular fire, sites rapidly succeed to a mixed closed-canopy forest. More favorable soil moisture and nutrient conditions allow fire-free stands to convert to mixed forests more quickly than would Arenic Longleaf Pine Uplands. Historically, these Dry-Mesic Longleaf Pine Uplands dominated uplands in much of the southern and eastern Pineywoods. They are now rare, persisting mainly on public lands in areas with prescribed burning programs. Even more rare in East Texas than Arenic Longleaf Pine Uplands, a few stands persist in the southern Angelina National Forest. Extensive areas can still be found in Louisiana's Kisatchie National Forest.

FIG. 55/ WET HERBACEOUS SEEP FROM ANGELINA NATIONAL FOREST NEAR ZAVALLA, ANGELINA CO. NOTE EXTENSIVE POPULATION OF *SARRACENIA ALATA* (YELLOW TRUMPET, PITCHER PLANT; SARRACENIACEAE) (PHOTO BY JVK).

WET HERBACEOUS SEEPS—These communities have generally been referred to as "bogs" (MacRoberts & MacRoberts 1991), "pitcher plant bogs" (Nixon & Ward 1986; Nixon 2000), "acid bogs" (Ajilvsgi 1979), "hillside seepage bogs" (Bridges & Orzell 1989a, 1989b), "hillside bogs" (Bridges & Orzell 1989a; MacRoberts & MacRoberts 2001), or "hanging bogs" (Watson 1975; Peacock 1994), even though little or no peat accumulates, as is the case for true bogs. Wet Herbaceous Seeps (Fig. 55) typically occur on upland hillsides where groundwater collects above an impermeable layer (clay or rock) and seeps to the surface, resulting in water-saturated, nutrient-poor, sandy soils—e.g., at the Willis-Catahoula contact. In general, slope tends not to be steep (average 7.6% grade), but it is "the few spectacular bogs with the steepest slopes that are responsible for the name 'hillside' bog" (MacRoberts & MacRoberts 2001). These seeps are generally small in size, typically less than 2 hectares (5 acres) in area, with many less than 0.4 hectares (1 acre) (Bridges & Orzell 1989b). The surrounding soils usually consist of sands, which have a high infiltration rate and provide an ample water supply for the seeps. Herbaceous Seeps are typically embedded in longleaf pine communities, and regular fires entering from the pyrogenic surrounding landscape prevent them from succeeding to Forested Seep or "baygall" communities. Trees are usually limited to scattered longleaf pines and occasional *Magnolia virginiana* (sweetbay magnolia) or *Nyssa sylvatica* (black-gum). Shrubs are kept sparse by fire, but can include *Myrica cerifera* (southern waxmyrtle), *Persea borbonia* (redbay), *Viburnum nudum* (possumhaw), and *Toxicodendron vernix* (poison sumac). Sedges, many from the genus *Rhynchospora*, dominate, along with grasses (especially *Dichanthelium dichotomum*—forked panic grass). In addition, a species-rich assemblage of forbs occurs, including carnivorous plants such as *Drosera brevifolia* (annual sundew) and *Sarracenia alata* (pitcher plant). *Eriocaulon decangulare* (ten-angle pipewort), *Sabatia gentianoides* (pinewoods rosegentian), *Helianthus angustifolius* (swamp sunflower), and *Sphagnum* spp. (peat mosses) may also be found. Rare and sensitive species sometimes present include *Calopogon tuberosus* (grass pink), *Pogonia ophioglossoides* (snake-mouth orchid), *Platanthera integra* (yellow fringeless orchid), and *Rudbeckia scabrifolia* (bog coneflower). Herbaceous seeps are rare as a result of the loss of longleaf pine woodlands, fire suppression, and the lack of suitable soils and hydrology in many areas. Good remaining examples exist in the southern part of the Angelina National Forest.

WET PINE SAVANNAHS—Also called "wetland pine savannas" (Marks & Harcombe 1981; Harcombe et al. 1993), "pine flatwoods," "longleaf-blackgum savannahs" (Ajilvsgi 1979), and "pine savannah wetlands" (Watson 1975), these are longleaf pine communities characteristic of poorly drained fine-sandy loams on nearly flat topography. They are found along the southern edge of the Pineywoods closest to the Gulf of Mexico. According to Bridges and Orzell (1989b), "Two major natural forces interact to produce this community—a fluctuating, seasonally high water table and frequent, low-intensity ground fires. The fluctuating water table naturally inhibits the range of tree and shrub species that can occupy the site, while the periodic fires eliminate species tolerant of wetland conditions." Sedges (especially *Rhynchospora* and *Scleria* spp.) dominate, along with *Schizachyrium scoparium* (little bluestem). *Drosera brevifolia* (annual sundew) may be abundant, but *Sarracenia alata* (pitcher plant) and *Sphagnum* mosses are less common than in Herbaceous Seeps (Harcombe et al. 1993). Like all longleaf pine communities, Wet Pine Savannahs have become increasingly rare in the absence of regular fires. They have become overgrown with woody plants and converted to closed canopy forests of *Nyssa sylvatica* (black-gum), *Liquidambar styraciflua* (sweetgum), *Acer rubrum* (red maple), *Magnolia virginiana* (sweetbay magnolia), and lowland oaks. Examples occur in the Big Thicket National Preserve (Ajilvsgi 1979; Marks & Harcombe 1981). According to MacRoberts and MacRoberts (2001), the Preserve probably has the best remaining areas of this community in the entire West Gulf Coastal Plain. Today less than one percent of the pre-European pine savannahs in southeast Texas and southwest Louisiana remain as the result of various anthropogenic activities including timbering, farming, urban sprawl, and fire suppression (MacRoberts & MacRoberts 2000).

CLAYEY DRY-MESIC UPLANDS—Soils supporting this vegetation type are clayey almost to the surface, with only a very thin loam topsoil. Often the clays have shrink-swell properties. The soils may be saturated during wet periods because of slow percolation, but once dry, water infiltrates slowly and drought conditions occur. On most landscapes these sites are rare, the clayey soil conditions occurring as isolated inclusions on an otherwise loamy or sandy landscape. Trees are often crooked or stunted and may have root damage from shrinking and swelling of clays. Natural sites develop a mixed overstory of *Pinus echinata* (shortleaf pine), *P. taeda* (loblolly pine), *Quercus stellata* (post oak), and *Q. marilandica* (blackjack oak). Fine-textured soils historically favored hardwoods over pines, and many such sites were probably oak-dominated even in presettlement times. Common shrubs are *Callicarpa americana* (American beauty-berry), *Ilex vomitoria* (yaupon), *Crataegus marshallii* (parsley hawthorn), and *Forestiera ligustrina* (upland swamp privet). A variety of ground layer species, most of which are also common on other mesic and dry-mesic sites, occurs. *Trachelospermum difforme* (climbing dogbane), *Chasmanthium sessiliflorum* (narrow-leaf wood-oats), and *Scleria oligantha* (little-head nutrush) tend to be abundant. The Redlands area near Nacogdoches is an example of such an area (Roberts 1881; Chambers 1941).

CLAYEY WET UPLAND DEPRESSIONS—These sites usually occur as isolated inclusions in most landscapes. They form in slight depressions or flats on broad uplands with poorly-formed drainage patterns and clayey or slowly permeable soils. A seasonally high water table develops near the surface in most years, resulting in vegetation that more resembles that of river floodplains than that of the surrounding uplands. *Quercus phellos* (willow oak), *Fraxinus pennsylvanica* (green ash), and *Crataegus opaca* (mayhaw) are particularly important. Good examples occur in the northern Angelina National Forest and in parts of the Davy Crockett National Forest. Marks and Harcombe (1981) described a "flatland hardwood forest" from the southwestern corner of the Pineywoods—possibly related to the "palmetto oak flats" of Ajilvsgi (1979) or the "palmetto hardwood flats" of Watson (1975)—with a species composition similar to that of Clayey Wet Upland Depressions, but which apparently occurs as larger patches on the landscape in flat, poorly drained areas.

Barrens, Prairies, and Glades—Although forest vegetation develops in the absence of disturbance in most Pineywoods ecosystems, a variety of localized herbaceous-dominated communities exist where unusual soil properties inhibit woody plants. Soils are often clayey or shallow to bedrock, and are sometimes calcareous. Species not common in most natural Pineywoods habitats, such as *Dalea compacta* (compact prairie-clover), *Callirhoe papaver* (winecup), *Bouteloua rigidiseta* (Texas grama), *Eustoma russellianum* (showy prairie gentian), and *Euphorbia bicolor* (snow-on-the-prairie), may be found on some of these sites. Often there are rare or sensitive species such as *Schoenolirion wrightii* (Texas sunnybell), which occurs on "barrens" associated with the Catahoula Formation in the southern Angelina National Forest (Marietta & Nixon 1984). "Prairies" on calcareous, clayey, shrink-swell soils occur in Sam Houston National Forest, the Big Thicket region, and in Louisiana (Ajilvsgi 1979; MacRoberts & MacRoberts 1997b, 2004d; Brown et al. 2002b). MacRoberts and MacRoberts (2004d) reviewed the literature on prairies of the West Gulf Coastal Plain, including the Pineywoods of East Texas.

A recent study by Brown et al. (2002b) of Windham Prairie in Polk County describes a good example. This small (2–3 hectares) area is apparently maintained at least in part by special edaphic conditions—the soil, derived from the Fleming Formation, is a gravelly, thin, well-drained calcareous clay with a high shrink-swell potential and slow permeability (McEwen et al. 1987; Brown et al. 2002b). Many species rare or unusual in the Pineywoods are known from this prairie (Brown et al. 2002b) including *Acacia angustissima* var. *hirta* (prairie wattle), *Allium stellatum* (autumn onion), *Carex microdonta* (little-tooth sedge), *Grindelia lanceolata* (narrow-leaf gumweed), *Liatris mucronata* (cusp gayfeather), *Penstemon cobaea* (cobaea beardtongue), and *Rudbeckia missouriensis* (Missouri orange-coneflower). Brown et al. (2002b) make the point that Windham Prairie shows strong affinities to the "upper clay/clay loam sections of the Fayette Prairie" and "also to the upland section of the Coastal Prairie."

Other herbaceous-dominated communities in the Pineywoods include sandstone glades associated with the Catahoula Formation (MacRoberts & MacRoberts 1993b) and glades characteristic of outcrops of the Weches Formation between Nacogdoches and San Augustine. These Weches outcrop communities (Fig. 28 on page 57) or "Glauconite shale glades" (Bezanson 2000), which include the rare white bladderpod (*Lesquerella pallida)* and Texas golden gladecress (*Leavenworthia aurea* var. *texana*), occur on rocky Trawick soils (George & Nixon 1990). No extant examples of "saline prairies" as described by Loughbridge (1880) are known in the Pineywoods, even though saline wetlands (associated with a salt dome) are known from northeastern Van Zandt County in the Post Oak Savannah just west of the Pineywoods.

Mesic Lower Slopes and Terraces—Also known as "Mesic uplands" (Nixon 2000), "beech-hardwood forest" (MacRoberts & MacRoberts 1997a), "lower slope hardwood pine forests" (Marks & Harcombe 1981), "beech-magnolia-loblolly slopes" (Ajilvsgi 1979), and "beech-magnolia-loblolly pine forests" (Watson 1975), these communities develop on lower slopes adjacent to rivers and streams, on steep slopes, and on the higher, inactive terraces of some rivers. In these areas, there is a strong tendency for hardwood-dominated forests (Figs. 56, 57) to develop in the absence of logging and other disturbances. Steep slopes and proximity

FIG. 56/ MESIC LOWER SLOPE AND TERRACE FROM ANGELINA NATIONAL FOREST, ANGELINA CO. (PHOTO BY JVK).

FIG. 57/ MESIC LOWER SLOPE AND TERRACE NEAR NACOGDOCHES, NACOGDOCHES CO. (PHOTO BY JVK).

to streams historically protected these sites from fires, most of which would have had to burn downhill to reach them. Moreover, lower hydrologic position on the landscape results in more available soil moisture and nutrients than for uplands. In presettlement times, fire-sensitive species including loblolly pine were probably more restricted to these sites than they are today.

Of all Pineywoods forest types, Mesic Lower Slopes and Terraces have the closest affinity with the Eastern Deciduous Forests of the Appalachians, the Midwest, and the northeastern U.S. (Braun 1950; Blackwelder 2000). Natural stands develop a diverse mixture of *Pinus taeda* (loblolly pine) and various deciduous hardwoods, including *Quercus falcata* (southern red oak), *Q. alba* (white oak), *Q. nigra* (water oak), *Nyssa sylvatica* (black-gum), and *Liquidambar styraciflua* (sweetgum). *Fagus grandifolia* (American beech) and *Magnolia grandiflora* (southern magnolia) often grow on undisturbed sites. *Ilex opaca* (American holly), *Ulmus alata* (winged elm), *Acer barbatum* (Florida maple), *Cornus florida* (flowering dogwood), *Ostrya virginiana* (eastern hop hornbeam), *Callicarpa americana* (American beauty-berry), and *Viburnum acerifolium* (maple-leaf viburnum) are important in the understory. *Chasmanthium sessiliflorum* (narrow-leaf wood-oats), *Parthenocissus quinquefolia* (Virginia creeper), *Mitchella repens* (partridge berry), *Smilax pumila* (sarsaparilla-vine), and *Sanicula canadensis* (black snakeroot) are common ground layer species. Vines such as *Vitis rotundifolia* (muscadine grape) commonly festoon the trees. Less frequent are "vernal herbs" more typical of the deciduous forests of the Appalachians or the Midwestern U.S: *Podophyllum peltatum* (mayapple), *Erythronium albidum* (white trout lily), *Arisaema triphyllum* (jack-in-the-pulpit), *A. dracontium* (green-dragon), and *Sanguinaria canadensis* (bloodroot). Such spring ephemerals typically flower in early spring as soon as suitable temperatures permit and before the canopy closes and available light is thus greatly reduced (Schemske et al. 1978).

Preliminary observations suggest the existence of both a "sandy soil" variant more likely to support high populations of *Mitchella repens*, *Smilax pumila*, *Fagus grandifolia*, *Magnolia grandiflora*, and others and a "rich-mesic" variant on nutrient-rich clayey-loamy soils where "vernal herbs" such as *Podophyllum peltatum*, *Arisaema dracontium*, *Erythronium* spp., and *Polygonatum biflorum* (great Solomon's seal), along with *Tilia americana* (American basswood), are more likely to occur. However, we have not yet documented these differences with quantitative data.

Mesic Stream Bottoms—On the narrow floodplains of small tributary streams, a mixed loblolly pine-broad-leaved deciduous forest very similar to that of adjacent Mesic Lower Slopes develops (Fig. 58). It is also known as "mesic creek bottom" (Nixon 2000), and "floodplain hardwood-pine forest" (Marks & Harcombe 1981). The small streams usually have a deep, well-developed stream channel and a narrow floodplain and drain only a small portion of the watershed. As a result, flooding is brief and infrequent. Occasionally, species characteristic of wetter sites, including *Quercus laurifolia* (laurel oak), *Boehmeria cylindrica* (false nettle), and especially *Carpinus caroliniana* (American hornbeam), may also be found, especially in low areas or adjacent to the stream channel.

Wet-Mesic Stream Bottoms—Downstream from Mesic Stream Bottoms, streams become larger, floodplains wider, floods more frequent, and flood duration longer. Often associated with third-order perennial streams, Wet-Mesic Stream Bottoms are transitional between Mesic Stream Bottoms and downstream Seasonally Flooded River Floodplains. The hydrologic regime corresponds to that of Zone V of Clark and Benforndo (1981), which is described as "irregularly inundated" in the *Wetlands Delineation Manual* (U.S. Army Corps of Engineers 1987). Flooding is not severe enough to eliminate many mesic species, but flood-tolerant species such as *Q. laurifolia* (laurel oak), *Q. phellos* (willow oak), *Betula nigra* (river birch), and *Boehmeria cylindrica* (false nettle) occur—especially in depressions and old stream channels.

FIG. 58/ MESIC STREAM BOTTOM FROM ANGELINA NATIONAL FOREST, JASPER CO. (PHOTO BY JVK).

Pinus taeda (loblolly pine), *Quercus alba* (white oak), *Q. pagoda* (cherry-bark oak), *Ilex opaca* (American holly), *Acer barbatum* (Florida maple), and *Carpinus caroliniana* (American hornbeam) are usually abundant in natural stands. A remnant cherry-bark oak in the Upland Island Wilderness Area, measured at 165 feet tall (50 m), gives an impression of the potential size of some tree species occurring in the Pineywoods (Fritz 1993). Old growth sites may support *Fagus grandifolia* (American beech) and *Magnolia grandiflora* (southern magnolia) (Fig. 59). *Quercus nigra* (water oak) reaches peak abundance in these habitats and may be dominant. *Arundinaria gigantea* (giant cane or switch cane) sometimes forms dense thickets called "canebrakes." Many forest floor species from Mesic Lower Slopes and Stream Bottoms, including, on occasion, vernal herbs, also grow here. In addition, *Elephantopus carolinianus* (Carolina elephant's-foot), *Bignonia capreolata* (cross vine), and at least seven characteristic *Carex* (caric sedge) species are often abundant. *Ligustrum sinense* (Chinese privet) is a locally problematic exotic shrub that has completely occupied the understory of some stands, especially in the Nacogdoches area. *Taxodium distichum* (bald-cypress) may be present along the immediate stream bank, especially on sandy soils.

WET FORESTED SEEPS AND STREAM BOTTOMS ("BAYGALLS")**—**These assemblages are also known as "baygalls" (Watson 1975— the name comes from two typical species, sweetbay magnolia and gallberry holly; MacRoberts et al. 2004), "wetland baygall shrub thickets" (Marks & Harcombe 1981), and "wet creek bottoms" (Nixon 2000). Their hydrology resembles that of sandy Wet Herbaceous Seeps, where soils are usually saturated with low-nutrient springwater filtered through surrounding upland sands. However, Forested Seeps tend to be lower on the landscape and larger. While also sharing floristic similarities with Wet Herbaceous Seeps, these areas are dominated by woody vegetation. A distinctive plant community develops where groundwater seepage occurs on lower hillsides or headslopes, along small streams, or into

FIG. 59/ WET-MESIC STREAM BOTTOM WITH *FAGUS GRANDIFOLIA* (AMERICAN BEECH) AND *MAGNOLIA GRANDIFLORA* (SOUTHERN MAGNOLIA), BEECH CREEK UNIT, BIG THICKET NATIONAL PRESERVE, TYLER CO. (PHOTO BY GMD).

FIG. 60/ FORESTED SEEP FROM ANGELINA NATIONAL FOREST, SAN AUGUSTINE CO. (PHOTO BY JVK).

various topographic depressions (Fig. 60). Characteristic tree species include *Magnolia virginiana* (sweetbay magnolia), *Nyssa biflora* (swamp tupelo), and *Acer rubrum* (red maple). Typical shrubs and vines include *Myrica heterophylla* (evergreen bayberry), *Toxicodendron vernix* (poison sumac), *Smilax laurifolia* (laurel-leaf greenbrier), *Viburnum nudum* (possumhaw), and *Persea borbonia* (redbay). In the southern part of the Pineywoods, but not in the northern, *Ilex coriacea* (gallberry holly) is also common. *Rhododendron canescens* (mountain azalea) and other wild azalea species provide showy flowers in spring. *Woodwardia areolata* (netted chain fern) typically dominates the ground layer. Other important forest floor species are *Osmunda regalis* (royal fern), *O. cinnamomea* (cinnamon fern), and *Eleocharis microcarpa* (small-fruit spikesedge). Patches of *Sphagnum* spp. (peat moss) may be present. Rare species that one may find in Forested Seeps include *Spiranthes* spp. (ladies'-tresses), *Bartonia texana* (Texas screwstem), *Parnassia asarifolia* (kidney-leaf grass-of-Parnassus), and *Burmannia biflora* (northern bluethread). Brooks et al. (1993) described a northern type of this community which occurs primarily north of southern Angelina County as well as a southern type which, among other differences, contains *Cyrilla racemiflora* (swamp titi). Well known examples of baygalls can be found in the Big Thicket National Preserve in the Jack Gore Baygall Unit, and along Village Creek (Watson 1975).

Irregularly Flooded Levees and Bottomland Ridges—On the higher and drier portions of the broad floodplains of major rivers, such as crowns of natural levees, meander scrolls, and other slightly elevated areas, a plant community similar to that found on Wet-Mesic Stream Bottoms develops. Soils, often sandy, are usually coarser in texture than soils on the rest of the floodplain because floodwaters deposit the coarse portion of their sediment load on the natural levees first when they overflow the riverbank and lose velocity (Mitsch & Gosselink 1993). Flood duration is shorter and flood frequency lower than for the adjacent lower portions of the floodplain (see Van Kley & Hine 1998). The hydrologic regime is "irregularly inundated" (U.S. Army Corps of Engineers 1987) and corresponds to hydrologic Zone V of Clark and Benforndo (1981). Typical plants include mesic and moderately flood-tolerant species such as *Pinus taeda* (loblolly pine), *Quercus nigra* (water oak), *Liquidambar styraciflua* (sweetgum), *Q. alba* (white oak), *Q. pagoda* (cherry-bark oak), and occasionally, *Q. falcata* (southern red oak). "Canebrakes," thickets of *Arundinaria gigantea* (giant cane or switch cane), are common.

Seasonally Flooded River Floodplains—Seasonally Flooded River Floodplains, the most extensive ecological type on most bottomland landscapes, occupies the broad flat portions of the floodplains of major rivers (Fig. 61). These communities correspond to the "sweetgum-oak floodplains" of Ajilvsgi (1979), "Floodplain hardwood forests" of Marks and Harcombe (1981), and "river bottom communities" of Nixon (2000). The hydrologic regime largely corresponds to Zone IV (Clark & Benforndo 1981), which is described as "seasonally inundated" (U.S. Army Corps of Engineers 1987), while lower *Quercus lyrata* (overcup oak)-dominated areas correspond to the "regularly flooded" hydrologic Zone III. Soils, subject to seasonal flooding, are generally loamy to clayey. Natural forests are a rich mixture of flood-tolerant deciduous hardwoods, including *Quercus phellos* (willow oak), *Q. laurifolia* (laurel oak), *Q. lyrata*, *Q. michauxii* (swamp chestnut oak), *Liquidambar styraciflua* (sweetgum), *Ulmus americana* (American elm), *Nyssa biflora* (swamp tupelo), and *Acer rubrum* (red maple). Overcup oak is the most flood-tolerant of the bottomland oaks and may form pure stands on lower portions of the floodplain and in slight depressions where flooding is more prevalent. *Ilex decidua* (deciduous holly), *Styrax americana* (American snowbell), and *Crataegus opaca* (mayhaw) are common understory shrubs. Ground cover

FIG. 61/ SEASONALLY FLOODED RIVER FLOODPLAIN, ANGELINA RIVER, STEPHEN F. AUSTIN EXPERIMENTAL FOREST, NACOGDOCHES CO. (PHOTO BY JVK).

may be sparse, especially in the absence of openings in the normally dense canopy, but important species include *Boehmeria cylindrica* (false nettle), *Carex joorii* (cypress swamp sedge), *Rhynchospora corniculata* (beak sedge), and *Justicia ovata* (water willow), while *Saururus cernuus* (lizard's-tail) occurs in wetter areas. *Brunnichia ovata* (American buckwheat-vine) is common as small, non-flowering individuals under the canopy but may form dense tangles along with *Mikania scandens* (climbing hempweed) in openings.

SEMI-PERMANENTLY FLOODED SWAMPS—Swamps are the lowest, wettest portions of floodplains and are generally flooded for much or all of an average growing season (Fig. 62). Their hydrologic regime is described as "semipermanently inundated" (U.S. Army Corps of Engineers 1987) and corresponds to Zone II of Clark and Benforndo (1981). Natural communities that develop in swamps are also known as "cypress tupelo forest" (Marks & Harcombe 1981). Swamps form in old stream channels and oxbows and other floodplain depressions. They also form in any other situation that creates areas of shallow, impounded waters, such as log jams (which initially formed Caddo Lake), beaver activity, or dam construction. At Caddo Lake in northeastern Texas, swamp vegetation was associated with plots that were below the normal pool elevation of the lake (Van Kley & Hine 1998). In many Pineywoods swamps, *Planera aquatica* (water elm) dominates seasonally-exposed, shallow-water sites where *Fraxinus caroliniana* (Carolina ash), *Salix nigra* (black willow), and *Taxodium distichum* (bald-cypress) may also be present. In deeper-water swamplands, with water up to 2 m deep, *T. distichum* dominates, along with *Nyssa aquatica* (water tupelo) in the southern and eastern portions of the Pineywoods. *Ceratophyllum demersum* (coontail), *Cabomba caroliniana* (fanwort), *Hydrilla verticillata* (hydrilla, an invasive exotic), *Lemna* spp. (duckweeds), *Spirodela polyrhiza* (duckmeat), *Wolffia columbiana* (water meal), and *Nuphar advena* (yellow pond-lily) are

FIG. 62/ SEMI-PERMANENTLY FLOODED SWAMP, CADDO LAKE, MARION CO. (PHOTO BY JVK).

among the floating and submersed plants, especially under canopy gaps. *Cephalanthus occidentalis* (button bush) and *Triadenum walteri* (marsh St. John's-wort) commonly grow on stumps and logs and in shallow-water areas.

MARSHES—Marshes are non-forested wetlands dominated by herbaceous vegetation (Mitsch & Gosselink 1993). If left undisturbed, most eastern Texas wetlands would eventually succeed to forest (swamps). Many marshes are temporary communities of the semi-Permanently Flooded Swamp ecological type, resulting from human activities or from natural processes such as riverbank erosion and sedimentation, oxbow creation, beaver activity, and windthrow. Marsh vegetation is also common along the edges of the numerous artificial reservoirs in eastern Texas. Sedges (Cyperaceae), grasses (for example *Zizaniopsis miliacea*, marsh millet and *Leersia oryzoides*, rice cut grass), and rushes (e.g., *Juncus effusus*, common rush) tend to dominate areas of wet soil and shallow water. *Typha* spp. (cattail) may also form dense stands in shallow areas. *Cephalanthus occidentalis* (buttonbush) is an important shrub in most non-forested or partially shaded wetlands. Deeper areas support emergent plants such as *Sagittaria platyphylla* (delta arrowhead), while the deepest areas contain floating and submersed species, including *Ludwigia peploides* (floating primrose willow), *Ceratophyllum demersum* (coontail), *Cabomba caroliniana* (fanwort), Lemnaceae spp. (duckweeds), *Nelumbo lutea* (American lotus), and *Nuphar advena* (yellow pond-lily). *Hydrilla verticillata* (hydrilla), an invasive exotic species, dominates the shallows of many local reservoirs.

HUMAN-DOMINATED ECOSYSTEMS—Much of the Pineywoods is under varying degrees of human influence, and vegetation may only partially or minimally reflect the potential natural plant communities as described above—although in the absence of continued disturbance, sites may revert to their potential natural communities. The many forms of human land management have produced a wide array of human-modified plant communities. Roadsides, maintained by mowing, often include a variety of planted wildflowers only occasionally encountered in natural Pineywoods habitats. *Oenothera speciosa* (showy evening-primrose), *Callirhoe papaver* (poppy mallow), *Coreopsis lanceolata* (lance-leaved coreopsis), and *Lupinus* spp. (bluebonnet) are common. Cut-over forests, in the absence of silvicultural site-preparation and planting, develop a dense growth of perennial herbs such as *Solidago canadensis* (Canadian goldenrod), vines and brambles including *Smilax* spp. (greenbrier) and *Rubus* spp. (blackberry), and residual or regenerating tree species—especially *Pinus taeda* (loblolly pine) and *Liquidambar styraciflua* (sweetgum). Exotic grasses, including *Paspalum notatum* (bahia grass), *Cynodon dactylon* (Bermuda grass), and *Bromus catharticus* (rescue grass), may dominate pastures. Urban areas are characterized by a variety of vegetation, including patches of natural or semi-natural vegetation along boundaries (fences, roads, and property lines). Cultivated exotic species and native species, often occurring in habitats which they would not ordinarily occupy, characterize the portions of urban areas fortunate enough not to have been converted to roads and parking lots. Elsewhere, large areas of former river floodplains have been converted to artificial reservoirs where the exotic weed *Hydrilla verticillata* is abundant.

The Future of the Pineywoods

The Pineywoods are fortunate relative to much of Texas to have significant areas of national forests and other public lands where high-quality remnants of natural ecosystems survive and where there is access for those who wish to enjoy them. However, while some Pineywoods ecosystems are robust and many good second-growth stands exist, valuable natural areas continue to be lost. Today represents a last chance to conserve truly natural examples of many ecosystems. Longleaf pine woodlands, Herbaceous Seeps, and mature-growth Mesic Lower Slope and Stream Bottom forests are particularly threatened and in need of urgent conservation. Opportunities also exist for ecosystem restoration (Allen et al. 2001), particularly with longleaf pine woodlands where appropriate management may include prescribed fire, thinning, destruction of shrubs, and planting of little bluestem and other native grasses and forbs. Decisions made by our generation may determine whether our children will be able to enjoy and experience this rich and diverse landscape as has been our privilege.

Post Oak Savannah

Occurrence of the Post Oak Savannah

The Post Oak Savannah (Figs. 63, 64), a region of about 53,400 square kilometers (20,600 square miles) or 5.3 million hectares (about 7.7 percent of Texas), is situated between the Pineywoods and Blackland Prairie vegetational zones, with some interdigitation with disjunct sections of the Blackland Prairie to the south (Figs. 2, 3). The region extends in an irregular northeast to southwest band occurring on predominantly sandy soils derived from Tertiary geologic layers. It ranges from Bowie County in the northeast corner of the state on the Arkansas border, southwest beyond the Guadalupe River to northern Wilson and Goliad counties. Precipitation level is an important determinant of its eastward transition to the adjacent Pineywoods, the demarcation between the two corresponding roughly with the 40 inch (98 cm) mean annual precipitation line (Larkin & Bomar 1983). In general, the Post Oak Savannah is a gently rolling to hilly, moderately dissected, woodland plain with elevations ranging from 300 to 800 feet (about 90 to 250 m) (Hatch et al. 1999; MacRoberts et al. 2002b).

The region has been variously considered either the western fringe of the eastern deciduous forest or part of the true prairie association (Allred & Mitchell 1955; Thomas 1962). According to some authorities, in terms of woody plants it is most similar to the Oak-Hickory Association of the eastern U.S., where mature stands are dominated by oaks, with hickories secondary in importance (Vankat 1979; Barbour & Christensen 1993). However, the Post Oak Savannah is clearly part of an ecotone (= transition zone/area of rapid change between two more homogeneous areas) between the eastern deciduous forests and the central North

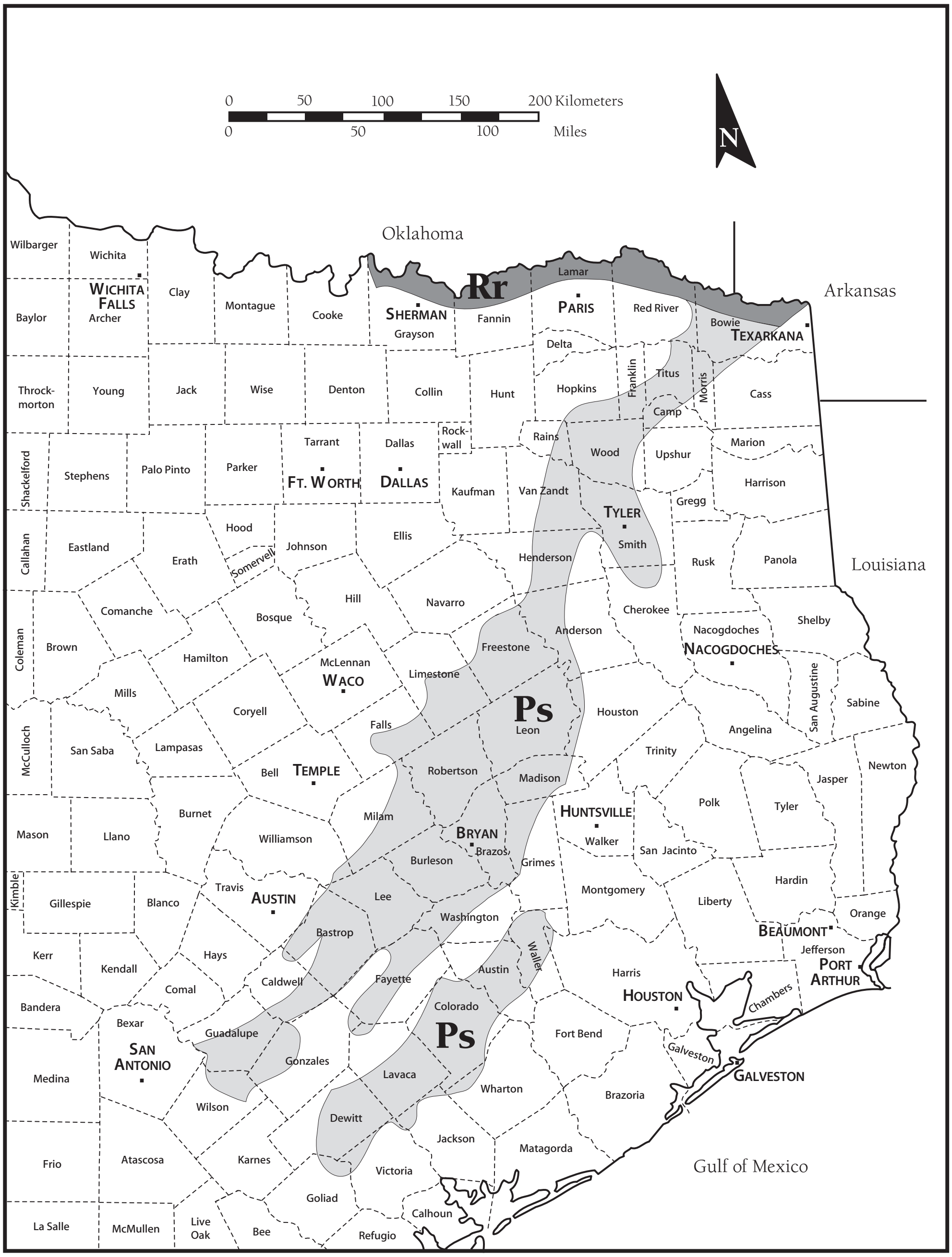


FIG. 63/ GENERALIZED MAP OF THE POST OAK SAVANNAH VEGETATIONAL AREA AND THE RELATED RED RIVER AREA. FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE; REPRODUCTION OF THIS IMAGE DOES NOT REQUIRE COPYRIGHT PERMISSION.

FIG. 64/ PHOTOGRAPH OF A POST OAK SAVANNAH SITE (PHOTO BY J.R. MANHART).

American grasslands (Barbour & Christensen 1993; MacRoberts & MacRoberts 2003b). The vegetation, which ranges from prairie inclusions and savannahs to forests, amply demonstrates its transitional nature. Relative to other vegetation types in Texas, at least in overall aspect, the Post Oak Savannah is most similar to the Cross Timbers, which are located to the west of the Blackland Prairie. In fact, in a narrow strip along the Red River, the Post Oak Savannah grades into the East Cross Timbers (Figs. 3 & 4). As with the Cross Timbers, the Post Oak Savannah can be broadly characterized as having a *Quercus stellata* (post oak)–*Q. marilandica* (blackjack oak) overstory and an understory of grasses, chiefly *Schizachyrium scoparium* (little bluestem) (Hatch et al. 1990). Some authorities (e.g., Diamond et al. 1987) even lump the Cross Timbers and Post Oak Savannah together into a single community, the Oak Woods and Prairies. However, the Post Oak Savannah differs in having a much greater diversity of both species and vegetational communities. A number of quite distinct communities exist (discussed in detail below), ranging from post oak-blackjack oak savannahs and forests to xeric sandylands on the well-drained uplands, various bogs (e.g., muck bogs) and wetlands, and rock outcrop communities (MacRoberts & MacRoberts 1998e; MacRoberts et al. 2002b; Singhurst et al. 2003b). Disjunct examples of nearly all of these can also be found in areas of appropriate edaphic conditions in the adjacent Pineywoods.

Further, recent work by MacRoberts and MacRoberts (2003a; 2004b) suggests that all three areas into which the West Gulf Coastal Plain (WGCP) has traditionally been divided (Post Oak Savannah, Oak-Pine-Hickory, and Longleaf Pine—the last two together referred to in Texas as the Pineywoods) (Fig. 65) are very similar from a floristic standpoint. MacRoberts and MacRoberts have argued that the West Gulf Coastal Plain, though heterogeneous, is a cohesive vegetational unit. The three subdivisions of the West Gulf Coastal Plain have more than 90% of their flora in common and share the great majority of communities—e.g., pockets of prairie occur in all three, as do bogs, baygalls, and xeric sandylands (MacRoberts & MacRoberts 2003a). In their words (2003a), "When traveling from one region to another [of the West Gulf Coastal Plain], the botanist does not encounter a new flora, the zoologist a new fauna, [nor] the ecologist a new set of plant and animal communities. What differences exist are not of kind but of degree. Sharp boundaries simply do not exist." This view agrees with

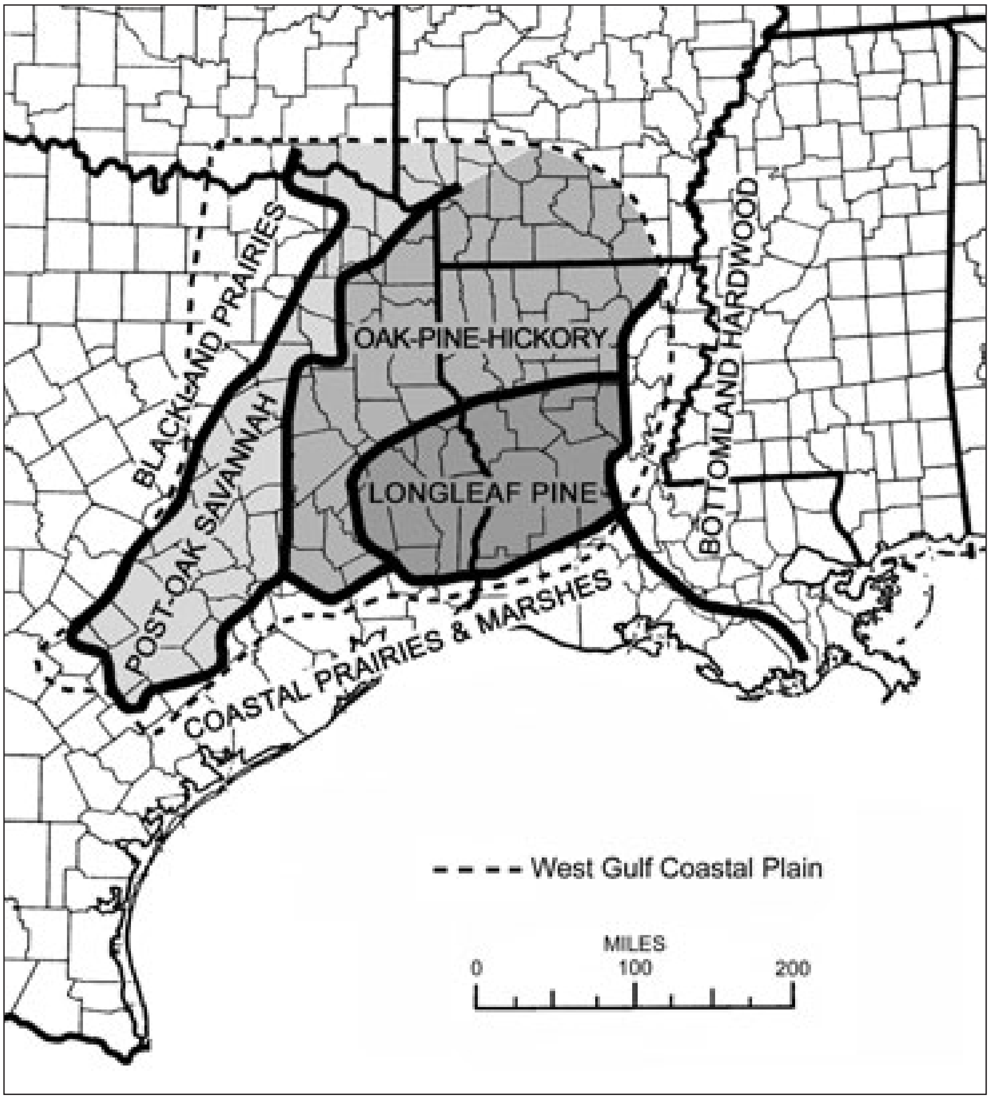


Fig. 65/ Standard/traditional delineation of West Gulf Coastal Plain vegetational areas and boundary (dashed line) of the West Gulf Coastal Plain phytogeographic pattern (MacRoberts et al. 2002c). Modified from MacRoberts et al. (2002c) and MacRoberts and MacRoberts (2003a), with permission of Michael MacRoberts and the Botanical Research Institute of Texas.

a number of past workers who also pointed out the lack of a sharp boundary between the Pineywoods and Post Oak Savannah. For instance, Tharp (1926) indicated that the transition to the Post Oak Savannah "... merely means the gradual decrease of pine until it has disappeared." Another example is McCarley's (1959) statement that the "boundary between the pine-oak region and the oak-hickory region is nowhere sharply marked, but is characterized by a gradual decrease in pine and an increase in oaks and hickories." In other words, "there is no floristic break ... or unique communities by which the [Post Oak Savannah] can be described" (MacRoberts & MacRoberts 2003a).

However, it can be argued that in many if not most cases that adjacent vegetational regions lack sharp boundaries (e.g., Edwards Plateau and South Texas Plains). It cannot be overemphasized that despite the seemingly sharp breaks indicated on vegetational maps, vegetational transitions are rarely sharp or well-defined—the Post Oak Savannah-Pineywoods transition is just one example of this phenomenon.

Nonetheless, the lack of the ability to draw an exact line of demarcation between two areas does not mean that major differences do not exist. While the Post Oak Savannah is closely linked floristically and ecologically to the Pineywoods and the rest of the West Gulf Coastal Plain, it is known that the Post Oak Savannah did have extensive areas of savannah that differed greatly in aspect from the Pineywoods. Even today, the overall appearance of the Post Oak Savannah is quite different, and most areas of Post Oak Savannah can be easily distinguished vegetationally from most areas of Pineywoods. Not only are the two areas largely different both in their original and modern day vegetational cover (Post Oak Savannah with more grasses, fewer trees, and pines mostly restricted to the eastern edge)—they also differ in terms of soil and rainfall. These differences were reflected in the quite different land use histories following European settlement: lumbering in the Pineywoods versus row cropping and ranching in the Post Oak Savannah. Thus, while these two parts of the West Gulf Coastal Plain share many similarities and have an indistinct boundary, recognition of two distinct areas is a useful, practical, and vegetationally accurate distinction. As a result, and following traditional practice in Texas, we believe it is appropriate to continue to recognize the Post Oak Savannah as a separate vegetational area.

While vegetational similarities exist throughout the Post Oak Savannah, there are numerous local differences. For example, the northeast portion is considerably wetter than the less mesic and warmer southwest, with significant impact on the vegetation—e.g., more *Quercus falcata* (southern red oak) in the northeast, in contrast to *Quercus virginiana* (live oak) in the south. Likewise, there is a narrow band of vegetation, found on the primarily sandy alluvial soils adjacent to the Red River in the northernmost portion of East Texas, that we are referring to as the Red River Area. Some of the Red River Area has traditionally been treated as part of the Post Oak Savannah, while the westernmost portion (northern Grayson County) has typically been classified as part of the somewhat similar Cross Timbers and Prairies (Correll & Johnston 1970; Hatch et al. 1990). While similar in many respects to the Post Oak Savannah and reasonably included in that category, the Red River Area differs significantly and is therefore discussed separately here as a distinct vegetational area (see page 127).

From a conservation perspective, MacRoberts and MacRoberts (2003a) point out that the manner in which ecological boundaries are drawn can have significant implications. "For example, Ricketts et al. (1999a) concluded that the OPH [Oak-Pine-Hickory] plus LLP [Longleaf Pine] ecoregions (their 'Piney Woods Forests') had only 7 endemic plants and the POSa [Post Oak Savannah] region (their 'East Central Texas Forests') also had only 7 endemic plants. However, by combining the POSa, OPH, and LLP regions, we calculate that these three 'regions' together have approximately 100 endemic or near-endemic plants, not 14!—thereby instantly changing the WGCP [West Gulf Coastal Plain] from an ecological cold spot to an ecological hot spot" (MacRoberts & MacRoberts 2003a). Such an example points to the critical need for further study and a better understanding of the flora of many areas.

Geology and Soils of the Post Oak Savannah

As discussed in the general sections on geology and soils of East Texas, the Post Oak Savannah has developed on sedimentary substrates of Tertiary age. The soils, developed from sandstone rocks of such geologic layers as the Carrizo and Wilcox, can be generally described as sandy (Sellards et al. 1932; Hartmann & Scranton 1992). More specifically, they are usually acidic, with sands and sandy loams occurring on the uplands and clay to clay loams on the bottomlands (Texas Parks and Wildlife 2002a). Often, but not always, a dense clay pan is present at a lower soil horizon. Because of this phenomenon, the Post Oak Savannah is sometimes referred to as the "Clay Pan Savannah." These clay pans, underlying the surface layers of the soil, are nearly impervious to water. As a consequence, the moisture available for plant growth is limited to that in the upper soil horizons—the result is that much of the Post Oak Savannah can be a "droughty" and surprisingly arid habitat at times (Texas Parks and Wildlife

2002a). However, the dominant aspect of Post Oak Savannah soils is their sandy nature. As noted in the following discussion of the soil-dependent fire frequency hypothesis, these sandy soils are an important determinant of the plant communities that occur on the Post Oak Savannah.

The Soil-Dependent Fire Frequency Hypothesis and the Distribution of the Post Oak Savannah

The distinctive historical vegetation pattern of alternating bands of tall grass prairies on clay soils and oak woodlands/savannahs on sandy soils in North Central and East Texas has been described for more than a century. From west to east, the prairie bands are the Grand Prairie, the main belt of the Blackland Prairie, the San Antonio Prairie, and the Fayette Prairie, while the woodland/savannah bands are the West Cross Timbers, the East Cross Timbers, and three bands of Post Oak Savannah (Fig. 66). Many authors (e.g., Hill 1887; Tharp 1926; Allred & Mitchell 1955) have attributed this striking pattern to relatively high levels of soil moisture available for tree growth on areas of sandy soil, and conversely, inadequate levels of soil moisture for tree growth on clay soils. However, this explanation is not consistent with present-day observations of rapid invasion of clay soils by woody vegetation on many areas of the Grand and Blackland Prairies (Fig. 67). A different explanation seems needed to account for the discrete areas of woody versus prairie vegetation observed by early explorers and settlers.

Diggs and Schulze (2003) proposed an alternative hypothesis, the soil-dependent fire frequency hypothesis, which postulates that the distribution of prairie and oak woodland/savannah in presettlement times was not due to insufficient moisture for tree growth on clay soils, but rather to differences in fire frequency on different soil types, with the higher fuel quantity on clay soil associated with increased likelihood and intensity of fire and the resulting suppression of tree growth. Prairie fires are fueled primarily by grasses, as opposed to forbs or woody vegetation, so an increase in fuel quantity would require an increase in grass biomass. The hypothesis further predicts that grass biomass is typically higher on clay soils, due to better moisture and nutrient availability at the rooting depth of grass plants. This situation would represent two alternative positive feedbacks. High fuel quantity on clay encourages fire, which stimulates subsequent grass growth (since grasses are fire-adapted), thereby maintaining high fuel quantity. Low fuel quantity on sand reduces the chance of fire, which fosters invasion by trees that then further suppress grass biomass and the subsequent likelihood of fire. These alternative feedbacks lead to alternative stable states, prairie and oak woodland/savannah (Fig. 68).

The key assumption of the hypothesis is that the difference in grass biomass on the prairies versus the oak woodlands/savannahs was of sufficient magnitude to substantially raise the likelihood, frequency, and intensity of fire on the clay soils of the prairies compared to the sandy or rocky soils of the Cross Timbers or Post Oak Savannah. In addition, the hypothesis leads to the prediction that patches of open grassland on sandy soil are rare except in instances of active management (e.g., suppression of woody species) or immediate proximity to clay soils (which would result in more frequent fires due to closeness to the fire-prone prairie vegetation).

This particular hypothesis for the distribution of prairies and oak woodland/savannah is consistent with the more general conclusions of Scholes and Archer's (1997) review of tree-grass interactions. They write that, "Moist fertile environments [e.g. Blackland Prairie] support a vigorous grass growth that, if not grazed, leads to frequent intense fires…. Semi-arid environments on sandy, low fertility soils [e.g. Post Oak Savannah or Cross Timbers] are seldom treeless."

The present invasion of the prairies by trees can be explained by a lack of fire that has resulted from intentional fire suppression, plus numerous and extensive firebreaks that have been created by human activities (roads, cultivated fields, overgrazed areas). Moreover, once

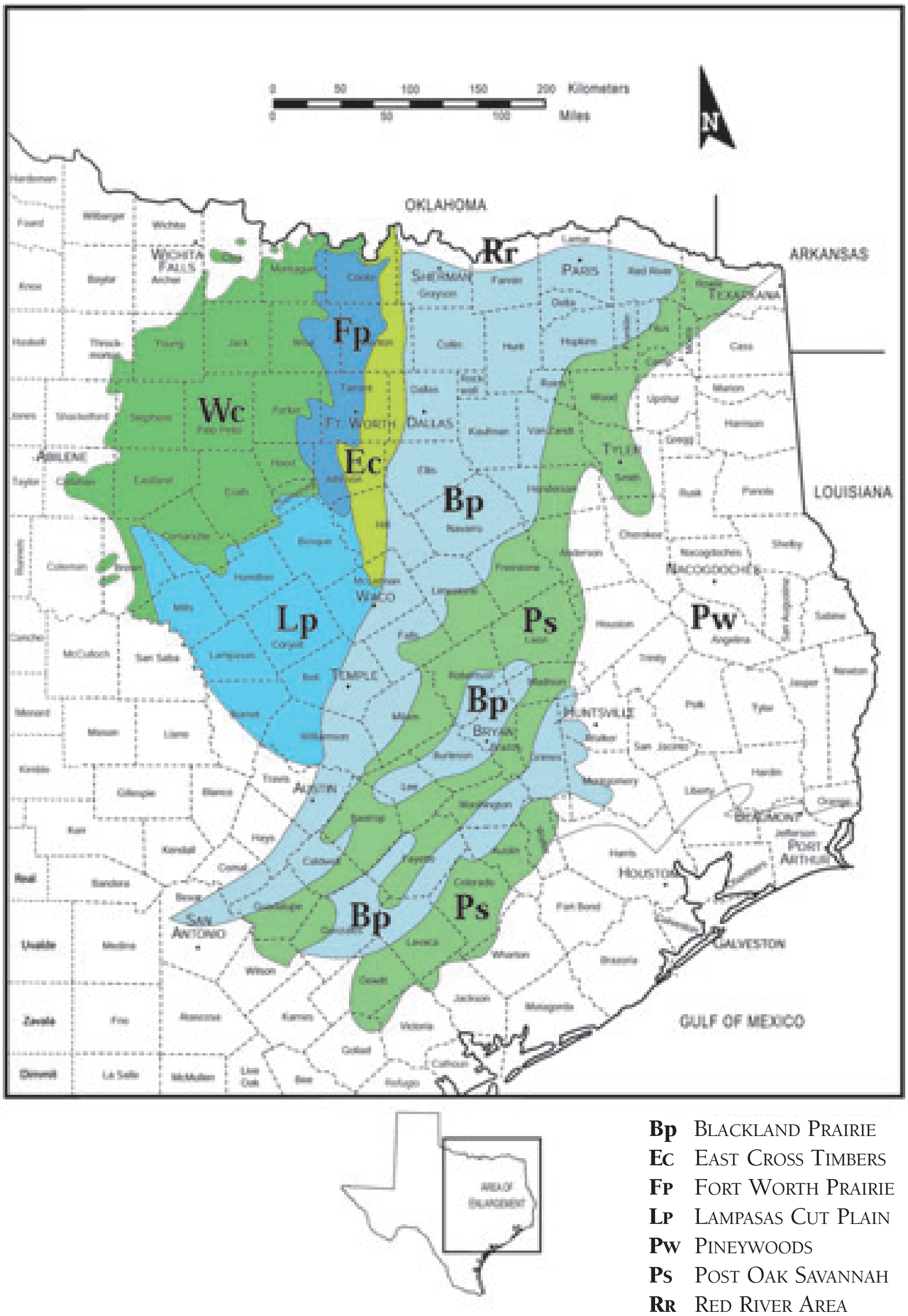


FIG. 66/ VEGETATIONAL AREAS OF EAST AND NORTH CENTRAL TEXAS. THE PRAIRIES ARE IN SHADES OF BLUE WHILE THE WOODLANDS/SAVANNAHS ARE IN SHADES OF GREEN. TWO EAST TEXAS VEGETATIONAL AREAS ARE NOT SHOWN IN COLOR—THE PINEYWOODS (FOREST) AND THE RED RIVER AREA (SOMEWHAT TRANSITIONAL BETWEEN THE PINEYWOODS AND THE POST OAK SAVANNAH) (FROM DIGGS & SCHULZE 2003).

this process begins, any prairie area that becomes substantially invaded by trees would lose grass biomass and come to serve as an additional firebreak, thereby further reducing the likelihood of fire on adjacent remaining prairies. Significantly, the result of the tree invasion is that many (but certainly not all) areas of the prairies (and of the Cross Timbers and Post Oak Savannah understory) is now dominated by *Juniperus virginiana* (eastern red cedar) and *Juniperus ashei* (Ashe's juniper), species that are sensitive to fire (easily scorched/ignited and unable to resprout from roots).

At this time, measurements of grass biomass on intact remnants of the prairies and woodlands have not been made. While some biomass and fuel loading data are available in the literature (e.g., Johnson & Risser 1974; Engle & Stritzke 1995), we have been unable to find directly comparable data for the area being considered. However, substantial indirect evidence is consistent with the assumption of higher grass biomass on clay soils. First, during dry periods clay soils generally hold more water at grass rooting depths than do sandy soils. This is due to the relatively large surface areas of the individual clay particles and the large number of very small pores acting as billions of capillary tubes, which collectively hold large amounts of water (Vankat 1979). The result of this increased water-holding capacity is that plants rooted in such soils may continue active growth much later in the dry season than plants rooted in coarser soils (Daubenmire 1974; Burgess 1995; McAuliffe 1995; Tucker 1999; Greeves et al. 2000; Ball 2001). Furthermore, undisturbed Blackland soils form gilgai, microtopographical surface features that function like shallow basins, increasing water retention during heavy rains (Hayward & Yelderman 1991; Diamond & Smeins 1993). Early settler accounts and observations of existing prairie remnants (e.g., the Nature Conservancy's Clymer Meadow preserve in Hunt County, the Matthews-Cartwright-Roberts Prairie in Kaufman County, and Austin College's Garnett Prairie in Grayson County) suggest that these "hog wallows," as they were known to early settlers, were apparently abundant on Vertisols of the presettlement Blackland Prairie (see page 63 for discussion of gilgai formation). Temporary water storage in the numerous gilgai depressions of one-half acre-foot of water per acre of flat prairie has been estimated. As much as six inches (15.2 cm) of rain could be temporarily trapped in these structures before runoff began (Hayward & Yelderman 1991).

FIG. 67/ AREA OF BLACKLAND PRAIRIE SHOWING INVASION BY WOODY VEGETATION UNDER CURRENT FIRE SUPPRESSION CONDITIONS (PHOTO BY WCW).

Meanwhile, the high surface area and negative surface charges of clay particles give clay soils high cation exchange capacity. This allows these soils to hold more ionized minerals or nutrients, including those essential for plant growth (Foth 1990; Whitehead 2000; Harpstead et al. 2001; O'Connell 2001). It is therefore not surprising that indirect evidence, such as agricultural productivity, suggests that the Blackland clay soils were among the most fertile soils west of the Mississippi River (Haywood & Yelderman 1991). In addition, the high below-ground biomass of prairie vegetation serves to continually add organic matter to the soil, thereby functioning as a positive feedback mechanism to increase fertility and water-holding capacity (in part due to the surface area provided by the additional organic material). Conversely, sandy soils have larger pores that allow water to drain more easily. They not only dry earlier during dry periods but "the more water that percolates through the soil, the more nutrients are washed out—particularly nitrogen, potassium and sulfur" (Tucker 1999). Therefore, soils that are high in sand, like those of the woodlands, are often poor for plant growth since they are relatively infertile and often too well-drained (Vankat 1979).

The soil-mediated fire frequency hypothesis is merely a special case of a generally accepted explanation for tree-grass interactions, based on mechanisms that, by reducing the frequency and intensity of fire, enable trees to grow where grass would otherwise dominate. The fire-induced state of grasslands on the prairies is therefore apparently destabilized when fire is suppressed for any of a number of reasons. In addition to the hypothesized effect of soil on grass biomass, other variables that can hinder fire and thus allow trees to invade include precipitation, grazing, and topography (Collins & Wallace 1990; McPherson 1995). Trees invade

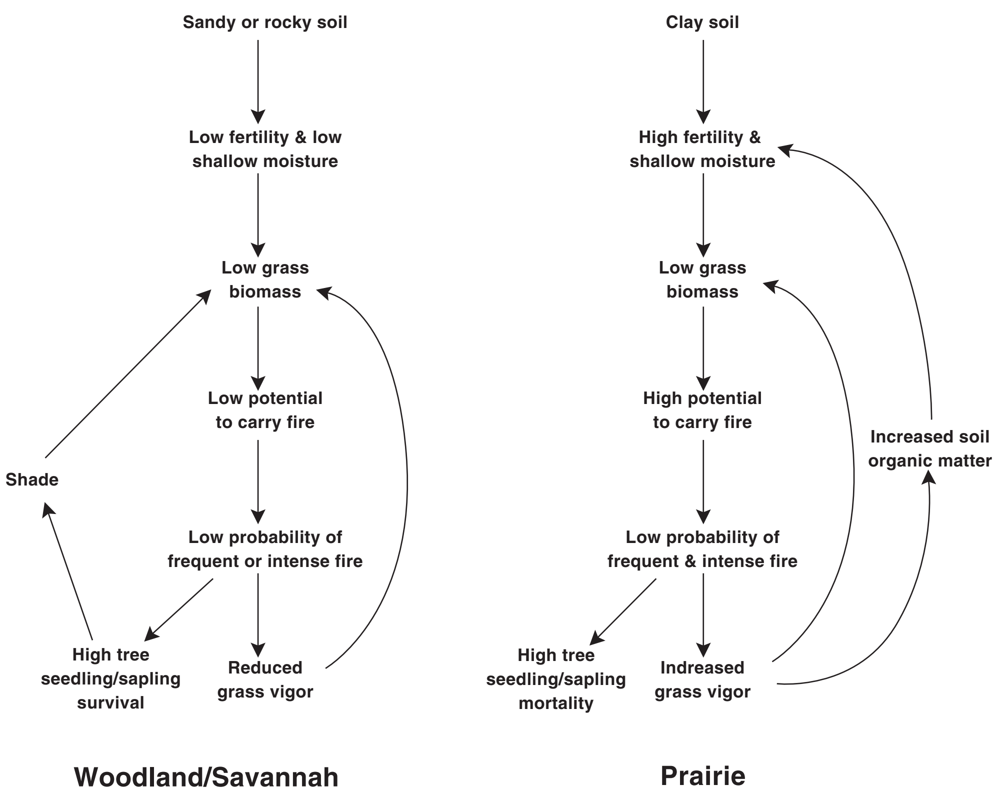


FIG. 68/ FLOW DIAGRAMS SHOWING POSITIVE FEEDBACK ROUTES TO TWO ALTERNATIVE STABLE STATES (FROM DIGGS & SCHULZE 2003). FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE; REPRODUCTION OF THIS IMAGE DOES NOT REQUIRE COPYRIGHT PERMISSION.

when rainfall prevents fire throughout the year (e.g., in areas of eastern deciduous forest in the eastern U.S.). Likewise, reduced grass biomass from grazing on the prairies reduces fire likelihood, which in turn enables invasion by trees (Smeins et al. 1982; Scholes and Archer 1997; Van Auken 2000). As noted by Van Auken (2000), "the driving force [for brush encroachment] seems to be chronic, high levels of herbivory by domestic animals. This herbivory has reduced the above ground grass biomass, leading to the reduction of fine fuel and a concomitant reduction or complete elimination of grassland fires. This combination of factors favors the encroachment, establishment, survival and growth of woody plants." Finally, where relief is extreme, as on scarps or cliffs, woodlands are often present. This is due to both the thin rocky soil (and hence low grass biomass) and the topography (e.g., abrupt scarps), which often creates natural firebreaks (Wells 1965, 1970; Axelrod 1985). Thus, any factor that reduces fire likelihood, frequency, or intensity can be expected to allow trees to invade grasslands in areas where there is sufficient moisture for tree growth. The soil-mediated fire frequency hypothesis for the historical distribution of the prairies and woodlands of North Central and East Texas is consistent with both historical vegetation patterns and recent changes in the vegetation.

Presettlement and Early Settlement Conditions in the Post Oak Savannah

One of the major differences between the Post Oak Savannah of presettlement times and that of the present is that (at least in uncleared areas) there is currently much more woody vegetation than at the time of European contact. With the suppression of naturally recurrent fire, brush encroachment—or as it is sometimes called, thicketization—has occurred, resulting in a reduction in grasses and an increase in trees and shrubs. The term Post Oak Savannah thus does not accurately reflect much of the region's current woodland/forest vegetation. However, according to early settler and explorer reports, it is a more accurate description of presettlement conditions. For example, McClintock (1930) in 1846 described an area of Post Oak Savannah (Freestone County) as "High rol[l]ing prairie, very sandy and covered in places with low scrubby blackjacks, wholly worthless, except for fuel." In many areas there was probably a complex mosaic of prairie and woodland varying from quite open to more closed. According to Olmsted (1857),

> We came to-day upon the first prairie of any extent, and shortly after crossed the Trinity River [probably at the Houston Co.–Leon Co. line]. After having been shut in during so many days by dreary winter forests, we were quite exhilarated at coming out upon an open country and a distant view. During the whole day's ride the soil improved, and the country grew more attractive. Small prairies alternated agreeably with post-oak woods. The post-oak... forms a very prominent feature in Texas scenery and impressions. It is a somewhat small broad-leaved oak of symmetrical shape, and appears wherever the soil is light and sandy, in a very regular open forest growth. It stands in islands in the large prairies or frequently borders an open prairie through a large tract.

In describing another area of Post Oak Savannah in Leon County, Olmsted (1857) said,

> During the first part of the day we went over small, level, wet prairies, irregularly skirted by heavy timber, with occasional isolated clumps and scattered bushes. Most of the prairies have been burned over. Both yesterday and to-day we have been surrounded by the glare of fires at night.... After a few miles began post-oak, which changed to blackjack, and for the remainder of the day the country was as forbidding as a moor.

When fires (whether set by lightning or started by Native Americans), such as those described, were more frequent, there were thus probably significant expanses of prairie vegetation in some places, broken by the occasional area of venerable "giants," lending a park-like atmosphere to the landscape (Texas Parks and Wildlife 2002a). The following quote by Gregg (in Weniger 1984b), who described the forest in Fayette County in 1846, gives such an impression, "The timber about our camp resembled, for all the world, an old waste orchard of large apple trees...." Similarly, Roemer (1849) described the southern Post Oak Savannah (Colorado County) as follows:

> These forests... have a remarkable resemblance in winter to the cultivated German oak forests.... In other forests of North America many varieties of trees are usually found, but in the post-oak forests all are excluded with the exception of a few walnuts. Underbrush is also lacking. The soil upon which the post-oaks grow is usually of average fertility, but also often sterile and unproductive.... [There] is a wide zone where deposits of gravel and sand are found, and where farming cannot be carried on successfully. Here the land is covered with post-oaks.

However, Roemer (1849) described another area in the southern Post Oak Savannah somewhat differently: "Our trail led us several miles along the summit of a range of hills until it descended on the other side and took us into a dense oak forest." He also described the area between Gonzales and La Grange as "a sandy, hilly country, covered almost entirely with post oak forests...." Likewise, Captain Domingo Ramón in 1716 noted about an area in what is probably present-day Burleson County that the woods were so dense that "there were not enough hatchets and knives to open a passage" (Foster 1995), and De Córdoba (1858) described a portion of Post Oak Savannah in Robertson County as "heavily set with post-oak timber." Similarly, Smythe (1852) described part of eastern Limestone County as "... having a more uniform Post Oak growth, and better grass; occasionally a small Prairie begins to make its appearance..."

Perhaps more surprisingly, "bottom prairie," a particularly interesting presettlement community (not known at present), was noted as occurring adjacent to rivers such as the Brazos and Trinity (e.g., in Fayette and Bastrop counties), in some cases occupying thousands of acres (Jordan 1973; Jurney 1987). McClintock (in Jordan 1973) in the 1800s described such a bottom prairie in present-day Anderson or Freestone County as "cover'd with coarse grass as high as a horses [*sic*] back, yet so level...that when on horse back you can see every part of the plain."

Thus, while descriptions such as the following probably give an accurate broad-scale impression—"widely spaced *Quercus stellata* (Post Oak) and *Q. marilandica* (Blackjack Oak) with an understory of tall grasses such as Little Bluestem, Indian Grass, and Switch Grass" (Simpson 1988)—the vegetation of the Post Oak Savannah apparently varied considerably. In fact, the Post Oak Savannah was much more diverse vegetationally than generalizations imply, with a number of well-recognized communities (see discussion in vegetation section) (Bezanson 2000). The early print (a frontispiece probably depicting the Post Oak Savannah) in Olmsted's (1857) *A Journey Through Texas* gives a visual impression of this diversity—a forested stream bottom with dwarf palmetto and Spanish moss and a rolling savannah upland with scattered trees (Fig. 69).

Analyses of surveyor records from the 1800s (Jurney 1987) and modern vegetational analyses also give insight into presettlement conditions on the Post Oak Savannah. An upland "post oak, blackjack oak, and hickory complex" was found extensively in Post Oak Savannah counties such as Freestone (Jurney 1987), but a variety of other vegetation types were also present (e.g., slope forest, floodplain forest, open prairie, closed prairie, and bottom prairie). Areas of xeric sandylands (MacRoberts et al. 2002b) and various bog and wetland habitats (MacRoberts & MacRoberts 1998e) found today undoubtedly reflect community types that were present long before settlement. For example, core samples from various bogs in the Post Oak Savannah indicate that these wetlands date back to near the end of the last glaciation (approximately 18,000–15,000 years ago) (Bryant 1977; Bryant & Holloway 1985a, 1985b).

Further direct evidence about presettlement conditions comes from dendrochronological (tree-ring) research (see page 74 and page 125 for more details). Such studies indicate that old growth remnants of post oak-blackjack oak forest are present in a number of localities,

FIG. 69/ FRONTISPIECE FROM OLMSTED'S (1857) *A JOURNEY THROUGH TEXAS*, PROBABLY DEPICTING AN AREA IN THE POST OAK SAVANNAH, SHOWING A FORESTED STREAM BOTTOM WITH DWARF PALMETTO AND SPANISH MOSS AND A ROLLING SAVANNAH UPLAND WITH SCATTERED TREES.

and tree-ring chronologies, based on trees from about 200 to more than 300 years old, have been obtained from numerous localities throughout the region (Stahle et al. 1985; Stahle 2002; D. Stahle, pers. comm.).

In summary, presettlement vegetation of the Post Oak Savannah was probably a complex mosaic of prairie, post oak-blackjack oak savannah/woodland/forest, xeric sandyland, isolated pine-oak forests (e.g., "Lost Pines" of Bastrop County), dry-mesic forests (particularly in the north), bogs and other wetlands, and river bottom forests. Further, it should be kept in mind that when Europeans first observed the area, even though the vegetation pattern encountered was interpreted as static, it was "in a state of flux" (Smeins 1984). The situation observed was "only one slice through a continuous, multi-temporal series of changes. Climate had been changing and continued to change, fire frequency and intensity varied from place to place, the diverse herbivore fauna of the Early Holocene was gone and in its place the grasslands were dominated by one major herbivore, the bison" (Smeins 1984). In addition, Native

Americans were present and possibly had significant impacts on the vegetation through such mechanisms as increased fire frequency. Holloway et al. (1987), based on pollen analysis of Weakly Bog in Leon County, suggested that the Post Oak Savannah became established only between 1,500 and 2,000 years ago as increasing aridity resulted in a vegetational shift from oak woodland to savannah-like plant communities. While the pollen data may represent a significant one-time shift in the vegetation, there have been numerous changes in vegetation since the end of the last glaciation (Bousman 1998), and the continuing "state of flux" (Smeins 1984) mentioned above should not be forgotten. Because of all these complexities, the exact presettlement vegetation pattern is particularly difficult to estimate.

Animal life on the Post Oak Savannah was in general a mixture of that found on the adjacent Blackland Prairies and Pineywoods. Since detailed discussions are given for the Blackland Prairie and Big Thicket portion of the Pineywoods, no further discussion of presettlement animal life is given here.

As settlers moved into the area, much of the Post Oak Savannah was rapidly converted to cropland or pasture. In the words of David Diamond of the Texas Natural Heritage Program (in Bartlett 1995):

> The prairies are more fertile, yet initially were harder to plow because they were clay soils, and so they were not plowed as quickly as the Post Oak Savanna. A lot of the savannas were plowed. They grew cotton or other crops, and the soil wore out quickly because it wasn't as fertile as the Blackland Prairies. Later on, when the prairies were plowed, the Post Oak Savanna went back into rangeland of some sort and today is no longer plowed.

Today, much has been cleared and large areas are occupied by economically useful exotics. As pointed out by Simpson (1988), it is "used largely for 'improved' pasture, with vast acreages sodded to Bermuda Grass and seeded to Bahia Grass." On the other hand, large expanses of once-cleared land are now in second, third, or fourth growth woody vegetation. Thus, as a result of human impacts, little of the Post Oak Savannah is as it was during presettlement times.

Vegetation of the Post Oak Savannah

As mentioned above, while probably dominated originally to a significant extent by savannahs/open woodlands/forests of post oak and blackjack oak with a tall grass understory, the Post Oak Savannah was a complex mosaic of plant communities. The communities listed below, modified in part from Wilson (1989), Bezanson (2000), and MacRoberts et al. (2002b), represent the primary plant communities and give some indication of the complexity of the vegetation of the Post Oak Savannah. It should be noted, however, that there were and still are small areas of different, and in some cases, quite distinctive communities. An excellent example of this can be seen at the Gus Engeling Wildlife Management Area in Anderson Co., where Singhurst et al. (2003b) recently documented a number of interesting "vegetation alliances," some of which have similarities to communities of the Pineywoods. These include the Sand Post Oak-Bluejack Oak Alliance (*Quercus margaretta-Q. incana*), the White Oak-Southern Red Oak-Post Oak Alliance (*Quercus alba-Q. falcata-Q. stellata*), the Loblolly Pine-Southern Red Oak Alliance (*Pinus taeda-Quercus falcata*), the Overcup Oak Seasonally Flooded Forest Alliance (*Q. lyrata*), and the Planer Tree Seasonally Flooded Forest Alliance (*Planera aquatica*).

POST OAK-BLACKJACK OAK UPLAND SAVANNAHS, WOODLANDS, AND FORESTS—The dominant natural vegetation for much of the upland Post Oak Savannah was an open deciduous savannah/woodland/forest composed of *Quercus stellata* (post oak), *Q. marilandica* (blackjack oak), and other drought-tolerant species (e.g., *Carya texana*, black hickory) (Bezanson 2000) and an understory of tall grasses such as *Schizachyrium scoparium* (little bluestem),

FIG. 70/ PRAIRIE INCLUSION IN THE POST OAK SAVANNAH, LICK CREEK PARK, BRAZOS, CO. (PHOTO BY JIM MANHART).

Sorghastrum nutans (Indian grass), and *Panicum virgatum* (switch grass). Rather than a zone of homogeneous vegetation, areas such as prairie inclusions (Fig. 70) were interspersed with woody vegetation of various types, including savannah/woodland/forest. Limited areas of somewhat similar vegetation can still be found today in the Post Oak Savannah and also to the west in the East and West cross timbers and to the east in well-drained xeric areas of the Pineywoods (Bezanson 2000).

DRY-MESIC MIXED PINE-HARDWOOD UPLANDS—Wilson (1989) described a community in Franklin County (northern Post Oak Savannah) where the canopy layer was dominated by (in order) *Pinus echinata* (shortleaf pine), *Quercus alba* (white oak), *Liquidambar styraciflua* (sweetgum), *Quercus falcata* (southern red oak), and *Quercus stellata* (post oak). Somewhat similar dry-mesic mixed forests have been documented from Sanders Cove in Lamar County (Wilson & Hacker 1986) and are found in other portions of the Red River Area (an area often included in the Post Oak Savannah, but treated separately here—see page 127). Such forests correspond to the Dry-Mesic Mixed Pine-Hardwood Uplands as described by Van Kley (page 95) for the Pineywoods.

XERIC SANDYLANDS—This distinctive vegetation type is developed primarily on the extremely droughty, rapidly draining, deep, loose, sandy soils of the Carrizo Formation (McBryde 1933; MacRoberts et al. 2002b), with some occurrences on sandy soils developed from other layers such as the Queen City and Sparta formations (Yantis 1998). Even though rainfall can be plentiful, surface moisture lasts only a few days (Price & Singhurst 2001), and the typically white to tan sands (sometimes called "sugar sand") support species able to withstand very dry conditions. It is similar to and sometimes lumped with the post oak-blackjack oak upland forests and woodlands (e.g., Bezanson 2000), but differs significantly from that community. The Xeric Sandylands are equivalent to the "Dry Uplands on Deep Coarse Sands" discussed by Van Kley as occurring in the Pineywoods (see page 92). The Xeric Sandylands (also called the Deep Sands Ecosystem—Yantis 1998) are characterized by such tree species as *Quercus incana* (sandjack oak), *Q. margaretta* (sand post oak), *Q. stellata* (post oak), and *Carya texana* (black hickory), as well as a variety of typical herbaceous/understory species including (to name a few) *Asimina parviflora* (small-flower pawpaw), *Brazoria truncata* (blunt-sepal brazoria), *Cnidoscolus texanus* (Texas bull-nettle), *Cyperus grayoides* (Mohlenbrock's sedge), *Opuntia humifusa* (eastern prickly-pear), *Polanisia erosa* (large clammy weed), *Selaginella arenicola* subsp. *riddellii* (riddell's spike-moss), and *Yucca louisianensis* (Louisiana yucca) (MacRoberts et al. 2002b, 2002c). An indication of the rather extreme edaphic conditions is that in undisturbed areas soils are often cryptogamic—with lichens (*Cladonia* spp.) common (MacRoberts et al. 2002c). Because of the porous nature of the deep sands underlying this vegetation type, Herbaceous Seeps and Bogs (discussed below) and other types of wetlands are typically found in close proximity to (topographically below) the Xeric Sandylands.

Loblolly pine-post oak upland forest—Small disjunct areas of *Pinus taeda* (loblolly pine) are found in the southern Post Oak Savannah, primarily in the "Lost Pines" area of Bastrop County, but also on the north banks of the Colorado River in Fayette County and near Carlos in Grimes County (Jackson & Garner 1982). The Bastrop forest is characterized by loblolly pine, post oak, blackjack oak, and *Ilex vomitoria* (yaupon holly), with associated species including *Vaccinium arboreum* (farkleberry) and *Pteridium aquilinum* (bracken fern) (Bezanson 2000). The deep sandy soils and hilly topography apparently combine to allow the survival of these isolated loblolly pines approximately 100 miles to the west of most populations of this species (Texas Parks and Wildlife 2002b). The stand is considered a relict of a much more extensive Ice Age forest (Maxwell 1970). This unusual habitat is one of the last refuges for the endangered Houston Toad, *Bufo houstonensis* (Texas Parks and Wildlife 2002a).

Eastern red-cedar chalk glades—Bezanson (2000) indicated that "Glades communities occur very infrequently at scattered sites in the Post Oak Savannahs and Blackland Prairies on ridges where the Annona, Gober, and Austin chalk formations are exposed." "Cedar glades" are well known in the southeastern U.S. and adjacent areas (see e.g., Baskin & Baskin 1985, 2000), and a comparison of glades in the Post Oak Savannah with the better studied areas to the east is needed. A detailed comparison with the "chalkland prairie biome" described by Stanford (1995) for areas of very thin soil on exposed outcrops of the Austin Chalk on the Blackland Prairie is also needed.

The glades of the Post Oak Savannah may support thin-soiled grassland communities with *Bouteloua rigidiseta* (Texas grama), *Bouteloua curtipendula* (side-oats grama), *Sporobolus vaginiflorus* (poverty dropseed), *Schizachyrium scoparium* (little bluestem), and other grasses (Bezanson 2000). Bezanson (2000) also noted that some glades could be dominated by "rock moss" (*Sedum pulchellum*[?]) and that the bluegreen bacterium, *Nostoc commune*, was often abundant. Common forbs include *Penstemon cobaea* (cobaea penstemon), *Echinacea* spp. (coneflowers), *Paronychia virginica* (Parks' nailwort), and numerous others. As indicated by the name of the community, scattered individuals of *Juniperus virginiana* (eastern red-cedar) are usually present. Bezanson (2000) pointed out that these "communities are uncommon and further study is warranted." Given the importance of fire during presettlement times and the susceptibility of *Juniperus virginiana* to fire, such glade communities probably occupied very limited areas. In this regard, it is interesting that Amos A. Parker (1968), who traveled through the area in 1834, noted for an area west of the Trinity River and east of the Brazos, that "Among the trees in the swamps, I noticed the red cedar, today, for the first time." Roemer (1849) also noted that red-cedars "are found singly among other trees in the lowlands of Texas, but nowhere forming a continuous forest of their own." These statements would suggest that *Juniperus virginiana* was somewhat limited in occurrence during presettlement times, apparently being more common in less fire-prone areas.

HERBACEOUS SEEPS AND BOGS—Herbaceous seeps and bogs (including types referred to as muck bogs and possum haw bogs) are well known from a number of localities in the Post Oak Savannah and have been discussed in detail by Nesom et al. (1997) and MacRoberts and MacRoberts (1998e, 2001). Examples on public land include those at Fort Boggy State Park in Leon County, Gus Engeling Wildlife Management Area in Anderson County (Telfair 1988; Singhurst et al. 2003b), and the Ottine Swamp at Palmetto State Park in Gonzales County.

Several sandstone formations (e.g., Queen City, Sparta) contribute to the formation of these bog habitats (Yantis 1998; Bridges & Orzell 1989a, 1989b; Bezanson 2000), but it is the Carrizo Formation that is particularly important in this regard. Because water moves easily through the sandy, porous Carrizo Formation, bogs and other wetlands are distributed along a line corresponding to the outcrop of the Carrizo at the surface. This line of wetlands runs roughly northeast to southwest from Henderson County to Palmetto State Park in Gonzales County (Bullard 1936; Rowell 1949; Kral 1955; Bradsby et al. 2000). Specific examples of the resulting bogs include several near Flynn in Leon County, Mill Creek and Southworth bogs in Robertson County, and Patschke, Boriak, and Wall bogs in Milam County. The xeric sandylands community that occurs on the Carrizo sands and the association of this community with seepage areas, "muck bogs," "possum haw bogs," and other wetlands were discussed by MacRoberts et al. (2002b). In essence, the adjacent xeric sandylands are the water source for the wetlands. Their deep, sandy, porous soils serve as a reservoir for rainwater that eventually percolates through the sand, reaches an impermeable layer beneath, and then moves laterally until it seeps out on a hillside, feeding seeps, springs, and wetlands (MacRoberts et al. 2002b). The Ottine Swamp (Gonzales County) is a particularly striking example of this type of habitat. Here a disjunct remnant population of *Sabal minor* (dwarf palmetto) and numerous other typically more eastern species have been able to survive since glacial times due to the unique hydrological circumstances. As pointed out by Bryant (1977), "Three elements of the Post Oak Savanna combine to form a favorable environment for the formation of peat bogs in central Texas: (1) the region is dissected by a number of major river systems (Sabine, Neches, Trinity, Brazos, Colorado, Guadalupe, San Marcos, and San Antonio Rivers) which isolate numerous ox-bows as they meander back and forth across the floodplains; (2) the acidic sandy loam and clay soils keep most small enclosed bodies of water (such as ox-bows and ponds) slightly acidic thereby favoring the growth of bog plants such as *Sphagnum* moss; and (3) the rolling and hilly topography causes stream dissection of the underlying permeable Carrizo Sands aquifer, thereby creating numerous seeps and artesian springs."

Some of the bogs (e.g., those in Leon and Robertson counties) are characterized by plants such as *Sarracenia alata* (pitcher plant), *Drosera* spp. (sundew), *Alnus serrulata* (hazel alder), *Myrica cerifera* (southern wax myrtle), *Pogonia ophioglossoides* (rose pogonia), *Lycopodiella appressa* (Chapman's clubmoss), *Sphagnum* spp. (peat moss), *Xyris* spp. (yellow-eyed-grass), *Sagittaria* spp. (arrowhead), *Utricularia* spp. (bladderwort), and numerous species of sedges and rushes. There are often species associated more with eastern forests, such as *Nyssa sylvatica* (black-gum) and *Decodon verticillatus* (water-willow). Low-lying woods around the bogs often feature such species as *Ilex opaca* (American holly), *Betula nigra* (river birch), *Peltandra virginica* (Virginia arrow arum), and various ferns (Reed 1997). Plants rare in Texas or with surprising disjunct distributions often are associated with these bog habitats. For example, Bridges and Orzell (1989a) collected *Cladium mariscoides* (twig-rush) from bogs in Anderson and Henderson counties—this is a very surprising discovery since twig-rush is a primarily northern fen/bog species occurring nearest to Texas in Florida, Illinois, Tennessee, and South Carolina (Tucker 2002c)—disjunctions of hundreds of kilometers. The herbaceous seeps and bogs of the Post Oak Savannah share some similarities with the Wet Herbaceous Seeps/hillside bogs/hanging bogs of the Pineywoods, but in general they have fewer species than the floristically richer bogs further east (Bridges & Orzell 1989b). In addition, "muck bogs," limited in Texas to the Post Oak Savannah, differ from most other East Texas bogs in a number of characteristics (e.g., they can have deep peat deposits) and generally share fewer than 50% of their species with other bog types (e.g., hillside seepage bogs) further east (MacRoberts & MacRoberts 1998e, 2001).

Many bog species (e.g., *Sarracenia alata*, *Eriocaulon* spp., *Rhynchospora* spp., *Xyris* spp.) reach their northwesternmost distribution in the state— and in the southeastern U.S.— in bogs at the Gus Engeling Wildlife Management Area in Anderson County (Singhurst et al. 2003b). As such, these bogs appear to "represent the western limit of the southeastern flora at this latitude (31º 58' N)" (Singhurst et al. 2003b).

WATER OAK-POST OAK FLOODPLAIN FORESTS—Floodplain forests in the Post Oak Savannah (Fig. 71) tend to be dominated by various oak species, the particular forest composition depending on proximity to the Pineywoods—in general, there is higher species diversity to the east. In some areas, *Quercus nigra* (water oak) and *Quercus stellata* (post oak) "may be codominant in low-lying flatwoods, along drainages, and in floodplains, with elms, green ash, eastern red-cedar, and other species of adjacent mesic woods or floodplains" (Bezanson 2000). Vines, including *Vitis* spp. (grapes), *Toxicodendron radicans* (poison-ivy), and *Berchemia scandens* (rattan-vine), and a ground layer of *Arundinaria gigantea* (switchcane), sedges (various Cyperaceae), *Elymus virginicus* (Virginia wild rye), *Chasmanthium* species (wood-oats), and other grasses and numerous forest forbs are typical. In the eastern part of the region, southeastern species such as *Quercus phellos* (willow oak) may be present (Bezanson 2000).

FIG. 71/ FLOODPLAIN FOREST IN POST OAK SAVANNAH, LICK CREEK PARK, BRAZOS, CO. (PHOTO BY JIM MANHART).

SUGARBERRY-ELM FLOODPLAIN FORESTS— Wooded slopes and floodplains of smaller streams draining the base-rich soils of the Blackland Prairies and adjacent Post Oak Savannahs are characterized by forests of *Ulmus crassifolia* (cedar elm), *Celtis laevigata* (sugarberry), *Fraxinus pennsylvanica* (green ash), *Ulmus americana* (American elm), *Acer negundo* (boxelder), *Carya illinoinensis* (pecan), *Sapindus saponaria* (western soapberry), and other species (Bezanson 2000). "Sugarberry, elms, green ash, and boxelder may be common in early-successional woodlands in drainages and floodplains throughout eastern and central Texas. Vines are often abundant, including Virginia-creeper, rattan-vine, poison-ivy, and pepper-vine. Giant ragweed and other weedy forbs are often abundant. If relatively undisturbed, the understory should include long-leaf spikegrass, sedges, Virginia wild rye, white avens, ruellias…, and other forbs and grasses. River banks

FIG. 72/ SEDGE MEADOW IN FLOODPLAIN FOREST OF POST OAK SAVANNAH, LICK CREEK PARK, BRAZOS, CO. (PHOTO BY JIM MANHART).

may support large specimens of American elm, eastern cottonwood, pecan, sycamore, and in some basins bald-cypress" (Bezanson 2000). One striking feature of some of these forests is the complete absence of a shrub layer; there is a canopy of elm and other tree species and a lush carpet of grasses, sedges (sometimes a near monostand of *Carex cherokeensis*, Cherokee caric sedge), and herbs. Such areas may be called "sedge meadows" (Fig. 72). A good example occurs in Lick Creek Park in Brazos County. Telfair (1988) also noted that some original bottomlands were open and dominated by large trees, with little underbrush and a park-like appearance. Bezanson (2000) indicated that Sugarberry-elm floodplain forest is a very widespread vegetation type in Texas, occurring in all vegetation zones except the Pineywoods, High Plains, and Trans-Pecos.

SANDSTONE OUTCROP COMMUNITIES—A botanically interesting type of community that adds variety to the flora but which is extremely limited in area is that found on rock outcrops (e.g., Oakville sandstone). For example, near Kountze Bayou in Burleson County, an Oakville sandstone outcrop at Old River Ranch hosts *Ungnadia speciosa* (Mexican buckeye), *Celtis laevigata* var. *reticulata* (netleaf hackberry), *Diospyros texana* (Texas persimmon), and *Tinantia anomala* (false dayflower), plants more typical of the Edwards Plateau than of the Post Oak Savannah. *Spigelia loganioides* (Florida pinkroot) is present, though this plant is associated with the South Texas Plains and the Gulf Prairies and Marshes. Other Oakville outcrops include areas northeast of the town of Navasota in Grimes County (Reed et al. 2002) and Monument Hill and Kreische Brewery State Historic Sites in Fayette County. The Grimes County localities feature a similar assemblage of woody species, and also have many interesting distributional records—the easternmost occurrence of *Lygodesmia texana* (Texas skeleton plant) and one of the two known localities of the East Texas endemic Navasota false foxglove (*Agalinis navasotensis*) (Canne-Hilliker & Dubrule 1993). Also present are herbs such as *Lesquerella gracilis* (white bladderpod) which are also more typical of the Edwards Plateau. The area around Sugarloaf Mountain, near Gause in eastern Milam County, features *Polygonella parksii* (Parks' jointweed), which is more common in the South Texas Plains, and *Euphorbia* [*Chamaesyce*] *geyeri* var. *geyeri* (Geyer's euphorbia), which is more common farther west.

Conditions Today on the Post Oak Savannah

As indicated earlier, most of the Post Oak Savannah probably bears little resemblance to its presettlement state. It is thought to be much more densely wooded now than it was two hundred years ago. With settlement came the control of fire (fire suppression), which meant that the woody underbrush was allowed to grow up rather than being periodically cleared away (resulting in brush encroachment/thicketization). In addition, fencelines created corridors for trees and shrubs to move into open areas—so much so that long-gone fencelines can be seen on aerial photos as long, thin woodlands only a few trees wide. These in some cases served as seed sources for further encroachment. Common fencerow species include *Ilex vomitoria* (yaupon), *I. decidua* (possumhaw), *Maclura pomifera* (horse apple, bois d'arc), *Celtis laevigata* (sugarberry), *Ulmus alata* (winged elm), *Prosopis glandulosa* (mesquite), *Vitis mustangensis* (mustang grape), and *Rubus trivialis* (southern dewberry).

It must also be noted that even much of what appears "undisturbed" is often second or third (or fourth, etc.) growth. Large areas of the region were cleared and planted in cotton until the 1920s and 1930s, when cotton production in Texas shifted largely to irrigated areas in the coastal plain and high plains. Now, a large portion of the Post Oak Savannah is maintained as pasture (planted with exotic grasses) or in cultivated acreage of sorghum, soybeans, hay, and cotton.

Currently, the few undisturbed open areas relatively free of grazing pressure have a grass flora probably somewhat reflective of presettlement conditions. These areas have *Schizachyrium scoparium* (little bluestem), *Andropogon* spp. (bluestem), native *Bothriochloa* spp. (bluestem), *Aristida* spp. (threeawn), *Panicum* spp. (especially *P. virgatum*—switch grass), *Dichanthelium* spp. (rosette grass), *Tridens* spp. (tridens, purpletop), *Sporobolus* spp. (dropseed), *Nassella leucotricha* (Texas winter grass), *Sorghastrum* spp. (Indian grass), and *Paspalum* spp. (paspalum). Native legumes such as *Baptisia bracteata* (wild indigo) and composites such as *Silphium* spp. (rosinweed) are common.

Along large areas of roadside and where grazing disturbs the native flora, the above-mentioned grass taxa are entirely or largely replaced by exotic species including *Bothriochloa ischaemum* (King Ranch bluestem), *Cynodon dactylon* (Bermuda grass), *Paspalum notatum* (bahia grass), *Sorghum halepense* (Johnson grass), *Avena fatua* (oats), *Lolium perenne* (perennial rye grass), and *Bromus catharticus* (rescue grass). Adaptable native perennials such as *Helianthus annuus* (sunflower), *Baccharis* spp. (groundsel-tree), and *Solidago canadensis* (common goldenrod) are prominent in the fall.

Overgrazed pastures are characterized by such species as *Helenium amarum* (bitterweed), *Solanum elaeagnifolium* (silverleaf nightshade), *Croton capitatus* (woolly croton), and *Euphorbia bicolor* (snow-on-the-prairie). Such overgrazed areas are obvious at a glance due to the huge populations of these inedible or unpalatable species. In some cases a large field can have literally hundreds of thousands or even millions of individuals of these and other toxic, spiny, or otherwise inedible species. Abusive overgrazing is an excellent example of a situation whereby the abuser of the environment (the individual responsible for the overgrazing) directly pays the price for his damage—the virtually complete loss of the grazing resource.

Present-day upland stands of trees and shrubs are often dominated by *Quercus stellata* (post oak) and *Ilex vomitoria* (yaupon). Where dense post oak woodland has developed, a nearly-closed canopy of post oak and *Ulmus alata* (winged elm) exists, with *Quercus marilandica* (blackjack oak) also common. Some woodlands also have a strong component of *Carya texana* (black hickory). Where there is sufficient moisture, *Quercus nigra* (water oak), *Q. phellos* (willow oak), and *Gleditsia triacanthos* (honey locust) are present. The understory layer in such post oak woodlands is composed largely of yaupon, *Vaccinium arboreum* (farkleberry), *Callicarpa americana* (American beauty-berry), *Crataegus* spp. (hawthorns), and *Forestiera ligustrina* (privet forestiera). *Sideroxylon lanuginosum* (gum bumelia) and introduced species of *Ligustrum* (privet) can also be noted. Common carpet-level plants include *Chasmanthium sessiliflorum* (narrow-leaf wood-oats), *Hypericum hypericoides* (St. Andrew's cross), *Symphyotrichum* spp. (aster), and *Spiranthes* spp. (ladies'-tresses orchids). With the exception of one location in the Pineywoods, the Post Oak Savannah is the only region where populations of the endangered Navasota ladies'-tresses (*S. parksii*) are found. There is also usually a strong vine component to Post oak woodlands, with grape (*Vitis mustangensis*, *V. rotundifolia*, etc.), greenbrier (*Smilax*, especially *S. bona-nox*), *Campsis radicans* (trumpet creeper), and *Berchemia scandens* (supplejack) often present. Where the flora has been disturbed, *Toxicodendron radicans* (poison-ivy) is common.

The Post Oak Savannah as Remnant Old Growth Forests

A striking feature of the Post Oak Savannah, the adjacent Red River Area, and particularly the Cross Timbers to the west of East Texas is that these vegetational areas contain significant remnants of old growth or virgin forest/woodland (Stahle & Hehr 1984; Stahle et al. 1985). According to Stahle (1996a), "… literally thousands of ancient post oak-blackjack oak forests still enhance the landscapes and biodiversity of … the Cross Timbers along the eastern margin of the southern Great Plains.…" As a result, this is one of the largest relatively unaltered forest vegetation types in the eastern United States (Stahle & Hehr 1984: Ancient Cross Timbers Consortium 2004). The small stature and often poor growth form of post and blackjack oaks made these species commercially unattractive and therefore less subject to systematic logging than other more productive forest types. Extensive dendrochronological (tree-ring) data from post oaks in East Texas (Post Oak Savannah and Red River Area) and adjacent areas of the Cross Timbers indicate that old growth remnants of post oak-blackjack forest can be found in numerous localities throughout the region. However, while extensive remnants remain, they are often highly degraded by various human activities such as heavy grazing or selective cutting, and their authenticity is rarely noticed or protected (Stahle & Hehr 1984; Stahle 1996a). Examples of old growth forests in East Texas are found in such sites as Brazos River in Milam county, Capote Knob and Ecleto Creek in Guadalupe County, Coleto Creek in Goliad County, Pecan Bayou in Red River County, and Yegua Creek in Burleson County (Stahle et al. 1985; Stahle 2002; D. Stahle, pers. comm.). Tree-ring chronologies extending from about 200 to more than 300 years have been obtained from these East Texas sites, with the oldest individual trees dating back to 1658 (D. Stahle, pers. comm.). Because of the low availability of moisture, rocky or infertile soil, and other factors, the trees of these relict forests, while old, have a slow rate of growth and are of relatively small size, the canopy ranging from only about 6 to 15 meters high (Stahle et al. 1985). Ironically, it is the poor conditions under which such trees grow that have resulted in their great age and survival. The stunted size and the poor quality of the wood obtainable from these ancient, often hollow and

FIG. 73/ AN ANCIENT *QUERCUS STELLATA* FOREST DRAWN BY RICHARD P. GUYETTE; USED WITH PERMISSION OF THE ARTIST. TWISTED STEMS, DEAD TOPS AND BRANCHES, CANOPIES RESTRICTED TO A FEW HEAVY LIMBS, BRANCH STUBS, FIRE AND LIGHTNING SCARS, LEANING STEMS, EXPOSED ROOTS OR ROOT COLLARS, AND HOLLOW VOIDS ARE ALL HINTS OF SIGNIFICANT AGE (STAHLE 1996A, 1996B). WHILE THE DRAWING IS FROM THE OZARK PLATEAU, SUCH TREES, SOME OF WHICH ARE MORE THAN 300 YEARS OLD, CAN BE FOUND IN THE POST OAK SAVANNAH OF EAST TEXAS.

damaged trees have prevented their destruction up to the present time. Such old growth forests or ancient individual trees can often be recognized by environmental factors such as steep, rocky, infertile soils or by the appearance of the individual trees (Stahle & Chaney 1994). Twisted trunks, dead tops and branches, canopies restricted to a few heavy limbs, branch stubs, fire and lightning scars, leaning trunks, exposed roots or root collars, and hollow voids are all hints of significant age (Stahle 1996a, 1996b) (Fig. 73).

The tree-ring chronologies obtained from these relict forests are a valuable source of information about past climate and are particularly important at a time when climate change is a topic of national and global concern. These forests also represent an irreplaceable resource and an unparalleled living record about the East Texas area prior to the time of European settlement. Further, the few relatively unaltered remnants may represent areas of significant remaining biodiversity in an otherwise highly altered, increasingly homogeneous, and diversity poor environment. Finally, they provide a unique opportunity to conserve some of the last remaining old growth/virgin North American forests.

RED RIVER AREA
AREA ADJACENT TO THE RED RIVER

There is a narrow band of vegetation, found on the primarily sandy soils adjacent to the Red River (Fig. 74) in the northernmost portion of East Texas, specifically in the northern parts of Bowie, Red River, Lamar, Fannin, and Grayson counties, that we are referring to as the Red River Area. The specialized habitats associated with the Red River have afforded plants sites where they could survive long-term changes in climate and have also provided a two-way migration corridor allowing plant species to extend their ranges westward from the forested areas to the east—and also eastward from the drier habitats to the west (Elisens et al. 2004). This region is in various ways quite different from the vegetational areas with which it has sometimes been included (see Fig. 3; Correll & Johnston 1970; Hatch et al. 1990). The westernmost part of this band, in Grayson County, has typically been classified as part of the Cross Timbers and Prairies (vegetational area 5), and indeed it closely resembles and grades into the East Cross Timbers. The eastern part of the band has often been classified as part of vegetational area 3 (Post Oak Savannah) (Correll & Johnston 1970; Hatch et al. 1990). Such a classification is justified, since portions of the vegetation do resemble the post oak-dominated savannahs/woodlands typical of vegetational area 3. However, significant components of the vegetation more typically associated with eastern or southeastern Texas (vegetational area 1—Pineywoods) extend west along the Red River in microhabitats with special soil or moisture conditions. In fact, many areas of northern Lamar, Bowie, and Red River counties are clearly tied vegetationally to the Pineywoods—a number are even dominated by pines. A specific example is the *Pinus echinata-Quercus alba* forest documented for Lamar County by Wilson and Hacker (1986). This forest is somewhat similar to the Dry-Mesic Mixed Pine-Hardwood Uplands described for the Pineywoods by Van Kley (page 95). Based on such vegetational patterns, Wilson (1990) has argued that the generally accepted boundaries of the Pineywoods in northeastern Texas

FIG. 74/ PHOTOGRAPH OF THE RED RIVER FROM CARPENTER'S BLUFF BRIDGE IN NORTHEASTERN GRAYSON CO. (PHOTO BY GMD).

are placed too far to the east and that there has been significant recession of the Pineywoods due to human impact beginning as early as 1815 (e.g., Jonesboro in Red River County, the site of the earliest Anglo settlement in Texas).

In northern Lamar County, the aspect of the vegetation is definitely similar to the mixed deciduous or deciduous-pine forests typical of some regions of the Pineywoods. Tall stands of *Quercus falcata* (southern red oak), abundant *Liquidambar styraciflua* (sweetgum), *Pinus taeda* (loblolly pine), *P. echinata* (shortleaf pine), *Quercus alba* (white oak), *Acer rubrum* (red maple), *Betula nigra* (river birch), *Carpinus caroliniana* (American hornbeam), *Crataegus marshallii* (parsley hawthorn), bottomland brakes of *Arundinaria gigantea* (giant cane), *Calycocarpum lyonii* (cupseed), *Trachelospermum difforme* (climbing dogbane), and herbs such as *Lysimachia lanceolata* (lance-leaf loosestrife), *Monotropa hypopithys* (American pinesap), *Osmunda cinnamomea* (cinnamon fern), *Polygala sanguinea* (blood milkwort), *Porteranthus stipulatus* (Indian-physic), *Saccharum contortum* (bent-awn plume grass), *Sacciolepis striata* (American cupscale), *Saururus cernuus* (lizard's-tail), *Stachys tenuifolia* (slender-leaf betony), and *Veronicastrum virginicum* (Culver's-physic) are just a few examples of eastern plants found in Lamar County. Even farther west, in Fannin County, there are still isolated pockets of eastern Texas vegetation (e.g., Talbot property). Species reaching to or near their western limits there include *Quercus falcata* (southern red oak), *Q. nigra* (water oak), *Q. phellos* (willow oak), *Nyssa sylvatica* (black-gum), *Sassafras albidum* (sassafras), *Chasmanthium sessiliflorum* (narrow-leaf wood-oats), *Erechtites hieraciifolia* (American burnweed), *Luzula bulbosa* (bulb woodrush), *Monotropa uniflora* (Indian-pipe), *Pedicularis canadensis* (common lousewort), *Pycnanthemum albescens* (white-leaf mountain-mint), *Sorghastrum elliottii* (slender Indian grass), and *Woodwardia areolata* (narrow-leaved chain fern). Grayson County, the next county to the west, does not have areas dominated by eastern Texas plants as do Lamar and Fannin counties, but there is a significant eastern Texas component to the vegetation. Numerous plant species reach their western limits in Grayson County, including *Agrimonia rostellata* (woodland groovebur), *Asimina triloba* (common pawpaw), *Cinna arundinacea* (stout wood reed), *Desmodium glutinosum* (tick-clover), *Impatiens capensis* (spotted touch-me-not), *Liatris aspera* (tall gayfeather), *Monarda lindheimeri* (Lindheimer's beebalm), *Podophyllum peltatum* (may-apple), *Polygonatum biflorum* (Solomon's-seal), *Quercus velutina* (black oak), *Thalictrum arkansanum* (meadowrue), *Triosteum angustifolium* (yellow-flowered horse-gentian), and *Vaccinium arboreum* (farkleberry). A few typically eastern plants extend even farther west into Cooke and Montague counties and beyond.

More typically western plants also extend eastward in the Red River Basin, though not as commonly as eastern plants range westward. One example of such a western species is *Heliotropium convolvulaceum* (bindweed heliotrope), known in Texas primarily from the Panhandle and Trans-Pecos but extending east in extremely dry sandy habitats along the Red River to Grayson and Lamar counties. Two other examples of species extending east in the same sandy habitats to Grayson County are *Croton texensis* (Texas croton) and *Euphorbia hexagona* (green spurge). Yet another example is *Dalea lanata* (woolly dalea), confined in Texas largely to the Panhandle but extending east along the Red River to Cooke and Grayson counties.

The area adjacent to the Red River in Grayson County is further complicated by the presence of the Preston Anticline, a post-Cretaceous (Bradfield 1957) fold in the sedimentary strata that brought deeper layers to the surface (Bullard 1931). In places the river valley is two hundred feet below the surrounding area and creeks have cut deep canyon-like valleys. The overall topography near the Red River is thus very rugged (Bullard 1931). Parker (1856) in an early account described the Texas shore of the Red River as "very bold, presenting a stratification of red clay and white sand, giving a striking and very peculiar appearance in the distance, like chalk cliffs." This different topography and the appearance at the surface of deeper strata otherwise only found far to the west in areas such as the Grand Prairie and West Cross Timbers (e.g., Goodland limestone, Duck Creek limestone, Trinity Group sands) make the vegetational picture of the area more complex. Some of the oldest bedrock found on the surface in East Texas occurs in Grayson County (Lower Cretaceous Trinity Group sands). Many microhabitats, and thus increased biological diversity, result from the outcropping of these deeper strata in the county. For example, in a number of places along the Red River (e.g., Eisenhower State Park, Preston Peninsula, Delaware Bend), the Goodland Limestone forms flat limestone outcrops at the top of rugged cliffs. These areas of very thin soil over flat rock and adjacent slopes and ravines have numerous interesting plant species often found nowhere else in Grayson County and only rarely anywhere in East Texas. These include *Coryphantha missouriensis* (plains nipple cactus), *Minuartia michauxii* var. *texana* (rock sandwort), *Talinum calycinum* (rock-pink), *Dodecatheon meadia* (common shooting-star), and *Melica nitens* (tall melic).

In the counties adjacent to the Red River, the presence of sandy and clayey soils in close proximity to one another, as well as some intermediate type soils, allows species normally separated ecologically to occur together. This sometimes results in hybridization. An excellent example can be seen in Fannin and Grayson counties where three species of *Baptisia* (wild indigo) and all three possible hybrids are found in close proximity (Kosnik et al. 1996). These occur either in what early settlers called "mixed soil" or in the area of the Preston Anticline where radically different soil types are found over quite small distances.

The basic pattern of the Red River Area is thus one of the eastern Texas forests grading gradually into the much less diverse and more xeric woodlands usually referred to as the Cross Timbers. From an even broader perspective, as discussed in the overview, the entire western portion of East Texas (Post Oak Savannah, Blackland Prairie) and the Red River Area are in an ecotone or ecological transition zone between two extensive ecosystems, the eastern North American deciduous forest and the central North American grassland or prairie (MacRoberts & MacRoberts 2003b). In virtually any ecotone, significant areas of vegetational interdigitation are seen; rarely is there a clearcut boundary. One type of vegetation extends deep into another along streams, in-pockets are found in protected areas, and special soil conditions often result in a patchwork pattern of vegetation that at the strictly local level seems confusing. The geographically intermixed pattern of the Blackland Prairie and Post Oak Savannah, the irregular boundaries of all the East Texas vegetation zones, and the unusual mixture of species seen in the Red River Area are all excellent examples of these phenomena.

BLACKLAND PRAIRIE

OCCURRENCE OF THE BLACKLAND PRAIRIE

The Blackland Prairie of Texas (Figs. 75, 76) is a well-defined band stretching roughly three hundred miles from the Red River (Oklahoma border) south to near San Antonio (Chambers 1948; Sharpless & Yelderman 1993). It is widest at the north, extending from Grayson County east to near Clarksville in Red River County. It narrows to the south, tapering to a point near San Antonio (Figs. 76, 77). The main belt of the Blackland Prairie occupies roughly 5.5% of the total land area of Texas and is a region slightly larger than the state of Maryland. It coincides almost exactly with a belt of outcropping Upper Cretaceous marine chalks, marls, and shales (Hayward & Yelderman 1991) that upon weathering form the characteristic black, calcareous, alkaline, heavy clay, "black waxy" soil. To the southeast of the main belt, within the Post Oak Savannah, are two small outlying areas of Blackland Prairie, the San Antonio Prairie (so named because it follows the old San Antonio road, but also known as the "String Prairie" [Jordan 1973; Jordan et al. 1984]) and the Fayette Prairie. Both prairies occur on Tertiary age deposits which upon weathering yield soils with significant amounts of clay—a condition atypical of the generally sandy soils of most of the Pineywoods and Post Oak Savannah. In total (including the two outliers), the Blackland Prairie occupies about 45,600 square kilometers (17,600 square miles) or 4.6 million hectares (11.3 million acres) and represents about 6.5% of the land area of Texas. Roughly speaking, the Texas Blacklands are bounded on the north by the Red River, on the east by the Post Oak Savannah (also called the Oak-hickory) vegetational area, and on the west by the East Cross Timbers and the Lampasas Cut Plain. North of Sherman in Grayson County, the trend of the

FIG. 75/ PHOTOGRAPH OF A BLACKLAND PRAIRE REMNANT AT THE NATURE CONSERVANCY'S CLYMER MEADOW PRESERVE IN NORTHWESTERN HUNT CO. NEAR GREENVILLE (PHOTO © ROBERT W. PARVIN).

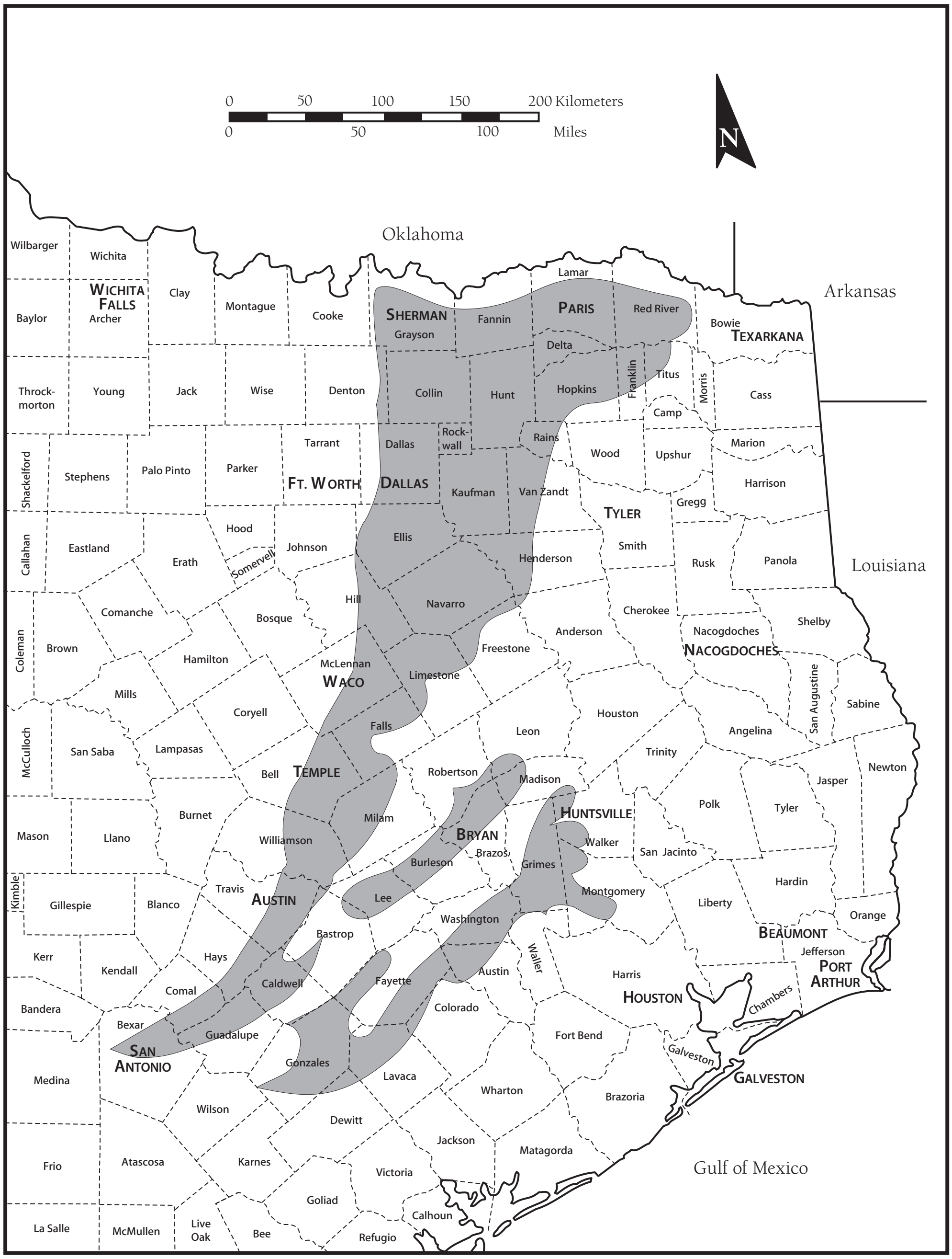


Fig. 76/ Generalized map of the Blackland Prairie vegetational area. Figure produced by BRIT/Austin College; reproduction of this image does not require copyright permission.

Blacklands undergoes a shift in direction, turning from north-south to east-west, before ending near Clarksville in Red River County. Topographically, the Blackland Prairie is a nearly level to gently rolling dissected plain (Hallmark 1993); elevations range from about 300 to 800 feet (92 to 244 meters) above sea level (Thomas 1962). In this work we use the terms Blackland Prairie and Blacklands interchangeably.

Geology of the Blackland Prairie

The main belt of the Blackland Prairie is on an erosional landscape developed from easily erodible Upper Cretaceous shales, marls, and limestones that dip gently to the east (Hayward & Yelderman 1991). It originally consisted of four somewhat different parallel north-south bands of vegetation: the Eagle Ford Prairie, the Whiterock Prairie, the Taylor Black Prairie, and the Eastern Transitional Prairie. These all correspond to underlying geologic layers (Hayward & Yelderman 1991). The two outlying areas of Blackland Prairie to the southeast of the main belt, the San Antonio Prairie and the Fayette Prairie, developed on younger Tertiary sediments and likewise reflect the influence of geology on vegetation.

The westernmost and geologically oldest portion of the Blackland Prairie, known as the Eagle Ford Prairie, developed on the Eagle Ford Shale, Upper Cretaceous material deposited about 92 to 90 million years ago (Hayward & Yelderman 1991). This layer crops out just east of the Woodbine Sand, on which the East Cross Timbers are found. While variable, the Eagle Ford Shale is principally a dark bluish-gray to nearly black shaly clay (Bullard 1931) that weathers to form black vertisol soils supporting prairie vegetation.

Outcropping to the east of the Eagle Ford Shale is the slightly younger Austin Chalk, deposited about 90 to 85 million years ago. This layer, which supports the Whiterock Prairie, forms the elevated backbone or "axis" of the Blacklands (Hayward & Yelderman 1991). It is a strikingly white, very fine-grained limestone, called chalk, made primarily of millions of calcium carbonate cell walls of tiny marine algae and foraminiferans but with substantial amounts of clay. Somewhat similar deposits make up the famous white cliffs of Dover in southern England and can be used to write with like blackboard chalk (which is actually calcium sulfate [gypsum]). The Austin Chalk is a relatively resistant, hard layer (Dallas Petroleum Geologists 1941) compared to the surrounding shales, and because of this hardness, it forms a rather conspicuous escarpment from Sherman to Dallas and south to Austin. This topographic feature is sometimes referred to as the "white rock escarpment," "white rock scarp," (Hill 1901) or "white rock cuesta," and although it never exceeds 200 feet in elevational difference from the surrounding terrain (usually much less), it is the most conspicuous topographic feature in the Texas Blacklands (Hill 1901; Montgomery 1993). It typically crops out as a west-facing bluff or escarpment overlooking a prairie formed on the less resistant Eagle Ford Shale (Bullard 1931). In striking contrast to the numerous resistant layers of the Grand Prairie, the Austin Chalk is the only resistant, escarpment-forming layer underlying the entire Blackland Prairie. As a result, most of the Blackland Prairie is gently rolling, in contrast to the sharper, more angular topography of the Grand Prairie (Hill 1901) to the west. Surprisingly, the extremely white Austin Chalk weathers to form a sticky black soil (Fig. 29 on page 60), typically thinner than, but similar to, that derived from the Eagle Ford Shale (Bullard 1931). Both Vertisols and Mollisols can be found on areas of Austin Chalk. Where this soil is eroded away, as on stream banks, a distinctive flora can be found on the exposed chalky limestone (see description under vegetation). Despite their biological diversity, these exposed chalky areas are of little commercial value and are thus often destroyed by contouring or other types of "remediation."

The layers that crop out to the east of the Austin Chalk are the Taylor marls and sandy marls, laid down about 79 to 72 million years ago. The Taylor Blacklands, the largest of the four Blackland Prairie belts, occurs on the soils derived from these rocks (Hill 1901; Hayward & Yelderman 1991). In fact, Taylor sediments underlie about two-thirds of the total Blackland Prairie (Hill 1901). The soils developed on Taylor rocks are the classic deep, rich, calcareous, heavy clay, "black waxy" vertisol soils that were formerly so valuable for cotton production.

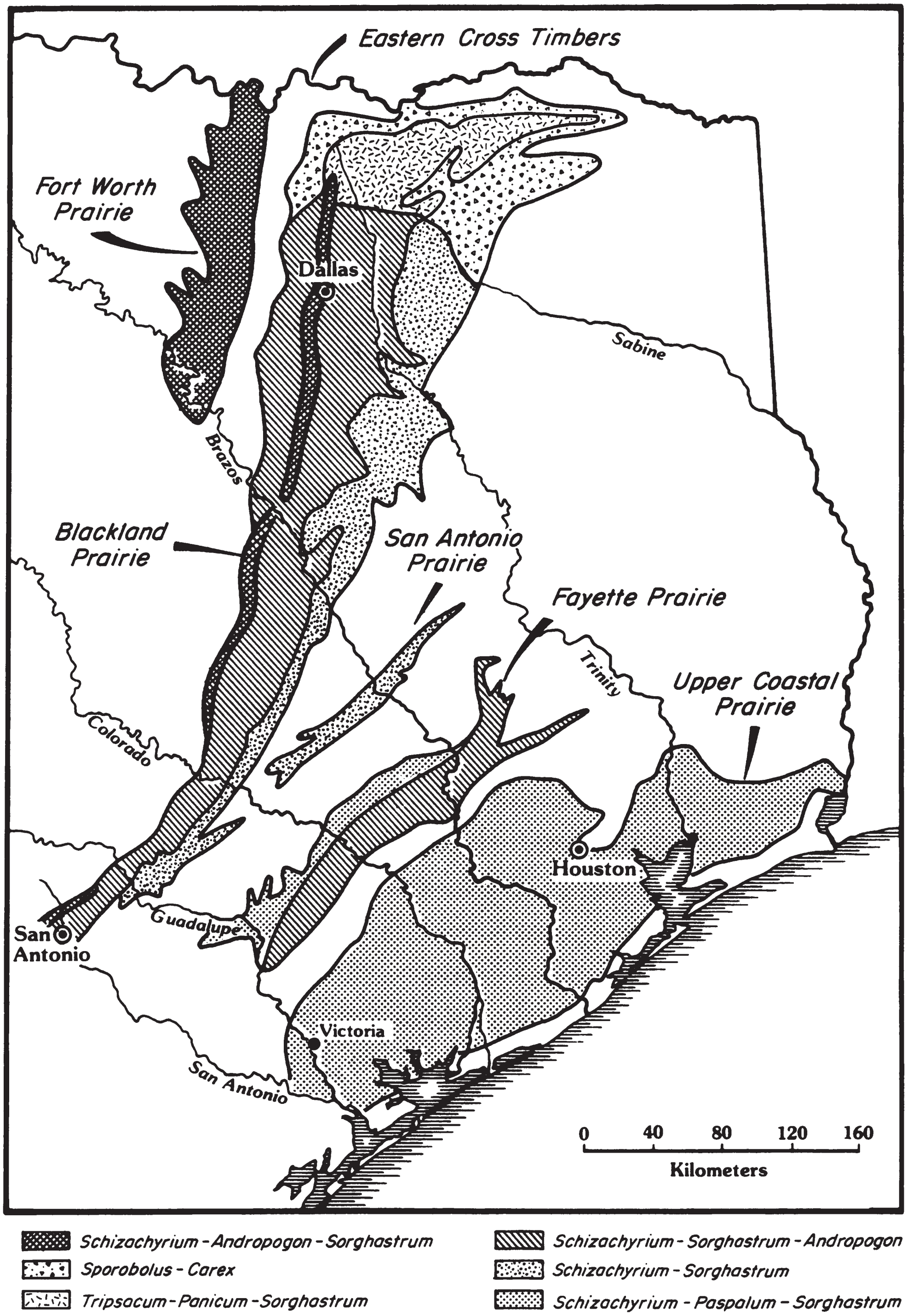


FIG. 77/ MAJOR PLANT COMMUNITY TYPES OF THE BLACKLAND PRAIRIE AND RELATED TALLGRASS REGIONS OF TEXAS (FROM DIAMOND & SMEINS 1993, IN M.R. SHARPLESS AND J.C. YELDERMAN, EDS. THE BLACKLAND PRAIRIE, LAND, HISTORY, AND CULTURE; WITH PERMISSION OF BAYLOR UNIV. @1993).

Finally, the easternmost and youngest Cretaceous rocks supporting the main belt of the Blackland Prairie are those of the Navarro Group, deposited about 72 to 68 million years ago (Hayward & Yelderman 1991). These deposits outcrop on the eastern margin of the Blackland, from Red River County in the north, through Kaufman and Navarro counties, south to Williamson County on the southeastern margin of the Blackland Prairie. They break down into soils (Alfisols) with a somewhat higher sand content than the Blackland soils farther west, and support the easternmost of the Blackland Prairies, the Eastern Transitional or Marginal Prairie (Hill 1901; Hayward & Yelderman 1991). While easier to till, these soils are poorer in nutrients and thus not as valuable for farming (Hayward & Yelderman 1991). Immediately to the east of the Navarro Group, on younger sandy deposits of Tertiary age, the Post Oak Savannah begins.

The Tertiary rocks underlying the spatially disjunct Fayette and San Antonio prairies (see Fig. 77) belong to the Fleming, Oakville Sandstone, and Cook Mountain formations (Smeins & Diamond 1983; Miller & Smeins 1988) dating from Miocene and Eocene times. The Fleming Formation underlies much of the Fayette Prairie. It "consists of a 400-m thick layer of calcareous silty clay sediment with some medium to coarse grained sandstone. The Oakville Sandstone is slightly older. It is found as a narrow strip on the NW side and in the S-central portion of the [Fayette] prairie, and consists of a 65-m-thick layer of medium grained calcareous sandstone with some calcareous clay" (Smeins & Diamond 1983). The still older Cook Mountain occurs at the southwestern tip of the Fayette Prairie and under part of the San Antonio Prairie and "consists of a 30-m-thick layer" (Smeins & Diamond 1983) "of fossiliferous marine muds and poorly indurated mudstones with minor interbeds of sand and limestone" (Miller & Smeins 1988). Under most of the Fayette Prairie and parts of the San Antonio Prairie, these rocks break down to form Vertisols (sometimes with gilgai), similar to those found on most of the main belt of the Blackland Prairie. The western margin of the Fayette Prairie and portions of the San Antonio Prairie are underlain by rocks with a higher sand content, resulting in the development of Alfisols similar to those of the eastern margin of the main belt of the Blackland Prairie (Smeins & Diamond 1983; Miller & Smeins 1988).

Presettlement and Early Settlement Conditions on the Blackland Prairie

VEGETATION OF THE PRESETTLEMENT AND EARLY SETTLEMENT BLACKLAND PRAIRIE—Conditions on the presettlement and early settlement Blackland Prairie were strikingly different from those found today. Probably, the most conspicuous feature of the original landscape was the presence of vast expanses of tall grass prairie (Fig. 78). In the words of Parker (1856), traveling with the 1854 Marcy expedition, "After leaving Preston [northern Grayson County], we entered upon the vast plains...." Dr. John Brooke, who emigrated from England in 1848, stated on arriving at the edge of the Blackland Prairie, "It was the finest sight I ever saw; immense meadows 2 or 3 feet deep of fine grass & flowers. Such beautiful colours I never saw...." (Brooke 1848). In describing the area where he settled near Dorchester in south central Grayson County, Brooke (1849) said,

> I can sit on the porch before my door and can see miles of the most beautiful Prairie interwoven with groves of timber, surpassing, in my idea, the beauties of the sea. Think of seeing a tract of land on a slight incline covered with flowers and rich meadow grass for 12 to 20 miles....

Hill (1901), speaking of the Blacklands in general, said,

> The surfaces of the prairies are ordinarily clad with thick mantles of grass, liberally sprinkled with many-colored flowers, broken here and there by low growths of mesquite trees, or in exceptional

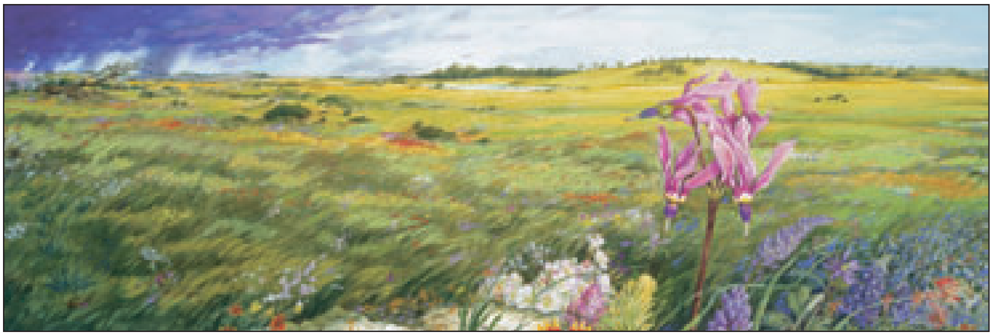


FIG. 78/ ARTIST'S RENDITION OF THE PRESETTLEMENT BLACKLAND PRAIRIE OF TEXAS. FROM THE DUST JACKET OF *SHINNERS & MAHLER'S ILLUSTRATED FLORA OF NORTH CENTRAL TEXAS* (DIGGS ET AL. 1999). PAINTING BY LINNY HEAGY COPYRIGHT ©1999. BY PERMISSION OF THE ARTIST.

> places by 'mottes' or clumps of live oaks on uplands, pecan, bois d'arc, walnut and oaks in the stream bottoms; juniper and sumac where stony slopes exist, and post oak and black-jack in the sandy belts.

Smythe (1852) described the eastern edge of the Blackland Prairie as having "…a view of almost boundless Prairie stretching to the north, as far as the eye could reach.…" He further referred to it as

> …a boundless plain scarcely broken by a single slope or valley, and nearly destitute of trees; (the mesquite appearing but seldom.) Several times during the forenoon not a single shrub or tree could be seen in any direction…. The grazing has reached its climax, it would be impossible for natural pasturage to excell [excel] this.

Olmsted's (1857) description of an outlying piece of the Blackland Prairie (Fayette Prairie) was almost poetic:

> …we came out suddenly, as if a curtain had risen, upon a broad prairie, reaching in swells like the ocean after a great storm, to the horizon before us.…

Gideon Lincecum in 1835 (Lincecum & Phillips 1994) described the southern Blackland Prairie as follows:

> The day's journey passed us over the most delightful prairie country I had ever seen. As we passed over the dividing ridge, between the two tributaries of the Colorado and the Navidad and La Vaca, there was a vast, greatly undulating plain looking South, and the branches of the two above named little rivers, lay spread out before us, resembling a pair of enormous fans. The course of their branches were distinctly marked by the streaks of timber on the margins, presenting to our view a shade of darker green engraved in the face of the boundless plain of grass that slightly dipped away gulf-wards to the far-off smoky obstruction.

Kendall (1845) also described the southern part of the Blackland Prairie as

> …rolling and beautiful prairies, occasionally relieved by the slight skirting of timber which fringes the margins of the small streams, or by a small grove of timber so regularly planted by nature that it would almost seem the hand of man had assisted in its production.

Ferdinand Roemer's (1849) descriptions of the same region included "open prairie," "extensive prairies" with mesquite trees and scattered oak groves, "undulating prairie extending… an immeasurable distance," and "gently rolling, almost treeless plain." Indeed, on the Blackland Prairie, trees were often rare except as riverine forests along streams or as occasional scattered groves or mottes "such as the one near Kentuckytown that gave Pilot Grove [in southeastern

Grayson County] its name, the trees being a major landmark in a featureless terrain." (McLeRoy 1993). The riverine forests along Big Mineral Creek (Grayson County) were described by Parker (1856) as "a rich bottom, thickly grown up with large cotton wood, honey locust, overcup [actually bur oak], and other heavy timber, besides plenty of the bois d'arc." *Maclura pomifera* (bois d'arc) was apparently endemic to a small area in northeast TX (12 counties, mostly in the Blackland Prairie) and adjacent OK and AR (Little 1971; Weniger 1996). Based on early explorer accounts (e.g., Marryat 1843), this species sometimes formed impenetrable thickets along creeks in the northern Blackland Prairie (see detailed discussion in Weniger 1996). Roemer (1849) described a trading post he visited in Falls County as "on a hill covered with oak trees, two miles distant from the Brazos, above the broad forested bottom of Tohawacony Creek." He further described the wooded bottomland as having "high, dense trees." The presence of such wooded bottomlands was probably quite striking in the midst of vast stretches of prairie.

In summary, the original vegetation of the Blackland Prairie seems to have been predominantly tall grass prairie with trees along watercourses, sometimes scattered on the prairie, or concentrated in certain areas (e.g., Pilot Grove), possibly as the result of locally favorable soil conditions or topography.

THE ROLE OF FIRE ON THE PRESETTLEMENT BLACKLAND PRAIRIE—Fire was probably an important (if not the most important) factor in the maintenance of the presettlement Blackland Prairie vegetation, and it undoubtedly had a major impact on the structure of plant communities (Anderson 1990; Collins & Gibson 1990; Strickland & Fox 1993; Jones & Cushman 2004). Axelrod (1985) argued that fire was a primary factor in the rise of the extensive North American grasslands after the end of the last glacial maximum. Unlike woody plants, which are usually killed or severely damaged by fire, grasses are highly fire-adapted, with a number of specific adaptations allowing them not only to survive but prosper under conditions of recurrent fire (and also grazing and trampling). These adaptations include the presence of intercalary meristems (located in the culms just above the nodes and in the leaves near the ligules, thus allowing growth from the base even if terminal parts are damaged), the large amount of below ground biomass, and the tendency to branch ("tiller") or produce stolons or rhizomes near or below ground level.

During early settlement times, huge grassland fires were well known in central North America—for example, a massive 1885 fire described by Haley (1929) began in western Kansas and burned across northern Texas, a total distance of 282 km (175 miles). Haley (1929) also gave many other examples of large-scale grass fires. He quoted Hank Smith, an early settler in Crosby County in the Texas plains country, about a fire in 1879:

> The fire swept thousands of square miles of country to the south and southwest, north and northeast of Mount Blanco. All through the country at that time, especially along the streams were hundreds of magnificent groves of fine timber, particularly cottonwood and hackberry.... That fire killed the timber and in effect literally wiped it out.

Another example is a 1905 fire that started at Hyannis, Nebraska, presumably ignited by lightning. "It traveled over 165 miles and finally burned out within the watersheds of the Middle Loup and Dismal Rivers, apparently stopped by both rivers" (Komarek 1966).

The Blackland Prairie, located at the extreme southern end of the True Prairie grassland association (Gould & Shaw 1983), would appear to have been especially susceptible to prairie fires. The high summer temperatures, extremely irregular summer rainfall, periodic droughts, strong winds, frequent summer lightning storms, and resulting recurrent fires during hot dry periods would have been potent forces in shaping the vegetation

(Collins & Gibson 1990). Roemer (1849), who traveled across part of the presettlement prairie, wrote of a prairie fire near Torrey's Trading Post close to present-day Waco at the western edge of the Blackland Prairie, as follows:

> …we, ourselves, were entertained before going to sleep by the spectacle of a prairie fire. Like a sparkling diamond necklace, the strip of flame, a mile long, raced along over hill and dale, now moving slowly, now faster, now flickering brightly, now growing dim. We could the more enjoy this spectacle undisturbed, since the direction of the wind kept it from approaching us. My companion was of the opinion that Indians had without doubt started the fire, since they do this often to drive the game in a certain direction, and also to expedite the growth of the grass by burning off the dry grass.

Such tall grass prairie fires, intensely hot, would have been stopped only by a lack of dry fuel or a change in topography. Even stream bank vegetation was susceptible during dry years. The end result was that trees were rare even along some stream banks, and prairie margins probably extended somewhat beyond the limits of the soil types usually associated with prairie (Hayward & Yelderman 1991).

Lightning was probably one important source of fires during presettlement times—based on extensive studies, Komarek (1965, 1966, 1968) concluded that lightning-caused fires were quite common and would have been frequent enough to maintain many fire-dependent plant communities. In the words of Komarek (1966), "The extent and frequency of lightning fires in the Great Plains was such as to be hardly conceivable." While lightning was undoubtedly an important source of naturally started fires, Native Americans were long present in the region and their use of fire is considered by some to be equally important in having maintained North American grasslands (Cronin 1983; Bragg 1995).

In summary, fire was probably critical in the formation and maintenance of the presettlement Blackland Prairie. From present-day observations, it is obvious that in the absence of fire, the Blackland Prairie is capable of supporting abundant woody plant growth—in fact, many areas of the Blackland Prairie currently are covered by dense thickets of such species as eastern red cedar (*Juniperus virginiana*), cedar elm (*Ulmus crassifolia*), and mesquite (*Prosopis glandulosa*), and prairie remnants have to be actively managed to prevent brush encroachment. However, in combination with climatic factors and the presence of ignition sources (lightning, Native Americans), the rich clay soils and resulting lush growth of grasses may have resulted in conditions favoring frequent fire and thus fire-adapted prairie vegetation on the Blacklands of Texas (see page 111 for a discussion of the soil-dependent fire frequency hypothesis).

PRESETTLEMENT ANIMAL LIFE—Present animal life is much less diverse and some species are greatly reduced in number compared to presettlement days or have been eliminated. Gideon Lincecum in 1835 (Lincecum & Phillips 1994) said of an area in the southern Blackland Prairie,

> That was the most plentiful place [for game] I have ever found in any country. There were buffalo, bear, deer, turkeys, grouse, jack rabbits, fish, and (during the winter and until the first of April) the wild geese and many species of duck, in countless thousands. I haven't the least doubt, after I had made myself acquainted with the ways and haunts of game, that I could have procured a bountiful supply of meats to feed twenty men, and I would have used nothing but my rifle and fishing tackle.

In addition to relatively large present-day species such as the white-tailed deer, coyote, fox, and bobcat, a number of other large or interesting species occurred. According to Brooke (1848) writing of Grayson County, black bears were quite common ("I…have never tasted

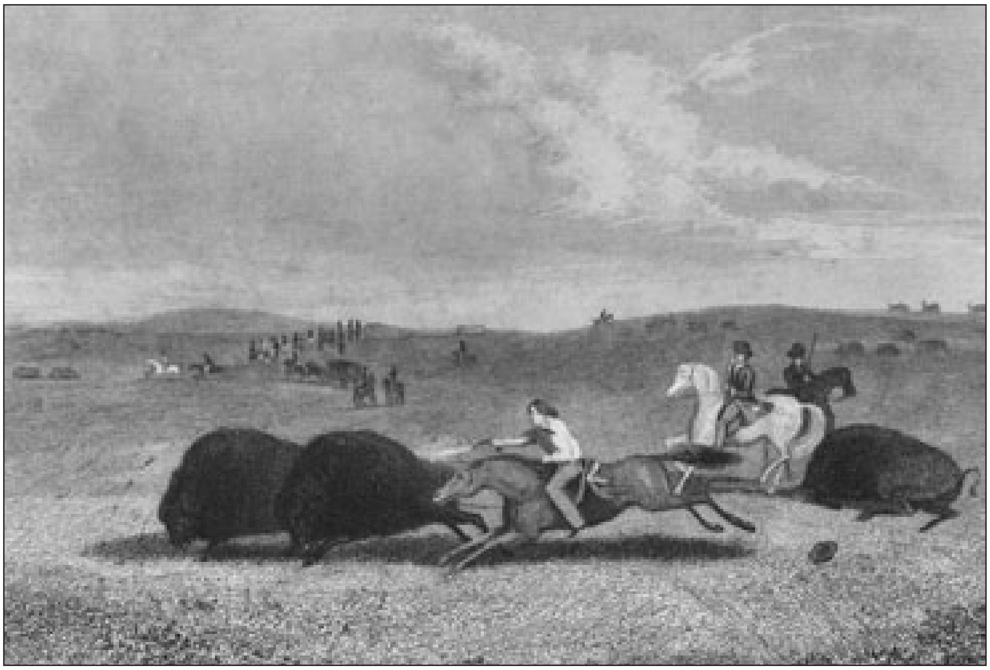


FIG. 79/ FRONTISPIECE FROM GEORGE W. KENDALL'S (1845) *NARRATIVE OF AN EXPEDITION ACROSS THE GREAT SOUTHWESTERN PRAIRIES FROM TEXAS TO SANTA FE*, DEPICTING A SCENE OF THE SLAUGHTER OF BISON. KENDALL DESCRIBED IN DETAIL A BISON HUNT FROM THE WESTERN EDGE OF THE BLACKLAND PRAIRIE.

any meat I like better.") as were deer; panthers [mountain lions] and wolves were also present. In Brooke's (1848) words, "I have been out a-shooting Deer and Turkeys alone, and when going up the branches of the Rivers I often come across either bear or wolf…." Strecker (1926a) (based on early fur-trader records) indicated that next to the skins of deer, "those of the black bear were of the most value to the Indians of McLennan County." Strecker (1926a) also reported that gray wolves occurred as far east as McLennan County. He indicated that they

> … may never have been very common permanent residents of McLennan County, but in late fall and winter, small packs followed the great herds of buffalo and deer from northwestern Texas and remained here for several months. It was probably only a minority that remained throughout the year. Old settlers refer to packs of from five to eight wolves which they considered small family groups.

Another predator, the ocelot, is thought to have ranged as far north as the Red River (Hall & Kelson 1959). Strecker (1924), for example, reported that ocelot occurred in the bottoms of the Brazos River near Waco in McLennan County. Even jaguar are believed to have ranged north to the Red River; the last jaguar record from the area was a large male killed in Mills County (Lampasas Cut Plain to the west of the Blackland Prairie) in 1903 (Bailey 1905). Mountain lions probably occurred throughout the region (Schmidly 1983), with Strecker (1926a) indicating they were common in McLennan County in the middle of the 1800s. However, they were rare by the beginning of the twentieth century (Bailey 1905), and since that time they have been eliminated over most of the region (Schmidly 1983). However, recently there have been reliable sightings of mountain lions in East Texas (e.g., Grayson Co. in 2003—Larry Hardesty, pers. comm.). The collared peccary or javelina, similar to a small wild pig, was also originally present in the southern portion of the area, north to at least the Brazos River valley near Waco in McLennan County (Strecker 1926a; Schmidly 1983; Davis & Schmidly 1994). Other noteworthy mammals that previously occurred in appropriate habitats of the Blackland Prairie (as well as throughout adjoining areas) include river otter, ringtail "cat" (actually in the same family as the raccoon), and badger (Schmidly 1983; Davis & Schmidly 1994).

The occurrence of bison on the Blackland Prairie is well-documented. Judge John Simpson of Bonham (Fannin County), in describing a bison hunt in 1833, reported that hunters found "an immense herd . . . on the prairie around Whitewright [Grayson County]" (McLeRoy 1993). George W. Kendall (1845), with the Santa Fe Expedition (Fig. 79), in describing bison in an area near the western margin of the Blackland prairie to the north of Austin said,

> Directly a-head, on the right and left of our road, innumerable small black objects could be seen more resembling stumps than aught else. As we slowly approached them, the objects became more distinct, gave signs of life, and appeared to be slowly moving about on the interminable prairie. When within half-a-mile it was evident, even to those who had only seen badly-executed woodcuts of the animal in 'picture books,' that they were buffalo, spread out over the immense space, and in countless numbers. . . . In the distance, far as the eye could reach, they were seen quietly feeding upon the short prairie grass. . . .

Parker (1856), in his 1854 journal, stated, "But eight years since, herds roamed around the City of Austin, and were frequently seen in the streets; now there are but few to be found south of Red River." Roemer (1849) described bison on the southern Blackland Prairie as follows:

> When on the following morning at daybreak we entered the prairie on which mesquite trees grew scatteringly, the first object that met our view was a buffalo herd, quietly grazing near us. . . . The whole prairie was covered with countless buffalo trails, crossing in all directions, reminding one of a European grazing ground.

On a different day, Roemer (1849) observed,

> They covered the grassy prairie separated into small groups and far distant on the horizon they were visible as black specks. The number of those clearly seen must have been not less than a thousand.

Pronghorns (sometimes referred to as antelopes, but actually in a unique family) were also native, occurring at least as far east as Fannin County (Hall & Kelson 1959). Smythe (1852) described a small herd on the eastern edge of the Blacklands, Roemer (1849) mentioned sighting pronghorns near where the Blackland Prairie and Lampasas Cut Plain come together, and Major G.B. Erath, a pioneer of Waco, indicated that pronghorns were common in what is now McLennan County in the early to middle 1800s (Schmidly 1983). Erath also reported that small herds penetrated as far east as Milam County on the eastern edge of the Blackland Prairie (Strecker 1926a). Unfortunately, this species was insatiably curious. According to Doughty (1983),

> Pronghorns had the vulnerable habit of investigating wagons and other objects that looked out of place in their prairie habitat. Marksmen capitalized on this curiosity by waving a bright cloth from a semiconcealed position and luring these fleet-footed, naturally timid Plains denizens within rifle range.

While not native, wild horses, descended from those escaped from the Spanish, were extremely common in Texas by the early 1800s and were probably having a significant impact on the vegetation. Ikin (1841), speaking of Texas as a whole, indicated,

> The wild horse which now roams every prairie, sometimes alone, sometimes in herds of more than a thousand, is not native, but the progeny of those which escaped from the early conquerors of Mexico. He is usually a small bony animal about fourteen hands high, with remarkably clean legs, and other signs indicative of good blood. When congregated in bodies of a thousand, these horses form the most imposing spectacle which the prairies present.

Strecker (1926a) also reported the wild horse as abundant throughout the Brazos Valley of McLennan County at the time of arrival of the first American settlers. He further indicated that early settlers sometimes shot the wild horses to prevent interference with their domesticated stock.

One mammal often associated with grasslands, the black-tailed prairie dog, did not occur in the vast majority of the Blackland Prairie. Prairie dogs "typically inhabit short-grass prairies; they usually avoid areas of heavy brush and tall grass, possibly because visibility is considerably reduced" (Davis & Schmidly 1997). While occurring primarily in the western half of the state, they did extend east as far as the southwestern margin of East Texas, reaching Bexar and Hays counties (Davis & Schmidly 1997). Because of perceived competition with livestock and farming interests and injury to ranch animals stepping in their holes, prairie dogs have been eliminated from most of their former habitats. However, "the desirability of eliminating them entirely from rangelands has not been satisfactorily demonstrated. Stockmen in certain parts of Texas, for example, claim that removal of prairie dogs has had some direct association with the undesirable spread of brush. This has had detrimental effects on the livestock industry which far outweighs the damage prairie dogs might do" (Davis & Schmidly 1997).

Early surveyor records (as far back as the 1830s) of mesquite as the most common tree in presettlement upland prairies in Navarro County suggest "…the legendary spread of mesquite into North Texas by longhorn cattle may be an errant concept" (Jurney 1987). Roemer's (1849) mention of "extensive prairies covered with mesquite trees" also points to mesquite as a natural component of the vegetation. Likewise, early Spanish expedition diaries (e.g., Fray Isidro de Espinosa noted mesquite in Williamson County in 1716—Foster 1995), point to its widespread natural occurrence in the state. However, mesquite undoubtedly has increased in many areas, and the observations mentioned above are not so early as to preclude it having already been spread to some extent by land use changes.

While some question the degree to which mesquite was spread by longhorns, animals have had profound impacts on the vegetation since long before settlement. These range from the obvious effects of the bison and beaver to the more subtle but essential roles of pollination and seed dispersal.

The bird, reptile, and fish faunas of presettlement times were also conspicuously different in significant ways from those of today. Brooke (1848), writing about early Grayson County, mentioned both wild turkeys and prairie chickens, and Smythe (1852) spoke of hunting "Prairie Hens" in what is now Limestone County on the eastern edge of the Blackland Prairie. According to Pulich (1988), greater prairie chickens were common in the area until the 1880s, and lesser prairie chickens, while generally found to the west of East Texas, were also possibly present in the area. Oberholser (1974) lists specimen records for the greater prairie chicken from Dallas, Milam, and Navarro counties, with a number of other sight records from the area. There is a questionable record for the lesser prairie chicken from Dallas and other records for this species from Cooke and Young counties to the west of the Blacklands (Oberholser 1974). Both of these species were locally extinct by the early 1900s, presumably due to overhunting and habitat destruction. The extinct passenger pigeon is also well-documented for the Blackland Prairie. These birds, known as "wild pigeons" by early settlers, were recorded from Bexar, Collin, Dallas, Fannin, Grayson, Henderson, Hunt, and Travis counties, with a number of records even farther west in the Grand Prairie, Lampasas Cut Plain, and West Cross Timbers (Oberholser 1974; Pulich 1988; Casto 2001). This once incredibly numerous species rapidly became extinct in the Blackland Prairie region, with 1896 being the last year one was recorded in the area (Van Zandt County) (Oberholser 1974; Pulich 1988). The ivory-billed, one of the world's largest woodpecker species and now presumably extinct, was also present in bottomland forests in the Blacklands. Oberholser (1974) listed records for Cooke, Dallas, Fannin, and Kaufman counties, with sightings in the area as late as the early 1900s (Pulich 1988). Another extinct species, the Carolina parakeet, was widely known from eastern Texas (Greenway 1958) and was present in the riverine forests adjacent to the Blackland Prairie (Goodwin 1983), especially along the Trinity and Red rivers. Oberholser (1974), for example, citeds records from Fannin and Lamar counties at the northern edge of the Blacklands. Even the now federally endangered Whooping crane was widely known from the Blackland Prairie. In the words of Olmsted (1857), describing a sighting between Austin and San Antonio,

> We were now within four or five hundred yards of them. Suddenly, they raised wings, stretched out their necks, and ran over the prairie, but presently left ground, and flew away. They were very large white birds, with black-edged wings, and very long necks and legs. They must have been a species of crane….

This magnificent bird, the tallest in North America (standing about five feet [1.5 m] and with a wingspan to around eight feet [2.5 m]), was known from numerous Blackland Prairie counties—Bexar, Comal, Dallas, Fannin, McLennan, Navarro, Williamson, and Travis (Oberholser 1974). According to White (2002), two additional bird species have been eliminated from the Blackland Prairie: scaled quail and Eskimo curlew. Specimens of scaled quail were known for Fannin County (and also further east in Bowie County) (White 2002). The Eskimo curlew is thought to have been "a fairly common spring migrant in the grasslands of the Blackland Prairie," even though few records exist—the only regional record is from Red River County (White 2002). Many other species were much more abundant in presettlement and early settlement times. For example, Gideon Lincecum in 1835 (Lincecum & Phillips 1994) described wild geese on the southern Blackland Prairie as "everywhere—thousands."

While variable, the primary causes of these extinctions and reductions in animal numbers seem all too clear. Overhunting certainly reduced some species, but probably more important was the loss of habitat. Where there were once millions of acres of Blackland Prairie, today only a few thousand remain. Without appropriate habitat to sustain them, the animals could not possibly survive.

Possibly even more surprising than the mammals or birds discussed above, alligators were abundant in places, with Kendall (1845) describing them along the San Gabriel in the southern Blackland Prairie as "too plentiful for any useful purposes." This large reptile occurred in appropriate habitats throughout most of the Blackland Prairie, west to Grayson, Dallas, McLennan, and Williamson counties (Brown 1950; Hibbard 1960; Dixon 1987). In fact, they are still known to occur as far west as Dallas and Grayson counties (Southerland 2003) and are reported to be currently expanding their range to the north (Southerland 2003), possibly due to climate change. Another reptile previously widespread in the Blackland Prairie (and throughout most of the state) is the Texas horned lizard, commonly but incorrectly called the horny "toad" or horned "frog." This small, fierce-looking though docile species is the official State Reptile of Texas (Donaldson et al. 1994). It is much less common than previously, is considered threatened, and is now confined primarily to the western half of the state. The exact cause of its dramatic decline is not completely clear, even though habitat alteration (e.g., agriculture, urbanization), pesticide use in the 1950s and 1960s, and over collection are thought to have played a part (Donaldson et al. 1994; Hodges 1996; Texas Memorial Museum 2000). In addition, in recent years, remnant populations have probably declined further due to the replacement of the main horned lizard food, harvester ants, by the invasive exotic fire ant. Biologists consider the horned lizard to be an "ecological indicator" species (equivalent to canaries in coal mines alerting miners to bad air) which can indicate environmental problems potentially harmful to humans in the future.

The relative lack of detailed knowledge about invertebrates even today is reflected by the relatively recent discovery of a new crayfish from the Parkhill Prairie Preserve, a Blackland Prairie site in Collin County (Hobbs 1991). This endemic upland species, *Procambarus steigmani*, Steigmans' crayfish, is just one example of what are probably numerous yet to be documented invertebrates. Unfortunately, due to extensive habitat destruction, many invertebrates that were present during presettlement times are now possibly extinct without ever having been recognized by scientists.

In general, the animals of the Blacklands have faunal affinities with the eastern woodlands, the Great Plains, and the southwestern United States (Schmidly et al. 1993). A recent, now very abundant, southern addition to the fauna is the nine-banded armadillo. This species is originally native to South America, and according to Foster (1995), no Spanish expedition diaries noted the presence of armadillos north of the Rio Grande River in the period 1689 to 1786. Permanent populations were first established in Texas in the 1850s (Foster 1995) and as recently as the 1870s to 1880 the species was found only at the southern tip of Texas (Strecker 1926b; Phelan 1976). Since that time it has spread extensively and is now found hundreds of miles north of Texas (Hall & Kelson 1959). Armadillos were at least sporadic as far north as the Red River by the early 1930s but did not become common there until the 1950s (H. McCarley, pers. comm.).

From this brief description of a few of the animals, it is clear that less than 200 years ago there was a dramatically different fauna on the Blackland Prairie than at present, including many large mammals that are absent today. If we go back further, to the Pleistocene, there is evidence that even larger mammals—a diverse megafauna—occurred in the area (Smeins 1988). For example, Dr. Daniel Schores and a student team from Austin College (D. Schores, pers. comm.) excavated a Pleistocene mammoth from near Flowing Wells in Grayson County. Further, fossils of at least three elephant species, including mammoth and mastodon, are known from the Dallas area (Shuler 1934). An even more impressive site containing a large (20+) mammoth herd was found near Waco in a Brazos River terrace dated around 28,000 years ago (Fox et al. 1992; C. Smith, pers. comm.). In fact, fossils of a wide variety of Pleistocene mammals, including mammoths, mastodons, ground sloths, giant bison, giant armadillos, giant beavers, tapirs, rhinos, llamas, extinct horses, camels, saber-toothed cats, and dire wolves, have all been reported from Texas (Shuler 1934; Geiser 1945b; Loughmiller & Loughmiller 1977; Truett & Lay 1984; Smeins 1988; Finsley 1989; Fox et al. 1992; Abernethy 1996; Pinsof & Echols 1997). Several woody plants found in the Blackland Prairie region seem to have adaptations that are difficult to explain based on interactions with the present fauna. Bois d'arc (*Maclura pomifera*), honey-locust (*Gleditsia triacanthos*), and mesquite (*Prosopis glandulosa*) all have fruits that are adapted for dispersal by large animals and seem to fit Janzen and Martin's (1982) hypothesis that large, now extinct animals were involved in the evolution of certain "anachronistic" plant characteristics we see today. Another such possible anachronism is the protective armature displayed by honey-locust. The long, stout, branched thorns, up to a foot or more long, would seem perfectly reasonable in Africa where there are abundant large herbivores, but they are rather out of place in northern Texas where currently no large native browsers exist.

EARLY SETTLEMENT USES OF THE BLACKLAND PRAIRIE—The earliest use of the Blackland Prairie by settlers was as grazing land for herds of cattle or horses. According to Hayward and Yelderman (1991) "… the Blackland Prairie supported some of the earliest of large-scale ranching efforts in Texas, complete with pre-Civil War cattle drives to St. Louis and Chicago." Brooke (1848) stated that, "… the cattle and horses feed on the prairies all winter; no need of laying up winter food." Parker (1856) wrote of a herd of 1,200 wild cattle being driven north across the Red River at Preston (Grayson County).

While limited "sod plowing" occurred quite early (Smythe 1852), it wasn't until the 1870s and 1880s, with the coming of the railroads and the development of special plows and favorable economic conditions, that extensive "breaking of the prairie" and exploitation of its agricultural potential finally occurred (Hayward & Yelderman 1991). Once farming on the Blacklands was possible, widespread cultivation of the rich soils, perhaps as rich as any in the nation (Hayward & Yelderman 1991), was inevitable, and farming quickly replaced ranching. Cotton soon became an important crop and it began to dominate local economies. According to Sharpless and Yelderman (1993), for seventy years more cotton was grown on the Blackland Prairie than any other region of the world. By the 1920s, "Texas produced over 25 percent of the world's cotton each year, ginned it in nearly four thousand gins, and led all other states in percentage of gross income derived from cotton. One economist estimated that one-third of the total population of the state was directly involved in cotton farming in 1929...." (Sitton & Utley 1997). Much of this cotton production was on the Blackland Prairie, and Hill (1901) said of the region, "In fact these calcareous soils ... of the Black Prairies are the most fertile of the whole trans-Mississippi region." Others (e.g., Sharpless & Yelderman 1993) have said the soil is arguably the most fertile west of the Mississippi River. Within a very short time, most of the accessible and desirable land was put into cultivation, and according to Burleson (1993), by 1915 the human population on the Blacklands was greater than on any other United States area of comparable size west of the Mississippi. The result was the virtually complete destruction of native Blackland Prairie communities. With the exception of small or inaccessible areas and a relatively few hay meadows valued for their native grasses, almost nothing remains of the tall grass prairies that were once so abundant. Estimates of the destruction of this ecosystem range from 98% (Hatch et al. 1990) or 99% (Riskind & Collins 1975) to more than 99.9% (Smeins & Diamond 1986; Burleson 1993), with only 5,000 acres (2025 hectares or 0.04%) recently estimated to remain (Appleton 2000). Ironically, high levels of cotton production lasted relatively few decades— cotton root rot soon became a serious limiting factor (Brown et al. 1969), as did factors associated with soil mismanagement (depletion, erosion, etc.).

Vegetation of the Blackland Prairie

According to Gould and Shaw (1983), the Blackland Prairie (along with the Post Oak Savannah) is part of the True Prairie grassland association which extends from Texas to southern Manitoba. This is one of the seven grassland associations of North America recognized in the classification system of Gould (1968a) and Gould and Shaw (1983) (Fig. 80). Based on location, climate, and vegetational characteristics, the tall grass prairies of the Texas Blacklands can be considered part of either the True Prairie or Coastal Prairie associations (Collins et al. 1975). They lie at the very southern end of the True Prairie association but show similarities to the Texas Coastal Prairie. Rainfall values are intermediate, and the Blackland Prairies have most of the vegetational dominants of both these areas. According to Collins et al. (1975), adequate data are not currently available for a clear determination and most of the Blackland Prairie that botanists would wish to study is gone. However, many authorities, including recent researchers, recognize the tall grass prairies of the Blacklands as an extension of the True Prairie, with little bluestem (*Schizachyrium scoparium*) as a climax dominant (Allred & Mitchell 1955; Thomas 1962; Correll 1972a; Gould & Shaw 1983; Diamond & Smeins 1993; Simpson & Pease 1995).

Seven different specific grassland communities occurring on three main soil associations were recognized by Collins et al. (1975) as occurring in the Blackland Prairie. Diamond and Smeins (1993), however, recognized five major tall grass communities in the main body of the Blacklands, with one additional community in portions of the Fayette Prairie (Fig. 77). Soil type was an important determinant in the distribution of all of these communities. We are following the Diamond and Smeins delineations in this discussion.

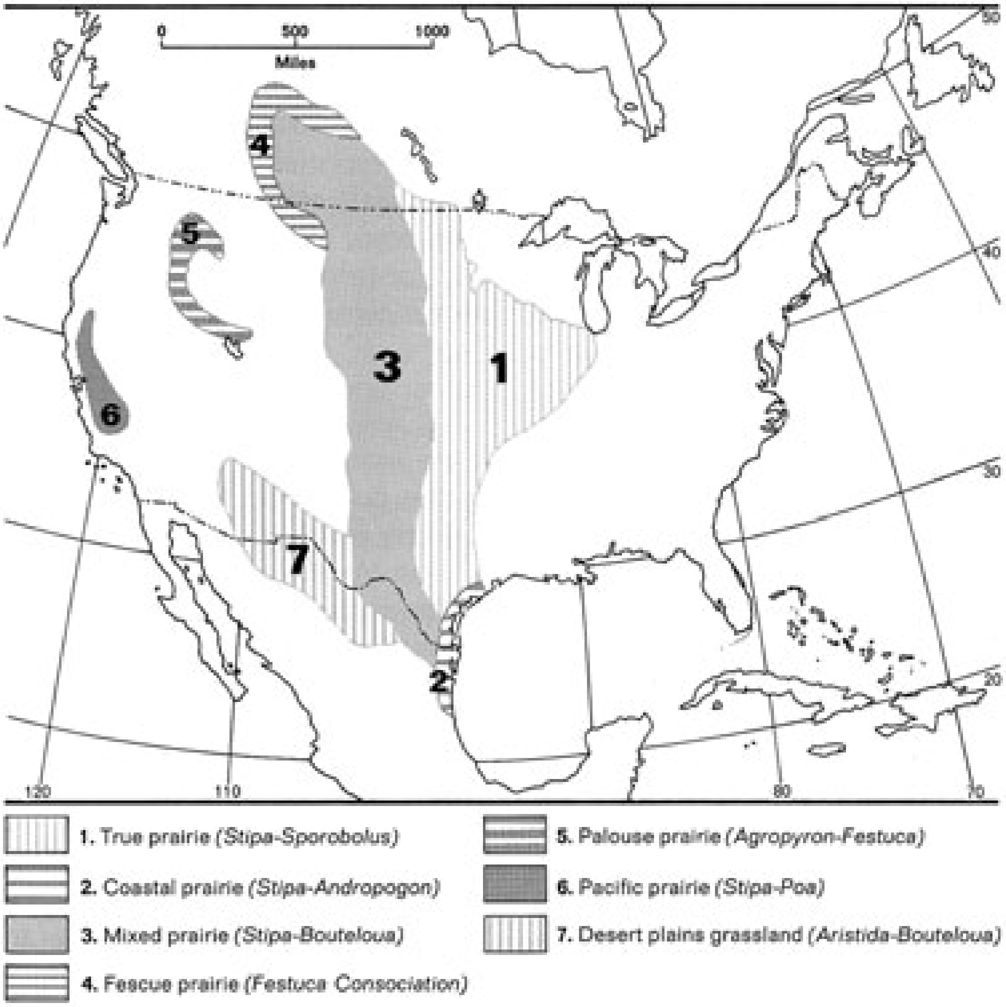


FIG. 80/ GRASSLAND ASSOCIATIONS IN NORTH AMERICA (FROM GOULD 1968A; USED WITH PERMISSION OF LUCILE GOULD BRIDGES, ©1968). NOTE THAT ACCORDING TO GOULD AND SHAW (1983) A SIGNIFICANT PORTION OF EAST TEXAS IS PART OF THE TRUE PRAIRIE ASSOCIATION.

***SCHIZACHYRIUM* DOMINATED COMMUNITIES—**Three of these community types, the *Schizachyrium-Andropogon-Sorghastrum* (little bluestem-big bluestem-Indian grass), *Schizachyrium-Sorghastrum-Andropogon* (little bluestem-Indian grass-big bluestem) and *Schizachyrium-Sorghastrum* (little bluestem-Indian grass), are relatively similar—they have little bluestem as the prevailing dominant and occur over the majority of the Blacklands (Diamond & Smeins 1993). Associated species include *Bouteloua curtipendula* (side-oats grama), *Carex microdonta* (small-toothed caric sedge), *Sporobolus compositus* (tall dropseed), *Nassella leucotricha* (Texas winter grass, formerly in the genus *Stipa*), *Acacia angustissima* var. *hirta* (prairie acacia), *Bifora americana* (prairie-bishop), *Hedyotis nigricans* (prairie bluets), and *Hymenopappus scabiosaeus* (old-plainsman) (Diamond & Smeins 1985). The microtopographical features known as “hog wallows” or gilgai (see page 63) are often found on prairies of these types and provide important microhabitat variation based on differences in water, nutrient relations, and frequency of disturbance (Diamond & Smeins 1993). Vegetational differences associated with the microhighs and microlows are easily observed.

***TRIPSACUM-PANICUM-SORGHASTRUM* COMMUNITY—**The other two communities on the main belt of the Blacklands are quite different vegetationally and are relatively limited in occurrence. The *Tripsacum-Panicum-Sorghastrum* (eastern gamma grass-switch grass-Indian grass) community is "… found over poorly drained Vertisols in uplands of the northern Blackland Prairie and in lowlands throughout the Texas tallgrass prairie region" (Diamond & Smeins 1993). It is especially associated with areas of gilgai topography (Eidson & Smeins 2001). Examples can be found in Grayson and Fannin counties. Additional common species include *Bouteloua curtipendula* (side-oats grama), *Carex microdonta* (small-toothed caric sedge), *Paspalum floridanum* (Florida paspalum), *Sporobolus compositus* (tall dropseed), *Acacia angustissima* var. *hirta* (prairie acacia), *Aster ericoides* (= *Symphyotrichum ericoides,* heath aster), *Bifora americana* (prairie-bishop), *Hedyotis nigricans* (prairie bluet), *Rudbeckia hirta* (black-eyed susan), and *Ruellia humilis* (prairie-petunia) (Diamond & Smeins 1985).

***SPOROBOLUS-CAREX* COMMUNITY—**The *Sporobolus-Carex* (Silveus' dropseed-mead sedge) community, dominated by *Sporobolus silveanus* (Silveus' dropseed) and *Carex meadii* (Mead's caric sedge), is found in the northern Blackland Prairie on low pH Alfisols in areas of relatively high precipitation (Diamond & Smeins 1993). An example can be seen on the Nature Conservancy's Tridens Prairie in Lamar County. Other common species found in this community type include *Dichanthelium oligosanthes* (Scribner's rosette grass), *Fimbristylis puberula*, *Coelorachis cylindrica* (Carolina joint-tail), *Panicum virgatum* (switch grass), *Paspalum floridanum* (Florida paspalum), *Sporobolus compositus* (tall dropseed), *Aster pratensis* (= *Symphyotrichum pratense,* silky aster), *Linum medium* (Texas flax), and *Neptunia lutea* (yellow-puff) (Diamond & Smeins 1985). The microtopographical features known as mima mounds are commonly associated with this community and in some areas can cover up to 25% of the landscape. Like gilgai, mima mounds provide microhabitat variation, increasing the overall biological diversity of the prairie ecosystem (Diamond & Smeins 1985).

***SCHIZACHYRIUM-PASPALUM-SORGHASTRUM* COMMUNITY—**The *Schizachyrium-Paspalum-Sorghastrum* (little bluestem-brown-seed paspalum-Indian grass) community is found in the Blackland Prairie region only in the disjunct San Antonio and Fayette prairies, generally over Alfisols. This is the only Blackland community in which *Paspalum plicatulum* (brown-seed paspalum) is typically found. Other common species include *Dichanthelium oligosanthes* (Scribner's rosette grass), *Fimbristylis puberula* (hairy fimbry), *Paspalum floridanum* (Florida paspalum), *Sporobolus compositus* (tall dropseed), *Aster ericoides* (= *Symphyotrichum ericoides,* heath aster), *Liatris* spp. (gayfeather), *Neptunia lutea* (yellow-puff), *Oxalis dillenii* (= *O. stricta,* slender yellow woodsorrel), *Schrankia uncinata* (= *Mimosa nuttallii,* catclaw sensitive-briar), and *Sisyrinchium pruinosum* (dotted blue-eyed-grass) (Smeins & Diamond 1983; Diamond & Smeins 1985). While limited in occurrence in the Blacklands, this community is dominant in the Coastal Prairie of Texas (Diamond & Smeins 1985). The similarity of some areas of the San Antonio and Fayette prairies with both the main belt of the Blacklands and the Coastal Prairie emphasizes that all of these prairie habitats form a related "continuum" with *Schizachyrium scoparium* (little bluestem) and *Sorghastrum nutans* (Indian grass) as general dominants and with *Andropogon gerardii* (big bluestem) and *Bouteloua curtipendula* (side-oats grama) increasing northward and *Paspalum plicatulum* (brown-seed paspalum) more abundant to the south (Diamond & Smeins 1985).

HERBACEOUS ASSEMBLAGE ON OUTCROPS OF THE AUSTIN CHALK—Also worth mention is the special assemblage of herbaceous plants often noted on areas of very thin soil, especially on exposed outcrops of the Austin Chalk (Stanford 1995). Species seen in this type of setting in the northern Blackland Prairie (Grayson County) include *Baptisia australis* (wild blue-indigo), *Callirhoe pedata* (finger poppy-mallow), *Eriogonum longifolium* (long-leaf wild buckwheat), *Grindelia lanceolata* (gulf gumweed), *Ipomopsis rubra* (standing-cypress), *Linum pratense* (meadow flax), *Marshallia caespitosa* (Barbara's-buttons), *Oenothera macrocarpa* (Missouri primrose), *Paronychia jamesii* (James' nailwort), and *Thelesperma filifolium* (greenthread). At some seasons, these outcrops have the aspect of barren eroded rock; in the spring, however, they are covered with spectacular displays of color.

THE BLACKLAND PRAIRIE AS A MOSAIC

As described above, there is considerable variation in the tall grass prairie communities of the Blacklands (Diamond & Smeins 1993), and there is disagreement about specific community types (Simpson & Pease 1995). However, common dominant grasses of most of this tall grass prairie ecosystem include *Schizachyrium scoparium* (little bluestem), *Andropogon gerardii* (big bluestem), *Sorghastrum nutans* (Indian grass), *Panicum virgatum* (switch grass), *Tripsacum dactyloides* (eastern gamma grass), *Sporobolus compositus* (tall dropseed), *Eriochloa sericea* (Texas cup grass), *Paspalum floridanum* (Florida paspalum), and *Tridens strictus* (long-spike tridens) (Collins et al. 1975). Despite similarities in general aspect and even the occurrence of certain species over broad areas, the particular community present and the dominants observed can vary considerably even over short distances, primarily on the basis of differences in soil. Localized patches of a community type well beyond its main zone of occurrence are common, based on soil or other factors. Therefore, most of the Blackland Prairie is a complex mosaic of tall grass communities; an example of this can be seen in northern Grayson County where four of the community types discussed above can be seen within a few miles.

WOODED AREAS OF THE BLACKLAND PRAIRIE

Although prairie vegetation predominates, some wooded areas are also natural components of the undisturbed Blackland Prairie. Examples include bottomland forests and wooded ravines along the larger rivers and streams, mottes or clumps in protected areas or on certain soils, scarp woodlands on slopes at the contact zones with the Edwards Plateau and Lampasas Cut Plain, and scattered upland oak woodlands similar to the Cross Timbers (Gehlbach 1988; Nixon et al. 1990; Diamond & Smeins 1993). In areas such as Dallas, where the Austin Chalk forms a conspicuous escarpment or bluff, a characteristic woody vegetation is also found in the varied microhabitats associated with this topographic feature. Kennemer (1987) noted that *Fraxinus texensis* (Texas white ash), *Quercus sinuata* var. *breviloba* (shin oak), and *Ulmus crassifolia* (cedar elm) are dominant. Other noteworthy woody plants of the escarpment include *Cercis canadensis* var. *texensis* (Texas redbud), *Juniperus ashei* (Ashe's juniper), *Morus microphylla* (Texas mulberry), and *Ungnadia speciosa* (Texas buckeye). Farther south, in Bell, Hill, and McLennan counties, the Austin Chalk scarp vegetation is similar. Depending on slope and moisture conditions, characteristic species may include *Celtis laevigata* (sugarberry), *Diospyros texana* (Texas persimmon), *Forestiera pubescens* (elbow-bush), *Fraxinus texensis* (Texas white ash), *Ilex decidua* (deciduous holly), *Juniperus ashei*, *J. virginiana* (eastern red-cedar), *Ptelea trifoliata* (hoptree), *Quercus buckleyi* (Texas red oak), *Q. fusiformis* (Plateau live oak), *Q. sinuata* var. *breviloba*, and *Ulmus crassifolia* (Gehlbach 1988).

The Future of the Blackland Prairie

As indicated earlier, with the exception of preserves, small remnants, or native hay meadows, almost nothing remains of the original Blackland Prairie communities. Unfortunately, the few small existing remnants are still being lost due to a variety of causes. An example is the destruction of Stults Meadow in Dallas, studied in detail by Laws (1962) and Correll (1972a). According to Diamond et al. (1987), all of the tall grass community types of the Blackland Prairie are "…endangered or threatened, primarily due to conversion of these types to row crops." Three specific Blackland communities, (*Schizachyrium scoparium-Paspalum plicatulum*, *Schizachyrium scoparium-Sorghastrum nutans*, and *Tripsacum dactyloides-Panicum virgatum*), are considered "threatened natural communities" by the Texas Organization for Endangered Species (TOES 1992).

Conversion of the Blackland Prairie for agriculture was the most important cause of the destruction of this ecosystem, with only marginal, often steeply sloped land not rapidly brought under cultivation. High prices for cotton and grains eventually resulted in the cultivation of even these marginal areas, "…with disastrous effects. Blackland soils on steep slopes, stripped of their protective grass, eroded rapidly. Gullying was everywhere, and in a few years, over much of the marginal slope-lands, as much as three feet of soil had been eroded, exposing barren rock where once was prairie soil" (Hayward & Yelderman 1991). Today, extensive eroded areas and large sections that have been contoured to remedy erosion can be seen in many places throughout the Blacklands.

More recently, urbanization became a significant cause of prairie loss, particularly around the larger metropolitan areas. In places such as Dallas, it is all too common to see the rich black soil of areas formerly covered by blackland prairie being covered by more highways, strip malls, shopping centers, and residential areas. Even putting aside issues of prairie destruction, it is interesting to contemplate the long-term consequences of using large amounts of our richest farm land for non-agricultural purposes.

In addition to direct destruction of prairie through cultivation or other uses (e.g., urbanization), existing isolated small prairie remnants are currently being lost through invasion by woody vegetation and introduced species. Recurrent fire and grazing by bison were natural processes that maintained the Blackland ecosystem; the removal of these processes causes changes in the vegetation (Smeins 1984; Smeins & Diamond 1986; Diamond & Smeins 1993). Given the relatively high rainfall over most of the Blacklands and with the suppression of fire by humans, native trees and shrubs (e.g., *Juniperus virginiana*—eastern red-cedar, *Ulmus crassifolia*—cedar elm), as well as introduced species, are able to invade and eventually take over areas that were formerly prairie. Similar encroachment by *Juniperus* spp. is known in adjacent Oklahoma and is widely recognized as a "threat to the ecological integrity of grassland ecosystems" (Hoagland 2000).

In this relatively high rainfall, ecotonal region, periodic appropriate disturbance (e.g., fire, enlightened grazing regime, mowing) is essential for the maintenance of prairie—without some type of disturbance, brush encroachment/thicketization rapidly occurs. However, even native hay meadows, which are routinely disturbed, are often markedly different from the original vegetation because of the substitution of mowing and herbicide use (particularly in the past) in place of fire and grazing. The results include a reduction in broad-leaved prairie species and an increased abundance of grasses (Diamond & Smeins 1993). While grazing was a natural component of the Blacklands and many other Texas ecosystems, overstocking with and overgrazing by domesticated animals has caused a dramatic decline and even near elimination of numerous plants from many areas (Cory 1949).

The cumulative effect of all these human-induced changes is that the Blackland Prairie communities have been largely destroyed. Large areas that were once tall grass prairie are now covered by crops or other introduced and now naturalized species such as *Bothriochloa ischaemum* (King Ranch bluestem), *Cynodon dactylon* (Bermuda grass), and *Sorghum halepense* (Johnson grass). Roadsides and pastures are particularly obvious examples; in many cases, hardly any native grasses can be found. In these areas, there has also been an accompanying dramatic reduction in native forb diversity.

In striking contrast to the loss of natural terrestrial communities of the Blackland Prairie, there has been a tremendous increase in aquatic habitats. Most native wetlands, including prairie "pothole-like" wetlands, have been lost. However, with the construction of

Fig. 81/ Photograph of prescribed burn during January 2002 on Austin College's Clinton and Edith Sneed Environmental Research Area in Grayson Co. (photo by Peter Schulze).

numerous reservoirs and ponds, there is vastly more habitat for aquatic vegetation than in presettlement days. With the exception of oxbow lakes along some of the larger streams, the only permanent surface water prior to human intervention was in rivers, streams, swampy or marshy areas, beaver ponds, and springs. Introduced, and native, aquatic plants are now widespread and in some cases so abundant as to be problematic weeds. Many aquatic plants probably have populations several orders of magnitude greater than in the relatively recent past. This same pattern holds not just for the Blackland Prairie, but for all vegetational areas within East Texas.

Because, as mentioned earlier, only a tiny amount of Blackland Prairie remains (5,000 acres or 0.04% of the original—Appleton 2000), a vigorous and varied conservation strategy will be necessary to preserve meaningful representatives of its constituent communities. Preserving as many of the remaining native fragments as possible is obviously critical, and this approach is being pursued by organizations such as the Nature Conservancy (e.g., Clymer Meadow in Hunt County, Tridens Prairie in Lamar County), Texas Parks and Wildlife Department, local governments (e.g., Collin County—Parkhill Prairie), Austin College (Garnett Prairie in Grayson County), Texas A&M University-Commerce (Cowleach Prairie Preserve in Hunt County), and private landowners (e.g., Matthews-Cartwright-Roberts Prairie in Kaufman County and the approximately 2,000 acre/800 hectare Smiley-Woodfin Prairie in Lamar County). Prairie restoration efforts are also being undertaken by a variety of organizations. Examples include The Heard Natural Science Museum and Wildlife Sanctuary (a tall grass prairie restoration project) and Austin College (Sneed Prairie Restoration Project). Such preserves and restoration sites require active management to prevent brush encroachment and invasion by native species, and a variety of techniques are being employed, including enlightened grazing regimes, mowing, and fire. Prescribed fire (controlled burning) is perhaps the most important tool used in Texas in prairie management at the present time. Fire is routinely used by a number of agencies/organizations in maintaining and restoring prairies in East Texas—examples include the Texas Parks and Wildlife Department, the U.S. Fish and Wildlife Service, the Nature Conservancy of Texas, and Austin College (Fig. 81).

Two Unique Areas of East Texas

Caddo Lake and the Big Thicket

Within the Pineywoods there are two long-famous areas that deserve special discussion because of their biological and historical significance. In northeast Texas, adjacent to the Texas-Louisiana border east of Jefferson, is Caddo Lake, a unique swamp ecosystem. In the southeastern part of the Pineywoods, north of Beaumont and just west of the Louisiana border, is found the Big Thicket, a vegetationally complex area and the site of Texas' only National Preserve.

Caddo Lake

…the surreal, swampy Caddo Lake—does not offer dramatic vistas, but instead envelops the visitor in an almost womblike enclosure of lush plants and water.

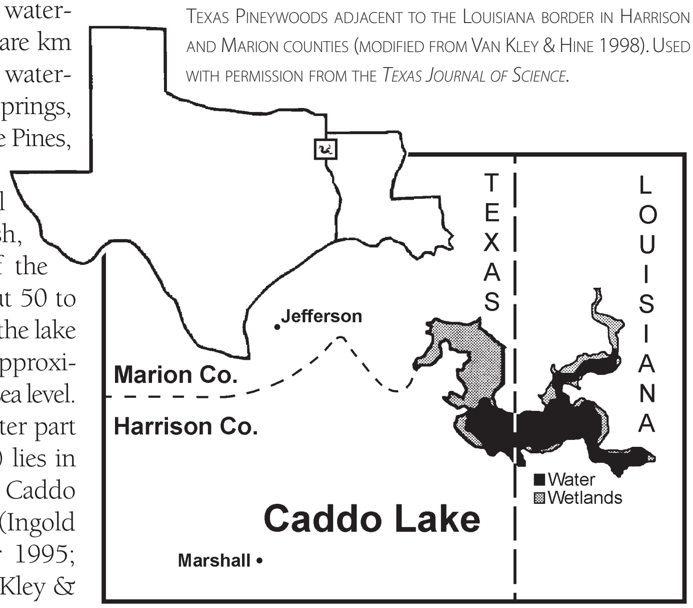
—Southall 1993

Fig. 82/ Caddo Lake, Mill Pond area (photo by David Gibson).

Location of Caddo Lake

Caddo Lake, an extensive bald-cypress (*Taxodium distichum*) swamp ecosystem (Fig. 82), is found in the northeastern part of the Texas Pineywoods and straddles the Texas-Louisiana border (Fig. 83). It is located in Harrison and Marion counties, east of Jefferson along Big Cypress Bayou, a tributary of the Red River. The Caddo Lake ecosystem is part of the Cypress Creek watershed, an area of 15,540 square km (6,000 square miles). The watershed includes Lake Cypress Springs, Lake Bob Sandlin, Lake O' the Pines, Caddo Lake, and parts of eleven Texas counties, as well as a portion of Caddo Parish, Louisiana. The elevation of the watershed ranges from about 50 to 180 m (160 to 600 feet) with the lake level of Caddo Lake being approximately 51 m (168 feet) above sea level. While much of the open water part of the lake (called Big Lake) lies in Louisiana, the majority of Caddo Lake's watershed is in Texas (Ingold & Hardy no date; Dahmer 1995; Giggleman et al. 1998; Van Kley & Hine 1998).

Fig. 83/ Location of Caddo Lake in the northeastern part of the Texas Pineywoods adjacent to the Louisiana border in Harrison and Marion counties (modified from Van Kley & Hine 1998). Used with permission from the *Texas Journal of Science*.



Presettlement and Early Settlement History and Conditions in the Caddo Lake Area

Caddo Lake has a unique, complex, colorful, and controversial history (Carter 1936; Dahmer 1995). Though an earlier Spanish expedition (De Soto-Moscoso in 1542, led by Luis de Moscoso Alvarado) contacted indigenous Caddoan people in both Louisiana and Texas and may have passed close to Caddo Lake (Bruseth 1996; La Vere 1998), the first known Europeans to visit the Caddo Lake area proper were members of the ill-fated seventeenth century French expedition originally led by the explorer René Robert Cavelier, Sieur de La Salle (Dahmer 1995; Smith 1995). La Salle had explored widely in the central part of the continent, from the mouth of the Mississippi to the Great Lakes, and had been granted permission to establish a colony in the New World (Cole 1946; Stephens & Holmes 1989). After founding a struggling colony on the Texas coast (Fort Saint Louis—on Garcitas Creek, a tributary of Matagorda Bay, located in present-day Victoria County—Weddle 1996), an apparently desperate La Salle with a contingent of nineteen men attempted to find his way back to the Great Lakes. Eventually, disagreements ensued and La Salle was killed by his own men in the spring of 1687, probably in what is now Grimes County (Foster 1998). Survivors of the expedition continued northeast across East Texas and passed through the Caddo Lake watershed later in the spring of 1687 before crossing the Red River and eventually making their way back to the Great Lakes (Ingold & Hardy no date; Cole 1946; Newcomb 1961; Stephens & Holmes 1989; Dahmer 1995).

As did subsequent French and Spanish expeditions, the seventeenth century La Salle Expedition encountered a tribe of indigenous people who called themselves the Kadohadacho (now considered one of the confederacies of the Caddos) (Newcomb 1961; Dahmer 1995; Smith 1995; La Vere 1998). The Caddos were part of the advanced farming culture that had at one time built ceremonial mounds widely in the eastern U.S. (Newcomb 1961; Phelan 1976; Smith 1995). Such mounds can still be seen today in some parts of East Texas (e.g., Caddoan Mounds State Historic Site in Cherokee County). It is from the Caddos that Texas derived its name. The Caddoan word *Techas* or *Tayshas*, meaning allies or friends, was mispronounced by the Spanish as *Tejas* and eventually came into English as Texas (Bolton 1908; Phelan 1976; Smith 1995). According to Dahmer (1995), the Caddos used the word so often that early explorers thought it was the native name for the area.

The political control of the Caddo Lake region has been marked by change—it was first controlled by the Caddos, then claimed by both Spain and France, and with Texas independence, at least a portion of it was considered part of that separate nation. With Texas statehood in 1845, the Texas-Louisiana boundary was drawn approximately down the middle of Caddo Lake (Dahmer 1995; Mallory 1997).

Caddo Lake, with its extensive areas of bald-cypress (Fig. 82) festooned with Spanish moss and with the water sometimes completely covered with a green carpet of floating aquatic plants, has caught the imagination of both local residents and those only newly introduced to the area. According to Dahmer (1995), a long-time resident and one of the most knowledgeable authorities on the lake, "Caddo Lake is the most beautiful lake you will ever see." Often stated to be the only natural lake in Texas, it is the largest naturally occurring body of freshwater in the state (Dahmer 1995). Rather than a single lake, Caddo Lake is actually a complex series of lakes and swamps interconnected by a maze-like series of channels. Among the most striking aspects of Caddo Lake are the bald-cypresses (*Taxodium distichum*) which dominate most views. These extremely water-tolerant, swollen-based trees not only line the margins of open portions of the lake and its channels, but also occur as isolated individuals in areas of shallow water.

Despite previous ideas about the origin of Caddo Lake (e.g., formed by earthquakes in 1811–1812—Weniger 1984b), recent consensus recognizes a different mechanism of formation. It is now thought that Caddo Lake is a drowned floodplain resulting from the Great Raft. Originally, Caddo Lake was probably a low "system of creeks, ponds, lakes, and swamps interspersed with islands and hillocks of dry ground. In the rainy season there were good-sized lakes; in the dry season it was a large swamp" (Dahmer 1995). Just to the east of Caddo Lake, the Red River flows south through an area where for millennia it has frequently changed course, as evidenced by such structures as oxbow lakes.

Around 1800, a huge series of log jams 120 km (75 miles) long called the Great Raft obstructed the main channel of the Red River, forcing water into side channels and backing up tributaries, including Twelve Mile Bayou, which drained the Caddo Lake area. While the exact cause of the Great Raft is not known with certainty, one widely held theory is that "flood waters from the Mississippi River engulfed the mouth of the smaller Red, forcing large amounts of driftwood up stream" (Vaughn-Roberson 2004). Once a portion of the Red River was so blocked, large amounts of debris washing downriver would presumably have continued to build up. Alternatively, logs and other material from upstream could simply have accumulated in the very meandering channel and blocked the river. Whatever the cause, a number of swamps and lakes, including Caddo Lake, was the result of the Great Raft (Barrett 1995; Dahmer 1995; Keeland & Young 1997; MacRoberts et al. 1997; Van Kley & Hine 1998; Texas Parks and Wildlife 2002c). Caddo Lake, in the early 1800s sometimes called Fairy Lake (or misspelled Ferry Lake—e.g., Kendall 1845—Fig. 84), is thus a drowned floodplain formed when water from the Red River was diverted into the naturally low area around Big Cypress Bayou and adjacent streams (Barrett 1995; Dahmer 1995; Van Kley & Hine 1998).

During the time of the Great Raft (indicated on a map in Kennedy 1841), river steamboats could travel up the Mississippi to the Red River and eventually through Caddo Lake upstream as far as Jefferson, Texas (e.g., Smith 1849, published in 1970). As a result, Jefferson was the most inland city in the region reachable by navigable waterway, and by

FIG. 84/ MAP OF THE REPUBLIC OF *TEXAS FROM NARRATIVE OF AN EXPEDITION ACROSS THE GREAT SOUTHWESTERN PRAIRIES FROM TEXAS TO SANTA FE* BY KENDALL (1845) (CROPPED AND SLIGHTLY MODIFIED FOR CLARITY). NOTE FERRY L[AKE], THE INDICATION OF "HERDS OF BUFFALO" NORTH OF AUSTIN, THE CLEAR INDICATION OF THE CROSS TIMBERS, AND THE SCARCITY OF CITIES IN ALL OF EAST TEXAS. FERRY LAKE [FARIY LAKE] WAS AN HISTORICAL NAME FOR CADDO LAKE.

the 1850s it entered a period of prosperity. Steamers arrived at Jefferson by the hundreds, commerce flourished, and it became the largest town in northeast Texas, with a population of 12,000 in 1870 (Maxwell & Baker 1983). However, once the Great Raft was removed (in 1874— Kleiner 1996), Caddo Lake began to slowly drain and revert to its original swampy state. Thus, steamboat traffic to Jefferson came to an end by the end of the 1800s (Dahmer 1995; Van Kley & Hine 1998) and the city declined (recently because of its historic significance and the beautiful nineteenth century buildings, Jefferson has experienced a revival as a tourist destination). By 1912, most of Caddo Lake was covered by less than eight inches of water (Texas Parks and Wildlife 2002c). Oil was discovered in the region shortly after the turn of the twentieth century and the hauling of equipment and other oil operations were very difficult in the now swampy Caddo "Lake." Apparently, lobbying by oil interests resulted in the construction of a small dam near Mooringsport, Louisiana in 1914, with the goal being to restore "enough depth of water in Caddo Lake to permit barge and workboat operation of their oil well activities" (Dahmer 1995). Caddo Lake thus became one of the first locations where oil exploration was done underwater, and many basic underwater drilling techniques, soon to be used all over the world, were developed there. Subsequently replaced in 1971, the dam at Mooringsport stabilized the lake and preserved the associated wetlands vegetation (Barrett 1995; Dahmer 1995; Van Kley & Hine 1998).

Presumably the vegetation of Caddo Lake at the time of European contact was similar to that found in relatively undisturbed areas of the Caddo Lake region today (Hine 1996; Van Kley & Hine 1998) and in other areas of the southeastern U.S. The animal life, however, was much different, and today's fauna is merely a remnant of the large and diverse animal populations previously found widely in the Pineywoods. More information on the Caddo Lake ecosystem can be found in Caddo Lake Institute (2001a), Texas Parks and Wildlife (2002c, 2002d), Van Kley and Hine (1998), and Van Kley (2002).

The Present and Future of Caddo Lake

Today, Caddo Lake covers 10,850 hectares (26,800 acres) (Giggleman et al. 1998) and is a "maze of channels, meandering bayous, and sloughs" (Hine 1996). Much of the area is technically Semi-Permanently Flooded Swamps (Fig. 85; see also page 104), with a diversity of other vegetation types in the immediately surrounding watershed. There are six major plant community types present in Caddo Lake State Park and Wildlife Management Area: Rich Mesic Slopes, Mesic Bottomland Ridges, Bottomland Oak Flats, Cypress-Water Elm Swamps, Closed-Canopy Cypress Swamps, and Deep Water Cypress Swamps (Van Kley & Hine 1998). A good first-hand introduction to the ecosystem is easily accessible at Caddo Lake State Park.

Caddo Lake is particularly valuable as a natural area both because of its size and because of the diversity of communities—few forested wetland landscapes of its scale remain today in all of the southeastern U.S. (Van Kley 2002). As the largest naturally occurring body of water in Texas, as a biologically valuable resource, and as an area rich in Texas heritage, it is clearly a conservation priority. Indeed, several areas have been protected, including Caddo Lake State Park (484 acres [196 hectares] in Harrison County) and Caddo Lake Wildlife Management Area (7,681 acres [3,108 hectares] in Harrison and Marion counties obtained by Texas Parks and Wildlife in 1992 with the help of the Nature Conservancy). In 2000, the 8,500 acre (3,440 hectare) Caddo Lake National Wildlife Refuge was approved. It occupies the area of the now closed Longhorn Army Ammunition Plant. The majority of the Refuge's land was turned over to the U.S. Fish and Wildlife

FIG. 85/ CADDO LAKE SHOWING *TAXODIUM DISTICHUM* (BALD CYPRESS) (PHOTO BY GMD).

Service in 2004, and control of the rest will be transferred after appropriate decontamination (Federal Register 2000; Texas Education Agency 2001; Draper 2004). A further indication of the region's value is its selection as a Ramsar Wetlands Area in 1993 (Ingold & Hardy no date; Caddo Lake Institute 2001b). The Ramsar Convention, named for its 1971 place of adoption (Ramsar, Iran), is officially known as the "Convention on Wetlands of International Importance Especially as Waterfowl Habitat," and is considered "the first modern global nature conservation treaty" (Navid 1989). The objectives of the more than 135 member nations are to stem the loss of wetlands and to ensure their conservation (Caddo Lake Institute 2001b; Ramsar.org 2004).

As with any natural resource having economic value, Caddo Lake is vulnerable to both misuse and non-sustainable uses. One such threat is the recent (2002) effort by the City of Marshall (Harrison County) to divert large amounts of water—approximately 5.5 million gallons (20.8 million liters) daily—from the Caddo Lake watershed for industrial use (Chapman 2002; Deluca 2002; Davis 2004). Such a major hydrological change would have devastating ecological consequences, as well as major negative impacts on the local economy, and it has been challenged in court by a group known as the Caddo Lake Coalition (Deluca 2002). Unfortunately, as water demand increases and drier western parts of the state need ever greater amounts of water, many of East Texas' rivers and reservoirs may be the target of such transbasin water marketing schemes (Davis 2004).

Another possible threat to Caddo Lake is pollution and the resulting contamination of the lake's water and living organisms. There has been considerable concern in the area about mercury levels in Caddo Lake, and in 1995 the state of Texas imposed a fish consumption advisory for largemouth bass and freshwater drum because of suspected mercury contamination. A subsequent study of various fish species (Giggleman et al. 1998) found levels of a number of metals (e.g., chromium, lead, mercury, selenium) that exceeded the State of Texas aquatic life protection criteria. However, levels of all of these "were below the established action levels for human consumption" (Giggleman et al. 1998).

A further source of pollution concern is the Longhorn Army Ammunition Plant (now the Caddo Lake National Wildlife Refuge), operated by the U.S. government from 1943 to 1997. That facility is known to have groundwater and soil contamination due to chlorinated solvents and spent explosives (Giggleman et al. 1998). In 1990 it was designated a superfund site, and cleanup activities, expected to continue until around 2015, have begun (Texas Education Agency 2001). The Army is reported to have already spent $82 million on the cleanup and another $23 will be needed to complete the effort (Associated Press 2004). Caddo Lake thus faces a number of conservation challenges and only time will tell how the people of Texas treat this unique component of their natural heritage.

THE BIG THICKET

One's fondness for the area [Big Thicket] is hard to explain. It has no commanding peak or awesome gorge, no topographical feature of distinction. Its appeal is more subtle. It must be experienced bit by bit, step by step. One can neither see far nor go fast. A hundred yards off the road without a compass and you are lost, and the dense understory of the ti ti thicket could give one claustrophobia. What is left of the Thicket is as wild as ever. Its wilderness character was, and still is, its essential appeal…

—LOUGHMILLER & LOUGHMILLER 1977

FIG. 86/ EXAMPLE OF BIG THICKET VEGETATION IN JASPER CO. (PHOTO BY DAVID GIBSON).

LOCATION AND DEFINITION OF THE BIG THICKET

WHAT IS THE BIG THICKET?—Another region of the Pineywoods deserving special discussion is the Big Thicket (Fig. 86, 87), found in the southeastern part of the Pineywoods, north of Beaumont and just west of the Louisiana border (see Parker 1977 and MacRoberts & MacRoberts ined. for detailed bibliographies). It is an area that has been difficult to precisely

FIG. 87/ AERIAL PHOTOGRAPH OF THE BIG THICKET WHERE THE NECHES RIVER CUTS A MEANDERING PATH BELOW LAKE B.A. STEINHAGEN (PHOTO © WYMAN MEINZER).

define either geographically or biologically and one that has been variously described as unique (Eisner 1973), exceptionally rich in species (Watson 1975; Loughmiller & Loughmiller 1977; Peacock 1994; National Park Service 1997), unusually diverse in terms of plant communities (Peacock 1994), and as the "Biological Crossroads of North America" (Gunter 1993). Eisner (1973), writing in *Science*, described it as follows:

> A region of extraordinary botanical exuberance, the Thicket is ecologically unique not only to Texas, but to the entire North American expanse as well. Located at the crossroads between the forests of the South and East and the vegetation of the West, the Thicket includes in its pine-hardwood stands elements from all convergent zones. A wet climate and a water-storing soil combine to nurture the mixture to lushness.

On the other hand, some authorities (e.g., MacRoberts & MacRoberts 2004a) dispute these characterizations, and some would even question the existence of the Big Thicket as a distinct entity or would suggest that it is undefinable (e.g., Lumberman O.R. Crawford—Cozine 1993). According to Cozine (1993), "These skeptics maintain that at best the area is simply the western extension of the Southeastern Evergreen Forest which begins in Virginia and extends across the entire South...." and that "...there is nothing within the East Texas pine forest to distinguish one area from another." MacRoberts and MacRoberts (2004a) in their recent analysis (*The Big Thicket: Typical or Atypical?*) concluded that, rather than being unique, the Big Thicket is typical of the same habitat that extends into Louisiana and eastward.

Several questions thus need to be asked about the Big Thicket. First, how is it defined geographically—exactly where is the Big Thicket and what are its boundaries? Second, how accurate are the various descriptions of the Big Thicket that have been given over the years? And third, can one define the Big Thicket biologically—is there something that makes it unique? The answers to these questions are examined in the sections that follow. For a concise summary definition, see page 172.

GEOGRAPHIC BOUNDARIES AND ORIGIN OF THE NAME—Depending on the source consulted, the Big Thicket is considered to have originally covered from over two (McLeod 1971, 1972) to nearly three and one-half (Owens 1978; Peacock 1994) million acres (809,000 to 1,416,000 hectares, the latter figure being approximately the size of Connecticut—Gunter 1993). However, there is much disagreement on what area should actually be called the Big Thicket (Fig. 88). In the words of Gunter (1993), the Big Thicket "is an ecological entity … and such entities rarely have perfectly precise boundaries." As emphasized by McLeod (1971), "The area, popularly referred to as the Big Thicket, has long been ill-defined, poorly bounded, and questionably named." Cozine (1993) noted that "What is the Big Thicket, and where is it located are questions which people have tried to answer for years." Weniger (1984b) argued that the term, "Big Thicket," "cannot be proved to be an ancient one," that it is a relatively modern (1800s) concept, and that it is "not … profitable to try to trace the concept of the Big Thicket back into the Spanish 18th century." Weniger, in fact, concluded that the first known published uses of the term "Big Thicket" are by Braman and De Córdoba in 1857 and 1858 respectively, and that the Big Thicket never was a clearly defined impenetrable area. Michael MacRoberts (pers. comm.) found a slightly earlier use of the name—Samuel Adams Hammett (1853), writing under the pseudonym Philip Paxton, described an area near the San Jacinto River as "… a thicket so dense that even in that country of tangled forest, it is known—par excellence—as the big thicket. …" It is worth noting that none of these uses are prior to 1850 and that well known maps of Texas in the mid-1800s (e.g., Kennedy 1841; Kendall 1845) do not mention the Big Thicket (e.g., Fig. 85).

Though the exact origin of the term Big Thicket is unknown, Tharp (1952b) gave a reasonable explanation when he described the area:

> Much of the ground water was returned to the surface in seepy areas along slopes in "bay galls," or through extensive swampy areas in the flood plains of the creeks feeding the Sabine, Angelina, Neches, and Trinity rivers. These swampy areas, in addition to being impassable themselves by reason of their miry nature, supported a growth of large and small hardwood vegetation so dense as to merit the name thicket. Since these thickets occupied an intricate network over the whole area, it was impossible for a traveler to proceed far without encountering one. It was small wonder that the notion grew that the whole area was a big thicket.

There is no question that there are some extremely dense thickets in the area. In particular, some authors have suggested that the name may be in reference to the virtually impassable groves of titi or "tight-eye" (*Cyrilla racemiflora*, Cyrillaceae) that made early travel in the area so difficult (Peacock 1994).

While uncertainty thus surrounds the origin of its name and boundaries, viewed in broadest terms the Big Thicket has been considered by some to be bordered on the north by the San Antonio-Natchitoches road (also known as the Old San Antonio Road, El Camino Real, or the King's Highway) or perhaps better by the ridge running between Jasper and Livingston (G. Watson, pers. comm.), on the south by the coastal prairies, the variously named Atascosito-Opelousas Trail/La Bahía Road/Opelousas Road/lower Camino Real (McLeod 1972; Ajilvsgi 1979; Abernethy 1996), or two meander ridges (the China Ridge and the Neches Ridge—G. Watson, pers. comm.), on the east by the Sabine River (Louisiana border), and on the west by the Brazos River (Abernethy 1966, 1996). The western boundary was soon realized to be further east and closer to the Trinity River. When defined in this way, as done in Parks and Cory's *Biological Survey of the East Texas Big Thicket* (1936), the Big Thicket "closely follows the description given by early settlers" (Gunter 1993). With such broad boundaries, this "primitive Big Thicket" encompassed approximately 3.35 million acres (1.36 million hectares) and all or part of fourteen counties (Parks & Cory 1936; Gunter 1993; Peacock 1994) (Figs. 88, 89). At the other extreme of the size scale, local residents of the area have generally considered the Big Thicket to be much smaller—about forty or fifty miles (64 or 80 km) long and twenty miles (32 km) wide

(130,000 hectares), mostly located in Hardin County and stretching from just south of Sour Lake north past Votaw into southern Polk County (Abernethy 1966, 1996, 2002; Loughmiller & Loughmiller 1977, 2002). Such a delineation (see Fig. 88), encompassing the "wooded swamps and junglelike palmetto flats around Pine Island and Little Pine Island bayous" is sometimes referred to as the Traditional or Hunter's Thicket (Ajilvsgi 1979). McLeod's (1972) ecological study of the region (discussed in more detail below)

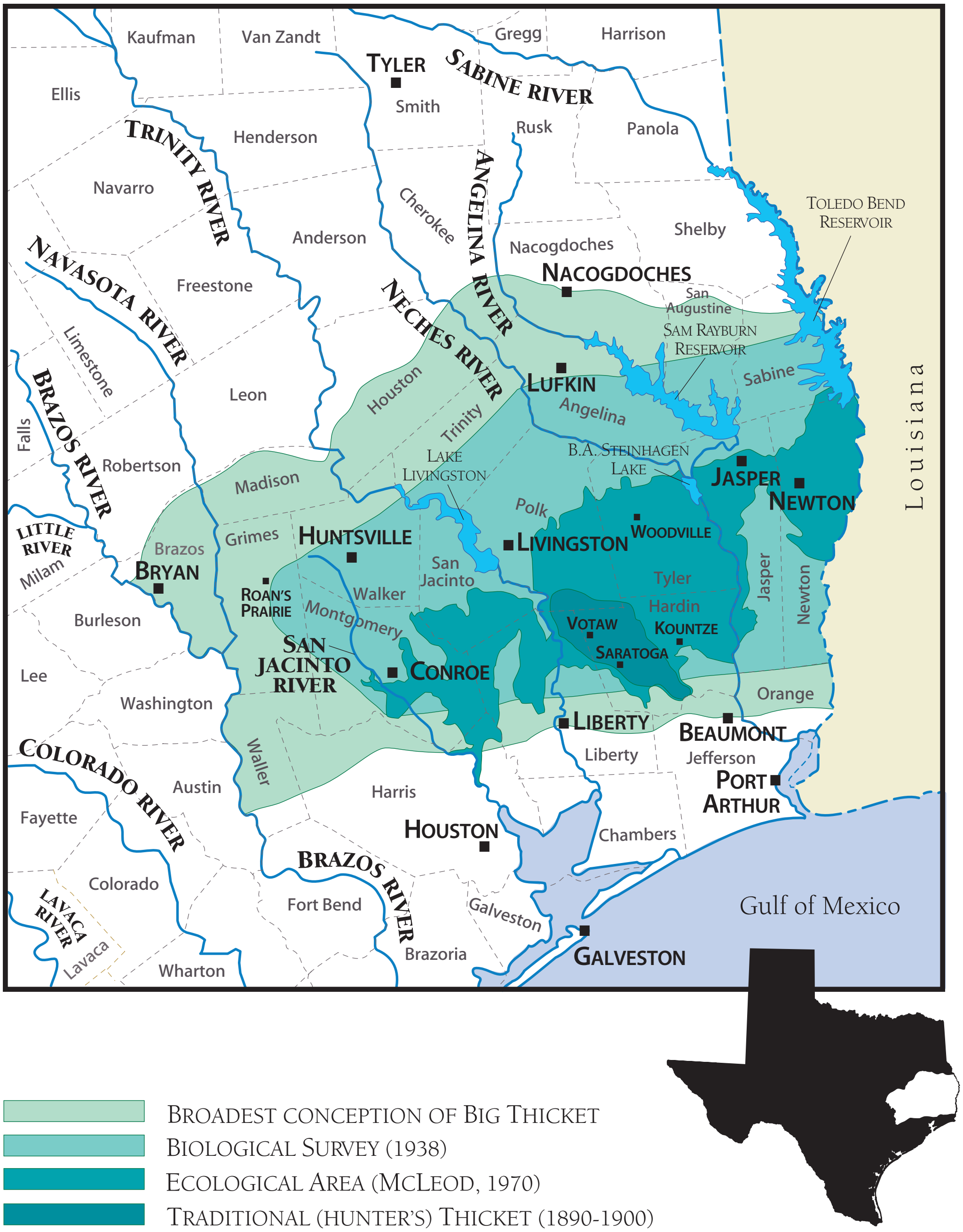


FIG. 88/ VARYING CONCEPTIONS OF THE BIG THICKET. MODIFIED FROM GUNTER (1971); FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE.

provides the most biologically meaningful conception of the Big Thicket. While larger than the Traditional Thicket, McLeod's ecological definition is much smaller than earlier, less precise delineations. This vegetationally based view treats the Big Thicket as extending from Newton County on the Louisiana border west to near Conroe in Montgomery County, and from north of Woodville in Tyler County south to northeastern Harris County near Houston (Figs. 88, 90)—an area exceeding two million acres (810,000 hectares or 3,125 square miles) (McLeod 1972). We are using McLeod's definition of the Big Thicket as the general basis for our discussion because it is a non-arbitrary delineation based on an actual survey of the vegetation of the region.

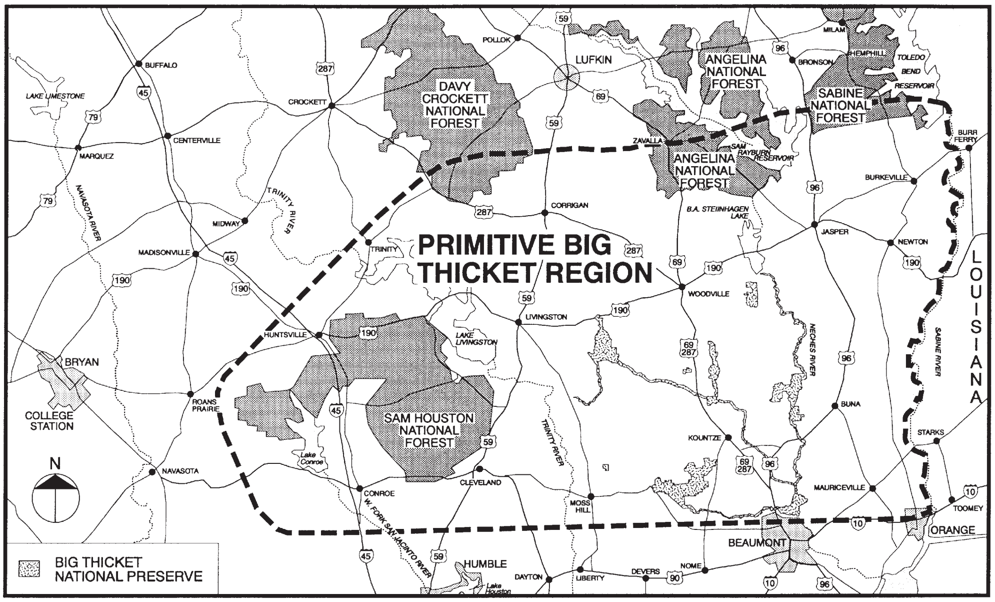


FIG. 89/ THE "PRIMITIVE" BIG THICKET REGION (REPRINTED FROM *NATURE LOVER'S GUIDE TO THE BIG THICKET* BY HOWARD PEACOCK BY PERMISSION OF THE TEXAS A&M PRESS. COPYRIGHT © 1994 BY HOWARD PEACOCK).

NATURAL HISTORY OF THE BIG THICKET

GENERAL DESCRIPTION OF THE VEGETATION—From a scientific standpoint, the Big Thicket, like all of the Pineywoods, is part of two broad-scale vegetational provinces: the Southeastern Mixed Forest Province and the Outer Coastal Plain Mixed Forest Province (Keys et al. 1995; Turner et al. 1999). In general, forests to the north and west of the Big Thicket, though part of the Pineywoods, "receive less precipitation, are shorter, and contain fewer tree species" (Marks & Harcombe 1981). Ecologically, McLeod (1972) considered the Big Thicket to have been originally an area of mixed mesic woodlands, and he noted that the species composition was sufficiently homogeneous to distinguish it from adjacent vegetational types. He described it as "predominantly a loblolly pine-hardwood association" and more specifically "a loblolly pine-white oak-beech-magnolia forest, rich in an understory of both evergreen and deciduous shrubs, a variety of climbing vines, and both annual and perennial herbs." He considered this forest to be the climax vegetation of the region and used it as the basis for his delineation of the Big Thicket (Fig. 90). He stressed the importance of the mixed hardwoods, noting that "it is the hardwood components, with their associated understory species, that define this forest type in relation to contiguous forest types." Even though emphasizing a common vegetational association, McLeod (1972) divided the area into an "upper thicket," to which American beech (*Fagus grandifolia*) is restricted, and a wetter, more poorly drained "lower thicket," where that species is largely replaced by oaks (*Quercus* spp.). However, Maxine Johnston

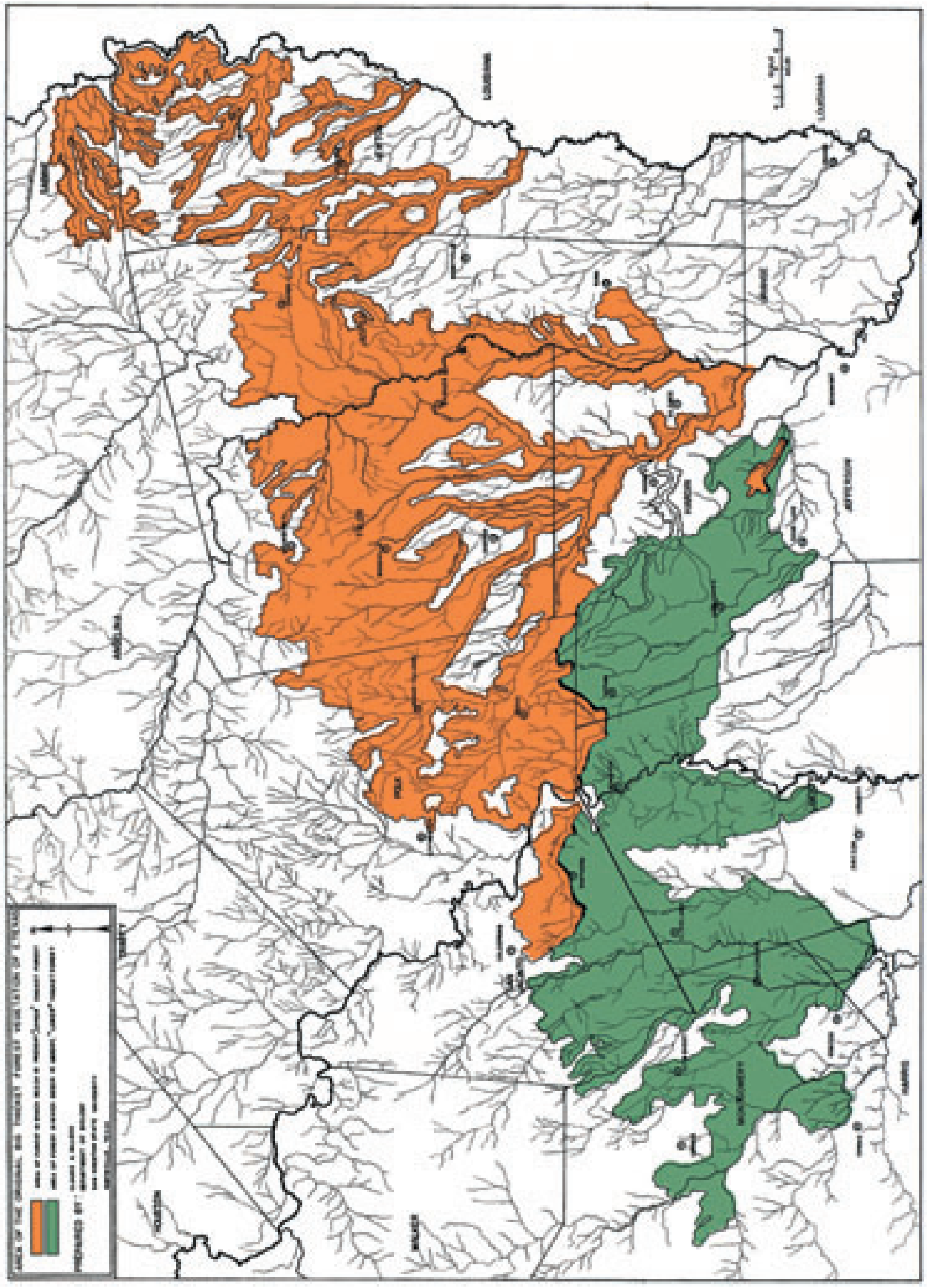


FIG. 90/ MCLEOD'S ECOLOGICAL DEFINITION OF THE BIG THICKET (FROM MCLEOD [1972], *THE BIG THICKET FOREST OF EASTERN TEXAS: A BRIEF HISTORICAL BOTANICAL AND ECOLOGICAL REPORT*. SAM HOUSTON STATE UNIV., HUNTSVILLE, TX). NOTE THE DISTINCTION BETWEEN THE "UPPER" AND "LOWER" THICKET.

(pers. comm.) points out that beech does occur in the Lance Rosier Unit of the Big Thicket National Preserve in the "lower thicket." While McLeod's ecological definition seems the most accurate way of generally delineating the Big Thicket, many other strikingly different vegetation types (e.g., xeric sandylands, baygalls) are interspersed throughout his "loblolly pine-white oak-beech-magnolia forest." These have been variously classified by subsequent authorities as follows.

Watson's (1975) early work divided the Big Thicket into seven plant communities: 1) Prairie; 2) Palmetto-hardwood flats; 3) Stream floodplains (subdivided into Lower bottomland and Upper bottomland); 4) Arid sandyland; 5) Acid bog-baygall; 6) Longleaf pinelands (subdivided into Longleaf pine uplands and Pine savannah wetlands); and 7) Beech-magnolia-loblolly pine association. The National Park Service (based in part on Watson) recognized 10 ecosystems in the Big Thicket National Preserve: Baygall, Beech-magnolia-loblolly, Cypress slough, Longleaf pine upland, Oak-gum floodplain, Palmetto-hardwood flats, Pine savannah wetlands, River edge, Roadside, and Arid sandylands (Peacock 1994). Ajilvsgi (1979, also based in part on Watson) distinguished nine communities: Mixed-grass prairies, Palmetto-oak flats, Sweet gum-oak floodplains, Bay-gallberry holly bogs, Longleaf-black-gum savannahs, Longleaf-bluestem uplands, Beech-magnolia-loblolly slopes, Oak-farkleberry sandylands, and Roadsides. Marks and Harcombe (1981) recognized four broad types and subdivided them as follows: Uplands (Sandhill pine forest, Upland pine forest, Wetland pine savannah), Slopes (Upper slope pine oak forest, Mid slope oak pine forest, Lower slope hardwood pine forest), Floodplains (Floodplain hardwood pine forest, Floodplain hardwood forest, Wetland baygall shrub thicket, Swamp cypress tupelo forest), and Flatlands (Flatland hardwood forest). While the terms used in each of these systems are descriptive and, in general, accurate in portraying the vegetational diversity present, plant ecologists currently give these communities different names more readily allowing comparison to communities in other geographic areas (see page 90 for a detailed classification and discussion of Pineywoods vegetation).

VARIABLES INFLUENCING THE VEGETATION—The plant life of the region is the result of complex interactions between a number of often highly related factors, including geological ones (e.g., type of parent material, topography, soils, hydrology), climate, succession, and fire. Though rainfall is heavy throughout the Big Thicket (Parent 1993) and well-distributed through the year—the difference between the driest and wettest months being only 5 cm (2 inches) (Marks & Harcombe 1981)—relatively small differences in topography and different parent materials and soils produce a striking diversity of vegetation types. The importance of soils in influencing Big Thicket vegetation is reflected by the following statement by Harcombe et al. (1993). "Most of this area is covered by closed forests which vary in structure and species composition *along a soil texture gradient*" [italics ours].

While a mosaic of vegetation can be found nearly throughout the Big Thicket, certain plant communities are much more common in some areas than in others. In the far north, on the Oligocene Catahoula and Miocene Fleming geologic formations, areas of "barrens" and small isolated prairies are found, as well as hardwood-dominated ravines and areas of upland longleaf pine. Limited areas of Wet Herbaceous Seeps ("hanging bogs") often form when the impenetrable Catahoula Formation is overlain by more porous layers. In contrast, where the calcareous (and thus basic) Fleming outcrops at the surface, there are unusual occurrences of calciphilic (= calcium-loving) plants in certain localities in Jasper and Newton counties (Bridges & Orzell 1989a; J. Liggio, pers. comm.).

A little to the south, the younger (late Tertiary, Pliocene), sandy Willis Formation (e.g., near Woodville) has eroded to form rolling topography and permeable, well-drained, but often relatively moist, rich, sandy soils. The increased soil moisture and relatively dissected topography apparently allow more fire-susceptible vegetation to survive here. The result is larger areas of beech-magnolia-loblolly forests (e.g., in the Beech Creek Unit of Big Thicket National Preserve) but fewer areas dominated by longleaf pine (Harcombe et al. 1993). Because the Willis is well-drained, wetland communities are in general restricted to stream bottoms or to Wet Herbaceous Seeps/hanging bogs on hillsides (Watson 1975).

Still further south, on the Pleistocene Lissie (including the Bently and Montgomery) Formation, xeric sandylands and longleaf pine uplands can be found on higher, dry sandy terraces between the streams, or in the case of longleaf pine, on mounds on the nearly flat savannah wetlands. In general though, the Lissie and the still younger Beaumont (also Pleistocene) (e.g., near Beaumont and Little Pine Island Bayou) underlie very flat areas close to sea level—hence they have a high water table and are more subject to flooding and water retention. In addition, the soils of the Lissie and Beaumont formations have a higher clay content, particularly in the subsoils. These soils are thus less permeable and often poorly drained, favoring plants with greater water requirements or tolerance. Wetland communities such as palmetto-hardwood flats, wetland longleaf pine savannahs, and bald-cypress sloughs are common in this flat terrain (Smeins et al. 1982; Bridges & Orzell 1989b; Parent 1993). Even here, slight differences in topography and soil moisture—such as mima mounds (see page 65), old terraces, or slightly higher areas between streams—can have a major impact on the plant species present. For example, on the Beaumont Formation, longleaf pines are essentially restricted to mima mounds (Watson 1975). On the very southern edge of the Big Thicket, on the Beaumont, wetland longleaf pine savannahs and scattered areas of prairie are transitional to what was in presettlement times a large expanse of Coastal Prairie, underlain in general by clay soils.

Two other cases further exemplify the influences of soil, topography, and hydrology on vegetation. Particularly interesting are areas where tight impermeable clay soils and flat terrain result in very poor drainage and standing water during part of the year. Such areas are known as Wet Pine Savannahs or savannah wetlands (see page 97). The growth of woody plants in these areas is apparently retarded by waterlogging and high acidity. In addition, because of their slow growth, trees in such areas are vulnerable to fire for relatively longer (MacRoberts & MacRoberts 1993a; 2001). Also, Wet Pine Savannahs have soils that tend to be acidic and very poor in nutrients, and carnivorous plants do well—in fact, 14 species in four different genera, *Sarracenia* (pitcher plants), *Drosera* (sundews), *Pinguicula* (butterworts), and *Utricularia* (bladderworts), are found in East Texas. As with all carnivorous plants, *nutrients* (especially nitrogen), rather than calories, are obtained through carnivory—these plants still obtain the energy they need for growth and development through photosynthesis.

In contrast to the poorly drained Wet Pine Savannahs, the excessively drained, dry, white quartz sand soils of the Dry Uplands on Deep Coarse Sands (also known as xeric or arid sandylands) (see page 92) support such dry-adapted plants as *Cnidoscolus* (bull-nettle), *Opuntia* (prickly-pear), *Quercus incana* (bluejack oak), *Vaccinium arboreum* (farkleberry), and *Yucca*.

Factors affecting succession have long been important in influencing the vegetation of the Big Thicket (and much of the southeastern United States). These include such diverse phenomena (at widely varying scales) as recurrent hurricanes, special edaphic conditions, beaver activity, oxbow lake formation, the gradual filling of bogs, and fire. Of all of these, fire is probably most important. According to MacRoberts and MacRoberts (2000), "about half of the plant communities of the Longleaf Pine Ecoregion require periodic fire or they gradually succeed to other communities, losing key species and structural integrity." For example, prairies, small seeps/bogs, pine savannah wetlands, and longleaf pine uplands were all pyrogenic communities maintained during presettlement times at least in part by fire (the fires due to both natural causes and the activities of Native Americans). Under current fire suppression regimes, these fire-adapted communities have been (and are still being) replaced by different suites of plants (Watson 1975; Simberloff 2000b). In fact, fire suppression is one of the most detrimental changes affecting natural communities in the Big Thicket at the present time. For example, MacRoberts and MacRoberts (2000) summarized numerous studies (e.g., McClung 1988; Bridges & Orzell 1989b) and observations pointing to the critical need for fire in maintaining Wet Pine Savannahs in the Big Thicket National Preserve (e.g., Hickory Creek Unit) and adjacent areas—many areas that were previously savannah have become, only a few decades later, so invaded by shrubs (e.g., *Cyrilla racemiflora, Ilex vomitoria)* that they can no longer be called savannah. Given the current low incidence of unintentional fire, only active intervention (frequent controlled burns) will result in the maintenance of significant areas of savannah (MacRoberts & MacRoberts 2000). Another example is the Loblolly Unit of the national preserve, which has undergone change from prairie to loblolly pine-hardwood forest in a little over 100 years (Watson 1975). Even now, however, small areas of prairie can still be found in the Big Thicket—Windham Prairie in Polk County is a good example. Brown et al. (2002b) found that this small (2–3 hectares) area is apparently maintained at least in part by special edaphic conditions. Its soil, derived from the Fleming Formation, is a gravelly, thin, well-drained, calcareous clay with a high shrink-swell potential and slow permeability (McEwen et al. 1987; Brown et al. 2002b).

DIVERSITY IN THE BIG THICKET—Two things in particular that have been noted during detailed studies of the vegetation of the Big Thicket (e.g., Marks & Harcombe 1975, 1981; Harcombe & Marks 1977) are 1) high beta diversity (= between-habitat diversity, i.e., many species because of many different habitats) and 2) high alpha diversity (= within-habitat diversity, i.e., many species within each habitat—e.g., high richness of woody species particularly in the understory). In general, the coastal plain of the southeastern U.S. is rich in species of vascular plants and is characterized by many community types (Braun 1950; Marks & Harcombe 1975). Marks and Harcombe (1975) suggested that the area of the Big Thicket displays both of these characteristics.

HABITAT DIVERSITY—One of the most visually striking features of the Big Thicket is the close proximity of numerous radically different habitats and communities. Some sources have even suggested that the Big Thicket contains more kinds of ecosystems than any other place

FIG. 91/ VIEW OF VILLAGE CREEK IN THE NATURE CONSERVANCY'S ROY E. LARSEN SANDYLAND SANCTUARY, HARDIN CO. (PHOTO BY GMD).

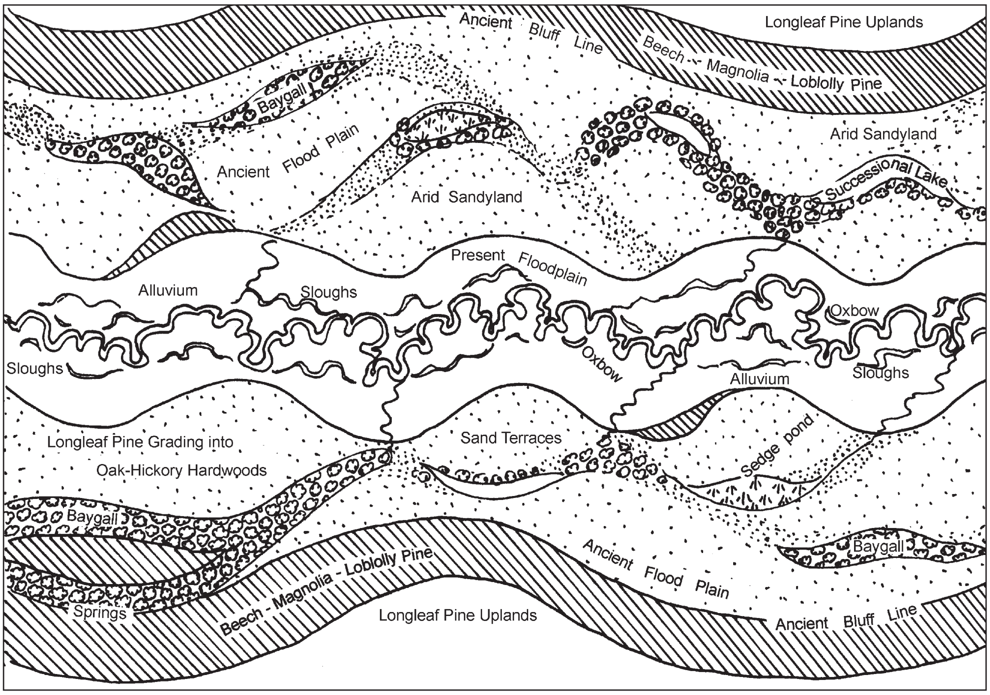


FIG. 92/ VEGETATIONAL COMPLEXITY SEEN IN THE VILLAGE CREEK FLOODPLAIN IN THE BIG THICKET; NOTE MEANDERING OF THE STREAM. MODIFIED FROM WATSON (1975) WITH PERMISSION OF GERALDINE WATSON AND THE BIG THICKET ASSOCIATION.

of similar size in North America (Peacock 1994). However, when examined closely, even though the Big Thicket is diverse in terms of habitats, there appear to be no studies demonstrating that it exceeds a number of other areas in the southeastern United States in this regard (MacRoberts & MacRoberts 2004a). The Big Thicket appears to display approximately the same number of plant communities as do other parts of this habitat-diverse region of the country.

As in other areas in the southeast, the complex vegetational pattern is controlled by slight variations in elevation, soil type, and available water (Watson 1975; Parent 1993). The Village Creek Floodplain (Fig. 91) is a particularly telling specific example as can be seen from the diagram (Fig. 92)—areas of arid (xeric) sandyland vegetation occur on well-drained, slightly higher, sandy areas representing old levees or terraces, while baygalls and other wetland vegetation types occupy abandoned stream channels. In some parts of the Big Thicket, walking a descending transect over a few tens of meters from a ridge top to a stream bottom can reveal the following—beginning in a xeric sandyland upland with *Pinus palustris* (longleaf pine), *Quercus incana* (bluejack oak), *Cnidoscolus texanus* (bull-nettle), *Yucca louisianensis* (Louisiana yucca), *Opuntia humifusa* (eastern prickly-pear), and *Pteridium aquilinum* (bracken fern); proceeding downhill to a midslope mesophytic *Fagus grandifolia-Magnolia grandiflora* (beech-magnolia) forest with *Lilium michauxii* (Carolina lily), *Tipularia discolor* (crane-fly orchid), and *Epifagus virginiana* (beech drops); and finally arriving at a bottomland baygall with *Magnolia virginiana* (sweetbay magnolia), *Ilex coriacea* (gallberry holly), *Cyrilla racemosa* (titi), *Apteria aphylla* (nodding-nixie), and *Osmunda regalis* (royal fern). At a larger scale, the complexity of the vegetation is still quite evident, with areas dominated by different communities extremely intermingled (Fig. 93). It is important to understand, as pointed out by Geraldine Watson (pers. comm.), that the complexity of the vegetation is such that there "is not one thicket, but many."

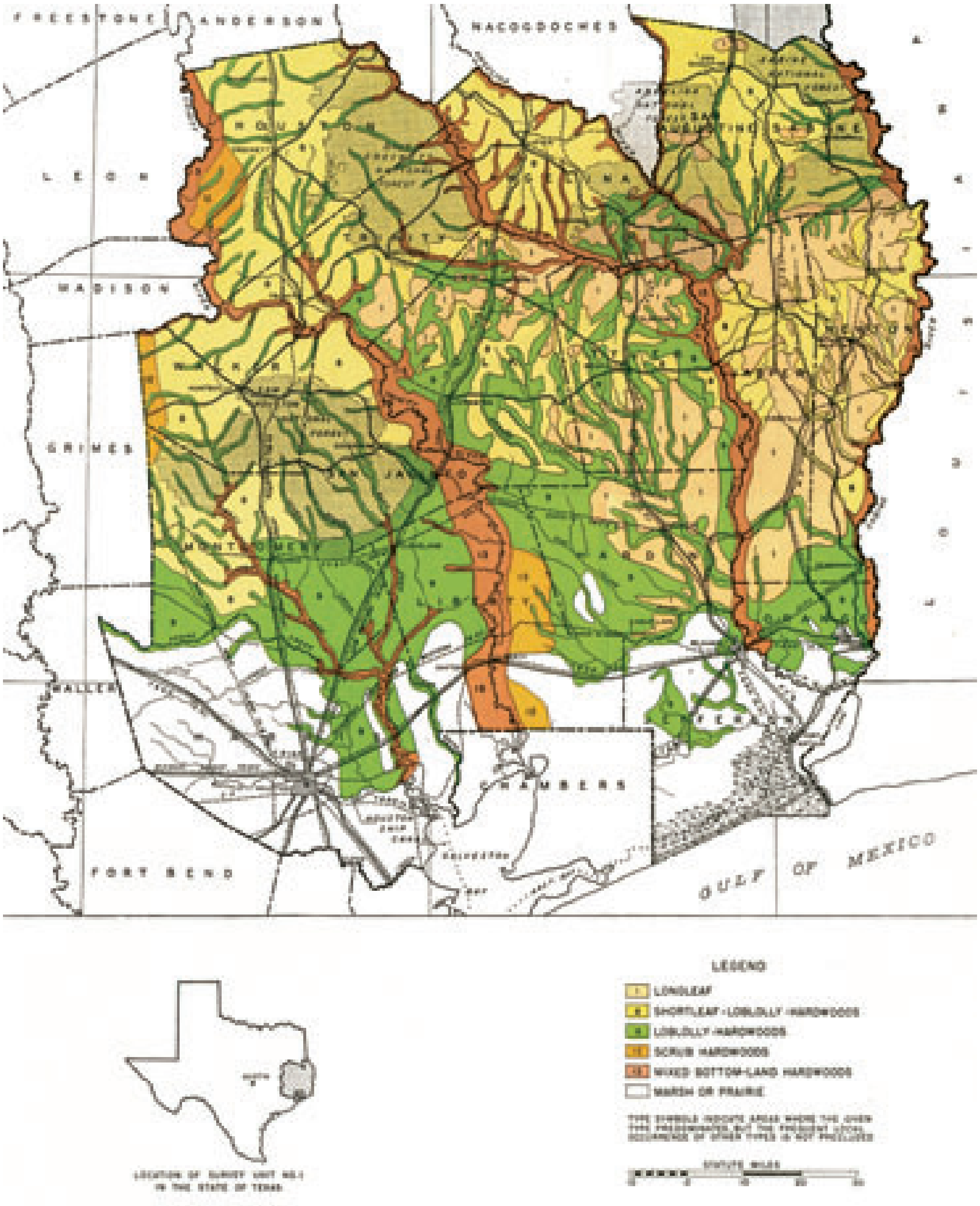


FIG. 93/ VEGETATION TYPES OF SOUTHEAST TEXAS (INCLUDING ALL OF THE BIG THICKET) AS MAPPED IN 1939 BY THE SOUTHERN FOREST EXPERIMENT STATION (CRUIKSHANK & ELDREDGE 1939).

SPECIES DIVERSITY (HIGH SPECIES RICHNESS)—The Big Thicket is not only rich in habitat types, it is also a region often described as having high species diversity, or more technically, high species richness (= total number of species) (e.g., Watson 1975; Loughmiller & Loughmiller 1977; Peacock 1994; National Park Service 1997). Some authors (e.g., Loughmiller & Loughmiller 1977) have suggested (based on empirical observations of large numbers of species but without detailed quantitative data) that the Big Thicket contains the greatest variety of plants of any comparable area in the United States. Because of this diversity, the Big Thicket has sometimes been referred to as "America's Ark" (Peacock 1994). On the other hand, MacRoberts and MacRoberts (2004a) have recently concluded that the Big Thicket has species richness values similar to other species-rich areas of adjacent Louisiana and the southeastern United States. These conflicting views need examination.

Given the high levels of species richness of East Texas as a whole (see page 225) and the habitat diversity seen in the Big Thicket, relatively high levels of species richness would be expected for the Big Thicket. Unfortunately, "botanically the entire area is understudied and underdocumented" (MacRoberts et al. 2002a), and enough data have not been available to adequately assess levels of diversity. Despite extensive collecting by numerous individuals (particularly Geyata Ajilvsgi, Larry Brown, Barbara and Michael MacRoberts, Geraldine Watson, etc.), no complete fully *vouchered* published plant list exists for the Big Thicket region or even the Big Thicket National Preserve (MacRoberts et al. 2002a; MacRoberts & MacRoberts 2004a). However, a few lists have been made that can give some idea of the diversity present. Examples include the approximately 1,200 species listed for the Big Thicket National Preserve (National Park Service 1995a, 1995b—based in part on Watson's work; Harcombe 2004), the 544 species collected in the Nature Conservancy's 920 hectare (2,273 acre) Larsen Sandylands Sanctuary in Hardin County (Matos & Rudolph 1985, 1986), the 485 species collected in the approximately 260 hectares (642 acres) of the Little Thicket Nature Reserve in San Jacinto County (Peterson & Brown 1983), and the 401 taxa known from the Hickory Creek Savannah Unit of the Big Thicket National Preserve in Tyler County (MacRoberts et al. 2002a). While each of these lists is valuable and can give some idea of local scale species richness, they do not provide even an estimate of the plant diversity of the Big Thicket *region* as a whole.

Several works by the Nature Conservancy also give indirect information on species richness in the Big Thicket (Halstead 2002; Nature Conservancy 2003). Two designated conservation areas within the Big Thicket region, Longleaf Ridge and the Big Thicket-Sandylands Complex, are considered by the Nature Conservancy to be among the top ten richest conservation areas in the West Gulf Coastal Plain ecoregion (richness in the Nature Conservancy studies refers to the number of occurrences of conservation targets including both communities and individual species). Longleaf Ridge is particularly important since it is considered to be the richest of the ten sites (Nature Conservancy 2003). This nearly 200,000 hectare area is located on the northern margin of the Big Thicket in Jasper, Newton, Tyler, and Angelina counties, and occupies a line/ridge of eroded sandstone and volcanic ash hills. As indicated by the name, it supports remnants of longleaf pine (*Pinus palustris*) woodlands, numerous distinctive embedded plant communities, and a large number of species, many considered to be of conservation significance (Halstead 2002).

In the absence of any specific study addressing overall species richness in the Big Thicket, we suggest that a reasonable estimate for the number of plant species in the Big Thicket region can be made by totaling all those known to occur in the seven and one-half county area (Fig. 94) comprised of Hardin, Jasper, Liberty (northern half including Trinity River National Wildlife Refuge), Montgomery, Newton, Polk, San Jacinto, and Tyler counties (Diggs et al. 2003). While these counties do not exactly coincide with the boundaries of the "ecological" Big Thicket as delineated by McLeod (1971, 1972), they do correspond reasonably well (Fig. 94). This artificial delineation (at the *county level*, except for the northern half of Liberty County) was chosen because detailed county level distributional data are available from Turner et al. (2003), supplemented by recent information of which we are aware, (e.g., Brown et al. 2002a; MacRoberts et al. 2002a; Harcombe 2004). Southern Liberty County is excluded, since the extensive area of Coastal Prairie in the southern part of that county would add coastal and even salt marsh species inappropriately. Western Montgomery County has some areas of prairie, but because of the numerous prairie inclusions that were well known in the Big Thicket in presettlement times (particularly on the Beaumont Formation—Watson 1975) and even today (e.g., on the Fleming Formation—Brown et al. 2002b), we do not believe that including all of Montgomery County inappropriately inflates the number of species. On the other hand, eliminating Montgomery County would be removing a significant segment of the Big Thicket. We suggest that, short of a detailed and time-intensive study, this is probably the best current method of obtaining an estimate of species richness in the Big Thicket region. The data on which it is based are readily available, were compiled in large part by experts on the Texas flora (Billie Turner, Larry Brown, Barbara and Michael MacRoberts), and are, in general, supported by vouchered specimens.

When analyzed as outlined above (seven and one-half counties—approximately 6,940 square miles or 2.6% of Texas), the Big Thicket region has 1,826 species (approximately 36% of the total Texas flora) in 174 families. While reasonably high, we believe that this is probably a significant underestimate because of the paucity of collections available.

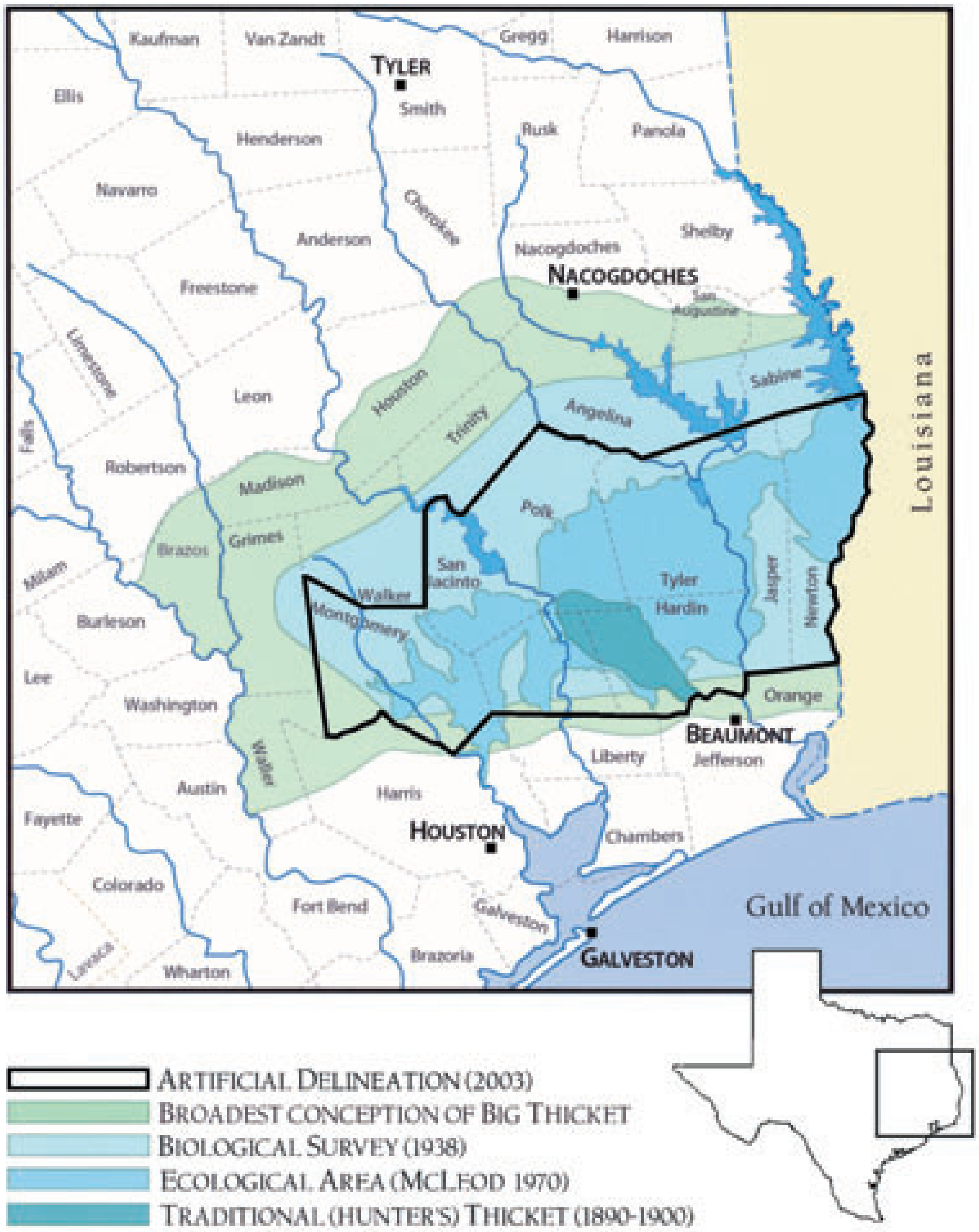


FIG. 94/ ARTIFICIAL DELINEATION OF THE BIG THICKET (COUNTY LEVEL) TO ESTIMATE SPECIES RICHNESS (OVERLAIN ON A MODIFIED FIG. 88). FIGURE PRODUCED BY BRIT/AUSTIN COLLEGE.

How does this compare with other areas of similar size? While the needed comparative data are not available, this analysis seems to agree with preliminary work by MacRoberts and MacRoberts (2004a, pers. comm.) suggesting that species richness of the Big Thicket may not be any greater than in certain other parts of the generally species-rich southeastern U.S., such as parts of Louisiana. When compared with larger areas such as North Central Texas (2,223 species in 40,000 square miles—Diggs et al. 1999), Kansas (1,807 species in 82,000 square miles—McGregor 1976), Oklahoma (2,549 species in 70,000 square miles—Taylor & Taylor 1994), or all of North America north of Mexico (about 18,000 species—Thorne 1993d), the Big Thicket can justifiably be considered a species-rich area. When one contemplates that the Big Thicket has approximately 10% of all the species in North America north of Mexico, past characterizations of the area as species-rich do not seem inaccurate. However, the same can be said for a number of other areas in the southeastern U.S.

It will be interesting in the future to compile similar data sets for other areas of Texas and do actual comparisons. We speculate that there may be a few other Texas regions of a similar size that have diversity levels approaching those of the Big Thicket. These probably include: 1) the area of the Edwards Plateau centered on Gillespie County or some nearby area (this region includes numerous Edwards Plateau endemics, Central Mineral Region granite-loving species, and a wealth of species found on various substrates including limestone and sand), 2) an area in the Trans-Pecos including the Big Bend (which has dramatic topographical variation, many endemics, and numerous species entering from Mexico), and 3) the region of Brazos and surrounding counties (an ecotonal area of rich habitat diversity).

It is also interesting to note that of the 1,826 species in the Big Thicket, 566 (31%) are monocots—the Big Thicket thus seems relatively rich in monocots when compared to North Central Texas, whose flora has only 26% monocots. This greater monocot diversity probably relates to the high percentage of mesic to wet habitats (favored by many monocots such as sedges, rushes, and xyrids) in the Big Thicket. For example, the floras of hillside seepage bogs and wetland pine savannahs have 55% and 51% monocots, respectively (MacRoberts & MacRoberts 2001).

As with East Texas as a whole (see page 226), a number of *interrelated* factors contribute to the species richness of the Big Thicket. These include: 1) geologic and associated hydrologic variation; 2) high habitat diversity; 3) position near the ecotone between the eastern deciduous forests and the central North American grasslands (e.g., prairie inclusions within the Big Thicket); 4) proximity to a number of other source floras; 5) rich biogeographic history (e.g., remnant northern species as the result of the last Ice Age); and 6) the present-day warm wet (humid subtropical) climate allowing many species to coexist.

The last of these factors reflects the general rule that within-habitat diversity of woody plants is higher in areas with warmer, wetter climates (Marks & Harcombe 1975). In the Big Thicket, abundant precipitation is well-distributed throughout the year—the average yearly precipitation is 48 to nearly 60 inches (122 to 152 cm), with the difference between the driest and wettest months being only 5 cm (2 inches) (Griffiths & Orton 1968; Marks & Harcombe 1981; Bomar 1995). With the exception of the Pacific Northwest, the Big Thicket is the westernmost area in the U.S. that receives such large amounts of precipitation. Because of the abundant rainfall and because of edaphic variation, soils vary from excessively drained to waterlogged. Therefore, species ranging from those requiring quite dry conditions to those needing extremely moist conditions can easily coexist in a relatively small area (i.e., there is a long topographic-moisture gradient—Marks & Harcombe 1975). Further, the relatively low latitude (approximately 30° N) and proximity to the Gulf of Mexico result in mild temperatures, with the frost-free season averaging between 230 and 260 days from north to south (Griffiths & Orton 1968). Snowstorms and hard freezes occur only rarely (Marks & Harcombe 1981). Because the mild winters are generally favorable for photosynthesis, many evergreen species can occur. Marks and Harcombe (1975) estimated that one-third of the tree and shrub species in mesic Texas forests are evergreen, and some forest types and strata of the Big Thicket can justifiably be called "semi-evergreen" (Harcombe & Marks 1977).

RARE AND ENDANGERED SPECIES OF THE BIG THICKET—Five plant species of the Big Thicket, as well as numerous animals, are considered to be of national conservation concern by the Big Thicket National Preserve (2002). These include bog coneflower (*Rudbeckia scabrifolia*, Species of Concern), Navasota ladies'-tresses (*Spiranthes parksii*, Federal Endangered), slender gay feather (*Liatris tenuis*, Species of Concern), Texas trailing phlox (*Phlox nivalis* var. *texensis*, Federal Endangered), and white firewheel (*Gaillardia aestivalis* var. *winkleri*, Species of Concern). Numerous other plants occurring in the Big Thicket are also quite rare in the state and are of conservation concern in Texas (Appendix 12). Many of these species, much more common further east, are known in the state only from one or two Big Thicket counties. While there is significant variation in the community affiliation of rare species, many of the rare plants of the Big Thicket (and East Texas in general) are pyrogenic (fire dependent) species associated with longleaf pine woodlands, a community that has been greatly altered by human activities including logging and fire suppression.

THE BIG THICKET AS A BIOLOGICAL CROSSROADS—As noted earlier, the Big Thicket has often been described as a biological crossroads where species typical of areas to the east, west, north, and south meet and intermingle. Indeed, dry area plants such as *Opuntia* (prickly-pear, Cactaceae) and *Yucca* (Agavaceae) do occur in close proximity to *Taxodium* (bald-cypress, Cupressaceae) and other plants typical of swamps. While the Big Thicket is near the ecotone or transition zone between the eastern deciduous forests and the central North American grasslands, MacRoberts and MacRoberts (2004a), concluded that there is no evidence to support the crossroads idea. For example, they note that over 99% of the species in the Big Thicket are endemic or eastern in affinity. Further, they note that the main source of the crossroads concept,

> …appears to be the presence of xeric sandylands and prairies in southeast Texas. Superficially, xeric sandylands resemble deserts and some of the genera, but not the species, found in this habitat originated under desert conditions; cactus, agave, and yucca are obvious examples. But xeric sandylands are by no means confined to southeast Texas but extend from East Texas northward to Oklahoma and eastward to North Carolina. The same is true for prairies, which are not confined to the central and western states but extend across the southern and eastern United States. There is no evidence that the Big Thicket is a floristic crossroads. Its flora is eastern, notably southeastern.

Indeed, at the species level, there is relatively little evidence of the Big Thicket as a biological crossroads. However, at the generic and family levels, the Big Thicket and much of the southeastern U.S. is an area of floristic intermingling. Plants with tropical origins (e.g., Mayacaceae, Melastomataceae), and those with affinities to the deserts of southwestern North America (*Opuntia*, *Yucca*), mix with plants more typical of the central North American grasslands and with plants pushed south during the climatic shift associated with glacial times (see page 208). While the Big Thicket is not unique in this regard, it does clearly share this interesting biogeographic history with other areas of the southeast.

SIMILARITIES TO TROPICAL RAIN FORESTS—A striking aspect of the Big Thicket is its resemblance in a number of respects to tropical rain forests. Similarities include:

- the very tall trees, in some cases over 150 feet (46 m) in height (Fritz 1993),
- the swollen buttressed bases on trees such as bald-cypress and water tupelo,
- numerous evergreen species (e.g., southern magnolia, sweet-leaf, wax myrtle, red bay, cherry laurel, American and other holly species, dwarf palmetto, *Smilax* species, etc.—in some areas about "50% of the forest composition is that of evergreens" (McLeod 1971),

- abundant lianas (= large woody vines) extending high into the canopy,
- the presence of epiphytes (e.g., Spanish moss, resurrection fern),
- the presence of abundant individuals of the palm family (*Sabal minor*, dwarf palmetto, sometimes dominating the forest floor—e.g., palmetto-hardwood flats),
- many species of orchids,
- numerous and often conspicuous ferns and fern allies,
- a conspicuous bamboo (*Arundinaria gigantea*, giant cane, historically forming large canebrakes),
- numerous representatives of many characteristically tropical plant families such as Annonaceae (including pawpaw), Araliaceae (e.g., hercules'-club), Bignoniaceae (e.g., crossvine), Lauraceae (e.g., red bay), Marantaceae (e.g., powdery thalia), Mayacaceae (e.g., bog-moss), Melastomataceae (e.g., meadow-beauty), and Symplocaceae (e.g., sweet-leaf),
- high species richness,
- areas with standing water for long periods of time (e.g. Neches River bottoms), and
- animal links to the tropics including the presence of leaf-cutting ants (Fig. 95), large crocodilians (American alligator), and even (until the early 1900s) jaguars (Bailey 1905).

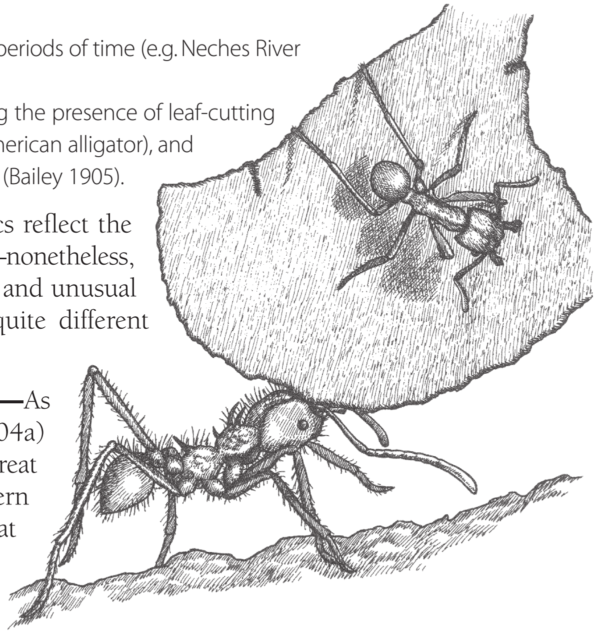


FIG. 95/ LEAFCUTTER ANTS (FROM COOKE & COOKE 1995, USED WITH PERMISSION OF LOIS LEONARD STOCK).

Clearly these similarities to the tropics reflect the humid subtropical climate of the area—nonetheless, they make the Big Thicket interesting and unusual in a state mostly characterized by quite different types of vegetation.

WHAT IS UNIQUE ABOUT THE BIG THICKET?—As MacRoberts and MacRoberts (2004a) pointed out, the Big Thicket shares a great deal with the rest of the southeastern U.S. It has similar levels of habitat diversity, appears to be comparable in terms of species richness, and is perhaps not a biological crossroads. Given these similarities, is there anything unique or special about the Big Thicket? The answer to this question is yes. While clearly part of the southeastern U.S., the Big Thicket represents the southwestern extreme of the Southeastern Mixed Forest Province and the Outer Coastal Plain Mixed Forest Province (Keys et al. 1995; Turner et al. 1999). Hundreds of species that occur in an arc from Virginia or North Carolina south to Florida and west to Texas reach the southern or southwestern limit of their ranges in the Big Thicket, or are confined or largely confined in Texas to the Big Thicket area. The reasons for their occurrence in the Big Thicket include the high rainfall and overall mesic conditions and the presence of specialized habitats (e.g., hillside seepage bogs, pine flatlands, etc.). A few of the hundreds of examples include *Bartonia texana* (Texas screw-stem), *Ctenium aromaticum* (toothache grass), *Dryopteris ludoviciana* (southern wood fern), *Lachnocaulon digynum* (pineland bogbutton), *Magnolia pyramidata* (pyramid magnolia), *Palhinhaea cernua* (nodding club-moss), *Rhynchospora tracyi* (Tracy's beak sedge), *Sabatia dodecandra* (marsh rose-gentian), *Stewartia malacodendron* (silky-camellia), and several *Xyris* (yellow-eyed-grass) species. In addition to widespread species reaching their distributional limit, a number of taxa in the Big Thicket are either rare, endangered, endemic to the West Gulf Coastal Plain, or endemic to the Big Thicket itself (e.g., *Yucca cernua*).

The Big Thicket thus represents a **biological boundary** and is therefore important for a variety of reasons. For one thing, populations at the extreme margin of a species' range are often unique genetically and represent an irreplaceable genetic resource. Second, peripheral populations are often more sensitive to environmental change and can act as ecological indicators, serving as an early warning system against changes that may possibly have broader implications. In the modern world, with humans having the capacity to influence global climatic processes, such indicators may be vital. From the Texas perspective, the Big Thicket is important because it represents a unique area within the state—it is only in this relatively small corner of Texas that numerous plant communities and hundreds of species can be found. From a slightly broader perspective, the Big Thicket is valuable since it contains one of the only relatively large protected areas in the entire West Gulf Coastal Plain, an important regional center of endemism (MacRoberts et al. 2002c). As such, it is critical in protecting representative samples of numerous unique West Gulf Coastal Plain plant communities and species. Exemplifying this importance is the fact that two areas within the Big Thicket (Longleaf Ridge and the Big Thicket-Sandylands Complex) are among the top ten richest conservation areas in the West Gulf Coastal Plain ecoregion, with Longleaf Ridge considered to be the richest (Nature Conservancy 2003).

The Big Thicket is also unique within Texas from the standpoint of ecosystem services. Given its position just north of one of the largest population centers in the state, the role of the Big Thicket in terms of hydrology (flood control, water purification, etc.) and other ecosystem services makes it uniquely important to Texas, not only ecologically, but economically as well.

Summary Definition Of The Big Thicket

Based on all of the preceding material, how then can one define the Big Thicket? While linked with the West Gulf Coastal Plain and the rest of the southeastern U.S., we suggest that *several highly interrelated factors when combined* can give a reasonable way of defining and delineating the Big Thicket:

- Ecological definition of the area as a loblolly pine-white oak-beech-magnolia forest, with a rich understory of evergreen and deciduous shrubs, numerous climbing vines, and varied herbs, *plus* included vegetation types (e.g., xeric sandylands, baygalls, etc.).
- Biological boundary as the southwestern extreme of the Southeastern Mixed Forest and Outer Coastal Plain Mixed Forest provinces.
- Humid subtropical climate—Mild temperatures and high, rather evenly distributed rainfall—approximately 48 to nearly 60 inches (122 to 152 cm) per year.
- Geological, hydrological, and edaphic complexity.
- High levels of habitat diversity and species richness.

In concise terms, the Big Thicket is thus *the biological boundary area at the southwestern extreme of the southeastern U.S., humid subtropical in climate, geologically and hydrologically complex, rich in species, and characterized by a loblolly pine-white oak-beech-magnolia forest with many associated and often very distinct vegetation types*.

While the Big Thicket is a meaningful and useful concept, its exact boundaries will continue to be imprecise. Individual species have ranges that can be determined with precision, but the ranges of different species rarely correspond. As a result, vegetational areas usually cannot be clearly delimited. Ultimately, it is clear that virtually any vegetational area is a human concept without precise boundaries. However, an artificial delineation of the Big Thicket, such as the one presented here (page 167; also see Fig. 94), can provide a practical approximation. This imprecision does not make the region any less interesting, valuable, or worthy of conservation. The Big Thicket by any definition is a rich and unique part of Texas and North America, and one which warrants long-term protection and preservation.

Geology of the Big thicket

The geology of the Big Thicket is a subset of that of the Pineywoods as a whole (see page 76). However, due to its position near the coast, the strata underlying the area are almost all quite young—at most, no more than a few million years old (late Tertiary and Pleistocene). As noted by Parent (1993),

> As glaciers advanced and retreated during recent ice ages, sea level rose and fell along the low-lying southeast Texas coast. During warm periods with high sea levels, the land flooded and rivers deposited vast deltas and alluvial plains of mud, sand, and silt on the seabed. When the ice returned and sea level fell, erosion cut into the newly deposited sediments. Over millennia, the weight of increasing sediments caused the land to subside, slanting the layers downward into the Gulf of Mexico. These layers are exposed to the surface as broad, irregular bands paralleling the gulf, with the oldest layers to the north and the youngest lining the coast.

The rising and falling sea levels and the meandering rivers typical of relatively flat areas combined to create an area of surprising hydrologic and soil complexity, despite the lack of topographic relief. Such phenomena as shifting and abandoned stream channels, sandy levees, oxbow lakes, and old river terraces contribute to the complexity (Watson 1975).

In a broad sense, the Big Thicket is a shallow basin sloping very gently from north to south (about five feet per mile (0.94 m per km)—Watson 1975). In general, it occurs on areas of low relief, with elevations ranging from approximately 365 feet (110 m) in the north to only slightly above sea level (about 5 m) at the southern extreme (Deshotels 1978). In the north, the topography is of low-lying hills moderately incised by numerous small streams (McLeod 1971) and has a more developed ridge system and better drainage, while in the southern part, the topography is lower and flatter and in general poorly drained. "The most conspicuous physiographic features of the region are the broad flat floodplains along the streams and rivers. They are generally well-defined by breaks or bluffs along the edges, and meander scars, abandoned channels, and backswamps are common" (Marks & Harcombe 1981).

Also geologically important is the diversity of different strata/parent materials. These result in a variety of soil and microhabitat conditions ranging from well-drained ridges to bogs and from highly acidic to basic soils—these different conditions have profound effects on the vegetation.

Presettlement and Early Settlement Conditions and History in the Big Thicket

Presettlement and Early Settlement Vegetation of the Big Thicket—Even though prior to European settlement there were extensive areas of forest and "thicket," the vegetation of the Big Thicket was never a homogeneous impenetrable area. Instead, based on early explorer and settler accounts and various studies of the vegetation (e.g., Schafale & Harcombe 1983—from original land surveys from the 1800s), we know it to have been an area of rich vegetational diversity ranging from dry pine-covered uplands to majestic beech-magnolia forests, bald-cypress swamps, impenetrable titi thickets, bogs, canebrakes, and even prairies. Geraldine Watson (pers. comm.), based on nearly 80 years of research, personal observation, and interviews with elderly members of families who settled the area, also notes that the Big Thicket was neither homogeneous nor impenetrable. It was an area of varied vegetation criss-crossed by trails made by Native Americans. These trails, which followed natural features of the landscape (e.g., ridges, hummocks in the bottomlands), were later used by the Spanish, French traders, explorers, and settlers. Eventually, in some cases, the trails were widened and paved.

One of the earliest written accounts of the vegetation of the Big Thicket comes from Gideon Lincecum (Brandford & Campbell 1949), who traveled through the heart of what is currently considered the Big Thicket in 1835 (Weniger 1984b). Lincecum noted in his journal (Brandford & Campbell 1949),

> This day passed through the thickest woods I ever saw. It perhaps surpasses any country in the world for brush. There are 8 or 10 kinds of green undergrowth, privy, holly, 3 or 4 sorts of bay, wild peach trees, bayberry, etc., and so thick you could not see a man 20 yards for miles. The soil is pretty good and the water the very best….

Another early account is seen in the journal of Gustav Dresel (published 1954) who moved south from Tyler County into present-day Polk County in 1839 (Weniger 1984b). His description of the area paints a somewhat different picture:

> Having left the forests of the Neches River behind, we came into a fertile prairie where the most excellent grass sprouted from black earth and the most diverse flowers grew exuberantly in between. Here and there the wide plain was broken by groups of trees … when the morning sun sent his first rays over the prairie, when all the blades and the whole magnificent ocean of flowers seemed to move, we quickly rose and prepared our teams for penetrating into the gloomy primeval forest.

Dresel (1954), that same year (1839) wrote of Jasper that it "…could hardly be seen on account of the many trees," and a few years later, De Córdoba (1858) wrote of Jasper County:

> This may be regarded as a heavily-timbered county.… On the banks of the water-courses is to be found a very heavy growth of magnolia, beech, walnut, and a variety of oak timber; but the majority of the uplands are covered with pine timber.… In the southwest corner of this county there is a region of country, known as the thickety country, which is regarded as valuable land.

Josiah Gregg, who traveled through the area in 1841 (Fulton 1941), gave some idea of the complexity of the vegetation when he variously described parts of what he encountered as follows:

> …a poor pine country (mostly long leaf) intermixt a little with oaks, gums, dogwood…very pretty land, timbered with beech, bay…beautiful looking undulating country, timbered with white oak, black oak…and what is most extraordinary these uplands are generally well set with cane…and…poor long leaf pine woods.

While discussing early Montgomery County, De Córdoba (1858) said,

> What is extensively known as Big Thicket lies on the eastern border of the county, between the forks of the San Jacinto. A great deal of this land is high, sandy and very productive, covered with a dense growth of large timber, post-oak, white oak, also black walnut, hickory, ash, and in some places magnolia and wild peach. There are extensive cane-brakes, similar to those on the Tombigbee, in Alabama.

Braman, who in 1857 made the second known published use of the term "Big Thicket," described Polk County as follows (from (Weniger 1984b):

> …here is the 'Big Thicket,' celebrated over the whole State for its extraordinarily fertile soil. The rich prairies of this county afford free commons to any number of herdsmen.

Interestingly, this and several other early descriptions mention not the thick vegetation, but rather prairie. While the presence of small areas of presettlement prairie may now be surprising, these were well known to early settlers—numerous areas were described in nineteenth century accounts as being prairie (e.g., Dresel quote above) or had the term prairie included in their place names (Jordan 1973). The existence of presettlement prairies is also supported by references to prairies in the original land surveys done of the area in the 1800s (Schafale

& Harcombe 1983). Specific examples include Marysee Prairie (currently considered to be the only protected prairie remnant in the Big Thicket area) in Liberty County (Ajilvsgi 1979), and Batson, Jones, Pelt, and Pigeon Roost prairies in Hardin County (Truett & Lay 1984; Schafale & Harcombe 1983). To the south of the Big Thicket, the vegetation graded into what in presettlement times was an extensive area of Coastal Prairie (with woody vegetation continuing along major drainages) (Smeins et al. 1982). While originally probably occupying only a small percentage of the area of the Big Thicket, prairies contributed to the vegetational complexity and species richness of the area.

Presettlement and Early Settlement Animal Life of the Big Thicket—The animal life of the presettlement and early settlement Big Thicket was diverse and was a good representation of that of the Pineywoods as a whole. As with plants, unexpected animals sometimes occurred together (Watson 1975; Gunter 1993) because of the proximity of habitats such as arid sandylands or prairies with more mesic mixed deciduous forests and wetland habitats. Roadrunners, jackrabbits, and (at one time) horned lizards could be found in close proximity to eastern bluebirds, pileated woodpeckers, swamp rabbits, and alligators (National Park Service 1974). There were more than 50 species of mammals (including 10 species of bats), 60 species of reptiles (including 37 species of snakes and 15 species of turtles), 30 species of amphibians, 98 species of fishes, and around 215 species of birds (National Park Service 1974, 1996, 1997; Peacock 1994). A few of these species are now extinct in the area, and many others have had their populations dramatically reduced, primarily due to habitat alteration and overhunting.

A case in point is that of the black bear. In the 1880s and 1890s the Big Thicket became renowned for its epic bear hunts (Gunter 1993). In fact, bears were so abundant that East Texas has been called the "Land of Bears and Honey" (Truett & Lay 1984). "Bear meat was eaten by settlers, crews of loggers and railroad workers, and slaves. Bear fat was standard cooking oil, both for white settlers and the Indians before them. The supply lasted about a century and a half after the first settlers arrived" (Truett & Lay 1984). Unfortunately, overhunting took its toll—two of the last authenticated records of bears killed in East Texas were a female and two young in Liberty County in 1919 and a large bear in Hardin County in 1928 (Truett & Lay 1984). The heavy mast (fruit) production from numerous tree species including American beech (*Fagus americana*) and various oaks (*Quercus* spp.) was an important food source for bears and a diversity of other wildlife (Parks & Cory 1936).

Other large mammals now gone from the Big Thicket include American bison and red wolves. While much more common on the prairies to the west and south, bison are thought to have ranged over almost the whole of the present state of Texas (Bailey 1905). Joutel, who was with the La Salle expedition in 1686, reported that in what is now northwestern Harris County, they "were favored in crossing [probably Cypress Bayou] by a way beaten by the bullocks [bison]" (Truett & Lay 1984). Overhunting quickly led to the extirpation of bison from Texas. The red wolf, intermediate in size between the gray wolf and coyote, was confined to the eastern part of the state, including the Big Thicket. U.S. Biological Survey biologist Gaut reported in 1915 that, "Wolves are numerous in the [Big] Thicket and do considerable damage to calves and pigs.…" (Truett & Lay 1984). This species declined due to habitat alteration, hunting (including for bounties), and hybridization with coyotes and dogs. By 1980, for all practical purposes, the red wolf was extinct in the wild (Schmidly 1983).

Though originally well known in the area, the mountain lion (also known as cougar, puma, or locally as "panther") (Fig. 96) was extremely rare or nearly extinct in East Texas by 1905 (Bailey 1905). In 1959 McCarley was unable to document any recent records. There are, however, reliable recent reports of mountain lions in various parts of East Texas including the Big Thicket (D. Fusco, pers. comm.), and the species is apparently present in low numbers.

Two other locally extinct cats, the jaguar and the ocelot, are known to have inhabited the Big Thicket forests. In 1902 there was a report of a jaguar killed south of Jasper a few years before, as well as reports of the former occurrence of the species along the Neches River near Beaumont and in the timber south of Conroe (Bailey 1905). Bailey (1905) reported that, "ocelots are still reported as very rare about Beaumont and Jasper." Schmidly (1983) noted that "George Walker (born before 1860) of Lufkin…remembered that ocelots (called "tiger cats" by locals) were found in Polk and Hardin counties." Even the sole relatively common wild cat species remaining in the Big Thicket, the bobcat, was much more abundant previously. Bailey (1905) wrote that the bobcat was "in no other locality so abundant as in the Big Thicket of Liberty and Hardin counties. Here its tracks were seen in every muddy spot in roads and trails, and on damp mornings the dogs started one about as soon as they got into the thicket.… Cat hunting is a favorite sport in this region.…"

Other previously abundant large species whose numbers were dramatically reduced have now made a comeback. McCarley, in 1959, indicated that the "native beaver of East Texas is apparently extirpated." However, this species made a surprisingly rapid recovery and is now common. Likewise, river otters, reported as "nowhere common" by McCarley (1959) can be seen "fairly often" (F. Abernethy, pers. comm.; e.g., Jack Gore Baygall—G. Diggs, pers. obs.).

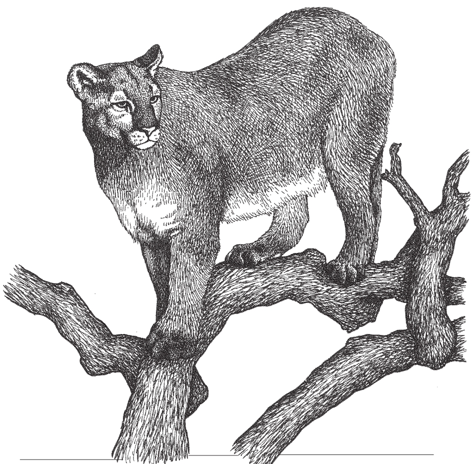


FIG. 96/ MOUNTAIN LIONS, LIKE MOST LARGE PREDATORS, WERE RAPIDLY ELIMINATED FROM THE BIG THICKET (FROM COOKE & COOKE 1995, USED WITH PERMISSION OF LOIS LEONARD STOCK).

Of all the large mammals previously found in the Big Thicket, only white-tailed deer remain in large numbers, and even this species was dramatically reduced during the first half of the twentieth century. Though Bailey reported deer as common in the Big Thicket in 1905, subsequent overhunting resulted in their "almost complete extirpation…in most areas of East Texas" (McCarley 1959). Restocking efforts have largely been successful, and the white-tailed deer is now very common in the Big Thicket.

The bird fauna of the early Big Thicket was also much richer than that of today. The globally extinct passenger pigeon (Fig. 97) was well-documented for the Pineywoods (and for virtually all of East Texas west to Bexar, Grayson, and Travis counties at the western edge of East Texas and well beyond—Oberholser 1974; Casto 2001) and may have been the most abundant bird species in East Texas. These birds were referred to as "wild pigeons" by early settlers, and huge flocks were reported from the Big Thicket (e.g., Hardin, Jasper, Polk, and Tyler counties—Oberholser 1974; Casto 2001). Descriptions such as the following by eyewitnesses were given for the Pineywoods—"millions of pigeons flying over," "roost covering ten acres," "wild pigeons robbing hogs of mast," or "millions roosting" (Casto 2001). One place in Hardin County southeast of Kountze, where early settlers would find large flocks roosting in trees, was even named "Pigeon Roost" Prairie (Loughmiller & Loughmiller 1977; Truett & Lay 1984). In the area slightly to the south, Oberholser (1974) reported, "… many old residents living in Houston, Harris County, recalled a great Passenger Pigeon invasion in the vicinity of that city during October, 1873…. One ranchman said that when he first saw the pigeons approaching in the evening he took them to be clouds of a great storm from the northeast, while others stated that at times clouds of pigeons darkened the sky." The passenger pigeon preferred acorn-abundant oak forests and when the flocks, sometimes numbering in the millions or even billions of individuals, descended upon an area, they could have a dramatic effect on the vegetation. Broken branches and other devastation were apparently a common result (Oberholser 1974). According to Casto (2001),

FIG. 97/ PASSENGER PIGEON (USED WITH PERMISSION OF SCOTT AND STUART GENTLING).

> The roosts of Passenger Pigeons often contained millions of birds and their evening arrival in vast converging flocks presented an almost indescribable spectacle. The combined weight of the enormous numbers of birds often broke even the stoutest branches leaving trees stripped of limbs and foliage as if a cyclone had passed (Terrell 1948). Smaller trees and saplings were sometimes crushed to the ground and broken off at the roots (Askew 1939). Guano, which accumulated to depths of a foot or more at roosts such as the one on Wolf Creek north of Palestine [north of the Big Thicket] (Anon. 1876b [Anonymous 1876]), completed the devastation by killing all ground level vegetation.

This once almost unbelievably numerous species was hunted extensively in Texas and elsewhere (often with nets or sticks while they were roosting), and populations were rapidly reduced. Such widespread overexploitation, coupled with extensive destruction of their forest habitat, resulted in the species' rapid extinction, with 1900 being the last record of one taken in Texas (Oberholser 1974).

The ivory-billed woodpecker (Fig. 98), one of the world's largest woodpecker species (19–20 inches (48–51 cm) long), was also present in the Big Thicket (Oberholser 1974; Shackelford 1998). Though not seen in Texas for decades and long thought to be extinct, this species was recently rediscovered in Arkansas (Fitzpatrick et al. 2005). According to Bailey (1905, in Oberholser 1974), this species was "well known to all the residents throughout the Big Thicket, and was reported as fairly common at every place we inquired. Even the boys could imitate its harsh notes. Still the only birds we saw were between Tarkington Prairie and the Trinity River [Liberty County], where, I saw six in one day—November 26, 1904." This dramatically crested, raven-sized, black, white, and red species, which inhabited densely wooded deciduous bottomlands and swamps bordering rivers, was extremely specialized. It was "…dependent, at least in the breeding season, on larvae of wood boring beetles…that live between bark and sapwood of large, recently dead limbs and trunks. Only trees dead from one to four years contain enough larvae to sustain Ivorybill populations" (Oberholser 1974). Therefore, huge forests were necessary for its survival—with the almost total destruction of these old growth forests by logging, the extinction of this species was probably inevitable. The last specimens taken in Texas were from Liberty County in 1904, with sightings in the Big Thicket by knowledgeable biologists (e.g., Manuel Armand Yramategui, Lance Rosier, Geraldine Watson) until the late 1960s and even 1970s (Oberholser 1974; Peacock 1994; Geraldine Watson, pers. comm.).

Another extinct species, the Carolina parakeet (Fig. 99), was widely known from East Texas (Greenway 1958; Forshaw 1977; Goodwin 1983), including the Big Thicket (e.g., Jasper and Jefferson counties—Oberholser 1974). This visually striking species was bright green in color with a yellow head shading to orange on the forehead and near the eye. These parakeets had a varied diet, but after the advent of agriculture they fed extensively on corn and cultivated fruits. As a result, they were a prime target of farmers (Oberholser 1974). Unfortunately, a quirk of their behavior made hunting them quite easy—"… members of a flock habitually hovered over a felled companion until all were gunned down" (Oberholser 1974). The last report of a Carolina parakeet killed in Texas was from Bowie County in 1897.

Another Big Thicket bird, the red-cockaded woodpecker, is not locally extinct but has suffered a dramatic decline. This federally endangered species originally occurred broadly in the pine forests of the eastern one-fourth of Texas. Unfortunately, it has quite specialized habitat requirements and needs old growth pine forest for its survival (Oberholser 1974; Rudolph & Conner 1991). For its nesting or roosting hole this small, cooperatively breeding woodpecker "… requires large, living pines—usually eighty years old or more—with centers rotted by red-heart fungus disease" (Oberholser 1974). "The bird pecks away the bark around the hole's entrance so that glistening pine pitch slowly drips like wax from a guttering candle"—perhaps as an anti-predator (e.g., snake) mechanism (Oberholser 1974). In addition, the trunks and upper limbs of large pines are its preferred foraging sites

FIG. 98/ Ivory-billed woodpecker (used with permission of Scott and Stuart Gentling).

(Oberholser 1974). The species is apparently quite intolerant of excessive hardwood midstory (Walters et al. in Halstead 2002) and prefers an open pine savannah with a sparse midstory and a dense herbaceous layer. Each family group needs an average of 81 hectares (200 acres) of mature pine woodland for survival (Halstead 2002). Because of these strict requirements for mature pines, the nearly complete destruction of the old growth pine forests of East Texas has brought this species to the brink of extinction.

Two other interesting and endangered bird species were present on at least the southern margin of the Big Thicket in prairie or open savannah habitats—the whooping crane and the greater prairie chicken. There are records of whooping cranes from Harris and Jefferson counties, and the Attwater subspecies of the greater prairie chicken was previously well known from Jefferson, Liberty, and Orange counties. This latter bird, in fact, occurred widely over the southern part of East Texas, ranging from Jefferson County north and west to Bastrop and Travis counties at the western margin of East Texas (Oberholser 1974). Suppression of fire, overgrazing, brush encroachment, land conversion, and overhunting have dramatically reduced numbers of this species, and it is now officially endangered (U.S. Fish and Wildlife Service 2002).

Many other bird species that are still present today in the Big Thicket were probably much more abundant in presettlement times. Just one example is the wild turkey. According to Morfi, a Spanish missionary in the early 1700s, "Along the banks of the streams and the outskirts of the woods the droves of wild turkeys are so numerous that they disturb the traveler with their clucking" (in Truett & Lay 1984). Sol Wright (1942), who grew up in the Big Thicket, reported that even in the 1870s, "Five or six old hen turkeys and fifty or sixty young ones would come into the field every summer." He further noted that according to his father, in the early 1800s, "…they would put bells on the horses and turn them out at night to graze, and in the spring, in turkey gobbling time, when he would go out in the early morning to drive them in, he could hardly hear the bells for the turkeys gobbling." Subsequently, overexploitation by humans so decimated wild turkey populations that by the 1890s the species was essentially extirpated from the eastern part of the state. A successful restocking of the area with birds from Louisiana and Mississippi was begun by the Texas Parks and Wildlife Department in 1978, aided by the National Wild Turkey Federation. As a result, this species is once again widespread in East Texas (Texas Parks and Wildlife 1998, 2002f).

Humans, predominantly through habitat alteration, and in some cases overexploitation, have detrimentally affected virtually every bird and other animal species. However, despite the loss of a number of species and dramatic population declines in many others (e.g., warblers), bird life in the Big Thicket is still quite diverse, with more than two hundred different species found there.

In terms of the reptile and amphibian fauna, the most striking species in the presettlement (and even modern) Big Thicket was certainly the American alligator. Large numbers were initially present, but by the twentieth century the species was in danger of extinction due to overhunting. With federal protection, the alligator has made a dramatic comeback. Individuals can be huge—up to approximately 4.5 m (15 feet) long and 473 kg (1,267 pounds) (Woodward et al. 1995). Truett and Lay (1984), for example, reported that an alligator shot near the Forks of the River (the Angelina and the Neches) weighed over 1,200 pounds (544 kg), and Sitton (1995) cited an example of one that measured thirteen feet three inches (4 m) long and weighed 1,040 pounds (472 kg). Numerous other reptile and amphibian species occur in the Big Thicket. There are many snakes (including five venomous species— southern copperhead, western cottonmouth or water moccasin, Texas coral snake, canebrake rattlesnake, and pygmy rattlesnake), at least 15 species of turtles, and 19 species of frogs and toads (Peacock 1994). Some of these organisms have fascinating life histories—a particularly good example is the three-toed box turtle (*Terrapene carolina triunguis*)

FIG. 99/ CAROLINA PARAKEET (USED WITH PERMISSION OF SCOTT AND STUART GENTLING).

Fig. 100/ Three-toed box turtle (*Terrapene carolina triunguis*), a reptile of the Big Thicket with a lifespan of more than 100 years (photo by GMD).

(Fig. 100). Individuals of this species can live for more than 100 years, and if conditions remain constant, may spend their entire life in an area hardly larger than a football field (Behler & King 1979). Their diet consists of such foods as slugs, earthworms, wild strawberries, and mushrooms—including some poisonous to humans. This has resulted in human fatalities as a result of eating "toxic" turtles (Behler & King 1979). Unfortunately, since they are slow to reach sexual maturity (five to seven years), and because of habitat alteration (e.g., clearcutting, urbanization, etc.) and premature death due to other human activities (e.g., being crushed on highways), populations are declining in some areas. One reptile of particular conservation interest is the Louisiana pine snake (*Pituophis ruthveni*), one of the rarest vertebrates in the U.S. and a candidate for federal endangered species listing. This species was historically known from longleaf pine-dominated habitats in Texas and Louisiana, but it is currently known from only five total areas, two of which are in the Longleaf Ridge Conservation Area on the northern boundary of the Big Thicket (Halstead 2002). In addition to habitat destruction, alteration of the fire regime is thought to be a primary cause of Louisiana pine snake decline. This is because the main prey of the species is the pocket gopher, which is dependent on the abundant herbaceous vegetation present in a frequently burned longleaf upland (Rudolph & Burgdorf 1997; Halstead 2002).

A stunning variety of other organisms, including fungi and insects, is also found in the Big Thicket (e.g., Abbott et al. 1997). Perhaps one of the most surprising insects is the Texas leaf-cutting ant (*Atta texana*) (Fig. 95), a fungus-farming, ground-dwelling species which would be much more expected in the tropics. In fact, leaf-cutting ants range from Argentina to Texas, with the Texas species being the northernmost (Kulhavy et al. 2004). Leaf-cutting ants, which are important ecologically in soil-improvement, cut small pieces out of leaves, carry them into their underground nests (to 8 m deep, with hundreds of chambers), chew and infect the pieces with a fungus, and later harvest and eat the fungal tissue (Kulhavy et al. 2004).

During the Pleistocene Epoch, the fauna of what is now the Big Thicket was even more varied. Much of East Texas had an extremely rich megafauna, including a wide variety of now extinct mammals, comprising part of an ecosystem that is now difficult for us to even imagine (see related discussion on page 142). Mammoths, mastodons, ground sloths, giant bison, giant armadillos, giant beavers, extinct horses, tapirs, llamas, camels, saber-toothed cats, and dire wolves have all been reported from Texas (Shuler 1934; Geiser 1945b; Loughmiller & Loughmiller 1977; Truett & Lay 1984; Smeins 1988; Finsley 1989; Fox et al. 1992; Abernethy 1996; Pinsof & Echols 1997).

Presettlement and Early Settlement History of the Big Thicket—The area now known as the Big Thicket had long been utilized by Native Americans such as the Bidai, Deadose, Patiri, and Akiosa (all subgroups of the Atakapa), particularly as a hunting area (Newcomb 1961; Gunter 1993; Smith 1995), and ceremonial mounds and rock rings can still be observed in the area today (D. Shine, pers. comm.). Two large mounds, locally known as the "mountains," are present near the Neches River in Hardin County. The largest of these is 15–20 feet (6.5–6 m) tall and nearly 100 feet (30.5 m) long (D. Shine, pers. comm.). In Tyler County, also on the Neches River, Shine (pers. comm.) has observed rock rings, apparently made by Native Americans.

It is unknown who the first Europeans were to traverse the region. While the Spanish were the earliest Europeans to establish settlements in Texas, they appear to have largely avoided the seemingly impenetrable area (e.g., El Camino Real skirted the northern boundary). For early European settlers, the Big Thicket, as the name implies, was an inaccessible area. According to Gunter (1993),

> The picture which comes down to us is of wagons, blocked time and time again by dense growth and swampy soils along innumerable streams. Frustrated, the pioneers turned back and pushed west instead, either along the open coastal prairie to the south or the rolling, more broken woods to the north. Mile after mile of meandering jungle streams must have seemed like a gigantic, forbidding wilderness indeed. They called the obstacle the Big Thicket, and the name endured. For the most part the settlers avoided it; the stream of settlement divided and flowed around it, leaving it largely undisturbed.

Travel in much of the region was indeed hard, particularly for wagons, and most "who penetrated and traversed this wilderness area prior to the early 1800s did so mostly on foot or on horseback" (McLeod 1972). However, the idea of inaccessibility should not be overemphasized since there were Native American trails as well as access by streams and rivers. Likewise, there were extensive areas of open longleaf pine woodland and other open plant communities (even prairie), even though these were embedded in a complex vegetational mosaic including extensive, difficult to traverse swamps, bogs, and thickets.

The first person known to actually "own" a portion of the Big Thicket was apparently Lorenzo de Zavala, who held claim through an 1829 Mexican land grant (Abernethy 1996). However, significant settlement of the region awaited Anglo immigrants from the southern U.S., who entered the area from the east by crossing the Sabine River. Lured in part by the promise of lavish Spanish land grants, they began settling areas on the edge of the Big Thicket in the 1820s and 1830s (McLeod 1972; Loughmiller & Loughmiller 1977; Owens 1978; Gunter 1993) and eventually began to move into and establish homesteads in the interior (e.g., John Bevil at Jasper in 1824 and settlements near Woodville and Hillister about 1830—McLeod 1972). Settlers came in increasing numbers and in 1836, the year of Texas independence from Mexico, the first four Big Thicket counties (Jasper, Liberty, Sabine, and San Augustine) were formed (Owens 1973). Owens (1973) wrote of the people who settled the area as having,

> …a character not too different from that to be found in any of the southern mountain or lowland states, coming as it did from essentially the same stock. Most of the early settlers in East Texas were

> descended from the English, Scotch-Irish, and Welsh who had populated Virginia and the Carolinas and by the time of the Revolutionary War had moved westward as far as Kentucky. As new territory opened up they flowed in great numbers into Georgia and then on to Alabama, Mississippi, Arkansas, Louisiana, and Texas, bringing with them the language, lore, and Calvinistic beliefs which were perpetuated as much in Big Thicket settlements as in lonely valleys in the Southern Appalachians. The few who owned slaves brought them. Most were poor whites who came by oxcart and brought with them only the tools to build log houses and clear land for crops.

Once they arrived, the Big Thicket put its stamp on the people who lived (and still live) there and shaped their lives and culture by the physical demands and the isolation it imposed (Loughmiller & Loughmiller 1977; Owens 1978). While roads were relatively easy to build on some of the pine-covered uplands, it was a very different story in the lower, wetter areas. Therefore, much early transportation utilized the waterways of the region (McLeod 1972). The isolation persisted in many unelectrified areas outside the towns even until after World War II. There was a rich tradition of oral history and square dancing to fiddle and guitar, and in "…log cabins lighted only with the flame of a pitch pine knot people sang ballads that stretched back to Shakespeare's time and earlier, songs of lords and ladies, ballads of love and murder and ghosts at night returning" (Owens 1978).

Legends rapidly grew about the Big Thicket, with Gunter (1993) describing them as:

> …luxuriant as its own swamps and choking undergrowth. In part the rapid growth of these legends stemmed from what was called the Neutral Ground, which bordered the region to the east. After the Louisiana Purchase the United States and Spain could not agree on a boundary between Louisiana and Texas. They did agree, however, on the existence of a neutral ground between the Arroyo Hondo on the east and the Sabine River on the west, where settlement was forbidden. Rather

FIG. 101/ STEAMBOAT LAURA BLOCKED BY LOG-RAFT JAM ON NECHES RIVER, ABOUT 1880. PHOTO COURTESY JASPER HISTORICAL COMMISSION, JASPER.

> than remaining unpopulated, the disputed area quickly became a refuge for murderers, horse thieves, and gamblers. So lawless was the Neutral Ground that it required the presence of military forces. When the region was finally acquired by the United States in 1821, its inhabitants moved to the Big Thicket, which quickly acquired the dual aura of a wilderness refuge and a dark and dangerous place.
>
> Stories of gangs of escaped slaves and organized bands of outlaws hung in the air around the Thicket like fog on a still fall morning. Tales of murder and mysterious disappearances were common. Sam Houston, one story runs, planned to hide his army there if his attack on Santa Anna's army at San Jacinto failed. There was, according to legend, at least one huge old hollow tree for each member of his troop.

Abernethy (1966, 2002), Loughmiller and Loughmiller (1977, 2002), and Sitton (1995) give detailed views of the rich and unique cultural history of the Big Thicket.

The early settlers used all the varied natural resources available to meet their needs. As Walker (1993) noted, they,

> …used 14-pound axes to cut virgin stems of loblolly and shortleaf pines as well as bald cypress for houses. Spanish moss draping from trees served for mattress stuffing and sewing thread. Occasionally squatters sectioned a white oak for barrel staves to hold whiskey distilled along the creeks. Barrels of red oak stored flour and sugar.
>
> Persimmons and plums from the woods provided fruit, locust pods served the need for beans, while walnuts and hickory nuts, pounded, boiled and strained, earned the name milk of honey. Rich as fresh cream, the oily liquid added sweetness to hominy grits and cornbread. Basket weavers utilized the bark of young shoots of the redbud, and boiled wild black cherry bark provided delicious tea.

Fig. 102/ Cutting old growth white oak to make barrel staves in the bottoms near Roganville, Jasper Co., ca. 1900. Photo courtesy Jasper Historical Commission, Jasper.

FIG. 103/ PARK-LIKE OLD GROWTH LONGLEAF PINE FOREST 12 MILES NORTHEAST OF DOUCETTE, TYLER CO., 1907–1908. PHOTO COURTESY TEXAS FORESTRY MUSEUM, LUFKIN.

For the first one or two generations following settlement, the settlers' impact on the Big Thicket was slight, with vegetation rapidly reclaiming small building sites or farmsteads once they were abandoned (Owens 1978). However, major change was inevitable—lumbering in the region began in the 1850s, with at least three steam sawmills operating in the vicinity of Orange and Beaumont. Given the lack of transportation facilities, most of the logs (e.g., bald-cypress) to supply the mills were floated down the Sabine and Neches rivers (McLeod 1972; Sitton 1995) (Fig. 101). Bald-cypress, sometimes called the "wood eternal" because of its decay-resistant durable heartwood (Hart & Price 1990), was important in the first timber boom, as were white oak and other hardwoods—cypress shingles and lumber, white oak staves, hickory barrel hoops, and furniture-grade walnut planking were all important early commodities (Sitton 1995) (Fig. 102).

It wasn't until the 1870s and 1880s, with the construction of the Houston-East-and-West-Texas Railroad, that the western part of the Big Thicket was readily accessible

FIG. 104/ SHAY LOCOMOTIVE AND LOG TRAIN. PHOTO COURTESY STEPHEN F. AUSTIN STATE UNIV., FOREST HISTORY COLLECTIONS.

for large-scale lumber extraction. At that point, exploitation of the extensive, park-like, longleaf pine forests (Fig. 103) could begin in earnest. This was followed in the 1890s by railroad building in the eastern part of the thicket (Gunter 1993). Soon, other railroads (Fig. 104) and temporary lateral spur lines (called trams or tramways) extending from the

FIG. 105/ TWO HUGE LOGS ON RAMP NEAR DOUCETTE, TYLER CO. PHOTO COURTESY TEXAS FORESTRY MUSEUM, LUFKIN.

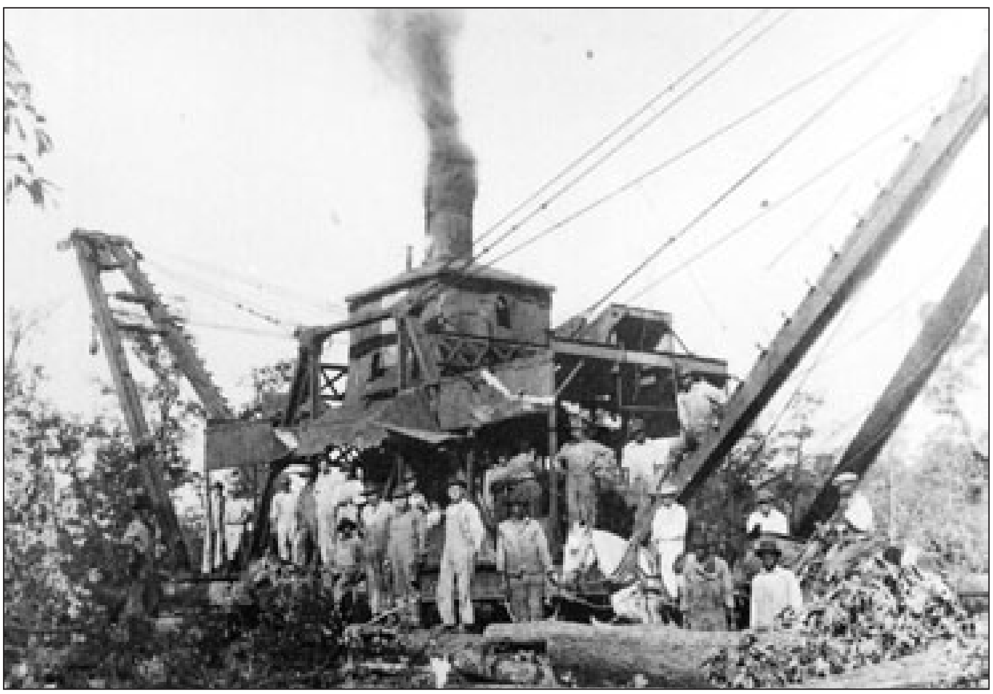


FIG. 106/ WIERGATE (NEWTON CO.) STEAM SKIDDER AND CREW. THE FRIGHTENINGLY POWERFUL SKIDDERS WERE ABLE TO RAPIDLY PULL IN LOGS FROM MORE THAN 200 YARDS AWAY. PHOTO COURTESY NEWTON HISTORY CENTER, NEWTON.

main lines were widespread, the entire region became a network of tracks, and the once vast longleaf pine forests that had been located mostly in Jasper, Newton, Polk, and Tyler counties were rapidly reduced (Fig. 105). Consistent with the mentality of the times, the lumber companies practiced "cut and get out" policies and "took every tree that could be sold, and left only wreckage" (Gunter 1993). Little heed was given to what remained after lumbering. The use of the powerful steam skidder is particularly indicative (Fig. 106). Steel cables were attached to huge logs which were then rapidly pulled by the skidder, sometimes over 200 yards, to the temporary lateral trams. Under the force of the skidder, the logs "raced through the woods like a battering ram, gouging up the ground, destroying small timber, and sometimes flipping end over end" (Sitton 1995). Forester W.G. Jones (in Sitton & Conrad 1998) observed in 1920 that the skidders,

> …lay low everything in their way. Standing trees that are not pulled down are skinned so badly as to be worthless. The remains of the forest are like the shell torn areas of France.

In 1939, Cruikshank and Eldredge stated that "About 200,000 acres, mostly in the longleaf pine type in Newton, Jasper, Angelina, and Tyler counties, are virtually denuded of trees, as a result of the skidder logging of past decades."

The toll of the lumbering boom on the vegetation began to rapidly become apparent. According to McLeod (1972),

> …by the beginning of the 1900's, the Big Thicket loblolly pine-hardwood forest, the adjacent shortleaf pine-hardwood forest to the west and north, and the magnificent longleaf pine forest contiguous on the northeast and east were under sustained assault that was not to end until practically all of the virgin pine forests were reduced to cut-over woodlands.

While most of the old growth pine forests of the Big Thicket were harvested before 1935, some remained as late as 1940. Today, only a very few old growth pines remain, typically found on the more remote inaccessible sites (McLeod 1972). The old growth hardwood forests lasted somewhat longer, but the heavy market demands before, during, and after World War II sharply reduced this resource as well (McLeod 1972). In recent decades, plywood, paper, pulp, and chip products have replaced traditional products requiring large timber, and as a result, fast-growing trees that can be harvested on a short-rotation cycle have been favored (Halstead 2002). Such operations are dependent on "chip-n-saws," machines that convert logs into wood chips. Since these chip mills can use small diameter timber, younger and younger trees can be harvested, with little opportunity for the forests to develop any value for wildlife (Fickle 2002). Further, modern forestry techniques including clearcutting, large-scale bulldozing, and widespread use of herbicides to suppress hardwoods have become widespread. As a result, large areas of high diversity forest have been replaced by plantations or tree farms of evenly spaced loblolly pines. From the standpoint of diversity, such monocultures are "biological deserts" (Ajilvsgi 1979) which are marginal for wildlife (Truett & Lay 1984). Under some circumstances, this type of monoculture forestry also contributes to bark beetle outbreaks (de Groot & Turgeon 1998), a recurrent problem in East Texas. Clearcutting and associated techniques such as bulldozing eliminate all or most hardwoods and leave no shelter for most native animals and little food to sustain them (Owens 1978). One of the most extreme examples of this approach is the "soil shredder." Employed in the conversion of hardwood forests to pine monocultures, this type of machine is used to clear not only stumps and all other above-ground material, but also the roots and all other living material to a depth of about three feet below the surface (Gunter 1993). Soil shredding, bulldozing, and other mechanical site preparation techniques are often highly destructive to natural hydrology and habitats (see Fig. 107) and irreversibly alter the landscape.

FIG. 107/ CLEARCUT AREA NEAR THE BIG THICKET NATIONAL PRESERVE AFTER MECHANICAL SITE PREPARATION (PHOTO BY GMD 2000).

Also, because many of the last remaining hardwood stands were in inaccessible river bottomlands, significant numbers have been lost due to the development of large-scale water impoundments (McLeod 1972). Such projects are a continuing threat, not only for the Big Thicket, but for much of the Pineywoods.

In addition to the ecological toll, the lumber boom also had a very human cost. "The full story of land acquisition by early lumbermen remains untold. With the aid of a powerful infusion of Northern capital, lumbermen took advantage of Texas' 'use and possession' laws to seize lands that had been in settlers' families, often for generations. Usually the forest was felled before the damage was found" (Gunter 1993). The lumber workers themselves suffered greatly under the almost feudalistic system. Lumbering was dangerous work, and salaries, living conditions, and educational levels long remained below those in other parts of the country (Gunter 1993). In fact, the East Texas timber counties have sometimes been called a "Land of Deep Poverty" (Allen 1961). The isolation and poverty of company towns and even company owned counties is a legacy which still persists—in 1993 sixty-five percent of the land in Hardin County and eighty percent in Tyler County was still company owned (Gunter 1993). This legacy is probably also reflected in the bitter history of attempts to protect even a small fraction of the Big Thicket, and it is at least partially responsible for the relatively small size and fragmented nature of what has been preserved.

Another development that profoundly affected the Big Thicket was the discovery of oil. The southern part of the Big Thicket was well known for salt domes, warm sulfur springs, and oil seeps, and Native Americans and early settlers used the oil from seeps (e.g., Sour Lake) as medicine (Gunter 1993). In fact, the mineral wells at Spindletop, a low salt dome mound south of Beaumont, had from the time of Native Americans attracted people because of the supposed healing properties of the waters (Owens 1973). However, the gusher at Spindletop in 1901 (Sanders 2000), and subsequent successful wells in Big Thicket localities such as Sour Lake (1901), Saratoga (1903), and Batson (1904), "transformed once isolated villages into roaring boomtowns knee-deep in mud, drilling rigs, tent saloons and tough men from the four corners of the world" (Gunter 1993). Batson's Prairie, where five families had lived before, swelled to ten thousand within a few years (Owens 1973). Unfortunately, the consequences of unregulated early oil-drilling activities, particularly the oil and saltwater overflow from wells and sludge pits, caused considerable ecological devastation (Gunter 1993). When spilled oil or saltwater runoff from the wells flowed down creeks or bayous or into swamps or lakes, vast numbers of tupelo and bald-cypress trees were poisoned, and another part of the Big Thicket was destroyed (Owens 1973; Edwards 2000). As Owens (1978) noted,

> Oil was black gold and men were willing to do to the land what was necessary to get it. They got more than they could use or sell and let the wells gush out of control till oil flowed over land and down ravines and streams, blackening the earth as it went.

Natural areas had little protection from such abuses. Fortunately, some of the worst examples (e.g., destruction of wetlands by saltwater overflow) were fought and to some extent curbed by agricultural interests such as rice farming (Owens 1978). From the standpoint of the Big Thicket ecosystems, it was also fortunate that the initial oil boom and the associated lack of any type of regulation were relatively short-lived. Nonetheless, oil continues to this day to play an important role in the local economy, and environmental problems associated with oil, though much lessened, still occur today.

Conservation in the Big Thicket

EARLY EFFORTS—The history of preservation efforts in the Big Thicket is complex and frustrating, with numerous failed or only partially successful attempts made over many years (Henley 1967; Cozine 1993; Gunter 1993; Johnston 2001). Conservation activities began in the Big Thicket as early as the 1930s, with the unsuccessful efforts of Richard E. Jackson (Fig. 108) of Silsbee to preserve part of the region as a national park (Parent 1993). Jackson, a conductor on the Santa Fe Railroad that ran through part of the area, was apparently the first person to suggest the preservation of a portion of the Thicket (Loughmiller & Loughmiller 1977). He was also instrumental in 1933 in the founding of the East Texas Big Thicket Association, the forerunner of the still active Big Thicket Association (Owens 1973, 1978; Gunter 1997 (detailed history); Johnston 2001). Because of his contributions, Jackson is sometimes referred to as the "Father of the Big Thicket" (Johnston 1997) and is credited as the individual who laid the foundations upon which subsequent efforts to preserve the Big Thicket were built (Gunter 1997). By the early 1930s, the Thicket was being rapidly reduced due to lumbering, clearing, and development, and Jackson's group began calling for action to set aside 435,000 acres as a preserve or park. The preservation movement eventually attracted a variety of supporters, including the Texas Academy of Science (Cozine 1993). Jackson and Don Baird (then president of the Texas Academy of Science) "became convinced that a biological and botanical

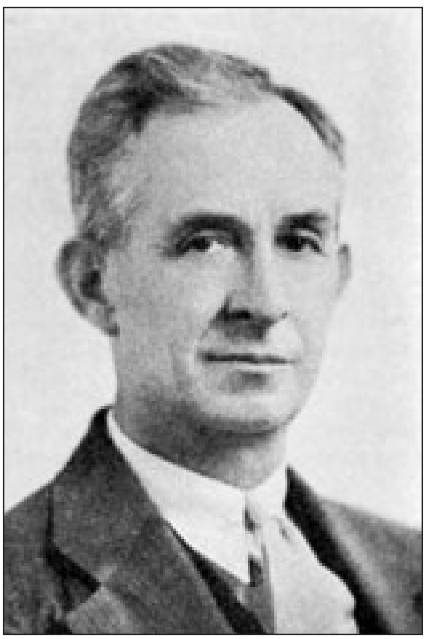


FIG. 108/ RICHARD E. JACKSON, APPARENTLY THE FIRST PERSON TO SUGGEST THE PRESERVATION OF A PORTION OF THE BIG THICKET AND PRESIDENT OF THE EAST TEXAS BIG THICKET ASSOCIATION (PHOTO FROM PARKS & CORY 1936).

survey establishing both the boundaries and the biological uniqueness of the Big Thicket was needed to generate popular support for the preservation movement" (Cozine 1993). The result was the first biological inventory of the region, the *Biological Survey of the East Texas Big Thicket Area*, published in 1936 by H.B. Parks (Fig. 109) and V.L. Cory.

Unfortunately, despite such organized grassroots efforts and scientific study, the early preservation attempts did not succeed—events conspired against and ultimately derailed them (Cozine 1993; Gunter 1997; Johnston 2001). Conditions were dire in much of the area during the Great Depression, and economic survival was of primary concern. In 1936 and 1942, large deposits of oil were found in Polk County (Fig. 110), further shifting the focus to economic considerations. Also, the Federal Government only a few years earlier had purchased extensive areas of National Forest land in East Texas, which reduced the likelihood of additional large land acquisitions in the area (Cozine 1993).

FIG. 109/ HARRIS B. PARKS. PHOTO COURTESY S.M. TRACY HERBARIUM, TEXAS A&M UNIV.

FIG. 110/ SCHWAB CITY OIL BOOM, 1938 (FROM HENLEY 1967, THE BIG THICKET STORY, WITH PERMISSION OF DEMPSIE HENLEY, ©1967).

Finally, and perhaps most importantly, World War II produced an unprecedented demand for lumber products (Cozine 1993). As a result, preservation efforts faded. Though the East Texas Big Thicket Association continued to exist mostly on paper for a number of years, it eventually expired in the late 1950s (Cozine 1993).

During this time, when little attention was focused on the area, Lance Rosier (Fig. 111; see Johnston 1972), resident of Saratoga, self-trained naturalist, and widely recognized authority on the Big Thicket, "almost single-handedly kept the Big Thicket movement alive" (Johnston 2001). Johnston (2001) noted that,

> His reputation and prestige grew as he interpreted Big Thicket to scientists, news reporters, and an endless succession of students, conservationists, and civic groups. Through the years, Rosier was the subject of numerous Sunday supplement stories and magazine articles. In the mid 1950 decade, Louis Hofferbert, Houston Post columnist, dubbed him 'Mr. Big Thicket' and the name became fixed in area history. Rosier and the Big Thicket were further immortalized by Texas writer Mary Lasswell, who wrote a perceptive chapter about Lance and the Big Thicket in her *I'll Take Texas* (1958). The book brought numerous recruits into the effort to save Big Thicket.

RENEWED EFFORTS—During the early to mid-1960s, organized conservation efforts were renewed (e.g., Big Thicket Association founded in 1964), and some high profile advocates (e.g., Supreme Court Justice William O. Douglas, Senator Ralph Yarborough, and Texas Governor Price Daniel) joined those concerned with preserving a portion of the Big Thicket. However, there was strong opposition from the politically and economically powerful timber industry. Lumber companies feared the loss of part of their "land base." They acted individually—and collectively through the Texas Forestry Association—against the creation of all but a token-sized park (Gunter 1993). It should be pointed out, though, that not all lumbermen or lumber companies approached the issue in the same way. According to Reinert (1973):

> Temple Industries, of all the major timber companies with large East Texas holdings, is the only one that is locally owned. Together with the other companies, Temple declared a voluntary moratorium on cutting in the general area of the proposed park, but their proscription was far more generous and extensive, not to mention adhered to, than any other company's. Moreover, Temple has foresworn practices that the rest of the industry has found economical and environmentalists have termed detestable: the wholesale clear-cutting of large timber stands and the razing of cut-over lands, the airborne use of herbicides and defoliants to erase underbrush. Temple has also shown a willingness to encourage slow-growing, often fragile stands of bottomland hardwoods . . . that other companies have ignored in favor of quick-and-easy pine plantations.

Unfortunately, conservation efforts in the area were frequently met with "rancor and bitterness" (Gunter 1993). Apparently, due to fear of change, worries about possible job losses, and ignorance of the actual situation, some local residents were scared and so angry that they cut down trees out of spite and threatened government appraisers with bodily harm (Owens 1978). In other cases, what can only be called anti-environmental vandalism was practiced. In one instance, a huge magnolia tree, the Witness Tree, estimated by some to be 1,000 years old, was killed when drilled in four places and poisoned with arsenate of lead (Gunter 1967, 1993). In another sad case, a large heron rookery was apparently intentionally poisoned by aerial spraying with pesticides (Gunter 1993; Norsworthy 2001). The thinking of some seemed to be that if the area was damaged enough, maybe a park would not be created.

Throughout struggles to conserve the Big Thicket, the desired size of the preserve varied greatly, ranging from the 435,000 acres originally called for by the East Texas Big Thicket Association to the 200,000 acres that was the consensus of scientists in the early 1970s

FIG. 111/ LANCE ROSIER (DIED 1970), KNOWN AS "MR. BIG THICKET." THE LANCE ROSIER UNIT OF THE BIG THICKET NATIONAL PRESERVE IS NAMED IN HIS HONOR (PHOTO FROM GUNTER 1993; USED WITH PERMISSION OF UNIV. OF NORTH TEXAS PRESS).

FIG. 112/ THE COMPROMISE ACTIVITIES AND SUPPORT OF LUMBERMAN ARTHUR TEMPLE WERE IMPORTANT IN THE CREATION OF THE BIG THICKET NATIONAL PRESERVE (REPRINTED FROM *SAWDUST EMPIRE* BY ROBERT S. MAXWELL AND ROBERT D. BAKER BY PERMISSION OF THE TEXAS A&M PRESS. COPYRIGHT © 1983 BY ROBERT S. MAXWELL).

FIG. 113/ GERALDINE WATSON, ARTIST, BOTANIST, WRITER, AND CONSERVATIONIST, WHO WAS ONE OF THE INDIVIDUALS RESPONSIBLE FOR CREATION OF THE BIG THICKET NATIONAL PRESERVE, NOW LIVES NEAR SILSBEE AND MAINTAINS THE WATSON PINELANDS PRESERVE, DEDICATED TO PRESERVING A PORTION OF THE DIVERSITY OF THE BIG THICKET. PHOTO COURTESY OF GERALDINE WATSON.

(Eisner 1973) or a much smaller area of 20,000 acres proposed in 1966 by those influenced by the timber companies (Cozine 1993). Some individuals advocated one large block of land, while others preferred a "String of Pearls" approach—a number of smaller separate parks preserving representative samples of the diverse vegetation types of the Big Thicket. Still other individuals and lumber companies actively worked to minimize the size of any park created and thus reduce the amount of land lost for lumber production (Cozine 1993). According to Howard Peacock (quoted in Cook 2001), one of the leaders of the preservation movement, "The guy who really turned the trick was Arthur Temple [lumberman and head of Temple Lumber/Temple Industries; Fig. 112]. . . . There was a complete standoff—I mean a hostile standoff—between the environmentalists and the timber companies. Then Arthur Temple broke the pattern." The compromise activities and support of Temple were critical to the eventual formation of a preserve, as were the legislative efforts of U.S. Senator Ralph Yarborough. It was Yarborough who led the fight in Congress and who had first introduced a controversial bill proposing a Big Thicket National Park in 1966.

Increasing national attention and a more sophisticated understanding of the value of the Big Thicket were growing. In 1972, McLeod was able to say:

> The forest is highly productive and its potentially sustained yield of timber is very great. Economically important as these forest products are to the economy of the area, this large forested area supplies even greater benefits indirectly. Because of the large water-absorbing and water-holding capacities of these forest soils and their underlying strata, great reserves of underground water are available for industrial development along its southern border. These luxuriant woodlands exert an ameliorating influence on the local climate, serving as a natural cushion or buffer to cold northers, local tornadoes, and destructive hurricanes.
>
> The location, size, and great natural beauty of this forest area makes it one of the most valuable and attractive recreational areas remaining in the state. Its present and future potential as a natural resource for out-of-doors recreation for the people of the area cannot be overestimated.

Many individuals, ranging from concerned local residents to writers, scientists, politicians, and even lumbermen, were instrumental in raising attention and serving as a national conscience to save at least something of the Big Thicket. Some of the most notable who influenced the formation of the national preserve include Lance Rosier, "Mr. Big Thicket" (Fig. 111); the botanist, artist, and writer Geraldine Watson (1975, 1979) (Fig. 113); Maxine Johnston (1972, 2001), conservationist and currently co-editor of the *Big Thicket Reporter;* Professor Claude McLeod (1971, 1972, 1975); Professor Pete Gunter (1967, 1993, 1997, 2000), author and musician; William Owens (1973, 1978), folklorist and author; guide Harold Nicholas; naturalist and author Howard "Tush Hog" Peacock (1994; also see Cook 2001); the "fire-eating" newspaperman Archer Fullingim; activist Ned Fritz (see Ostdick 2000); Dempsie Henley (1967, 1970), author and politician; Billy Hallmon, graphic artist who also did field work to define the preserve boundaries; lumberman Arthur Temple; Congressmen Bob Eckhardt and Charles Wilson; and Senator Ralph Yarborough (Cox 2002), considered by some to be the most effective conservationist in Texas history (he also co-wrote the Endangered Species Act of 1969 and was instrumental in the formation of Padre Island National Seashore and Guadalupe National Park—Odintz 1996; Johnston 2001).

CREATION OF THE BIG THICKET NATIONAL PRESERVE—Finally, after 27 other unsuccessful Big Thicket bills had been introduced in Congress (Cozine 1993), a bill creating an 84,550 acre (34,216 hectare) Big Thicket National Preserve was signed into law by President Gerald R. Ford in October of 1974. This culminated the nearly half-century long, often rancorous environmental struggle. The Big Thicket was the country's first designated National Preserve (Owens 1978), but even this was a compromise—while logging was not permitted, hunting and oil and gas production could still continue (Fountain 1986).

Unfortunately, by the time of the preserve's creation, only tiny remnants of the once vast old growth forest were left. One of the best remaining examples of such old growth forest was outside the preserve on the small Alabama-Coushatta Indian Reservation in the northern portion of the Big Thicket near Livingston—a striking commentary on the value placed on the natural world by different cultures.

On the positive side, significant areas of high diversity second or third growth forests still remained, and knowledgeable preserve supporters and local residents (e.g., Billy Hallmon, Geraldine Watson) assisted in establishing the most appropriate boundaries for the newly created preserve (Gunter 1993). The 84,550 acres saved were divided into eight widely spaced land units and four connecting water corridors—the goal being to include and link as many different habitats as possible (Fig. 114). According to the National Park Service (http://www.nps.gov/bith/), the preserve was created "to protect the area of rich biological diversity where the eastern hardwood forests, the southern coastal wetlands, the western prairies and the arid southwest converge."

In 1993, President Clinton signed an "additions" bill that would increase the size of the preserve by 10,766 acres (4,357 hectares), to be acquired by an exchange of national forest land for land owned by timber companies (Peacock 1994). The additional acreage was to be divided between three newly created units—the Village Creek Corridor, the Big Sandy Creek Corridor, and the Canyonlands Unit—all ecologically important areas. With other minor additions, this would bring the preserve to a total of 96,804 acres (39,175 hectares) (Big Thicket Association 2002). Unfortunately, lack of cooperation between government agencies brought the expansion to a standstill, and efforts are currently being made to finalize this addition. Only the future will tell if this modest addition to one of the nation's most important protected areas will become a reality.

Fortunately, in the more than twenty-five years since the creation of the preserve, attitudes have gradually changed, and there is now even local pride in and appreciation of the local economic benefit from what has been set aside and brought to national attention as the Big Thicket National Preserve (Owens 1978). In 1981, the United Nations Education, Scientific and Cultural Organization (UNESCO) Man and the Biosphere program selected the preserve as

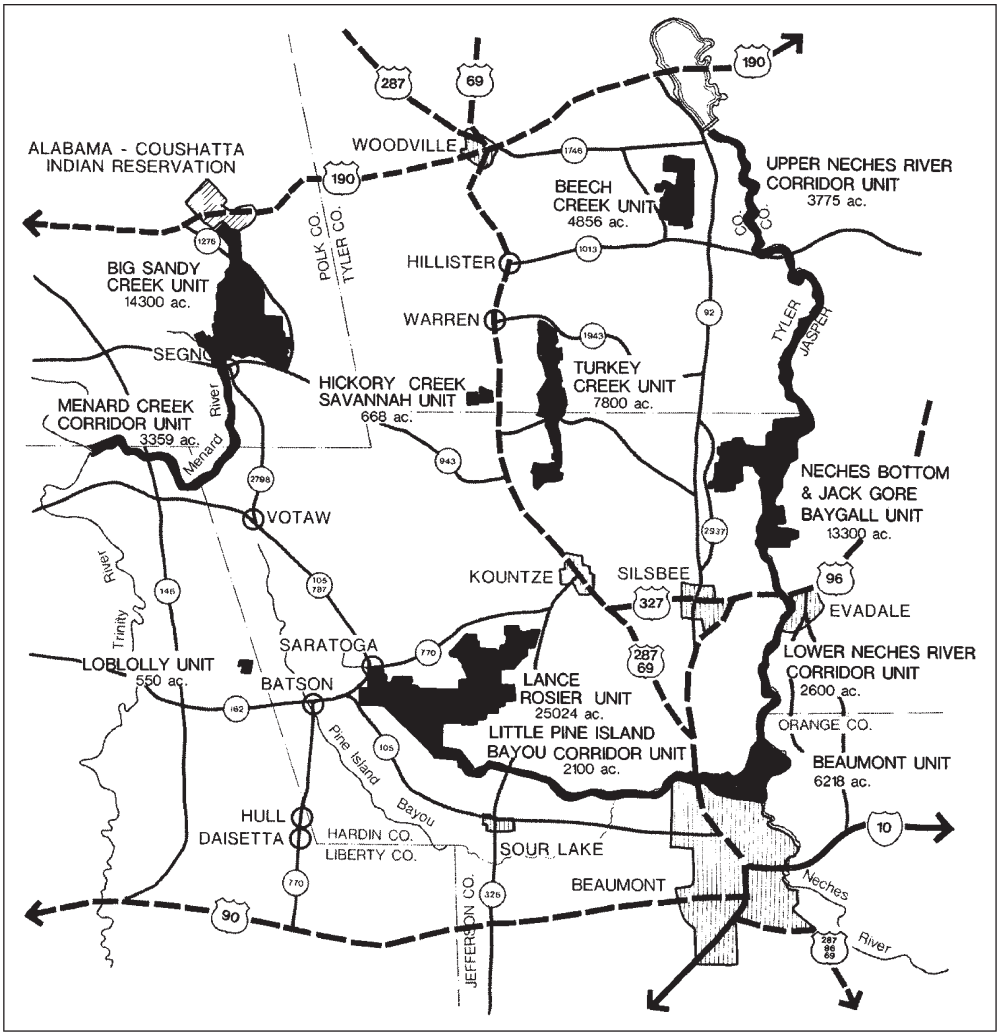


FIG. 114/ BIG THICKET NATIONAL PRESERVE SHOWING THE LAND UNITS AND WATER CORRIDORS (FROM PITTMAN 1978, WITH PERMISSION OF TEXAS A&M UNIV. PRESS, ©1978).

an International Biosphere Reserve, based on research by the School of Forestry of Stephen F. Austin State University (Gunter 1993). More recently, in 2001, the American Bird Conservancy recognized the preserve as a Globally Important Bird Area (Big Thicket National Preserve 2002). Texans can be proud that a small example of the natural vegetation of the state has been preserved for future generations and internationally recognized.

OTHER CONSERVATION EFFORTS—There have been a number of other significant conservation efforts in the area. These include the formation of three state Parks—Davis Hill in northern Liberty County, Martin Dies, Jr. in Jasper and Tyler counties, and Village Creek in Hardin County—and the creation of the approximately 10,000 acre (4,050 hectare) Trinity River National Wildlife Refuge in Liberty County. An important non-governmental preserve in the region is the Roy E. Larsen Sandyland Sanctuary, a 5,561 acre (2,250 hectare) private nature preserve in Hardin County. The Sanctuary consists of this core area owned by The Nature Conservancy plus an additional 2,778 acres (1,124 hectares) protected through a conservation easement (Nature Conservancy 2004). In 2003, an exciting announcement was made of a 33,000 acre (13,355 hectare) area to be preserved at the northern margin of the Big Thicket on the “Middle Neches.” This was achieved through a creative conservation-sustainable forestry strategy organized by the Conservation Fund and Renewable Resources, LLC (Limited Liability Company) and supported by a variety of Texas foundations, including the T.L.L. Temple Foundation, the Meadows Foundation, and the Houston Endowment (Conservation Fund 2004). It is hoped that such creative and positive partnerships will be more common in the future and contribute to conserving portions of the Big Thicket.

While the creation of the national preserve and other protected areas were tremendous steps, when compared with the vast clearcuts and huge areas of loblolly pine monocultures, the preserved areas represent a tiny remnant of the once vast Big Thicket ecosystem. As described by Pete Gunter (1993), "Against this backdrop of massive, destructive change, the achievements of conservationists seem small indeed: mere green fly specks against an immense and growing industrial emptiness. The great long-term problem lies in lumber company policies. The real long-term solution must lie in having those policies changed." Gunter, through research and discussions with representatives of the forest products industry, came to believe that significant changes in this area were occurring. He pointed to Temple-Inland, Champion International, and Louisiana-Pacific, at that time the three largest forest landowners in the Big Thicket region. According to the representatives he contacted, all three companies were either modifying or abandoning large-scale clearcutting as a basic tool in East Texas. Louisiana-Pacific, for example, was practicing "selective harvesting" or tree-by-tree removal, instead of destroying a whole forest. The other two companies had also created special programs. Champion International created a "Special Places in the Woods" program in which more than 1,600 acres (650 hectares) of unique woodland areas were set aside. Temple-Inland began a "Best Use Policy" that allowed bottomland forests to grow much longer than previously, and it set aside "environmental management zones" along streams in areas that are particularly rich botanically (e.g., Wild Azalea Canyons in Newton County—Sitton & Meyers 2000). Gunter compared the situation in 1993 with the view in the 1960s that "Every swamp was to be drained if it could be… and at the rate at which the pillage was proceeding it was only a question of time, not only until the Big Thicket lost its biological identity, but also until southeast Texas became a biological desert…." Concerning the goal of preserving the biological richness of the Big Thicket, he indicated that:

> Though this goal has been only partly achieved, the moral is clear—it is infinitely better than what could have happened. Infinitely more hopeful, overwhelmingly more living. For those who have struggled, and will continue to struggle, to make it so, there is not only joy but a profound consolation. In a world where good causes often die and honest hopes lose themselves in sheer futility, something lasting and living has been actually achieved.
>
> People tried, and it mattered.

Gunter (1993) concluded by saying,

> So there is a change: the beginnings, at any rate, of policies which will be kinder to the land, less destructive of soils, streams, and hardwoods. How far these policies will go towards sustaining forest habitats and the creatures that live in them remains to be seen. Hunters, environmentalists, proprietors and tourists need to understand that a change is taking place. They also need to remain skeptical. Understanding is essential; but so is the will to keep up persistent pressure. If eternal vigilance is the price of liberty, it is the price of ecology also.

The situation today has changed again. Recently, for economic reasons, Champion International and Louisiana-Pacific, two of the largest timber companies in the area, have decided to withdraw from Texas. How new landowners will manage the vast areas now changing hands remains to be seen. A current bright spot in the overall conservation picture is the series of efforts being taken by Temple-Inland. Through their Conservation Forest program, numerous sites are being designated as warranting protection in four categories: rare ecosystems, wildlife management areas, distinctive sites (e.g., waterfalls, places of historical interest), or areas with endangered species. The Conservation Forest Team spearheads this effort, with the goal being to maintain the environmental qualities of the sites. This is not a wilderness approach—however, significant efforts are being made to be environmentally sensitive. Examples of areas now protected through this approach include Beef Creek Waterfall (Jasper County), Little Cow Creek (Newton County; only Texas site of the silky-camellia), a Navasota ladies'-tresses site (Jasper Co.), Peach Tree Village (Tyler County; largest remaining native prairie in the Big Thicket area), a pyramid magnolia site (Newton County), Scrappin Valley (Newton County), and Wild Azalea Canyon (Newton County). Fortunately, many of the sites of particular ecological interest are not good for growing timber (e.g., Catahoula barrens, saline prairies)—thus, setting aside such areas as Conservation Forests is a win-win proposition from the standpoint of both the company and conservationists. The company is also allowing many remaining native forest stands to naturally regenerate. These will still be working forests—trees will be harvested and the forest managed. But rather than being replaced by genetically improved loblolly pines, natural regeneration of a diversity of tree species will be allowed to occur. Further, in some areas the company is now replanting with native longleaf and also shortleaf pine. Such varied, environmentally conscious approaches are indeed refreshing and potentially quite important, particularly in light of Temple-Inland's position as the largest owner of forest land in the state of Texas (over a million acres) (Stan Cook, pers. comm.).

The future of the Big Thicket

When one looks ahead at the future of Texas, it is easy to see a time when access to natural areas is even more important than at present. With rapid population growth and continued development in the state, there will be great demand by future Texans for parks, hiking trails, recreation areas, and other venues where they can escape the increasingly large and congested urban areas. The Big Thicket, with its proximity to Houston, one of the largest population centers in the state, has the potential of partially meeting this need. Likewise, the Big Thicket, with its rich diversity of habitats and large number of species, can serve as an important preserve of biological diversity. Increasing the size of the preserve to one that is both ecologically sustainable and appropriate for large numbers of potential visitors thus seems a wise investment for the future.

The conservation status of the Big Thicket as of 2004 reflects some significant gains but still includes many unanswered questions and challenges. Managing a preserve of significant size takes substantial resources, which are difficult to obtain in times of increasing pressure on the federal budget. The fate of all the additional 10,766 acres (4,357 hectares) (approved but not acquired) of the Big Thicket National Preserve is still not completely settled, though federal appropriation of $3 million for fiscal year 2003 and $3.5 million for 2004 is allowing acquisition of some of the area (D. Fusco, pers. comm.). Perhaps more importantly, when considering the Big Thicket as a whole, various development pressures (urbanization, water diversion, etc.) continue to accelerate. The effects, which include fragmentation of habitats and modifications of hydrology, have potentially serious ecological consequences. Disturbingly, two recent dam proposals (enlarging the Town Bluff Dam which creates Steinhagen Lake and building Rockland Dam on the Neches River above Steinhagen Lake) could alter critically important water flows through Big Thicket National Preserve, inundate parts of a wildlife management area, and almost completely submerge Martin Dies, Jr., State Park, which protects examples of Big Thicket vegetation (Warchut 2003; National Parks Conservation Association 2004a).

Possibly even more significantly, as mentioned earlier, Champion International and Louisiana-Pacific, are withdrawing from Texas with vast areas (more than 1.5 million acres) of the Big Thicket having either been sold or now for sale (National Parks Conservation Association 2004b). As a result, the buffering from development previously provided by timber company lands is in question. The large amount of land currently changing hands presents both an unparalleled conservation opportunity and the potential for widespread loss of forest land through various types of development. As a result of these concerns, the National Parks Conservation Association recently named the Big Thicket National Preserve as one of its "Ten Most Endangered Parks" (National Parks Conservation Association 2003; Warchut 2003).

A longer-term concern is the effect rising atmospheric CO_2 levels and possible global climate change will have on the Big Thicket and its species. The local consequences of such climate change are particularly difficult to predict, but the Big Thicket and East Texas as a whole could see substantial effects. As noted by Cameron et al. (1997), the boundaries of the Big Thicket National Preserve are static, while many of the habitats and species being protected may face significant shifts in their ranges in response to climate change (e.g., northern movement of climatic zones). In an area such as the Big Thicket, where most areas outside the Preserve have been highly modified by human activities, the ability of species to move and thus survive changes in climate is highly limited. Emphasizing this point, Cameron et al. (1997) noted that while global climate change "is a serious threat to the integrity of all natural systems and nature preserves, natural habitats in east Texas along with their associated fauna are particularly vulnerable to environmental change because of their extreme fragmentation…."

Faced with these challenges, conservationists are actively working in a variety of ways. Numerous individuals, both inside and outside of government, are involved in efforts to secure the remainder of the funding for the previously approved "additions" to the national preserve. Because of the large amount of timber company land now for sale, efforts are being made at this critical juncture to purchase some of the available acreage to increase the area permanently protected. For example, organizations such as the Conservation Fund are attempting to buy areas adjacent to the preserve, including a 1,000 acre (405 hectare) plot which will provide a buffer zone around the new visitor center. The Big Thicket Association (www.btatx.org) still actively engages in conservation activities, including publication of the *Big Thicket Reporter* (through which information on preservation and related efforts can be obtained), co-hosting Big Thicket Science Conferences, and supporting efforts to expand the national preserve. Numerous other organizations and individuals are involved in various activities to focus attention on the preserve and the larger ecosystem, with the goal ultimately being to protect the Big Thicket. These activities range from creating and managing small preserves (e.g., Watson Pineland Preserve), to research (e.g., Paul Harcombe), writing and publishing (e.g., James Cozine, Pete Gunter, Maxine Johnston), fund-raising, and political action—all are important. One specific example is Lamar University's Center for the Study of the Big Thicket (http://dept.lamar.edu/artssciences/BIGTHICKET/home.htm), which is promoting the study of the natural and cultural history of the Big Thicket.

Such varied conservation approaches are essential, since what is done now and in the next few years will forever determine the fate of the ecosystem, and future generations will look back to this time as a turning point in efforts to save the Big Thicket of East Texas.

Origin and Diversity of the East Texas Flora

Introduction to the East Texas Flora

The flora of East Texas, like that of any relatively large region, has a complex and varied origin. Ultimately, it is the result of the evolutionary and distributional history of each of the component species, as well as a reflection of past and present climate and soil conditions. However, several influences can be observed which together allow at least a broad understanding of how the present flora originated. East Texas contains components of four major floristic provinces as defined by Thorne (1993d): the Appalachian Province, the Atlantic and Gulf Coastal Plain Province, the North American Prairies Province, and the Sonoran Province.

There are also considerable numbers of Texas endemics. In addition, the modern flora contains 18% introduced species, these having come from various parts of the world.

It should be noted that this book is a snapshot of the flora as it currently exists and that the flora will continue to change. Natural causes—glacial cycles, shifts in weather patterns, etc.—have had and will continue to have an effect. For example, studies of bogs at various Texas localities (e.g., Patschke Bog, Lee County; Boriack Bog, near Austin; Gause Bog, Milam County), as well as larger scale studies and analyses, indicate that near the end of the last glacial maximum, species currently present only much further north (e.g., white spruce) were present in Texas, suggesting a very different climate (Potzger & Tharp 1943, 1947, 1954; Bryant 1977; Bryant & Holloway 1985b; Delcourt & Delcourt 1993; Stahle & Cleaveland 1995). Certain present-day plant distributions may thus be relicts of these past climatic conditions (Kral 1966c). The current occurrence of the predominantly northern American beech (*Fagus grandifolia*) in the eastern part of the Pineywoods or the unusual occurrence of plants normally found in Eastern Texas in microhabitats of the Edwards Plateau, the Trans-Pecos, or the Cross Timbers and Prairies are examples of this pattern. Human activities (e.g., habitat alteration, human-induced climate changes, introduction of exotic species, etc.) will also cause the flora to change. For example, some of the introduced species are currently having significant adverse impacts on the native ecosystems. Specific cases include hydrilla (*Hydrilla verticillata*), which now chokes many miles of Texas waterways, and Chinese tallow tree (*Sapium sebiferum*), which is invading extensive areas in the Big Thicket.

In general, with the exception of the wetter extreme eastern portion, much of East Texas can be considered ecotonal—a transition zone. When looking back over thousands of years, the "history of this ecotonal region involved introduction of *Picea* [spruce] and mesic deciduous vegetation from the north during cool moist intervals, the establishment of oak savannah or an oak–hickory (*Carya illinoinensis*) association in warmer drier times, and possibly the incursion of arid elements from the west during periods of maximum temperature and dryness" (Graham 1999). In other words, the region has had a varied climate and complex floristic influences. A number of these influences will be described below.

Influence of the Eastern Deciduous Forest on the East Texas Flora

The eastern deciduous forest, which covers only approximately 11% of the North American continent, "is the most diverse and species-rich component of the North American vegetation" (Graham 1999). This forest extends as far west as East Texas, where a number of temperate genera reach the southwestern limit of their present distribution in the continental U.S. (Graham 1999). In East Texas, the influence of the eastern deciduous forest is represented by plants from two floristic provinces, the Appalachian Province and the Atlantic and Gulf Coastal Plain Province (Thorne 1993d). This component of the flora is particularly important in the Pineywoods, the Post Oak Savannah, and the Red River drainage, but eastern deciduous forest elements occur across all of East and adjacent North Central Texas and even make up an important component of the flora of the Edwards Plateau to the south and west (Amos & Gehlbach 1988). The vast deciduous forest biome of eastern North America is composed of a number of plant communities, and the various forests and savannahs of East Texas represent a diversity of these community types. They range from wet and mesic communities dominated by species such as bald-cypress and water tupelo or beech and magnolia in the eastern part of East Texas, to drier pine-dominated ones (e.g., Arenic Longleaf Pine Uplands), to various oak-hickory or oak communities further west in the Post Oak Savannah. The latter, in combination with the Cross Timbers just to the west, represent the relatively dry western fringe of the eastern deciduous forest (Thorne 1993d).

From the historical biogeography standpoint, eastern deciduous forest elements are one of the most fascinating components of the East Texas flora. Since the breakup of the supercontinent Pangaea, extensive dispersal of plants and animals between the Eurasian and North American continents has occurred, and the combined area (previously the northern part of

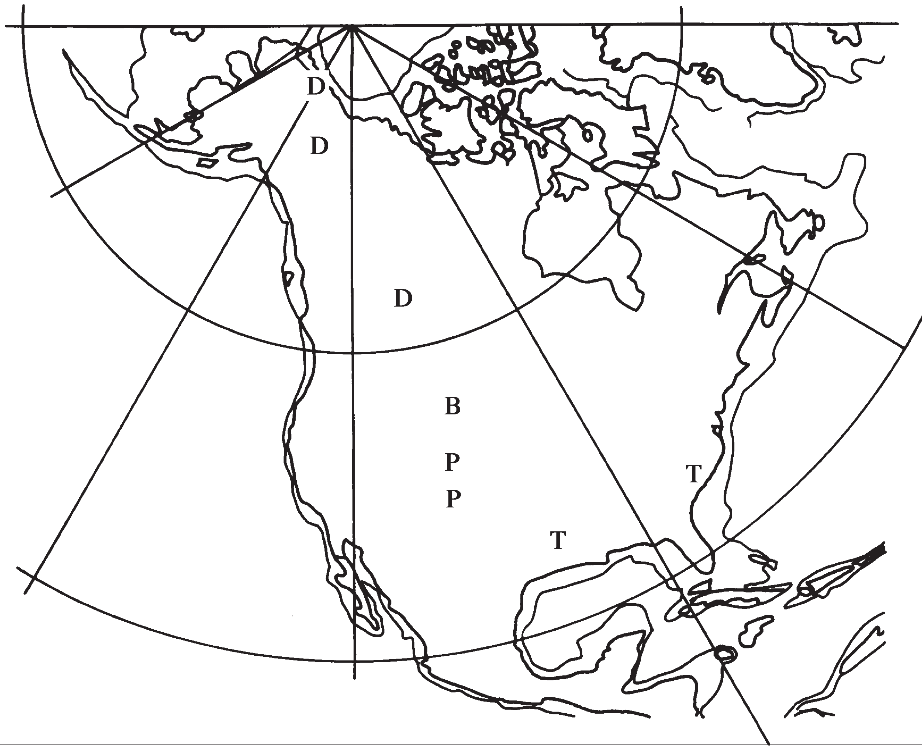


FIG. 115/ GENERALIZED MAP OF LATE CRETACEOUS VEGETATION FOR NORTH AMERICA SHOWING VEGETATION ZONES. T, TROPICAL FOREST; P, PARATROPICAL FOREST; B, BROAD-LEAVED EVERGREEN FOREST; D, POLAR BROAD-LEAVED DECIDUOUS FOREST (MODIFIED FROM UPCHURCH & WOLFE 1987, WITH PERMISSION OF CAMBRIDGE UNIV. PRESS, ©1987).

Pangaea known as Laurasia) is considered a single "Holarctic" biogeographic region. Two major dispersal routes into North America existed, one from Europe (the North Atlantic land bridge) and the other from Asia across the Bering Sea area (the Beringian pathway/Bering land bridge). It should be emphasized that average global temperatures were much warmer during portions of the Cretaceous and Tertiary periods (Fig. 11), with ecosystems expanded much beyond their current distributions. Fossil evidence shows that tropical rain forests ultimately extended as far north as 45º to 50º N latitude, paratropical (= near-tropical) rain forests to 60º to 65º (70º in coastal areas), and broad-leaved deciduous forests to polar areas (Wolfe 1975; Upchurch & Wolfe 1987; Wolfe 1987; Wendt 1993; Graham 1999) (see Fig. 115 for map of Late Cretaceous North American vegetation). Specific examples of extended ranges include broad-leaved evergreen paratropical rain forest in Alaska, alligators from Ellsmere Island in northern Canada (then at 79º N latitude), and deciduous trees (e.g., *Alnus*, *Larix*, *Ginkgo*) in the Canadian high Arctic (Graham 1993a, 1999). The striking global high temperatures ("hothouse" conditions) causing these distribution patterns reached their maximum during the Early Eocene Epoch (55 to 50 million years ago) and represent the highest temperatures of the entire Cenozoic Era. They were associated with an increase in volcanic activity worldwide and a concomitant increase in atmospheric CO_2 (Graham 1999).

Sea levels also varied significantly, with areas now underwater (e.g., Bering Sea between Alaska and Asia) sometimes exposed and providing extensive terrestrial migration corridors. Thus, at times, migration across high northern latitudes was probably relatively uninhibited. Temperate plants are thought to have migrated across both dispersal routes (North Atlantic land bridge, Beringian pathway), and significant numbers of tropical plants also migrated across the North Atlantic land bridge (then at 45º to 50º N latitude) and possibly (in a more limited way) across Beringia.

The fossil record, reflecting these connections of North America to Europe and Asia, shows that many plant and animal groups had widespread distributions across much of the Northern Hemisphere—temperate forests, for example, occurred very broadly as early as the Late Cretaceous and reached their maximum extension in the Middle to Late Miocene Epoch (the Miocene extended from 23.8–5.3 million years ago (mya)) of the Tertiary Period (Graham 1993a). Particularly during the Tertiary, "there was a belt of vegetation similar in structure and composition extending around much of the northern hemisphere" (Graham 1999). This widespread largely temperate flora has sometimes been referred to as the Arcto-Tertiary geoflora or the Tertiary mesophytic flora (e.g., Graham 1993a). It should be noted that this extensive temperate forest included various gymnosperms (e.g., *Ginkgo*, *Metasequoia*, *Sequoia*) as well as deciduous angiosperms (Davis 1983; Manchester 1999). Other authors, recognizing numerous connections between Old World tropical plant groups and taxa in the New World, have referred to a Tertiary boreotropical flora (Wolfe 1975; Tiffney 1985a, 1985b; Zona 1990; Lavin & Luckow 1993; Wendt 1993; Pipoly & Ricketson 1999, 2000). These workers have emphasized the tropical components of the Tertiary flora and clarified the dispersal of tropical elements from the Old World to the New. Called by whatever name, the resulting widespread Tertiary flora was characterized by both temperate deciduous and tropical components and developed into a "Mixed Mesophytic forest" that "was once more or less continuously distributed throughout the Northern Hemisphere" (Xiang et al. 1998).

According to Graham (1999), "With reference to the modern deciduous forest formation [of eastern North America], it is now clear that this community is a complex mixture of elements derived from various sources. Some certainly came from mesic Cretaceous ancestors and evolved in the high northern latitudes. Others are clearly derived from tropical groups that have evolved temperate components (e.g., *Diospyros virginiana*, the persimmon, a New World temperate representative of the primarily tropical family Ebenaceae). The contribution of Old World tropical elements to the composition of New World temperate deciduous and tropical forests is only now becoming fully recognized and constitutes support for the concept of a boreotropical flora." It is thus now clear that the present eastern deciduous forests, including those of East Texas, have a complex origin including both temperate and tropical elements from the Old World that arrived during the Cretaceous and Tertiary periods. Other species have evolved in place in eastern North America and still others represent more recent arrivals.

There also have been extensive geohistorical changes from the mid-Tertiary Period to the present that have had a profound impact on the development of the plant communities we see today. These include alterations in the shapes of the northern land masses (e.g., separation of North America and Eurasia due to tectonic plate movement), fluctuations in sea levels, mountain building, and profound changes in the climate (e.g., major change in average global temperature, glaciation). As a result of these events, there have been great changes in both the composition and the disposition of the flora. In particular, many once widespread plant groups have experienced restrictions in their ranges, resulting in a number of interesting disjunct distribution patterns.

Cooling in the Late Tertiary (Late Miocene to Pliocene) and the approximately 20 glacial-interglacial cycles of the Pleistocene Epoch ("ice ages") were particularly important in determining the survival of species in various parts of the northern hemisphere. During the Late Tertiary and Quaternary (including the Pleistocene) in eastern North America, the "diverse physiography and the north-south orientation of the American mountains allowed the deciduous forest to persist in local refugia and to migrate in response to changes in climate" (Graham 1999). In other words, as glaciers moved down from the north, there was no east-west mountain barrier to prevent the southern migration of plants. Graham (1999) stressed that the north-south alignment of the mountains and the "continuous land connections to boreal zones to the north and tropical zones to the south made the region both a pathway and a refugium for plants and animals." Likewise, in eastern Asia, conditions were conducive to the persistence of the once widespread Tertiary forest elements—in fact, more have sur-

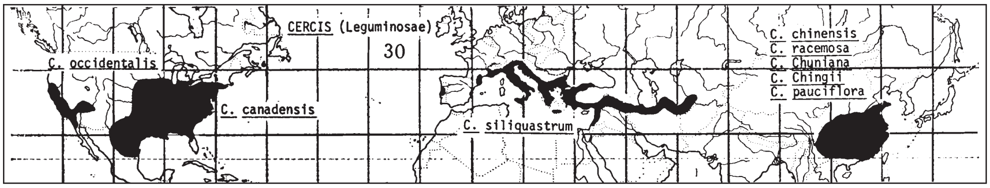


FIG. 116/ GENERALIZED DISTRIBUTION MAP OF *CERCIS* (FABACEAE) (E.G., REDBUD) SHOWING OCCURRENCE IN ALL FOUR MAIN WIDELY SEPARATED TERTIARY RELICT AREAS (FROM WOOD 1970, WITH PERMISSION OF VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIV.).

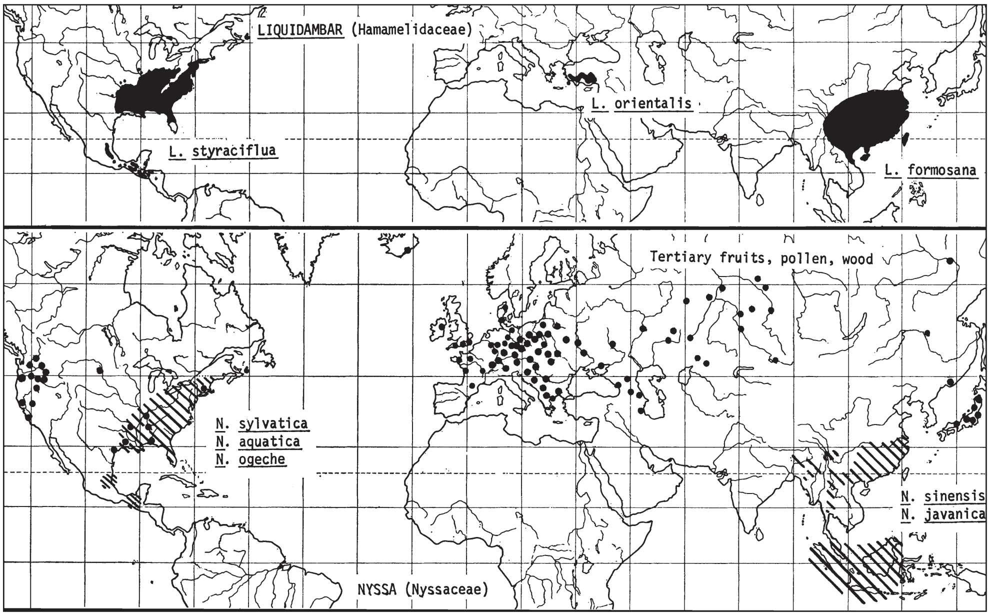


FIG. 117/ GENERALIZED DISTRIBUTION MAP OF *LIQUIDAMBAR* (HAMAMELIDACEAE) (E.G., SWEETGUM) SHOWING OCCURRENCE IN THREE OF FOUR MAIN WIDELY SEPARATED TERTIARY RELICT AREAS; GENERALIZED DISTRIBUTION MAP OF *NYSSA* (NYSSACEAE) (E.G., BLACK TUPELO) SHOWING PRESENT DAY OCCURRENCE (CROSS-HATCHING) IN ONLY EASTERN NORTH AMERICA AND EASTERN ASIA, BUT WITH WIDESPREAD FOSSIL EVIDENCE (FROM WOOD 1972, WITH PERMISSION OF THE MISSOURI BOTANICAL GARDEN).

vived to the present in eastern Asia than anywhere else—probably due to the more complex Asian topography and the resulting reduced impact of Pleistocene glaciations and more active speciation (Wen 1999). Western North America, however, had undergone a period of mountain building and associated climate and habitat change and was not as conducive to the persistence of extensive deciduous forest elements—many fewer survived there. “As temperatures continued to decrease and rainfall became more seasonal, high elevation and high latitude coniferous evergreen forests expanded. This occurred at the expense of broad-leaved deciduous forests, which were eliminated from many areas of western North America during the Pliocene” (Graham 1993a). The deciduous forests of Europe also fared poorly. There, changes prior to and during glaciation resulted in the local extinction of many deciduous forest lineages (Davis 1983). During the various glacial advances, European vegetation was caught between an advancing ice sheet from the north and “the alpine glaciers of the east-west trending Pyrenees-Alp mountain system to the south” (Graham 1999). The result was that many fewer deciduous forest elements have survived to the present in Europe.

Because of such geohistorical factors, a number of species of the once widespread Northern Hemisphere Tertiary flora have survived only in one or more of four main, widely separated Tertiary relict areas—1) eastern Asia; 2) eastern North America; 3) western North America; and 4) southeastern Europe—but with the most in eastern Asia and eastern North America (Li 1952; Little 1970; Wood 1970, 1972; Graham 1972, 1993a, 1999; Boufford &

Spongberg 1983; Hamilton 1983; Hsü 1983; Wu 1983; Ying 1983; Cox & Moore 1993; Stuckey 1993; Xiang et al. 1998; Wen 1999, 2001; Xiang & Soltis 2001). Examples of East Texas genera found in all four of these areas include *Cercis* (Fig. 116), *Aesculus, Erythronium*, *Juglans*, *Ostrya*, *Philadelphus*, and *Platanus* (Wood 1970, 1972). Other East Texas genera (e.g., *Liquidambar*) survive in only three of the four areas (Fig. 117) (Wood 1972). In addition, some groups which today are found in only one or two of the relict areas are known as fossils from other relict areas—examples include *Nyssa* (Fig. 117), *Ailanthus*, *Dulichium*, *Ginkgo*, *Halesia*, *Metasequoia*, and *Taxodium*, all of which had much broader Tertiary distributions than at present (Wood 1970; Manchester 1999).

Because the Tertiary flora suffered in the center of North America, some groups remain today in separate eastern and western regions of the continent. Wood (1970) and Thorne (1993d) estimated that about 65% of the genera of southern Appalachian seed plants also occur in western North America and emphasized the strong floristic relationships between eastern and western North America. Numerous genera are found today only in these two separate areas—examples of East Texas genera with such a distribution include *Ceanothus*, *Collinsia*, *Eriogonum*, *Oxypolis*, *Pycnanthemum*, *Schoenolirion*, and *Trichostema* (Wood 1970). Even some species show this disjunct distribution on the two sides of the continent—e.g., three-way sedge, *Dulichium arundinaceum* (Fig. 118); brownish beak sedge, *Rhynchospora capitellata* (Fig. 119); globe beak-rush, *Rhynchospora globularis*; and flux-weed, *Isanthus brachiatus* (Wood 1972). Likewise, Wen (1999) indicated that “there is a closer biogeographic relationship between eastern North America and western North America than between eastern North America and eastern Asia,” often with the phylogenetically most closely related species being in the two regions of North America. According to Xiang et al. (1998), about 30 genera have closely related species in both

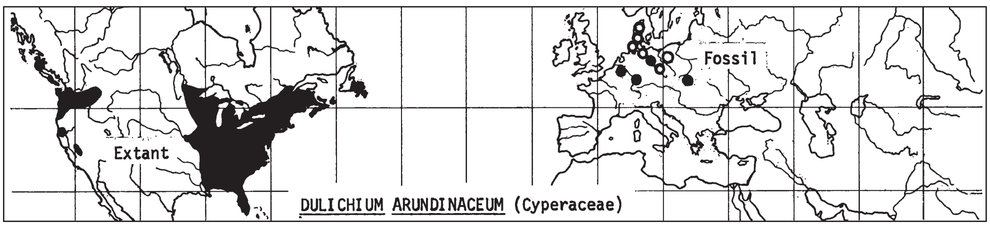


FIG. 118/ GENERALIZED DISTRIBUTION MAP OF *DULICHIUM ARUNDINACEUM* (CYPERACEAE) (THREE-WAY SEDGE), AN EXAMPLE OF A SPECIES DISJUNCT BETWEEN EASTERN AND WESTERN NORTH AMERICA. ALSO NOTE THE FOSSIL OCCURRENCE (TERTIARY) IN EUROPE (FROM WOOD 1972, WITH PERMISSION OF THE MISSOURI BOTANICAL GARDEN).

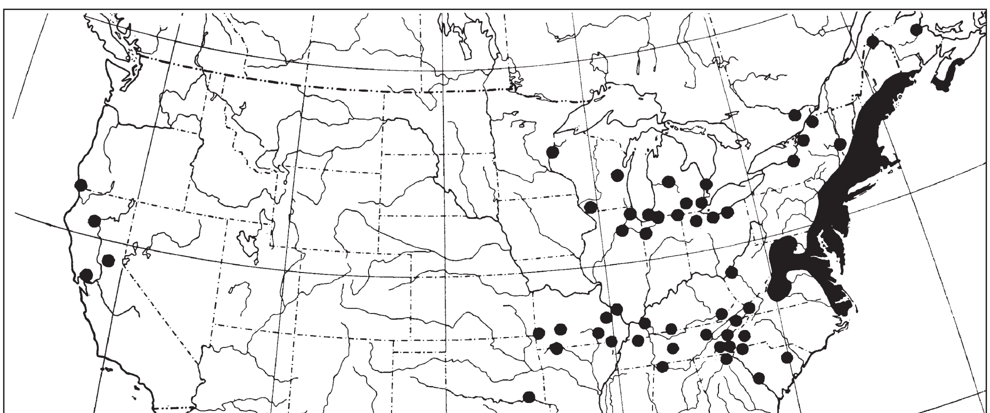


FIG. 119/ GENERALIZED DISTRIBUTION MAP OF *RHYNCHOSPORA CAPITELLATA* (CYPERACEAE) (BROWNISH BEAK SEDGE), AN EXAMPLE OF A SPECIES DISJUNCT BETWEEN EASTERN AND WESTERN NORTH AMERICA (FROM WOOD 1972, WITH PERMISSION OF THE MISSOURI BOTANICAL GARDEN).

eastern and western North America and eastern Asia (an East Texas example is the genus *Trillium*). Molecular phylogenetic work suggests that for a number of genera, the eastern and western North American species are sister groups, "which in turn are the sister of the Asian species" (Xiang et al. 1998). Such a consistent pattern suggests a common geographic history and can "be viewed as support for the long-standing hypothesis that the disjunction in eastern Asia, eastern North America, and western North America represents the fragmentation of a once continuous plant community" (Xiang et al. 1998). Unfortunately for the Tertiary floras of western North America (and Europe as indicated above), geologic and climatic changes resulted in the elimination of many species from those areas.

However, a significant number of genera have survived in only two geographically distant Tertiary relict areas, eastern Asia and eastern North America. This striking distribution pattern has long been of interest to botanists (e.g., Linnaeus in Halenius 1750—the dissertation of one of his students; Gray 1846, 1859) and continues to be so today (e.g., Li & Adair 1994, 1997; Xiang et al. 1998; Graham 1999; Wen 1999, 2001; Xiang & Soltis 1999; Donoghue et al. 2001). Because of Gray's early work on this biogeographic pattern, it has sometimes been referred to as the "Asa Gray disjunction" (Wen 1999). Some of the most recent research (Wen 1999) indicates that this disjunct distribution pattern occurs in 65 genera of flowering plants. The genus *Carya* is one example (Fig. 120); other East Texas examples include *Aletris*, *Ampelopsis*, *Apios*, *Brachyelytrum*, *Campsis*, *Diarrhena*, *Halesia*, *Hamamelis*, *Lindera*, *Lyonia*, *Menispermum*, *Nyssa, Parthenocissus, Penthorum*, *Phryma*, *Podophyllum, Sassafras*, *Saururus*, *Stewartia*, *Tipularia*, *Trachelospermum*, *Triosteum*, *Wisteria*, and *Zizania* (Li 1952; Little 1970; Boufford & Spongberg 1983; Hamilton 1983; Hsü 1983; Wu 1983; Ying 1983; Cox & Moore 1993; Graham 1993a; Wen 1999). In fact, representatives of 33 of the 65 genera (51%) cited by Wen (1999) as eastern Asia-eastern North America disjuncts occur in East Texas. In the words of Graham (1993a), "It is well known that the broad-leaved deciduous forests of eastern North America and eastern Asia are floristically related…. It results from the maximum extension of the temperate deciduous forest in the mid-Tertiary and its disruption in western North America during the Pliocene and in western Europe during the Quaternary." This is one of the most ancient components of the East Texas flora—by at least the Early Tertiary Period (Eocene Epoch—55.5–33.7 mya), deciduous vegetation was present across the middle of the North American continent, including such familiar genera as *Acer*, *Celtis*, *Liquidambar*, *Populus*, and *Rhus* (Graham 1993a). In addition to present-day disjuncts between the two areas, fossils of numerous present-day Asian genera (e.g., *Ailanthus*, *Ginkgo*, *Metasequoia)* have been found in North America (Graham 1999).

FIG. 120/ WORLDWIDE DISTRIBUTION MAP OF *CARYA* (JUGLANDACEAE) SHOWING ITS DISJUNCT OCCURRENCE IN EASTERN ASIA AND EASTERN NORTH AMERICA (FROM WU 1983).

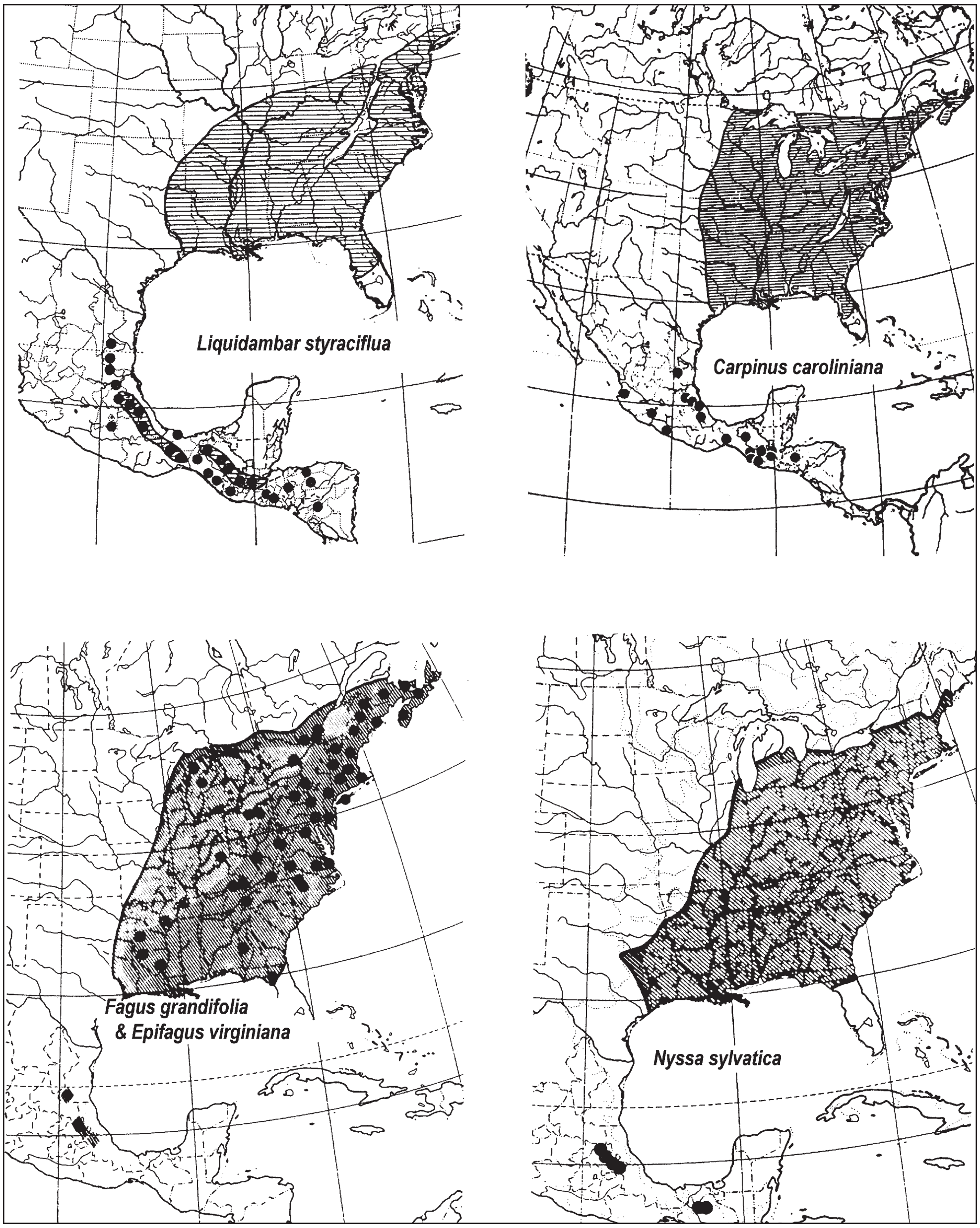


FIG. 121/ DISJUNCT DISTRIBUTIONS BETWEEN EASTERN NORTH AMERICA AND EASTERN MEXICO (FROM MARTIN & HARRELL 1957, WITH PERMISSION OF THE ECOLOGICAL SOCIETY OF AMERICA).

As discussed earlier, the vegetation of the eastern deciduous forest has a complex origin. Tiffney (1985a, 1985b) hypothesized multiple origins of the eastern Asia-eastern North America disjunction, proposing migrations dating to five major periods—pre-Tertiary, Early Eocene, Late Eocene-Oligocene, Miocene, and Late Tertiary-Quaternary. Dilcher (2000) also emphasized that different routes between the Old and New worlds have been open at different times in the past and that the shared vegetational elements between Asia and North America are possibly derived from multiple introductions (in other words, the same disjunct distribution pattern may have more than one origin—including long distance dispersal). Likewise, work by Xiang et al. (1998), Wen (1999), and most recently, studies by Donoghue et al. (2001) and Xiang and Soltis (2001) supported this complex and multiple origin scenario, with Xiang and Soltis (2001) suggesting that at least three independent events contributed to the disjunction. It thus now seems clear that while the similarities between the eastern Asian and eastern North American floras in general are explained by the widespread Tertiary distribution of North Temperate forest elements and subsequent extinctions in western North America and Europe, the pattern is the result of multiple origins and a complex series of causes.

Another interesting floristic relationship is seen between some isolated forests in the mountains of Mexico and those in the eastern United States (Fig. 121). Numerous East Texas deciduous forest genera (e.g., *Acer*, *Alnus*, *Carpinus*, *Cercis*, *Crataegus*, *Cornus*, *Epifagus*, *Fagus*, *Fraxinus*, *Juglans*, *Liquidambar*, *Magnolia*, *Mitchella*, *Myrica*, *Nyssa*, *Ostrya*, *Pedicularis*, *Platanus*, *Prunus*, *Quercus*, *Rhus*, *Smilax*, *Tilia*, *Ulmus*, and *Vaccinium*), and even a few individual species (e.g., *Carpinus caroliniana* (American hornbeam), *Epifagus virginiana* (beechdrops), *Fagus grandifolia* (American beech), *Nyssa sylvatica* (black-gum), *Liquidambar styraciflua* (sweetgum), and *Mitchella repens* (partridge berry)) occur broadly across the eastern United States as far west as eastern Texas and then reappear in the Mexican highlands, and in some cases even in Guatemala (Miranda & Sharp 1950; Martin & Harrell 1957; Thorne 1993d; Graham 1993a, 1999). Most of the deciduous forest "temperate" genera occur in Mexico in "isolated patches of humid montane forest, typically in the Sierra Madre Oriental," usually above 1,000 m (3281 feet) elevation (Martin & Harrall 1957). These occurrences in Mexico represent a disjunction across 500 km (311 miles) or more of arid grassland and thorn scrub (Martin & Harrall 1957). At one time, the floristic similarities were thought to be the result of the migration of vegetation zones associated with Pleistocene glaciation (Dewey 1949). However, the fact that this relationship exists primarily at the generic level implies a substantial period of isolation of the Mexican components, during which speciation occurred. This conclusion is in line with recent paleobotanical evidence showing that the relationship was established long before the glacial cycles of the Pleistocene (Graham 1999). In actuality, this relationship represents a Middle Miocene (Miocene Epoch—23.8–5.3 mya) extension of deciduous forest and associated fauna (particularly amphibians) into Mexico during a period of widespread climatic cooling (e.g., Antarctic glaciation) (Burnham & Graham 1999; Graham 1999). In the words of Graham (1999), a "major decline in temperature occurred in the Middle Miocene (15–14 mya)," and "global temperatures reached new lows, allowing the deciduous forest to reach its southernmost extent." Subsequently, during the Pliocene (5.3–1.8 mya) and later, the climate warmed and dried, and other types of vegetation (e.g., prairie and dry area shrub communities) spread at the expense of deciduous forest. As a result, the once continuous deciduous forests became fragmented, surviving in the eastern U.S. and eastern Mexico. During the subsequent millions of years, evolution has resulted in the differentiation of some disjunct populations into separate species, while others are still similar enough to be considered one species. With continued climatic change, this forest type has been further reduced in Mexico, until at present it survives in only limited isolated pockets of appropriate microclimate in the highlands (Miranda & Sharp 1950; Graham 1993a, 1993b, 1999).

More recently, during the Quaternary Period (beginning about 1.8 mya and including the Pleistocene and Recent epochs), there have been profound changes in the vegetation of the southeastern U.S., including East Texas. During the Pleistocene Epoch there was significant climatic variability and at least 20 glacial-interglacial cycles. Not surprisingly, widespread changes in vegetation were associated with these climatic fluctuations (Delcourt & Delcourt 1993). This is true even in southern areas such as Texas, even though actual glaciers were hundreds of miles to the north of Texas. During the last major period of full glaciation (100,000 to about 18,000-15,000 years ago), the vegetation of the eastern U.S. was radically different than at present. Sea level was 100–120 m lower than in modern times, and the Laurentide Ice Sheet extended south to approximately 40º N latitude (Fig. 122). It is now known that the boreal forest region "was more than 1,200 km south of its modern southern

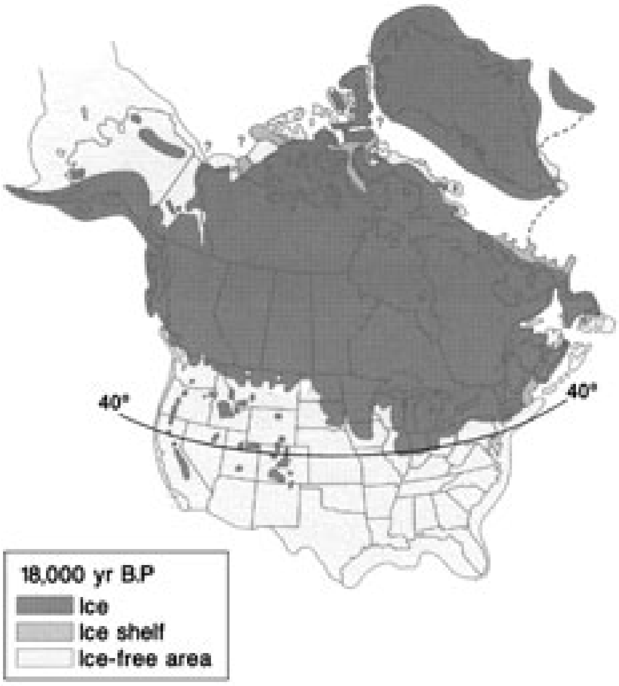


FIG. 122/ EXTENT OF ICE IN NORTH AMERICA AT THE END OF THE LAST GLACIAL MAXIMUM 18,000 YEARS BEFORE PRESENT; NOTE ALSO THE DIFFERENCE IN CONTINENTAL MARGINS DUE TO LOWERING OF SEA LEVELS AS A RESULT OF LARGE AMOUNTS OF WATER BEING TIED UP IN GLACIAL ICE (ADAPTED FROM BROUILLET & WHETSTONE 1993, WITH PERMISSION OF OXFORD UNIV. PRESS).

border in Canada" (Delcourt & Delcourt 1985). In fact, boreal forest extended south to about 34° N latitude, and a narrow ecotone existed between 34° and 33° N latitude between "northern boreal and more southern temperate communities" (Delcourt & Delcourt 1993). It should be noted that this ecotone cut across the northern several tiers of East Texas counties (e.g., Bowie, Grayson, Hunt, Red River). "South of latitude 33°, across the southern Atlantic and Gulf coastal plains, floristic elements of temperate deciduous forest occurred with plant taxa characteristic today of southeastern evergreen forests" (Delcourt & Delcourt 1993).

It was in far southern areas such as East Texas that some eastern deciduous forest species found refuge during full glacial times (Fig. 123). Indeed, data from East Texas bogs (e.g., Boriack Bog, Lee County) in the Post Oak Savannah confirm the presence of such deciduous forest genera as *Acer*, *Alnus*, *Carya*, *Castanea*, *Cornus*, *Corylus*, *Myrica*, and *Tilia* more than 15,000 years ago and suggest the region was heavily forested near the end of the last glaciation (Bryant 1977; Bryant & Holloway 1985b). While these genera can still be found in East Texas today (generally further east), the profound climatic differences at that time are reflected in the presence of small amounts of *Picea glauca* (white spruce) pollen in late glacial deposits at Boriack Bog (radiocarbon dated as older than 15,000 years) (Bryant 1977; Holloway & Bryant 1984; Bryant & Holloway 1985b). This cold-tolerating species occurs today only much farther north (Fig. 124). Bryant and Holloway (1985b) concluded that as post-glacial warming occurred in East Texas, the glacial age forest lost certain key components such as *Picea* and *Corylus*, yet the region remained forested with a wide variety of deciduous trees.

Another significant vegetational change in North America as a whole has been the great fluctuation in the amount of grassland versus forest/woodland vegetation. This fluctuation can be associated with glaciation and deglaciation—e.g., areas now covered with grassland vegetation, such as the Texas panhandle, supported forest prior to post-glacial warming (Webb 1981; Axelrod 1985). All of Texas was thus under very different conditions during the last full-glacial interval. At that time, there existed across the unglaciated parts of southwestern North America (e.g., Edwards Plateau), a cool, moist "pluvial" climate (Delcourt & Delcourt 1993) with forest species expanding their ranges. Subsequently, the climate moderated between 15,000–10,000 years ago, with interglacial conditions (i.e., warmer and drier) prevailing for the last 10,000 years (Delcourt & Delcourt 1993). According to Bryant and Holloway (1985b), since late glacial times there has been in general a warming and drying trend in the western part of East Texas. Data from Weakley Bog (Leon County) indicate that vegetation from about 2,400 to 1,500 years before present was open woodland dominated by

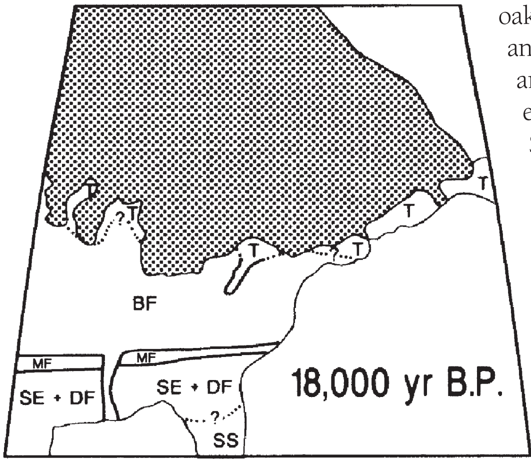


FIG. 123/ MAP SHOWING EXTENT OF ICE AT END OF THE LAST GLACIAL MAXIMUM (18,000 YEARS BEFORE PRESENT) WITH LOCATION OF VEGETATION TYPES AT THAT TIME. T—TUNDRA; BF—BOREAL FOREST; MF—MIXED FOREST (CONIFER-NORTHERN HARDWOOD); DF—DECIDUOUS FOREST; SE—SOUTHEASTERN EVERGREEN FOREST; SS—SAND DUNE SCRUB. (MODIFIED FROM DAVIS 1983 AND DELCOURT & DELCOURT 1993).

oaks with some open grassland areas. Bryant and Holloway (1985b) further suggested that around 1,500 years before present, the modern day oak-savannah vegetation (Post Oak Savannah) became established, reflecting "a prolonged period of drier, and perhaps warmer, climatic conditions." However, Bousman (1998) has more recently concluded that arboreal cover reached its low point in the area about 5,000 years ago and has increased since that time. Given the difficulty of determining with confidence the changes in paleoclimates, he emphasized that there probably have been "numerous shifts between forest, woodland, and open plant communities" in the area since the end of the last glaciation (approximately 18,000–15,000 years ago). The vegetation pattern present at the time of settlement, while often mistakenly viewed as static, was in a state of flux, and was thus just one point in a continuing series of changing conditions (Smeins 1984).

It is interesting to consider the effects of past glaciation on the present flora. Many otherwise difficult to explain modern plant distributions may be easily accounted for by regarding them as the result of changing climatic conditions of the past. One example is the occurrence of *Cladium mariscoides* (smooth saw-grass, Cyperaceae) disjunct to a few bog localities in East Texas and the far southeastern U.S., but otherwise known only from southeastern Canada and the northeastern U.S. as far south as South Carolina and Tennessee (Bridges & Orzell 1989a; Tucker 2002c). Another possible example is the occurrence of jack-in-the-pulpit (*Arisaema triphyllum*) in Parker County in the West Cross Timbers. This species is generally limited to mesic environments in the eastern part of the state. Nonetheless, a thriving population can be found in a mesic "rockhouse" microhabitat between sandstone rock walls in Parker County, well to the west of other known locations of this species (Diggs & O'Kennon 2003). It seems likely that this population is a relict from a previously extensive forest that was largely lost as the climate warmed and dried. Such persistence in climatically moderated "rockhouse" environments has been documented for a variety of plant species, including endemics, in the eastern U.S. (e.g., Walck et al. 1996; Farrar 1998). Other eastern species that have been found surprisingly far west in Texas include eastern hop-hornbeam (*Ostrya virginiana*) in Tarrant County and shag-bark hickory (*Carya ovata*) in Parker County, both separated by more than 120 miles (193 kilometers) from their present distributions in East Texas. Numerous other examples could be given, including many species and genera

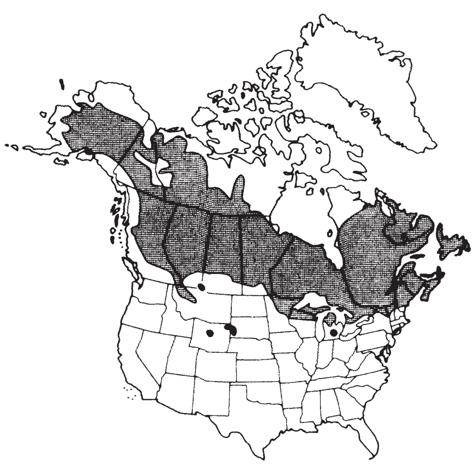


FIG. 124/ MODERN DISTRIBUTION OF *PICEA GLAUCA* (PINACEAE) (WHITE SPRUCE) (FROM TAYLOR 1993, WITH PERMISSION OF OXFORD UNIV. PRESS).

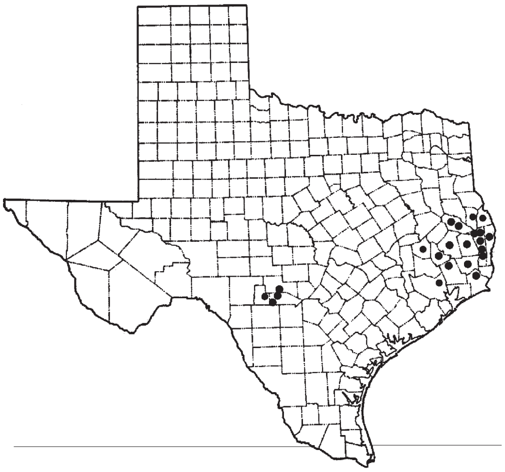


FIG. 125/ TEXAS DISTRIBUTION OF WITCH-HAZEL (*HAMAMELIS VIRGINIANA*), AN EXAMPLE OF THE NUMEROUS SPECIES THAT OCCUR IN TEXAS PRIMARILY IN EAST TEXAS, BUT WITH ISOLATED OCCURRENCES ON THE EDWARDS PLATEAU (FROM TURNER ET AL. 2003, WITH PERMISSION OF BILLIE TURNER AND THE BOTANICAL RESEARCH INSTITUTE OF TEXAS).

typical of East Texas which show up in isolated pockets on the Edwards Plateau (e.g., groundnut (*Apios americana*), cross-vine (*Bignonia capreolata*), witch-hazel (*Hamamelis virginiana*) (Fig. 125), spicebush (*Lindera benzoin*), barbed rattlesnake-root (*Prenanthes barbata*), Carolina rose (*Rosa carolina*), dwarf palmetto (*Sabal minor*), and American basswood (*Tilia americana*)). Likewise, many other typically eastern species extend west in the Red River valley (e.g., numerous species reach their western limits in Grayson County, including beaked groovebur (*Agrimonia rostellata*), black oak (*Quercus velutina*), may-apple (*Podophyllum peltatum*), and great Solomon's-seal (*Polygonatum biflorum*)). In addition, many herbaceous species common farther north and east in the U.S. occur in Texas only rarely and erratically in the Pineywoods and have extremely limited distributions. Kral (1966c) and MacRoberts and MacRoberts (1997a) discussed a number of these "northern woodland elements" south of their normal range (e.g., *Erythronium rostratum* (yellow trout-lily), *Lilium michauxii* (Carolina lily), *Sanguinaria canadensis* (bloodroot), *Silene stellata* (widow's-frill), *Trillium recurvatum* (prairie trillium), *Uvularia sessilifolia* (sessile-leaf bellwort)), and indicated that they appear to be relicts of glacial times surviving in areas with particularly favorable soil and moisture conditions (i.e., refugia). Kral (1966c) noted that he could walk for miles and then find a large colony of one of these species, apparently reproducing predominantly via vegetative means. These species may thus be "Ice Age holdovers hanging on precariously to the older geologic terraces in the coolest locations in the forest" (MacRoberts & MacRoberts 1997a). Even the presence of the drought-intolerant American beech (*Fagus grandifolia*) in East Texas is surprising, given its ecological requirements. This species reaches its southwestern limit in the U.S. in Montgomery County (not far north of Houston)—here beech appears to do best when protected from the intense Texas summer sun by a canopy of associated trees (McLeod 1975). Perhaps most surprisingly, a single plant of yellow lady's-slipper orchid (*Cypripedium parviflorum* var. *pubescens*) was found somehow surviving near Muleshoe in Bailey County in the Texas Panhandle—it was possibly a relict of a widespread northern coniferous forest that at one time extended to the south during a colder and wetter period of the Pleistocene Epoch (Liggio & Liggio 1999). All of these examples may be relicts of populations much more widespread during glacial times when the climate in Texas was quite different and conditions much more mesic (Palmer 1920; Kral 1966c; O'Kennon 1991; Delcourt & Delcourt 1993). It is not surprising that isolated populations are able to persist in small areas of special microclimate or unusual geology—in fact, such persistence would be expected. Thus, the flora of East Texas is in part a unique reflection of glacial times—when northern species like *Fagus grandifolia* (American beech) and *Carya alba* (mockernut hickory) were brought together with southern plants like *Magnolia grandiflora* (southern magnolia) and *Sabal minor* (dwarf palmetto) (Fritz 1993).

In addition to individual species, several unique habitats occur in East Texas which reflect the different climatic conditions of the past. The "Lost Pines" of Bastrop County, an area of about 181 square km (70 square miles) of pine-oak woodland isolated west of the main body of East Texas pines by approximately 162 km (100 miles) (Texas Parks and Wildlife 2002b), is probably the remnant of a more extensive Ice Age forest (Maxwell 1970).

Here, special soil (derived from the Eocene Carrizo and Reklaw geologic formations) and topographic conditions have allowed the survival of a loblolly pine-dominated community disjunct to the west from other such habitats. The Ottine Swamp at Palmetto State Park in Gonzales County is another unusual, surprisingly isolated habitat. This "boggy oasis most notable for the thick understory of dwarf palmettos" seems quite out of place in the surrounding relatively dry portion of the southern Post Oak Savannah. It occurs on a terrace in the San Marcos River valley and is fed by flooding and springs from the "Carrizo sands that are exposed at the base of the bluff that lines the river valley" (Parent 1997). The unusual physiographic situation (the confluence of the Guadalupe and San Marcos rivers—Bousman 1998), the occurrence of certain geologic strata, and the unique microhabitat created have fostered the presence of numerous disjunct species. This isolated wetland is probably the remnant of a much more extensive area of Ice Age swamp that has been able to survive to the present due to its unique hydrological circumstances. Such remnant habitats are also known from various other parts of Texas. Just one example found in the Hill Country of the Edwards Plateau just west of East Texas is the Lost Maples State Natural Area. Here in the protection of deep canyons are found a number of species unusual in the area, including *Acer grandidentatum* (plateau big-tooth maple), *Cotinus obovatus* (American smoketree), *Hamamelis virginiana* (common witch-hazel), *Philadelphus texensis* (canyon mockorange), *Platanus occidentalis* (American sycamore), and *Styrax platanifolius* (sycamore-leaf snowbell) (Parent 1997). Only because of the special microclimate provided by the canyons have such species been able to survive the drying and warming that have occurred since the end of the last Ice Age.

In summary, the influence of the eastern deciduous forest on the flora of East Texas is an extremely complex and interesting story written across tens of millions of years, with untold upheavals in geology and climate and profound evolutionary change. Yet it is a story that can be deciphered using modern concepts and techniques in geology, paleobotany, paleoclimatology, and evolutionary biology. Having an understanding of the geohistorical roots of the modern day flora makes it a profoundly more interesting and rewarding subject of study. It is hoped that this type of information will encourage preservation of at least small areas of these fascinating ecosystems. While forestry practices of the past 150 years have eliminated virtually all old growth forest in East Texas, significant second or third growth stands still survive. Unfortunately, even these are now being destroyed by economic pressures and accelerating development. It is difficult not to question such actions. Should the shortsightedness and greed of humans be allowed to destroy within a span of a few hundred years an ecosystem with geohistorical roots extending back tens of millions of years?

Influence of the North American Prairies Province on the East Texas Flora

The second major floristic component of East Texas is derived from the grasslands comprising the North American Prairies Province (Thorne 1993d). At the time of European settlement, grassland was the most extensive North American vegetation type, covering approximately 30% of today's U.S. and 21% of North America north of Mexico (Sims 1988; Barbour & Christensen 1993; Graham 1999; Sims & Risser 2000). According to Graham (1999), "When French explorers moved south from eastern Canada into the central plains, they encountered a vast expanse of grassland never before witnessed by western Europeans, and applied the closest French word for a community dominated by grasses and forbs—*prairie* (meadow)." Grassland vegetation historically covered the western portion of East Texas (Blackland Prairie), shared dominance with woody plants in the Post Oak Savannah, and occurred as isolated pockets of prairie even within the Pineywoods on areas of special soils. Allred and Mitchell (1955) viewed much of East Central Texas as prairie. In their broad classification of Texas vegetation, they considered not only the Blackland Prairie, but also the eastern Texas Post Oak belt (Post Oak Savannah) to be part of the True Prairie Association. They supported this contention by pointing out that the grasses of the True

Prairie are important components in the vegetation of the Post Oak Savannah. Barbour and Christensen (1993) included all of East Texas except the Pineywoods in their tall grass prairie vegetation type, and stated that in the southern part of the tall grass prairie—deciduous forest boundary (including Texas), the ecotone is an oak savannah 50–100 km (31–62 miles) wide. Graham (1999) also considered the savannah to be "primarily grassland—deciduous forest boundary vegetation." Since it is clearly composed of components of both prairie and deciduous forest, viewing the Post Oak Savannah as an ecotone seems the most reasonable approach. Vankat (1979) and Graham (1999) emphasized that open savannah is fire-dependent and that fire is important to the perpetuation of this type of vegetation. Graham (1999) also noted that "because fire is now controlled in many areas, woodland or forest vegetation has invaded areas once occupied by oak savanna." This is certainly true for East Texas where recent human activities, particularly the suppression of fire and the conversion to cropland, have greatly reduced the amount of grassland and open savannah present. Even where not completely destroyed, the Post Oak Savannah of East Texas is thus probably significantly different than in presettlement times, with tree densities much higher at present than previously.

Axelrod (1985) argued that North American grasslands are geologically recent, and that the rise of extensive grasslands probably dates only to the Miocene-Pliocene transition (about 7–5 mya), the driest part of the Tertiary. Fossil evidence shows that the Great Plains were largely forested from the Middle Miocene into the Early Pliocene. As the climate dried toward the end of the Miocene, forests gradually became more restricted (e.g., confined to mesic areas such as moister valleys and stream bottoms), grasslands were able to spread rapidly, and there was an "explosive evolution of grasses and forbs" (Axelrod 1985). Fossil floras from the Great Plains area dated between about 18 to 4 million year ago indicate that prairie grasses and herbs became more abundant, widespread, and diverse throughout the period (Graham 1999). The increasing number of grazing animals seen in the fossil record also reflects the shift toward increasing aridity and drought in the region (Axelrod 1985). At least part of the climatic drying of the continental interior resulted from the continued rise of the Rocky Mountains. "The upper flow of the atmosphere was blocked…, preventing tropical moisture from the Pacific Ocean…from reaching midcontinent.…" (Van Devender 2002). The midcontinent region was thus in the "rain shadow" of the Rockies and the climatic conditions were created which resulted in the development of grasslands.

Fossil evidence also suggests that subsequently, during the Pleistocene Epoch beginning 1.8 million years ago, there was great fluctuation in grassland versus forest vegetation. These changes were associated with glacial cycles (Delcourt & Delcourt 1993). According to Axelrod (1985), during the Pleistocene, "the treeless plains were reduced in area as forests and woodlands spread under moister climates." Warmer, drier interglacial periods promoted the spread of grasslands, while moister, cooler glacial periods favored forest or woodland. During full-glacial times, boreal forest (e.g., spruce) dominated much of the Great Plains (e.g., spruce forest in Kansas—Graham 1999), with mixed conifer-northern hardwoods to the south and deciduous forest to the south of these (Delcourt & Delcourt 1993). Extensive areas of grassland probably did not exist during full-glacial conditions (Wright 1981). During interglacial periods, deciduous forest (oak-hickory), savannah, and grassland expanded as the climate warmed and dried. As late as from 15,000 to 12,000 years ago, areas now covered with grassland vegetation (e.g., parts of the Texas panhandle) supported forest or woodland (Delcourt & Delcourt 1993), with drier areas of the region having oak savannah and grassland (Hall & Valastro 1995). Central Iowa went from fir-spruce forest at 14,500 years ago to a vegetation dominated by deciduous trees at 8,300 years, to a succession of oak-grassland and then grass around 3,000 years ago. (Axelrod 1985).

It is thus now clear that at the end of the last glaciation (approximately 18,000–15,000 years ago), with increasing temperatures and aridity, there was a profound shift in vegetation across much of North America. Grasslands were favored by these changes, due to a combination of interacting factors. In the words of Axelrod (1985), "The rise of the [modern] grassland biome was thus due to occasional periods of increased aridity that restricted forests and woodlands and favored grasses and forbs; to increasing drought…which created a flammable source (dry grass); to natural and man-made fires on the relatively flat plains over which fire could spread uninterruptedly; to fire that destroyed relict trees and groves on the flat grasslands, restricting them to rocky ridges removed from fire; and probably also to large browsing mammals (many now extinct) that may have destroyed scattered trees and shrubs…." According to Axelrod (1985), the widespread central North American grasslands present at the time of European settlement thus probably date to post-glacial times only 12,000 to 10,000 years ago. Prior to that time, grasslands probably predominantly formed small- to moderately-sized patches in semi-open forests and woodlands—"there is no definitive evidence that continuous grassland covered tens of thousands of square kilometers until well into Holocene time, after extensive areas of open grassy woodlands and forests had been removed by repeated burning…." (Axelrod 1985). He supported his view of the grassland as a young biome with the following evidence: 1) there are few endemic taxa, with most of the grassland species being present in adjacent forests and woodlands; 2) populations of trees widely scattered over the grassland region are readily interpreted as relicts of a once more widely distributed forest; and 3) fossil evidence of forests in the recent past occurs over much of the present grasslands. According to Axelrod (1985),

> That grasslands spread following the last glacial is apparent from data provided by bogs at Boriack, Gause and Soefje, central Texas (Bryant, 1977). During late glacial time, central Texas was covered with an open deciduous forest with some conifers and an understory of mixed grasses and shrubs. With retreating glaciers, warmer and/or drier climates developed over central Texas. Forests were restricted, leaving parkland vegetation dominated by grasses, shrubs, and herbs, but including trees in protected sites. During post-glacial time, many mesic trees disappeared from the pollen record. It was the continual increase in non-arboreal taxa, and especially grasses, throughout post-glacial time that led to the establishment of the present post oak-grassland vegetation of central Texas (Bryant, 1977).

Axelrod (1985) also stressed that almost all modern grasslands, when protected from fire, will support forests and woodland. This is certainly true for almost all grasslands in East Texas (e.g., Blackland Prairie remnants are easily invaded by native cedar elms, eastern red cedar, etc.), and the invasion of other Texas grasslands by various junipers, mesquite, etc. is all too well known. Since European settlement, trees and shrubs have spread into many grasslands throughout central and western North America. Fire suppression, overgrazing (which removes fuel for fires and exposes open ground, allowing establishment of woody plants), and other changes have resulted in the conversion of prairie to savannah, woodland, and forest (Axelrod 1985). It has long been suggested (e.g., Gleason 1913) that "prairie fires have been the deciding factor in determining the distribution of forests in the Middle West" (Axelrod 1985). A very important conclusion can be drawn—it is clearly not simply climate (e.g., an amount of rainfall insufficient to support trees) that explains the distribution of modern grasslands. Rather, Axelrod (1985) argued that climate is "a determinant in the spread and dominance of grasslands in plains regions with a dry season," primarily due to the ability of dry grass to serve as a fuel for fires (and thus destroy woody vegetation). He concluded that in combination with climate, it was fire, whether caused by lightning or by Native Americans, that may have been critical in establishing and maintaining the large expanses of grassland that were present at the time of European settlement. Grasses, which have their growing point at or near the soil surface and thus protected from most fires, are at a great advantage compared to shrubs or small trees. Another advantage for grasses in the face of frequent fire is that, "whereas perennial grasses produce abundant seeds in one or two years following germination, woody plants take several years to produce seeds" (Axelrod 1985). Grasslands are thus favored by fire, while forests and woodlands are promoted by a decrease in fire frequency. Thorne (1993d) also considered the grasslands of the Prairies Province to be "… mostly recent and adventive. …"

If the prairies are of recent origin, their lack of endemics makes sense—the plants of the Prairies Province have their origins in adjacent areas. Short grass and mixed prairie taxa have affinities with the vegetation to the southwest, while "the more mesic eastern tall-grass prairie includes eastern and southeastern forest-border species from those regions of higher rainfall" (Axelrod 1985). In summary, as Axelrod (1985) suggested, there seems to be good evidence that North American grasslands are geologically recent, and that they were established and are maintained in large part, not by lack of moisture, but rather by fires—including those of human origin.

A substantial proportion of the total East Texas flora is composed of grassland species. Thus, even though the grasslands are geologically recent, the presence of 410 grass species (296 native) in East Texas (roughly 12% of total species) is a good indication of the importance of the influence of the North American Prairies Province on the modern East Texas flora. Likewise, this importance, even in the most forested region of the state, is indicated by the fact that the combined area of prairie and savannah (Blackland Prairie and Post Oak Savannah) makes up approximately 61% of the total area of East Texas as defined here.

Influence of the North American Sonoran Province on the East Texas Flora

A third, albeit less important, component of the East Texas flora is derived from the Sonoran Province to the southwest (southwestern United States and northwestern Mexico, including the Mojave, Sonoran, and Chihuahuan deserts). According to Thorne (1993d), the Sonoran Province is part of the broader Madrean Region, which has an exceedingly diverse and distinctive flora that is mostly locally derived and very rich in endemics. Takhtajan (1986) indicated that probably more than one-half of all the Madrean species are endemic. Thorne (1993d) further indicated that the xerophytic flora of the Sonoran Province is subtropical and largely Madro-Tertiary in origin. He noted that the plants of the Sonoran Province "… seem to have originated as the arid areas of North America expanded through the Tertiary—for the past 65 million years, and especially in the last 15 million years." Families in the East Texas flora that Thorne (1993d) emphasized as examples of this diversification include Agavaceae, Cactaceae, Menispermaceae, Nyctaginaceae, Passifloraceae, Rafflesiaceae, and Sapotaceae. While some desert species are quite old, this emphasis on the last 15 million years seems to support the prevailing opinion that the modern North American deserts and their floras are relatively young geologically (Axelrod 1950, 1979; Barbour & Christensen 1993).

One part of the Sonoran Province (the Tamaulipan Subprovince) occupies about 8 million hectares (20 million acres) in south Texas, where it is usually referred to as the South Texas Plains or Rio Grande Plains (Correll & Johnston 1970; Thorne 1993d). Because of its proximity, a number of species of Sonoran origin have moved into East Texas—possibly in response to past periods of increased aridity. In East Texas, some Sonoran elements, including species of *Aloysia* (Verbenaceae), *Condalia* (Rhamnaceae), *Garrya* (Garryaceae), and *Nolina* (Agavaceae), are found mostly in the drier southern and southwestern parts of the region. Others, such as species of *Acacia* (Fabaceae), *Opuntia* (Cactaceae), and *Yucca* (Agavaceae), occur more broadly—even in the Big Thicket, the wettest part of East Texas. Cylindropuntias (members of the genus *Opuntia* with ± cylindrical stems, Cactaceae) and *Yucca* species, for example, are the most common tall plants in some parts of the Sonoran Province (Thorne 1993d), and a connection is seen to East Texas which has one species of cylindropuntia (*Opuntia leptocaulis*, desert christmas cactus) and nine native species of *Yucca*, four of which are endemic to Texas. It is quite striking to be in the Big Thicket in deep East Texas on a dry sandy ridge (but only a stone's throw from beech-magnolia forests and bogs) and see large populations of yuccas, prickly-pear cacti, and bull-nettle (*Cnidoscolus*—Euphorbiaceae).

While the influences of the eastern deciduous forests, the prairies, and the Sonoran Province, as discussed above, explain the origin of much of the East Texas flora, Thorne (1993d) noted that there are other minor components of the North American flora which have very different origins. East Texas genera such as *Prosopis* (Fabaceae) and *Nicotiana* (Solanaceae) seem to have strong links with South America, while *Thamnosma* (Rutaceae) is related to African taxa. Such relationships are beyond the scope of this discussion.

The Influence of Endemics on the East Texas Flora

East Texas has a total of 163 species endemic to Texas, of which 26 are limited to East Texas itself, i.e., their natural occurrence is restricted to that area (Carr 2002b, 2002c; see Appendix 11). Some of these endemics are extremely local in occurrence (e.g., *Gaillardia aestivalis* var. *winkleri*, Winkler's gaillardia, limited to the Village Creek watershed in Hardin County), and others display no obvious similar distribution. However, a number do fall into clearly defined patterns. Several categories that warrant special discussion are West Gulf Coastal Plain endemics and Edwards Plateau endemics.

WEST GULF COASTAL PLAIN ENDEMICS—The West Gulf Coastal Plain (Fig. 126) is part of the Atlantic and Gulf Coastal Plain Floristic Province (Fig. 127), which in North America is second only to California in the number of endemics—27% of its native species are endemic or near endemic (= species at least 90% centered on an area) (Takhtajan 1986; Sorrie & Weakley 2001; MacRoberts et al. 2002c). Hundreds of East Texas plants are endemic to the Atlantic and Gulf Coastal Plain Floristic Province, and this connection clearly links East Texas with

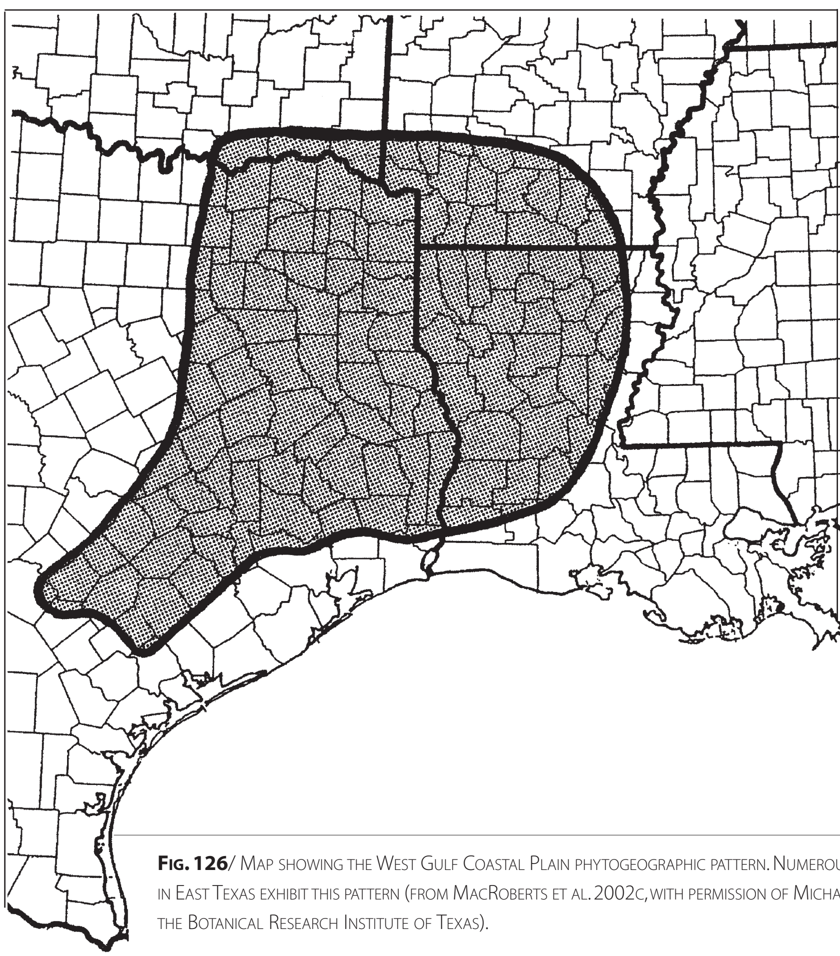


FIG. 126/ MAP SHOWING THE WEST GULF COASTAL PLAIN PHYTOGEOGRAPHIC PATTERN. NUMEROUS PLANTS OCCURRING IN EAST TEXAS EXHIBIT THIS PATTERN (FROM MACROBERTS ET AL. 2002C, WITH PERMISSION OF MICHAEL MACROBERTS AND THE BOTANICAL RESEARCH INSTITUTE OF TEXAS).

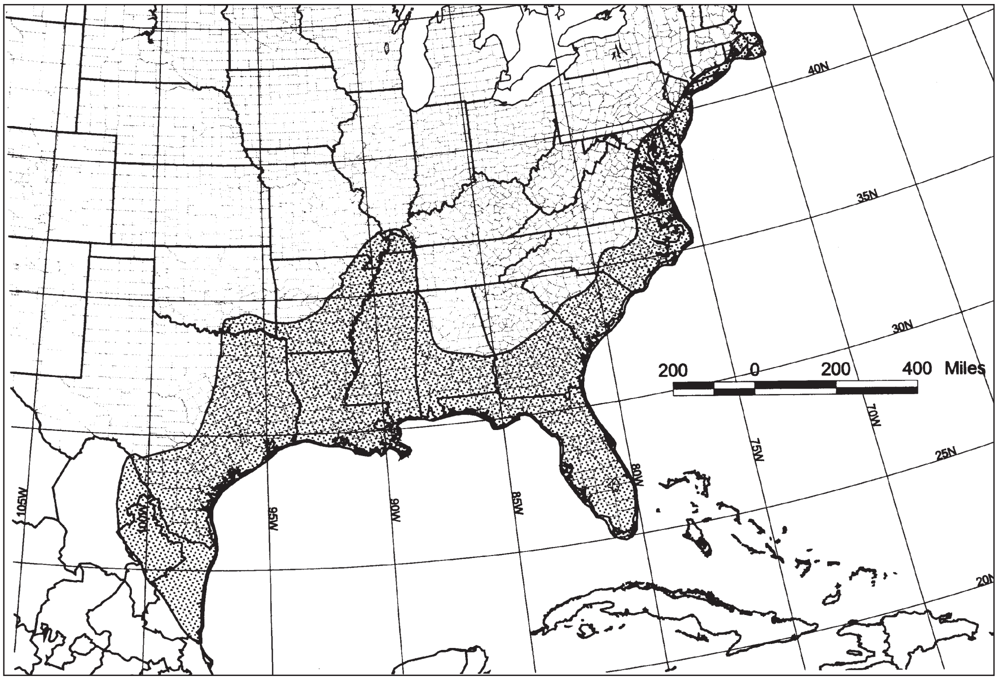


FIG. 127/ MAP SHOWING THE ATLANTIC AND GULF COASTAL PLAINS OF NORTH AMERICA. ALL OF EAST TEXAS LIES WITHIN THE GULF COASTAL PLAIN (FROM SORRIE & WEAKLEY 2001, WITH PERMISSION OF THE SOUTHERN APPALACHIAN BOTANICAL SOCIETY).

the rest of the southeastern U.S. Examples of East Texas genera endemic to this floristic province include *Brunnichia* (Polygonaceae), *Cynosciadium* (Apiaceae), *Leitneria* (Leitneriaceae), and *Planera* (Ulmaceae) (Sorrie & Weakley 2001). One of the most common distribution patterns in the Atlantic and Gulf Coastal Plain Floristic Province is that of limitation to the range of *Pinus palustris*, the longleaf pine (Fig. 128) (Walker 1993; Sorrie & Weakley 2001). Examples of the numerous East Texas species which display this pattern include *Aletris aurea* (yellow star-grass), *Anthenantia rufa* (purple silkyscale), *Bartonia verna* (white screwstem), *Leucothoe axillaris* (coastal dog-hobble), *Magnolia grandiflora* (southern magnolia), *Rhexia alifanus* (savannah meadow-beauty), *Rhynchospora latifolia* (giant white-top), *Sabatia gentianoide*s (pinewoods rose-gentian), *Stylisma aquatica* (water dawnflower), and *Stylodon carneus* (Carolina false vervain) (Sorrie & Weakley 2001).

However, while the importance of the Atlantic and Gulf Coastal Plain Floristic Province has long been recognized, the West Gulf Coastal Plain as a specific regional center of endemism has until recently "received almost no attention in the published literature" (MacRoberts et al. 2002c; e.g., Estill & Cruzan 2001; Sorrie & Weakley 2001). The West Gulf Coastal Plain (Fig. 126) includes all of East Texas, much of northern Louisiana, and small portions of southern Arkansas and southeastern Oklahoma (Sorrie & Weakley 2001; MacRoberts et al. 2002c). Bridges and Orzell (1989b) discussed endemism in the area, and MacRoberts et al. (2002c) found 96 taxa endemic or near endemic to the region, a number of which are restricted to the East Texas portion, including *Bartonia texana* (Gentianaceae), *Gaillardia aestivalis* var. *winkleri* (Asteraceae), and the newly described *Yucca cernua* (Agavaceae) (Keith 2003).

Of the 96 taxa, 51 (53%) are endemic to areas of xeric sandylands (also referred to as Dry Uplands on Deep Coarse Sands—page 92). Most other taxa can be linked to various community types—the next two most numerous being barrens/glades/Weches (see page 56), with 9% of the total, and bogs and wet pine savannahs, also with 9%. Further, of the three genera endemic to the West Gulf Coastal Plain (*Maclura* (Moraceae), *Brazoria*, and

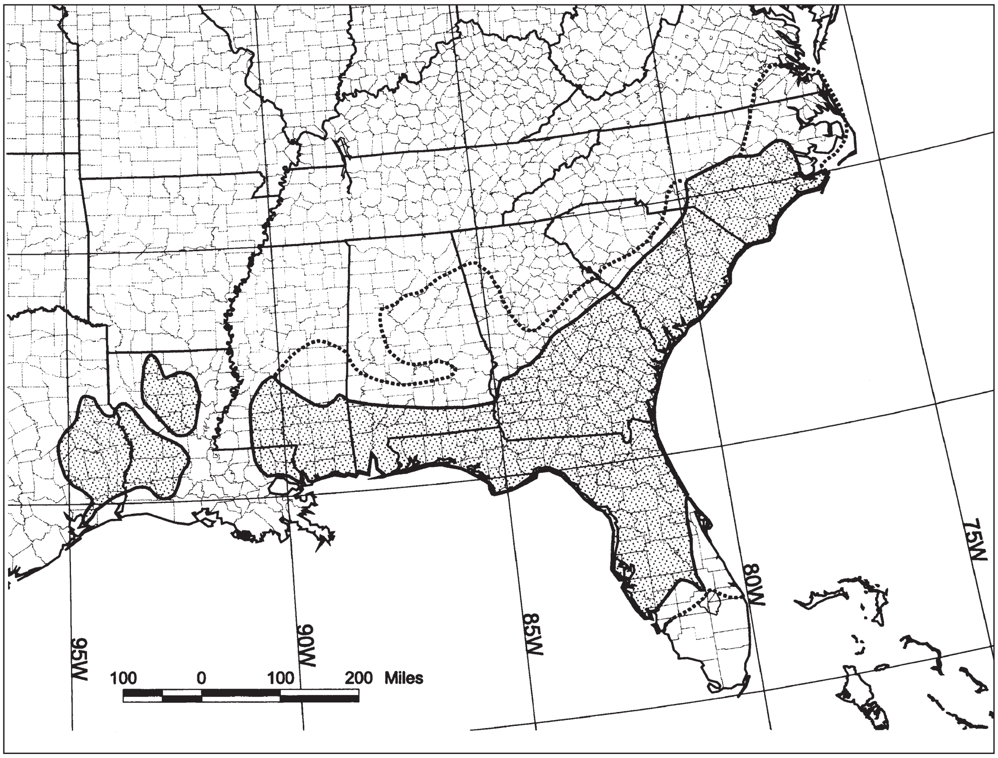


Fig. 128/ Map showing a major phytogeographic pattern of the Gulf Coastal Plain—the "Longleaf Pine" pattern. Stippled area is the core region for *Pinus palustris* (longleaf pine); dotted line encloses the area of discontinuous or disjunct occurrences of longleaf pine. Numerous plants occurring in East Texas exhibit this pattern (from Sorrie & Weakley 2001, with permission of the Southern Appalachian Botanical Society).

Rhododon), two (*Brazoria* and *Rhododon*—both in the Lamiaceae) are associated with xeric sandylands (Turner 1995, 1996; MacRoberts et al. 2002c). MacRoberts et al. (2002c) define xeric sandylands as "open to sparsely wooded areas that typically occur on terraces or ridges composed of deep sand, generally of marine Tertiary origin." This habitat occurs widely in the West Gulf Coastal Plain on a variety of sandy strata (MacRoberts et al. 2002c). The deep, coarse, sandy soils are extremely well-drained and become droughty even during brief periods without rain—hence, they are prone "to frequent water deficits and nutrient limitations" and "undoubtedly have always dramatically affected vegetation structure and composition" (MacRoberts et al. 2002c). MacRoberts et al. (2002c) suggested that in this center of endemism, xeric habitats have been available since at least the end of the last glaciation and possibly before—thus there has been sufficient time for the evolution of species or other taxa adapted to the special conditions present. Some abundant East Texas plants (e.g., *Yucca louisianensis*, Louisiana yucca) fit this xeric sandylands pattern, as well as a number of Texas endemics.

One special component of the arid sandylands are the Carrizo Sands (McBryde 1933), and Carrizo Sands endemics are a special (and numerically important) case of West Gulf Coastal Plain endemism. Species confined (or nearly so) to the Carrizo Formation, which lies wholly within Texas (Fig. 129), include *Abronia macrocarpa* (large-fruit sand-verbena), *Brazoria pulcherrima* (rattlesnake-flower), *Chaetopappa imberbis* (mostly; awnless least-daisy), *Coreopsis nuecensis* (mostly; crown tickseed), *Crataegus nananixonii* (Nixon's hawthorn), *Hymenopappus carrizoanus* (Carrizo sands woollywhite), *Monarda viridissima* (green beebalm), *Palafoxia hookeriana* var. *minor* (sand palafox), *Paronychia setacea* (bristle nailwort), *Polygonella parksii* (Parks' jointweed), *Rhododon ciliatus* (Texas sand-mint), and

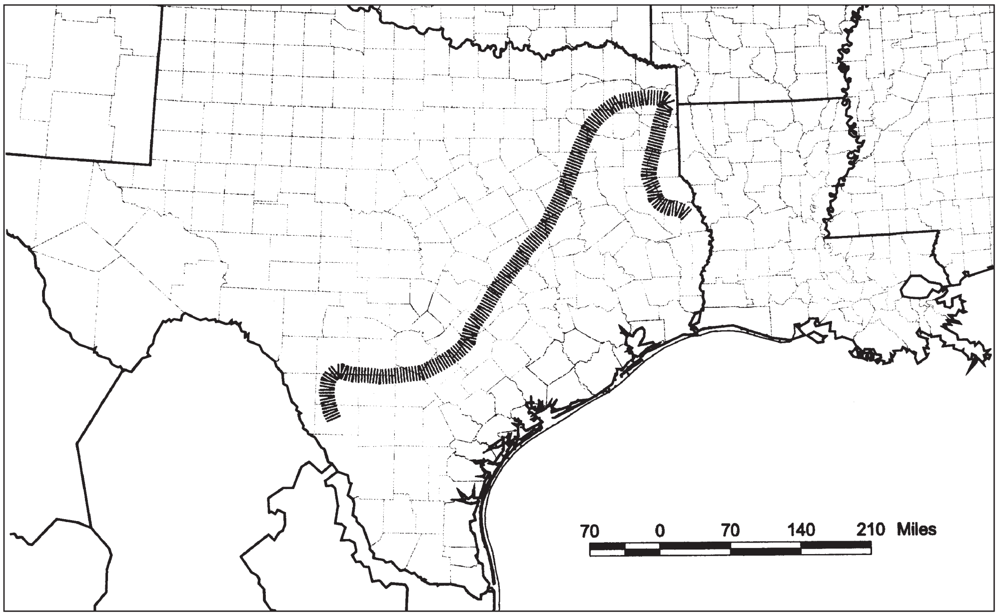


FIG. 129/ MAP SHOWING SURFACE EXTENT OF THE CARRIZO SANDS. ONLY 19 KM (12 MILES) WIDE, THE CARRIZO FORMATION TRENDS SOUTHWEST TO NORTHEAST FOR 720 KM (450 MILES) (FROM SORRIE & WEAKLEY 2001, WITH PERMISSION OF THE SOUTHERN APPALACHIAN BOTANICAL SOCIETY).

Thelesperma flavodiscum (East Texas greenthread) (Sorrie & Weakley 2001).

A different pattern of West Gulf Coastal Plain endemism (and one with fewer examples) is shown by those species that occur only on the Weches Formation (thin rocky soils with high pH and glauconite). Two such East Texas endemics are Texas golden glade cress (*Leavenworthia aurea* var. *texana*) (Mahler 1987; Poole et al. 2002) and the federally endangered white bladderpod (*Lesquerella pallida*) (George & Nixon 1990).

EDWARDS PLATEAU ENDEMICS—Many endemics that were once thought to be restricted to the Edwards Plateau are now known to reach the westernmost edge of East Texas. Additionally, many of the Edwards Plateau endemics also occur in the Lampasas Cut Plain in the southern part of the Cross Timbers and Prairies vegetational area (Amos & Gehlbach 1988; Diggs et al. 1999). The explanation for the endemism seen in the Edwards Plateau and adjacent areas, while not completely clear, may be the result of the climatic history of the last 1.8 million years. During the Quaternary Period (beginning about 1.8 mya), there were significant climatic variability and at least 20 glacial-interglacial cycles. Widespread changes in vegetation were associated with these climatic fluctuations (Delcourt & Delcourt 1993). For example, during the last full-glacial interval (100,000 until approximately 18,000–15,000 years ago), there was a cool, moist "pluvial" climate across the unglaciated parts of southwestern North America (Delcourt & Delcourt 1993) with forest species presumably expanding their ranges. Bryant's data (1977) indicated an open deciduous forest in central Texas during the last full-glacial interval. The climate moderated from 15,000–10,000 years ago, with interglacial conditions (i.e., warmer and drier) for the last 10,000 years (Delcourt & Delcourt 1993), (e.g., *Nolina lindheimeriana* (devil's-shoestring), *Tinantia anomala* (false dayflower, *Tradescantia edwardsiana* (plateau spidewort), and *Yucca rupicola* (twist-leaf yucca)). The Edwards Plateau endemics are typically found in moist areas such as canyons along wooded streams and have presumably survived in the favorable microclimate pockets as the overall climate of the area has warmed and/or dried. Many of these species have affinities with eastern taxa and may be relicts of a more widespread flora that became restricted as the result of climatic or geologic changes (Palmer 1920; Amos & Gehlbach 1988).

The Influence of Introduced Species on the East Texas Flora

DEFINING INTRODUCED SPECIES

Introduced species, defined here as those *non-natives introduced from outside the U.S.*, comprise the last major component of the flora. These nonindigenous taxa are also variously referred to as alien, exotic, foreign, or naturalized species. For the purposes of this book, a naturalized species is simply *a non-native that is reproducing in the area without human assistance*. Nesom's (2000) more detailed definition of naturalized plants is as follows: "Plants of non-native species accidentally or deliberately introduced into the flora, now reproducing and maintaining viable populations from year to year (more than just one or a few seasons), and dispersing without deliberate human assistance beyond the population or populations of original establishment." Of the 3,402 total species known for East Texas, 619 species, or 18% of East Texas' flora, have been introduced since the time of Columbus and have become naturalized. The species count and percentage would be slightly higher if species that have entered Texas from elsewhere in the United States were included.

These introduced species are also sometimes called "weeds," but that word can have different meanings (Baker 1974; Randall 1997). From the sociological or human perception standpoint, a weed is a plant growing where it is not wanted, a "plant-out-of-place" (Stuckey & Barkley 1993); if defined in this way, introduced species are indeed often weeds. From an agricultural perspective, weeds are plants that reduce agricultural yields—again many introduced species do so (Holm et al. 1977). Biologically, weeds (sometimes termed colonizing plants or colonizers) are species that "have the genetic endowment to inhabit and thrive in places of continual disturbance, most especially in areas that are repeatedly affected by the activities of humankind" (Stuckey & Barkley 1993). They are "species whose ecological style is to keep moving to fresh territory, species whose population in one small place is not permanent" (Williamson 1996). Again, many introduced plants fall within this definition of weedy species (as would successional native species). However, it should be noted that the above sociological, agricultural, and biological definitions of weeds overlap with, but are not synonymous with, the concept of introduced species.

DETRIMENTAL IMPACTS OF INVASIVE INTRODUCED SPECIES

Introduced species include some of our most beautiful ornamentals (e.g., *Iris*, *Narcissus*, *Rhododendron*, *Rosa*, *Tulipa*, and *Wisteria* species), provide many of our most important crops (e.g., *Glycine*-soybean, *Triticum*-wheat, *Zea*-corn), and are among the most widely used landscape plants in East Texas today. On the other hand, some are also extremely aggressive organisms capable of invading native habitats and in the process having a negative impact on native species. An invasive species is sometimes defined as "one that becomes so well adapted to its new environment that it interferes with native species" (Tellman 2002b). More specifically, invasive species can be defined as those that are 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Invasivespecies.gov 2004). Indeed, Wilson (1992) lists non-native (alien) species as one of the four "mindless horsemen of the environmental apocalypse" contributing to the worldwide extinction crisis (along with habitat destruction, overexploitation, and diseases carried by non-natives).

While the negative impact of invasives has long been recognized (e.g., Elton 1958), attention to the problem has recently become much more widespread, with a significant number of articles and books examining the issue being published within the past few years (e.g., Luken & Thieret 1993; Cronk & Fuller 1995; Bryson 1996; Westbrooks & Eplee 1996; Williamson 1996; Luken & Thieret 1997; Cox 1999; Galatowitsch et al. 1999; Lonsdale 1999; Parker et al. 1999; Callaway & Aschehoug 2000; Davis & Thompson 2000; Pimentel et al. 2000; Van Driesche & Van Driesche 2000; Lambrinos 2001; Mack & Lonsdale 2001;

Reichard & White 2001; Rossman 2001; Sakai et al. 2001; Todd 2001; Baskin 2002; Lambrinos 2002; Low 2002; Matlack 2002; Pimentel 2002a; Tellman 2002a; Daehler 2003; de Poorter et al. 2003; Simberloff 2004). Luken and Thieret (1997) examined the assessment and management of plant invasions and gave a selected list of species interfering with resource management goals in North America. Particularly problematic for native plants are those nonindigenous species that aggressively invade native ecosystems, reproduce extensively, and occupy the habitat of indigenous species. In some cases, invasive species can come to dominate communities and occur in near monocultures, completely changing the species composition, structure, and aspect of an ecosystem. Native species are thus excluded by the dense concentrations of the invader, a phenomenon sometimes referred to as swamping (Williamson 1996). Invasive species can also cause other, less obvious problems, including reducing the supply of water in streams, lowering of water tables, serving as vectors for diseases, altering native plant regeneration patterns, modifying the cycling of nutrients or other materials (e.g., nitrogen or salt), releasing toxins that prevent other plants from growing (allelopathy), or changing the fire ecology of an area. A specific example is buffel grass (*Pennisetum ciliare*), which was intentionally introduced from Africa and India in the 1940s by the Soil Conservation Service (SCS) as a forage species and for erosion control; it was formally released from a SCS nursery in San Antonio in 1946 (Tellman 1997; Búrquez-Montijo et al. 2002). This species invades desert grasslands and shrublands and can dramatically change the fire ecology of an area—the “great quantities of tinder-dry biomass” (Enyedy 2002) produced by huge numbers of buffel grass plants contribute to devastating fires that threaten the whole ecosystem in areas of the Sonoran Desert in Arizona and Mexico (Tellman 1997; Búrquez-Montijo et al. 2002; Enyedy 2002). In some places, cacti and other native plants have been almost eliminated (Tellman 1997).

Globally and nationally, the detrimental effects of alien plant and animal species (e.g., competition, predation, herbivory, parasitism, disease, etc.), though sometimes underestimated, are now collectively considered as the second most important threat (following only habitat alteration) affecting imperiled species (Wilson 1992; Simberloff 2000a; Wilcove et al. 2000; Pimentel 2002b). On the local scale in East Texas, after habitat alteration, invasion by exotics also appears to be the most serious threat facing native plants. Further, it is a potentially long-lasting—and in many cases uncontrollable—hazard to natural ecosystems (Coblentz 1990). As pointed out by Cronk and Fuller (1995), invasive exotics are a “lasting threat because when exploitation or pollution stops, ecosystems often begin to recover. However, when the introduction of alien organisms stops the existing aliens do not disappear; in contrast they sometimes continue to spread and consolidate, and so may be called a more pervasive threat.” In fact, some authorities (e.g., Vitousek et al. 1996) consider biological invasions to have become so widespread as to constitute “a significant component of global environmental change.” They further note that humans are “redistributing the species on the earth at a pace that challenges ecosystems, threatens human health and strains economies.” The latter point is important since it is now obvious that the effects of invasive plants are not limited to their impact on native plants. They are capable of becoming serious agricultural pests (thus causing huge economic losses), damaging aquatic ecosystems (and preventing boating, fishing, recreation, etc.), and affecting human health (e.g., allergies).

The economic cost of exotic species (including animals and fungi) is high, with national cost estimates ranging to billions of dollars per year (Pimentel et al. 2000; Sakai et al. 2001). In fact, several recent estimates of damages resulting from this problem in the U.S. range from over $120 billion dollars annually (Simberloff 2000a) to $137 billion annually (Pimentel et al. 2000, 2002). Together, the damages and costs of controlling invasive plants alone are estimated at $34 billion (Pimentel 2002b). In U.S. agriculture, “weeds [the majority introduced] cause an overall reduction of 12% in crop yields” (Pimentel et al. 2002). As a result, a number of control efforts are being undertaken at the federal as well as state levels (Floyd 2002). According to Sakai et al. (2001), “In response to this problem, Executive Order #13112 of

February 1999 directed several federal agencies 'to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause'; (Fed. Regist. 64(25):6183–86)." Thus, the National Invasive Species Council, an inter-departmental council that coordinates effective federal governmental activities regarding invasive species, was formed (Invasivespecies.gov 2004). Unfortunately, more nonindigenous species are being introduced each year, and the problem of invasives is "clearly worsening" (Wilcove et al. 2000). Despite the seriousness of the problem, Texas was until recently one of only 16 states without a noxious plant program (USDA Natural Resources Conservation Service 2002). This lack of an official policy has hindered effective control efforts. In 2003, a state bill authorizing the publication of a list of noxious plants was passed (Hibbs 2003; Texas Parks & Wildlife 2003) and that list is now available on-line (Texas Administrative Code 2005). However, Texas still has no single authority in charge of addressing invasive species issues and detailed policies for effective and coordinated control efforts are still lacking. Fortunately, attention is now focused on the problem and a major collaborative conference addressing the issue, the statewide Texas Invasive Plant Conference (The Pulling Together Initiative), is scheduled for November 2005 (TexasInvasives.org 2005).

While usually not discussed in detail, the interaction of invasions with various aspects of human-caused global environmental change (e.g., climate change, modified nutrient cycles including carbon and nitrogen, changes in fire regimes, and land use changes) deserves significant attention (Mooney & Hobbs 2000; Simberloff 2004). Without some of these changes, many invasions would simply not be able to occur.

Invasive exotics are an example of the phenomenon of ecological release—an introduced species is released from the ecological constraints of its native area (e.g., diseases, parasites, pests, predators, nutrient deficiencies, competition, etc.) and is consequently able to undergo explosive population growth in its new home. Elton (1958), one of the founders of the field of invasion ecology, used the term "ecological explosion" for this phenomenon, because the invasions display a "bursting out from control of forces that were previously held in restraint by other forces." Unfortunately, ecological release is well known in East Texas. For example, *Pueraria montana* var. *lobata*, kudzu, an aggressive vine which can completely cover native forests, is already well-established in a number of East Texas counties (e.g., Colorado, Grayson, and Lamar). This species, which has taken over more than 7 million acres of land in the southern U.S. (Lembke 2001), is one of the most notorious examples of an invasive exotic plant. *Festuca arundinacea*, tall fescue, is capable of invading intact native tall grass prairies and is considered by some (e.g., Fred Smeins, pers. comm.) to be the most serious invasive threat to tall grass Blackland Prairie remnants such as the Nature Conservancy's Clymer Meadow in Hunt County. The eastern Asian *Sapium sebiferum*, usually known as Chinese tallow tree or as popcorn tree, has been widely used in landscaping in East Texas, in part because of its brilliant fall color. However, this species is now widely recognized as one of the most serious invasive exotics in East Texas and in the adjacent Gulf Prairies and Marshes (e.g., Barrilleaux & Grace 2000; Keay et al. 2000; Loos 2002). It is particularly problematic in invading and destroying native Coastal Prairie habitats and is showing a rapid increase in sapling populations in some floodplain forests of the Big Thicket National Preserve (Harcombe et al. 1998; Keay et al. 2000). There are numerous other examples in East Texas of ecological release. Some of the most serious or potentially serious include *Bothriochloa ischaemum* var. *songarica* (King Ranch bluestem), *Cuscuta japonica* (Japanese dodder), *Hydrilla verticillata* (hydrilla), *Imperata cylindrica* (cogon grass), *Lespedeza cuneata* (sericea lespedeza or Chinese bush-clover), *Ligustrum sinense* (Chinese privet), *Lonicera japonica* (Japanese honeysuckle), *Orobanche ramosa* (branched broom-rape), *Salvinia molesta* (giant salvinia), *Solanum viarum* (tropical soda-apple) and *Sorghum halapense* (Johnson grass).

It should be pointed out that while this discussion focuses on plants, there are numerous problematic invasive animals, fungi, microorganisms, and viruses that have tremendous negative impacts in the U.S. (e.g., European zebra mussels, fire ants, Africanized (killer) bees, gypsy moths, chestnut blight, Dutch elm disease, West Nile virus). Unfortunately, a number of these are currently affecting East Texas. Of particular importance for many plant communities is the direct negative impact caused by feral hogs (*Sus scrofa*). This species causes various types of damage ranging from exposing soil to erosion to general destruction of vegetation, hindering longleaf pine restoration efforts (by uprooting plants while searching for longleaf seedlings), disturbing habitats in and around small streams where they wallow, changing successional patterns, affecting water infiltration rates (Synatzske 1997; Halstead 2002), and damaging populations of herbaceous species with underground storage structures.

CHARACTERISTICS OF INVASIVE EXOTICS

Most introduced plants do not become problematic invaders because they face a variety of environmental hazards in their new surroundings, and most are unable to persist and naturalize (Williamson 1996; Williamson & Fitter 1996; Mack & Erneberg 2002). Of the more than 30,000 introduced plant taxa commercially available in the U.S. today, it is estimated that fewer than 3,000 (10%) have become naturalized (Mack & Erneberg 2002), and even fewer have become problematic invaders. Whether or not a particular species becomes invasive depends upon complex interactions between several factors: 1) the characteristics of the invading species (i.e., invasion potential—including competitive ability, reproductive rate, persistence of seeds, disease and herbivore resistance, climatic compatibility, ecological distinctiveness, genetic variability, etc.); 2) propagule pressure (how many seeds or other propagules are introduced); and 3) the properties of the ecosystem that is being invaded (e.g., level of disturbance, resistance to invasion, vacancy of niches, etc.) (Williamson 1996; Lonsdale 1999; Lambrinos 2002). One of the most important ecosystem factors is disturbance—disturbance reduces the ability of native species to compete with potential invaders (Lonsdale 1999). Unfortunately, most habitats worldwide—and virtually all in East Texas—are now disturbed.

Because so many interacting factors are involved, it is very difficult to predict with certainty whether a species will become invasive or not. This low level of predictability has long been noted (e.g., Elton 1958) and is a serious problem. The literature of invasion ecology is full of examples of presumed-harmless species intentionally introduced for specific purposes (e.g., erosion prevention, forage, biological control) but which become horrible pests as the result of unanticipated consequences. Some species, because of frost sensitivity, sterility, or similar known limiting factors, can be assumed to be relatively safe. Others (e.g., species known to be problematic in other parts of the world) may have a much greater probability of becoming invasive. However, for many species, the invasion potential is uncertain. Thus, individuals intentionally introducing plants (i.e., those in the horticultural trade) should take precautions and be alert for evidence of high invasion potential. A useful, albeit rough, rule of thumb regarding the frequency of invasion has been called the "tens rule" (e.g., Williamson 1996). By this it is meant that roughly 10% of plant species imported become feral (found in the wild), 10% of these become established (naturalized, with self-sustaining populations), and 10% of these become pests (invasive). Given the many thousands of species that have been introduced into the U.S., it is fortunate that the percentage is not higher.

One curious aspect of invasive species is that there often appears to be a time lag between their actual introduction and their widespread impact (J. Taylor, pers. comm.; Simberloff 2000a, 2004). Sometimes a species is seen only rarely and appears innocuous for a significant period of time, after which its spread appears rapid—the invader seems to undergo a population explosion. These species are sometimes referred to as "sleepers" (Simberloff 2004). The cause of this phenomenon is not clear, but possibilities include adaptation to the local environment or quirks of dispersal (e.g., getting into roadside environments where highway mowing equipment can result in extremely rapid and widespread dispersal). Insight on the spread in Texas of a number of introduced species can be obtained by comparing their distributions as recorded by early maps, early published reports (e.g., Cory 1940, 1950b; Shinners 1948), or herbarium records, etc., with their current day distributions (e.g., Turner et al. 2003).

EXOTICS IN EAST TEXAS

Some exotic species are at the present time rapidly spreading in East Texas or have the potential to do so. For example, the offensive *Carduus nutans* subsp. *macrocephalus*, musk-thistle or nodding-thistle, is each year becoming more abundant in the northwestern part of East Texas (e.g., Collin and Grayson counties). A possibly even more serious threat, *Scabiosa atropurpurea*, pincushions or sweet scabious, is currently taking over roadsides and adjacent areas in the northern part of East Texas (e.g., Collin and Dallas counties) and has the potential of becoming one of the most destructive invasive exotics in grassland habitats. A potentially economically devastating weed, *Orobanche ramosa,* branched broom-rape, is now spreading in the west central part of East Texas and is known from at least 22 counties (Texas Cooperative Extension 2003). Recently (2004), it was discovered as far north as Dallas County (J. Quayle, pers. comm.). It is apparently being spread widely by highway mowing equipment. This chlorophyll-less plant is a well known root parasite of agricultural crops and has the potential to have a significant economic impact in Texas. It is classified a federal noxious weed (USDA Natural Resources Conservation Service 2002). Texas cities, too, are under attack. *Cuscuta japonica*, Japanese dodder, is a federal noxious weed currently known only from Houston (Harris County), but there is concern about its possible spread (Huber 2002). It is an aggressive parasitic vine which attacks a variety of woody plants and has the potential to have serious ecological and economic consequences if not eradicated. Troubling also are observations that a number of previously known introductions such as *Rapistrum rugosum*, annual bastard-cabbage, and *Silene gallica*, windmill-pink, are at present becoming noticeably more common, and other species once found primarily in southeast Texas have now spread further north (e.g., *Trifolium resupinatum*, reversed clover, and *Youngia japonica*, Japanese hawkweed).

Nor are aquatic habitats exempt from the threat of exotic species. *Hydrilla verticillata*, hydrilla, is a serious pest which can completely dominate aquatic habitats, eliminating native species, clogging waterways, and severely curtailing recreational use (Steward et al. 1984; Flack & Furlow 1996). This federal noxious weed is rapidly spreading at present in East Texas (M. Smart, pers. comm.), probably from lake to lake via boats or boat trailers. It may also be intentionally spread by fishermen (L. Hartman, pers. comm.) to "improve" the habitat, which is both illegal and ill-advised since it ultimately degrades the fishery. Likewise, *Salvinia molesta*, giant salvinia, considered by some to be "one of the world's worst weeds" (Jacono 1999c), is at present spreading in the eastern part of the state and "all reservoirs in East Texas are imminently threatened" (R. Helton, pers. comm.). Plants used in aquaria or water gardens are among the likely sources for the escaped populations. This species, which has a very rapid growth rate and the ability to form thick mats on the water surface, can cover lakes and streams, crowd out native plants, and cause physical problems by impeding boats and clogging water intakes (Jacono 1999a, 1999b, 1999c; Wood et al. 2001). It is listed as a federal noxious weed (USDA Natural Resources Conservation Service 2002), and as such is prohibited in the U.S. by federal law. In fact, because of their potential as problematic invaders, seven aquatic species that occur in East Texas, *Alternanthera philoxeroides*, alligator-weed (Amaranthaceae); *Eichhornia crassipes*, common water-hyacinth (Pontederiaceae); *Hydrilla verticillata* (Hydrocharitaceae); *Myriophyllum spicatum*, Eurasian water-milfoil (Haloragaceae); *Pistia stratiotes*, water-lettuce (Araceae); *Salvinia minima*, common salvinia (Salviniaceae); and *Salvinia molesta*, giant salvinia, are considered "harmful or potentially harmful exotic plants," and it is illegal to release, import, sell, purchase, propagate, or possess them in the state (Harvey 1998).

The alien taxa now naturalized in East Texas are from nearly all parts of the world (e.g., *Bromus catharticus*, rescue grass, from South America; *Chenopodium pumilio*, ridged goosefoot, from Australia; *Eragrostis curvula*, weeping love grass, from Africa; *Bothriochloa ischaemum* var. *songarica*, King Ranch bluestem, from Asia; *Orobanche ramosa*, branched broom-rape, from Europe) and have arrived in East Texas via assorted ways. However, most introduced weeds in eastern North America, including many in East Texas, are from central and western Europe. It is thought that many weedy colonizing species evolved in Europe over thousands of years as humans disturbed and modified the environment for agricultural purposes; these

TABLE 2/ INTRODUCED SPECIES RECENTLY REPORTED FOR EAST TEXAS (AND TEXAS).

Scientific Name	Common Name	Reference
Alstroemeria pulchella	parrot-lily	E. Keith, pers. comm. 2004
Alternanthera sessilis	sessile joy weed	Brown & Marcus 1998
Anthoxanthum odoratum	sweet vernal grass	W. Holmes, pers. comm. 2003
Ardisia crenata	hen's-eyes	Singhurst et al. 1997 (Myrsinaceae, a new family for Texas)
Cardamine debilis	roadside bittercress	Brown & Marcus 1998
Carthamus tinctorius	safflower	Diggs et al. 1999
Cerastium pumilum	dwarf mouse-ear chickweed	Rabeler & Reznicek 1997
Cerastium brachypetalum	gray chickweed	Diggs et al. 1999
Chaenorrhinum minus	dwarf snapdragon	Diggs et al. 1997
Cryptocoryne beckettii	water-trumpet	Rosen 2000
Cuscuta japonica	Japanese dodder	Huber 2002
Cuscuta polygonorum	smartweed dodder	Brown & Marcus 1998
Cynosurus echinatus	bristly dog-tail grass	Thomas 2002
Dimorphotheca sinuata	cape-marigold	Keith 2004
Dipsacus fullonum	fuller's teasel	Singhurst & Holmes 2001a
Glaucium corniculatum	red horned-poppy	Kirkpatrick & Williams 1998
Hovenia dulcis	Chinese raisin tree	Goldman 1998b
Hypochaeris glabra	smooth cat's-ear	Diggs et al. 1997; Brown & Elsik 2002
Hyptis mutabilis	tropical bush-mint	Brown & Elsik 2002
Imperata cylindrical	cogon grass	Van Loan et al. 2002
Lactuca saligna	willow-leaf lettuce	O'Kennon et al. 1998; Turner et al. 2002
Lilium philippinense	Philippine lily	Brown & Elsik 2002; L. Brown, pers. comm. 2003
Linaria maroccana	Moroccan toadflax	M. Reed, pers. obs. 2003
Linaria vulgaris	toad-flax	Turner et al. 2003
Lindernia crustacea	Malaysian false pimpernel	Brown & Marcus 1998
Linum grandiflorum	flowering flax	M. Reed, pers. obs. 2003
Luziola peruviana	Peruvian water grass	Hatch et al. 1998
Lycianthes asarifolia	bitter ginger-leaf	Reed & Ketchersid 1998
Orobanche ramosa	branched broom-rape	Texas Cooperative Extension 2003; first collected 1997
Polygonum meisnerianum var. *beyrichianum*	branched tear-thumb	Brown & Marcus 1998
Raphanus raphanistrum	wild radish	Brown & Elsik 2002
Salvinia molesta	giant salvinia	Jacono 1999c
Silene conoidea	conoid catchfly	Reed 2004
Solanum viarum	tropical soda-apple	Reed et al. 2004
Stellaria pallida	lesser chickweed	Rabeler & Reznicek 1997
Stellaria parva	pygmy starwort	Brown & Marcus 1998
Themeda triandra	kangaroo grass	T. Wendt, pers. comm. (collected 1997)
Thymelaea passerina	mezereon	Holmes et al. 2000 (Thymelaeaceae, a new family for Texas)
Vicia grandiflora	large yellow-flowered vetch	Singhurst et al. 2002
Vicia lutea	smooth yellow vetch	Neill 1999
Zinnia violacea	youth-and-old-age	Keith 2004

same species do well in the disturbed habitats of the eastern United States (Stuckey & Barkley 1993). Numerous such European species entered North America at seaport cities along the Atlantic coast and spread westward across the continent (Stuckey & Barkley 1993). An excellent example of this phenomenon can be seen with *Chaenorrhinum minus*, dwarf snapdragon, which was first observed growing in North America in New Jersey in 1874 (Martindale 1876) and has since spread to over 30 states and nine Canadian provinces (Widrlechner 1983).

In some cases, seeds were introduced with soil, sand, or rocks being used as ballast in seagoing ships; Mühlenbach (1979) discussed the role of maritime commerce in dispersal. Other currently problematic taxa were intentionally introduced as ornamentals (e.g., *Ligustrum* species, privets), as windbreaks (e.g., *Tamarix* species, salt-cedar), as pasture (e.g., *Cynodon dactylon*, Bermuda grass), or in misguided attempts at habitat improvement, erosion control, soil stabilization, etc. In yet other cases, exotics are thought to have been accidentally introduced with crop seeds (e.g., *Myagrum perfoliatum*), hay (e.g., *Carduus nutans* subsp. *macrocephalus*), cotton, or wool, or else are species associated with livestock yards. Still others are transported by cars, trucks, or trains (e.g., *Chaenorrhinum minus*—Widrlechner 1983); Mühlenbach (1979) discussed the importance of railroads as a means of dispersal.

The percentage of exotics in the East Texas flora—18% as previously stated—is approximately what would be expected based on data from other parts of the United States. Elias (1977) estimated the level of exotics at 22% in the northeastern United States, and more recently Stuckey and Barkley (1993) indicated that in northeastern states the percentage of foreign species ranged from 20% to over 30%. Their data, compiled from a number of sources, showed that there are higher percentages of foreign species in those states that have been occupied the longest by non-native humans and in those that have been most extensively involved in agriculture. Some northern and western states, with less human influence and disturbance, have figures below 20%. While rather recently colonized by European settlers, East Texas has been extensively cultivated and logged. Nearly all of its habitats have been seriously altered, and numerous exotic species have arrived and become naturalized. Comparable percentages of foreign species are seen in the floras of California (17.5%), Colorado (16%), Iowa (22.3%), Kansas (17.4%), Missouri (27.7%), North Central Texas (17.7%), and North Dakota (15%) (Stuckey & Barkley 1993; Rejmánek & Randall 1994; Diggs et al. 1999; Yatskievych 1999; Yatskievych & Raveill 2001). A disturbing increase in the percentage of exotics can be seen in data from Missouri when comparing tallies from 1963 (Steyermark) and 1999 (Yatskievych). During that 35 year interval, the proportion of non-native components increased from 22.8 to 27.7% (Yatskievych & Raveill 2001). A similar increase is expected to occur in East Texas.

Indeed, a significant number of introduced species new to Texas have only recently (since 1997) been reported in East Texas or immediately adjacent areas (i.e., in a non-included portion of a county partly treated in this flora). Some examples are listed in Table 2. Additional exotics can be expected to become part of the East Texas flora in the future, many with serious negative consequences to the remnant native vegetation and to the Texas economy.

Diversity (Species Richness) of the East Texas Flora

The 3,402 vascular plant species found in East Texas (slightly more than two-thirds of the total for Texas) make it particularly rich in species for its size (about 62,600 square miles or about 23% of Texas; roughly the size of Georgia). This can be put in perspective when it is realized that the vascular plant flora of the entire Great Plains (which make up one-fifth of the area of the contiguous United States) consists of 3,067 taxa (Great Plains Flora Association 1977, 1986; Thorne 1993d). When the entire flora of North America north of Mexico is considered (estimated at approximately 18,000 species—Thorne 1993d), East Texas includes about one out of every six plant species known in the continental United States and Canada. Likewise, when the number of species in three adjacent states, Arkansas

(2,877—Arkansas Vascular Plant Manual Committee 2002), Louisiana (2,952—MacRoberts 1984), and Oklahoma (2,549 species—Taylor & Taylor 1994), is considered, East Texas again appears particularly diverse. The striking diversity of the area is also apparent when it is realized that there are 202 vascular plant families (as treated here) in East Texas. This diversity at the family level exceeds all but a handful of states (e.g., Alabama, Florida, Texas). When compared (using the same taxonomic approach to families) with its nearest neighbor to the north, East Texas has 11 more families than all of Oklahoma (Taylor & Taylor 1994), even though Oklahoma is substantially larger.

A number of *interrelated* factors contribute to this diversity:

- **Geologic and associated hydrologic variation** resulting in considerable edaphic variation—e.g., very dry to very wet conditions including bogs and baygalls; acidic to calcareous substrates ranging from Carrizo sands to Weches outcrops and Catahoula sandstone; deep highly fertile soils to highly leached areas and rock outcrops.
- **Climatic variation—**e.g., average annual rainfall ranges from nearly 60 inches at the southeastern portion of the area to less than 28 inches at the southwestern margin.
- **High habitat diversity—**Large numbers of different habitats occur in a relatively small area, each of these supporting a diverse assemblage of species (this is particularly noteworthy for the Big Thicket; see further discussion on page 164).

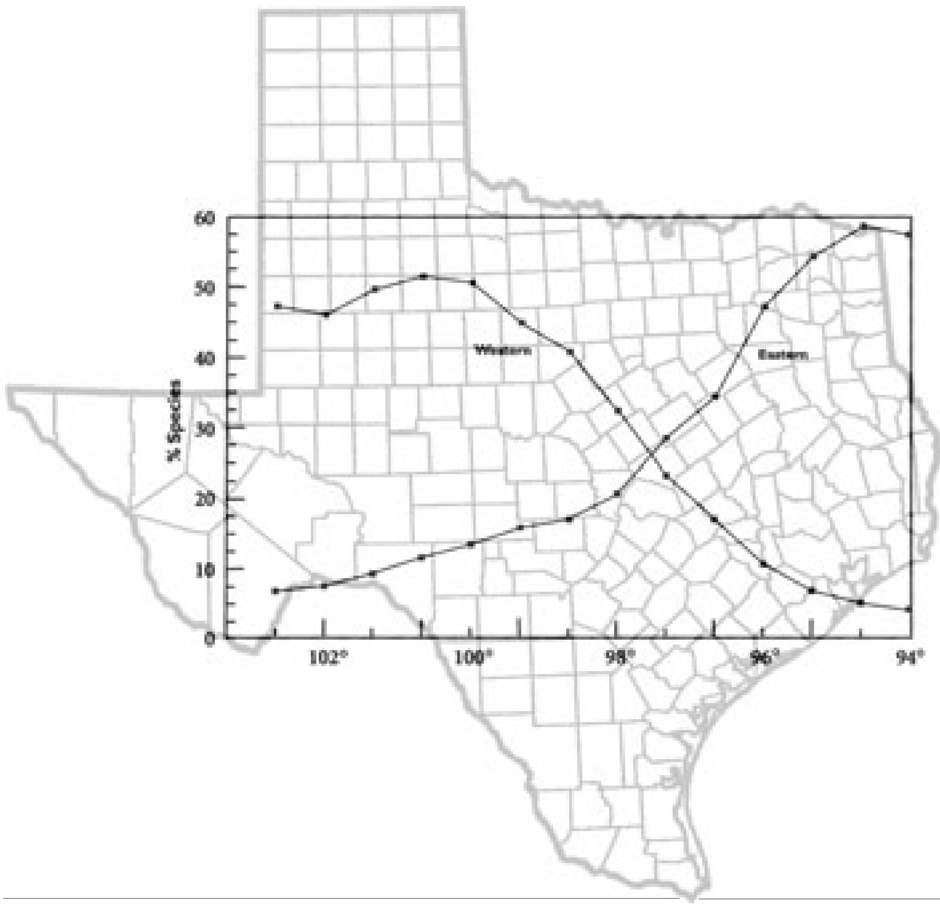


Fig. 130/ Percentage of eastern and western species versus longitude across Texas. (modified from MacRoberts & MacRoberts 2003b), with permission of the authors.

■ **POSITION ON THE ECOTONE** or transition zone between the eastern deciduous forests and the central North American grasslands (ecotones frequently contain high levels of diversity—Risser 1995). A quantitative analysis of the east-west floristic transition across Texas (MacRoberts & MacRoberts 2003b) demonstrated that this change occurs in an approximately 300 km wide band (see Fig. 130) extending from around 95° to 99° west longitude (roughly from Houston and Tyler on the east to Wichita Falls and San Antonio on the west), with much of this area being within the boundaries of East Texas (depending on the latitude, East Texas as defined here extends from just east of 94° to just west of 98° longitude). Austin, at the western margin of East Texas, is one of the areas where the east and west influences are approximately balanced. While Texas has long been recognized as a transition zone, (e.g., Blair 1950; Gehlbach 1991; Diggs et al. 1999), the MacRoberts and MacRoberts study is the first to quantitatively document the area of most rapid change.

■ **PROXIMITY TO OTHER SOURCE FLORAS—**The intermingling of elements typical of the eastern deciduous forest, southeastern swamps, central North American grasslands, southwestern deserts, and even the tropics is striking and contributes greatly to the overall biological diversity of the area. The tropical and southwestern desert components of the East Texas flora are probably the least obvious. Sorrie and Weakley (2001) discussed these elements in relationship to the diversity of the Atlantic and Gulf Coastal Plain Floristic Province, and plants of these origins are particularly evident in the flora of East Texas. A few examples of the many genera with tropical affinities include *Asimina*, *Eriocaulon*, *Hymenocallis*, *Sabal*, *Tillandsia*, and *Zephyranthes*. In contrast, *Abronia*, *Coryphantha*, *Lesquerella*, *Manfreda*, *Mentzelia*, *Nolina*, and *Opuntia* are a few of the genera which have affinities with the Sonoran Floristic Province to the west and southwest.

■ **RICH BIOGEOGRAPHIC HISTORY—**e.g., remnant Tertiary components (see page 202); remnant northern species as the result of glaciation—e.g., American beech (see page 210).

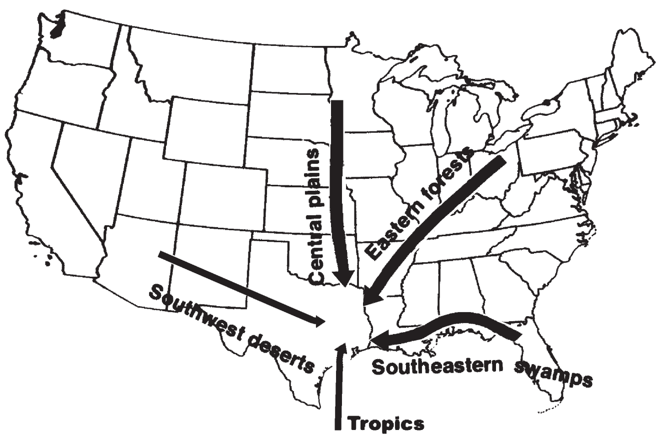


FIG. 131/ THE BIG THICKET AND EAST TEXAS AS A WHOLE AS A "BIOLOGICAL CROSSROADS" (MODIFIED FROM NATIONAL PARK SERVICE 1997).

Perhaps the most important of these factors are the area's position on the ecotone between the eastern deciduous forests and the central North American grasslands and its proximity to the southeastern swamps, the desert southwest, and the nearly tropical area of south Texas. The result is that the East Texas flora is a complex and diverse mixture derived from several major, and quite different, floristic provinces (Thorne 1993d). Because of the disparate floristic elements and its mid-continental position, one part of East Texas, the Big Thicket, has been referred to by some as the "Biological Crossroads of North America" (e.g., Gunter 1993). Given the location of the transition zone (MacRoberts & MacRoberts 2003b), the description is even more fitting for East Texas as a whole (Fig. 131).

When all information is considered, the East Texas flora is seen to be a unique assemblage of many different elements all coming together and coexisting in a relatively small area—creating an extremely rich flora.

Conservation in East Texas

During the past 200 years, human activities, particularly logging, conversion of habitats for agriculture, flooding of river bottoms for reservoirs, urbanization, and other types of development, have profoundly altered the ecosystems of East Texas. Only tiny remnants of the original habitats have survived to the present day in anything resembling their presettlement state. This is particularly tragic, because in many ways, East Texas is a botanically unique region (Diggs 2002; also Appendix 10) and an area of high biological diversity. As a result of these changes, there are now numerous species that are of conservation concern (Appendix 12). Different organizations and agencies have tracked endangered, threatened, or rare species in the state over the years. Examples include the Texas Organization for Endangered Species (TOES 1993), the Nature Conservancy of Texas (Carr 2001, 2002d), and the Texas Parks and Wildlife Department (Poole et al. 2002).

Several categories (sometimes overlapping) of such plants are of particular interest. Of greatest conservation concern are those plants that have an official designation such as "federally endangered" (see page 20 and Appendix 12). While these are limited in number, they generate great publicity and are potentially significant economically. Another large group of species is endemic to Texas (see page 215 and Appendix 11), and many of these are likewise vulnerable. Such plants are of major conservation concern because they are known from nowhere else in the world—they are unique aspects of Texas' natural heritage. Finally, hundreds of species of plants reach the southwestern limits of their ranges in East Texas and are rare or of very limited occurrence in the state. Many of these species are probably Ice Age relicts, surviving only in a few areas of favorable microclimate or geology (Kral 1966c; MacRoberts & MacRoberts 1997a). Such species are particularly vulnerable to habitat change and could easily be eliminated from the state by the type of widespread habitat transformation now occurring throughout most of East Texas.

Like individual species, a number of entire ecosystems/communities are currently of significant conservation concern. The Blackland Prairie (and its constituent communities), for example, originally covered a huge area but has been reduced to a few tiny remnants, more of which are lost each year. Communities on the Carrizo Sands, some of which are unique to Texas, are also under pressure, and what remains are often significantly degraded by grazing, fire exclusion, or other pressures (M. MacRoberts, pers. comm.). Further, a number of communities reach their western limit in Texas and are now vulnerable. Examples include wetland pine savannah (limited in Texas to Hardin, Jasper, Newton, and Tyler counties—MacRoberts & MacRoberts 1998d), hanging bogs (also known as hillside bogs or Wet Herbaceous Seeps), muck bogs, beech-magnolia forest, beech-hardwood forest, etc. These communities face various threats ranging from conversion to pine monoculture, fire suppression, drainage, overgrazing, cultivation, or invasion by exotics to total destruction by development. Each community faces a unique set of problems and, like individual species, these communities need protection, and in some cases active management, if they are to survive into the future.

Among the most noteworthy large-scale conservation efforts in East Texas have been the creation of the National Forests, attempts to save part of the Big Thicket (see section on Conservation in the Big Thicket on page 190), the struggle to set aside wilderness areas in the National Forests, efforts to establish and expand a number of National Wildlife Refuges, and the successful creation of an extensive Texas State Park system. The results have included the establishment of the Big Thicket National Preserve, four National Forests (Figs. 89, 132), four major National Wildlife Refuges (including Caddo Lake created in 2000), and dozens of state parks and wildlife management areas (discussed further below). Another major event was the passage of the 1984 East Texas Wilderness Act, which resulted in five officially designated

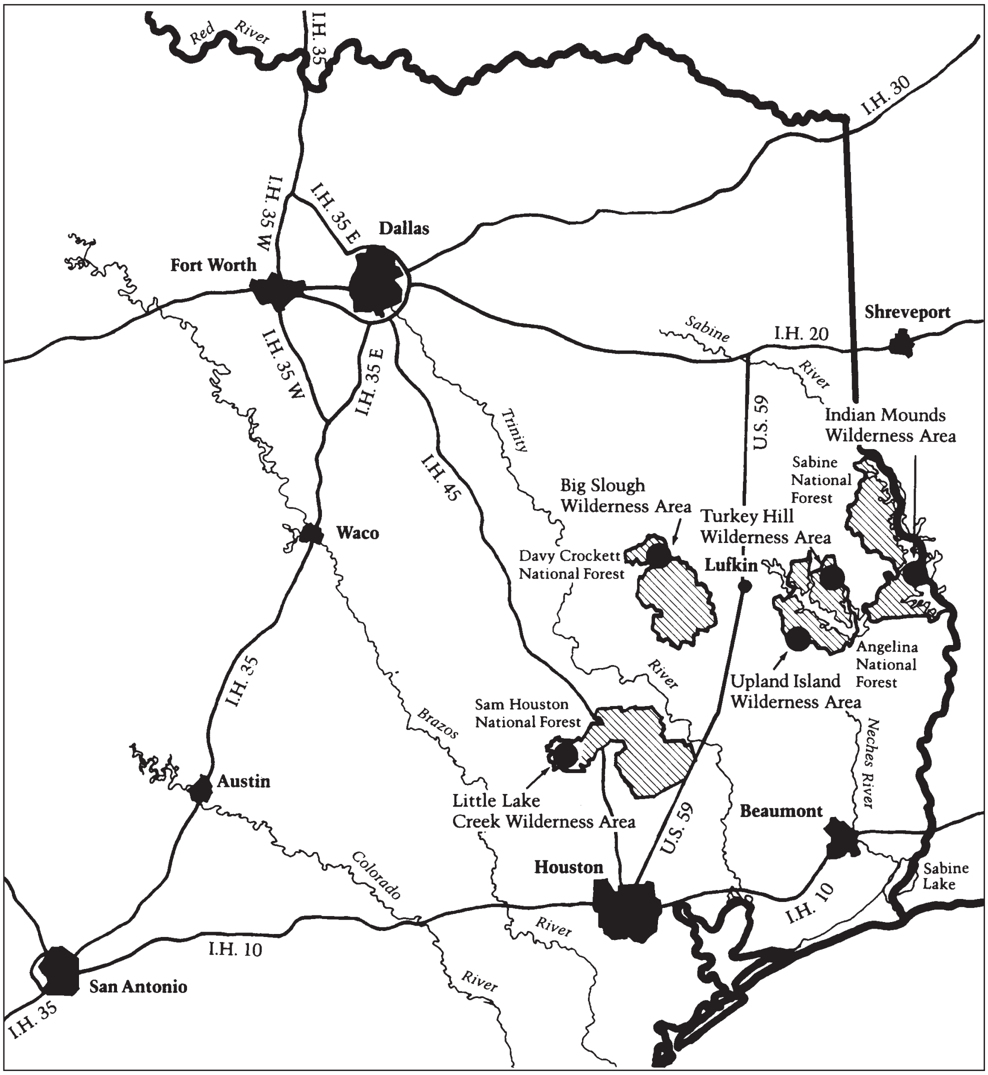


FIG. 132/ MAP SHOWING NATIONAL FORESTS AND WILDERNESS AREAS IN EAST TEXAS (FROM *REALMS OF BEAUTY: THE WILDERNESS AREAS OF EAST TEXAS* BY EDWARD C. FRITZ, PHOTOGRAPHS BY JESS ALFORD. COPYRIGHT © 1986. BY PERMISSION OF THE AUTHOR AND THE UNIVERSITY OF TEXAS PRESS).

wilderness areas (Big Slough, Indian Mounds, Little Lake Creek, Turkey Hill, and Upland Island totaling about 35,000 acres—Fig. 132), being preserved for future generations (Fritz 1993).

Currently, a variety of conservation efforts are underway in East Texas in an attempt to preserve at least some small examples of the rich natural heritage of the state. Addresses and telephone numbers of the organizations mentioned below are provided in Appendix 13.

A significant amount of land in East Texas (approximately 1 million acres = approximately 400,000 hectares, or a little more than two percent of the total land) is controlled by various federal or state agencies. Ecosystems on this public land are given various levels of protection ranging from excellent (wilderness areas in the national forests and the Big Thicket National Preserve) to poor (intensive logging in some areas of the national forests). Areas of land controlled by the federal government include the Big Thicket National Preserve (north of Beaumont), four National Forests (Angelina, Davy Crockett, Sabine, Sam Houston), Caddo Lake National Wildlife Refuge (Harrison County), Hagerman National Wildlife Refuge

(Grayson County), Balcones Canyonlands National Wildlife Refuge (Burnet, Travis, and Williamson counties), Trinity River National Wildlife Refuge (Liberty County), Camp Maxey (U.S. Army) in Lamar County, the Caddo National Grasslands in Fannin County, and U.S. Army Corps of Engineers land around numerous impoundments. Examples of state land include numerous state parks and wildlife management areas (Appendix 13). The Texas Parks and Wildlife Department is protecting, and in some cases attempting restoration of numerous tracts throughout East Texas. For example, fire is now being used in restoration efforts in some state parks.

A number of far-sighted local governments are also protecting natural habitats. Specific examples include the Gambill Wildlife Refuge in Lamar County (maintained by the City of Paris), Harry S. Moss Park in Dallas, Lee F. Jackson Spring Creek Forest Preserve in Garland, Parkhill Prairie Preserve in Collin County, and Windmill Hill Nature Preserve in Desoto. The government agencies listed above not only control and protect land, but also carry out numerous research, educational, and outreach activities designed to promote conservation.

Non-governmental organizations protect and manage particularly critical pieces of habitat. Several well known examples of Nature Conservancy projects are the Fred and Loucille Dahmer Caddo Lake Preserve near Uncertain in Harrison County, Lennox Woods Preserve in Red River County (Sanders 1994), the Roy E. Larsen Sandyland Preserve in Hardin County, Clymer Meadow in Hunt County, and Tridens Prairie in Lamar County. The Nature Conservancy of Texas also recently (January 2004) entered into a conservation partnership with Texas A&M University-Commerce regarding preservation of the Cowleech Prairie Preserve in Hunt County. The Natural Area Preservation Association (NAPA) manages approximately 40 properties in East Texas and nearly 60 in Texas, totaling more than 35,000 acres. The Conservation Fund has been instrumental in preserving nearly 112,000 acres of natural habitat in Texas including the 33,000 acre Middle Neches River tract in East Texas (Andy Jones, pers. comm.). The Trust for Public Land has protected more than 26,000 acres in the state, including the recent acquisition of a 302 acre "Yegua Knobs" tract at the boundary of Bastrop and Lee counties. The 4,600 acre Alabama-Coushatta Indian Reservation near Livingston in Polk County has some of the best remaining examples of old growth forest in the Pineywoods. The National Audubon Society is currently managing the Cedar Ridge Preserve (formerly the Dallas Nature Center) in Dallas County. The Heard Natural Science Museum and Wildlife Sanctuary, a 287-acre protected area in Collin County, has numerous conservation activities, including a raptor rehabilitation program and a tall grass prairie restoration project (e.g., Steigman & Ovenden 1988). Austin College through its Center for Environmental Studies protects five field laboratories and preserves totaling nearly 365 acres in Grayson County. The Connemara Conservancy has preserved 72 acres in Collin County and has expanded its mission to protect land in Delta and Hunt counties. The East Texas Arboretum and Botanical Society (Athens, Henderson County) is protecting 100 acres of native habitat. The Watson Pinelands Preserve in Tyler County is dedicated to preserving a portion of the diversity of the Big Thicket. Other organizations, such as the Big Thicket Association, the Caddo Lake Institute, the Native Plant Society of Texas, the Native Prairies Association of Texas, and the Texas Committee on Natural Resources, are actively engaged in educating the public and promoting the importance of plants, natural areas, and conservation. The Ancient Cross Timbers Consortium was recently established to promote research, education, and conservation of the old-growth forests of the Cross Timbers and Post Oak Savannah (Ancient Cross Timbers Consortium 2004). The Lady Bird Johnson Wildflower Center, located in Travis County, is dedicated to the study, preservation, and reestablishment of North American native plants in planned landscapes. It has had an important impact throughout Texas and beyond. Likewise, the Pineywoods Native Plant Center in Nacogdoches focuses on plants of the Pineywoods. The Texas Organization for Endangered Species (TOES) has monitored and published information about endangered and threatened species and natural communities in East Texas and throughout the state. The Botanical Research Institute of Texas, in addition to its research activities, has an environmental education program which provides appropriate publications and educational opportunities for school children and teachers state-wide, but particularly in the Fort Worth area.

Some corporations are also involved in conservation activities. For example, Temple-Inland, through its Conservation Forest program, is protecting numerous sites designated in four categories: rare ecosystems, wildlife management areas, distinctive sites, and areas with endangered species (see page 198 for further details).

Many individual landowners are also making significant contributions by managing their properties in ways that preserve natural diversity. Switching to enlightened grazing regimens, removing particularly fragile or erosion-prone parcels from use, implementing habitat restoration projects, implementing management policies that favor rare species, or the simple purchasing of areas to protect are some of the strategies being used. These efforts are particularly important because, unlike many other states, Texas has proportionally very little public land (ca. 2%—R. Telfair, pers. comm.). Because most rare species are on privately owned and managed land, the Texas Parks and Wildlife Department has a Landowner Incentive Program "to assist private landowners in protecting and managing rare species" (Texas Parks and Wildlife 2002e). The U.S. Fish and Wildlife Service also has programs focusing on helping individual landowners protect and restore habitat—examples in East Texas include Gregory Hall of Fannin County and Bob Long of Bastrop County (Wolfshohl 2004). Hall, for example, has been undertaking wetlands restoration efforts on 570 acres near Mulberry. He has participated in the Partners for Wildlife Program (U.S. Fish & Wildlife Service) and in the East Texas Wetlands Project (ETWP), a cooperative venture between landowners and Ducks Unlimited, the Texas Parks and Wildlife Department, the Natural Resources Conservation Service, and the U.S. Fish and Wildlife Service. The purpose of the ETWP is to provide landowner assistance and incentives to restore, enhance, and manage wetlands and associated uplands in East Texas (Ducks Unlimited 2004).One of the finest examples of habitat restoration in Texas today is at Selah Ranch in Blanco County (http://www.bambergerranch.org/) in the Texas Hill Country just to the west of East Texas. Here J. David and Margaret Bamberger have converted "the worst piece of land in Blanco County" into an internationally recognized example of restoration, land stewardship, and environmental education. It is to be hoped that such outstanding examples will inspire further conservation efforts by individual landowners.

Creative private-public cooperative efforts are also increasing and are potentially of major importance for the future. A particularly noteworthy example is the Middle Trinity River Basin Conservation Cooperative, a group of private landowners (e.g., Robert McFarlane of Palestine) in the Middle Trinity Basin (e.g., Anderson County) which has banded together with the Texas Parks and Wildlife Department and other state agencies. The cooperative, which has seen its land base grow to nearly 150,000 acres, is dedicated to preventing fragmentation of natural habitats, restoration activities, and maintaining travel corridors for wildlife. A variety of funding techniques are being used or envisioned including mitigation banking (i.e., corporations paying to restore natural habitats in exchange for areas that they are developing elsewhere), sustainable sale of water, sale of carbon credits, wastewater purification, and ecotourism (Cartwright 2004).

Finally, innumerable individuals have contributed their time and resources, both individually and collectively, to conservation efforts. It is impossible to name them all in a summary such as this. Many are discussed in the section on Conservation in the Big Thicket (page 190). Even before 1900, individuals like W. Goodrich Jones ("the father of Texas forestry") (Fig. 49) realized that timber industry policies were not sustainable (Maxwell 1996b) and called for reforms. Other early voices for conservation included William L. Bray (1901b), who pointed out the "urgent need of conservative forestry," and R.E. Jackson, who in the 1930s began conservation activities in the Big Thicket (Gunter 1997). Another name always mentioned in relationship to Texas conservation in the past several decades is E.C. (Ned) Fritz. Fritz co-founded and for many years chaired the Texas Committee on Natural Resources (TCONR), led a coalition to establish the wilderness areas in East Texas, helped with preservation efforts in the Big Thicket, authored several books on conservation topics (Fritz 1983, 1989, 1993), and in 1982 co-founded the Natural Area Preservation Association (NAPA), a Texas-based organization dedicated to preserving natural areas in the state. Other particularly noteworthy individual conservation efforts have been Andy Sansom's many years of leadership efforts at the Texas Parks and Wildlife Department and Don Henley's support for protection of the Caddo Lake watershed. Rosa Finsley, Howard Garrett, the late Lynn Lowrey (see Appendix 25), Jill Nokes, the late Benny Simpson, and Sally and Andy Wasowski have also made large contributions by calling attention to the superiority of using native plants in landscapes and other environmentally sensitive strategies. Still other individuals have brought conservation efforts to public attention in the state through their books—e.g., R. Bartlett, *Saving the Best of Texas: A Partnership Approach to Conservation* (1995); J. Cozine, *Saving the Big Thicket: From Exploration to Preservation, 1685–2003* (2004); W.O. Douglas, *Farewell to Texas, A Vanishing Wilderness* (1967); J. Graves, *Goodbye to a River: A Narrative* (1960); P.A.Y. Gunter and M. Oelschlaeger, *Texas Land Ethics* (2000); M. Sanger and C. Reed, *Texas Environmental Almanac* (2000); D.J. Schmidly, *Texas Natural History: A Century of Change* (2002); R. Telfair, *Texas Wildlife Resources and Land Uses* (1999); and J.C. Truett and D.W. Lay, *Land of Bears and Honey: A Natural History of East Texas* (1984). As stressed by various of these and other authors, and also by numerous individuals (e.g., Andrew Sansom), and organizations (e.g., Texas Parks and Wildlife Department), cooperation between individuals (including landowners), non-governmental organizations, corporations, and governmental entities is essential for significant progress to be made in Texas conservation.

All of these efforts are critical because, given the rate at which remaining areas of natural habitat are disappearing, unless action is taken by those living today, the opportunity to provide future generations with the chance to experience natural areas in East Texas will soon be lost. As pointed out by Gunter (2000), Texas is no longer an open frontier with unlimited space and resources. Rather, it is a land with finite space and a rapidly growing population. Problems such as unchecked and unplanned urban sprawl, land fragmentation, pollution, the waste of natural resources, and often an ignorance of or contempt for natural ecosystems are serious and will have to be faced in the near future. Indeed, Gunter (2000) argues that a new approach, a new "land ethics" is needed whereby respect is given to the land and the natural ecosystems and organisms it supports. Clearly, respect and careful and sustained planning and action are needed to insure the future of the magnificent natural ecosystems that Texans are justifiably proud of.

When one considers that within the last 150 years virtually all of the Pineywoods was cut for timber and virtually all of the Blackland Prairie was destroyed for cotton production and other uses, many questions, both practical and philosophical, come to mind regarding the use of land and natural resources. Is it our responsibility to preserve at least a minute fraction of this wonderful and unique natural heritage? How can we justify destroying absolutely everything in the name of so-called progress and economic prosperity? What will future generations of Texans say about the actions of those alive today? Are we the stewards of the natural world or merely its exploiters?

A Sketch of the History of Botany in Texas with Emphasis on the Eastern Half of the State

Early Botany in Texas

Prior to the Republic of Texas / before 1836

Fig. 133/ Edwin James (1797–1861). Used with permission, Archives of the Gray Herbarium, Harvard Univ., Cambridge, MA.

Botanical work in Texas had its beginnings in the early 1800s, while what is now Texas was part of Mexico and afterwards a separate republic. According to Winkler (1915), "The study of Texas plants ... is as old as the state itself. Prior to her annexation to the Union, and even before the period of the Republic of Texas, Texas had become an interesting field of observation and research for botanists and naturalists." In fact, much of the earliest natural history work in Texas was botanical in nature (McCarley 1986). The first expedition reaching Texas known to be accompanied by a dedicated naturalist/botanist (Peter Custis) was the Freeman and Custis Red River Expedition of 1806 (Morton 1967b; Flores 1984; MacRoberts et al. 1997; MacRoberts & MacRoberts 2004c). The party entered the Red River from the Mississippi River and proceeded mostly through what is now Louisiana until they were turned back by a Spanish force near the present-day Spanish Bluff, Bowie County, Texas near the Arkansas-Louisiana-Texas meeting point (Morton 1967b, including map). While there is no evidence of any specimens being collected in Texas (out of a total of 26 collected, only two from Louisiana are known to have survived—MacRoberts et al. 1997) and the expedition barely reached Texas, "it did uncover a wealth of ecological, botanical, and zoological data" (MacRoberts et al. 1997). Of particular interest is the fact that numerous prairies were described near the Red River in an area now dominated by bottomland forests, "owing to the custom which these nations of hunters [Native Americans] have, of burning the grass at certain seasons" (Freeman in Flores 1984).

The first known collection of plants from what is now the state was made by Edwin James (Fig. 133) in August 1820 in the Texas Panhandle as part of Major S.H. Long's expedition to the Rocky Mountains (Shinners 1949). Details of the expedition's route are provided by Goodman and Lawson (1995). However, the first person to make more extensive collections in the area that would become Texas was Jean Louis Berlandier (1805–1851), a French (or Swiss, if today's borders are considered) botanist. Berlandier collected in Texas from 1828 to 1834, with his earliest collections being made in 1828 between Laredo and San Antonio while on a Mexican Boundary Commission expedition to explore the area along the proposed United States-Mexico border (Winkler 1915; Geiser 1948a; Berlandier 1980). On April 14 of that year (1828), Berlandier departed from San Antonio for Nacogdoches (Berlandier 1980). It was on this journey that the scientific study of plants in East Texas began—

FIG. 134/ THOMAS DRUMMOND (1780–1835). FIGURE COURTESY OF HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION, CARNEGIE MELLON UNIVERSITY, PITTSBURGH, PA. USED WITH PERMISSION OF ROYAL BOTANIC GARDENS, KEW, ENGLAND, UK.

it is thought that Berlandier may have been the first botanist to collect in East Texas. Further, Berlandier's journal from that trip contains what may be the first written record of the Texas bluebonnet (Andrews 1986). He noted, "A lupine [Texas bluebonnet], verbena, delphinium, some lilies, and a great many evening primroses contrasted with the tender green of the grasses, from which sprang flowers of various colors." In addition, he apparently made the first collection of the species that would eventually be named *Lupinus texensis*, one of the six *Lupinus* species which are the state flowers of Texas (Andrews 1986; Turner & Andrews 1986). Thousands of his collections were sent to the famous botanist Alphonse de Candolle of Geneva, Switzerland (Reveal & Pringle 1993), who described many as new to science. Berlandier is immortalized in many scientific names, including the genus *Berlandiera*, greeneyes, a composite genus of four species native to the southern United States and Mexico. A two volume translation of his journal has been published (Berlandier 1980), as have his important early observations on Native Americans—*The Indians of Texas in 1830* (Berlandier 1969). Despite Berlandier's botanical importance, no portrait, drawing, or sketch of him is known (Geiser 1948a).

Another early plant collector was Thomas Drummond (1780–1835), a Scottish botanist and naturalist who came to Texas in 1833 (Fig. 134). While in the area for only a brief period (1833–1834), he made important collections in southeast Texas and stimulated such later collectors as Lindheimer and Wright (discussed below). Drummond's were the first Texas collections that were widely distributed to museums and herbaria, with many of them going to Sir William Jackson Hooker in London (Geiser 1948a; Reveal & Pringle 1993). While many Texas plants are named for him, perhaps none is better known than *Phlox drummondii*, commonly known as Drummond's phlox or pride-of-Texas. Also of note is that it was from several of Drummond's collections that W.J. Hooker described both *Lupinus subcarnosus* and *Lupinus texensis* (Hooker 1836; Turner & Andrews 1986).

A final early collector, Melines Conkling Leavenworth (1796–1862), an army surgeon and another pioneer naturalist, collected in East Texas in 1835. He is commemorated by names including *Carex leavenworthii*, Leavenworth's caric sedge, *Eryngium leavenworthii*, Leavenworth's eryngo, and the genus *Leavenworthia* (Brassicaceae), gladecress.

DURING REPUBLIC OF TEXAS TIMES AND EARLY STATEHOOD / 1836–1890S

While not chronologically the first collector in the state, Ferdinand Jakob Lindheimer (1801–1879), a German-born and educated collector, is often referred to as the "father of Texas botany" because of his important botanical contributions, particularly to the knowledge of the central Texas flora (Fig. 135). Lindheimer's botanical work in the state, supported in part by George Engelmann (German-born botanist and physician of St. Louis; Fig. 136) and Asa Gray (the pre-eminent Harvard botanist sometimes referred to as the "Patriarch" of American botany; Fig. 137), spanned the years from 1836 to 1879 (Geiser 1948a; Hatter 1991; Reveal & Pringle 1993). Lindheimer's collections were widely distributed by Engelmann and Gray under the title "Flora Texana Exsiccata" (Blankinship 1907; Boensch 2000), and numerous new species were described in the

FIG. 135/ FERDINAND JAKOB LINDHEIMER (1801–1879). COURTESY OF THE SOPHIENBURG MUSEUM AND ARCHIVES, NEW BRAUNFELS, TX.

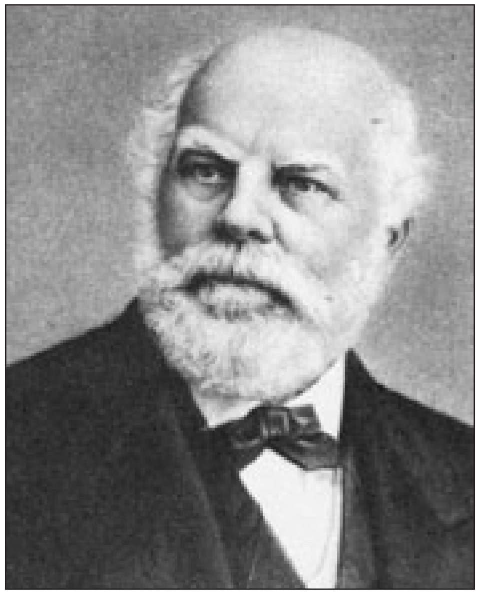


FIG. 136/ GEORGE THEODOR ENGELMANN (1809–1884). USED WITH PERMISSION OF THE HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION, CARNEGIE MELLON UNIV., PITTSBURGH, PA; PHOTOGRAPH BY BRIMMER & KALB, ST. LOUIS, MO.

well known *Plantae Lindheimerianae* (Engelmann & Gray 1845). Lindheimer's love of botany can be seen in the following quote from his 18 April 1845 letter to Engelmann (in Boensch 2000):

> Forest, grazing land, and land for cultivated fields of the best quality are available. But what does that matter to me? Palmate yuccas, cactus, and mimosas and the fragrance and blossoms of them all, that's for me. Here I have seen for the first time the total splendor of the prairies.

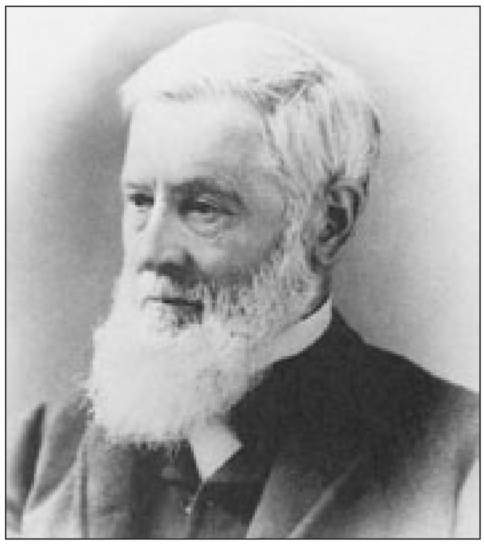


FIG. 137/ ASA GRAY (1810–1888). USED WITH PERMISSION OF THE HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION, CARNEGIE MELLON UNIV., PITTSBURGH, PA.

Adolf Scheele (1808–1864) published in the middle 1800s (in the European journal *Linnaea*) a number of articles based on Lindheimer's collections (Reveal & Pringle 1993). Many Texas plants are named for Lindheimer, including *Lindheimera texana*, Texas-star, yellow Texas-star, or Lindheimer's daisy, and *Gaura lindheimeri*, white gaura. Details about his life and botanical contributions can be found in Blankinship (1907) and Geiser (1948a). Lindheimer's letters to Engelmann have been edited, translated, and discussed by Goyne (1991). According to Hatter (1991), Lindheimer's house and a collection of memorabilia is maintained by the New Braunfels Conservation Society.

A friend and sometime collecting companion of Lindheimer was another German, Ferdinand Roemer (1818–1891) (Fig. 138), who spent the years 1845 to 1847 in Texas (Geiser 1948a). While a geologist and sometimes referred to as the "father of the geology of Texas," he is probably best known for his book, *Texas with Particular Reference to German Immigration and the Physical*

FIG. 138/ FERDINAND ROEMER (1818–1891). USED WITH PERMISSION OF UT INSTITUTE OF TEXAN CULTURES AT SAN ANTONIO, NO. 068-0694

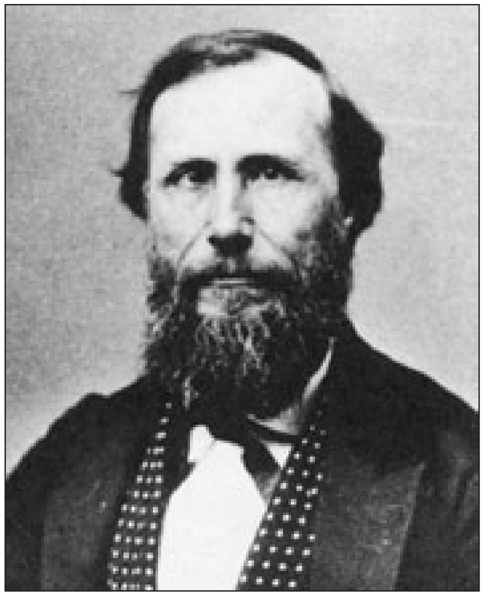


FIG. 139/ CHARLES WRIGHT (1811–1885). USED WITH PERMISSION, FROM THE ARCHIVES OF THE GRAY HERBARIUM, HARVARD UNIVERSITY, CAMBRIDGE, MA.

FIG. 140/ JOHN LEONARD RIDDELL (1807–1865). PHOTO FROM RUDOLPH MATAS MEDICAL LIBRARY. COURTESY OF TULANE UNIVERSITY HEALTH SCIENCES CENTER, NEW ORLEANS, LA, 70112.

Appearance of the Country (Roemer 1849). Roemer, however, also collected plants (Winkler 1915), and his botanical contributions are recognized in such names as *Phlox roemeriana*, gold-eye phlox, and *Salvia roemeriana*, cedar sage.

Yet another German-born naturalist was Louis Cachand Ervendberg (1809–1863), active in Texas from 1839 to 1855. He corresponded with and collected plants for Asa Gray, working in Comal County and later in Veracruz, Mexico (Geiser 1948a).

A further early Texas collector was Charles Wright (1811–1885) (Fig. 139), a Phi Beta Kappa graduate of Yale who collected for Asa Gray from 1837 to 1852 (Geiser 1948a). While he botanized in Angelina, Jasper, Newton, and Tyler counties in East Texas, much of his collecting was in western Texas. Some of his work was conducted while accompanying troops to that part of the state, an example being his 1849 expedition across the unexplored region between San Antonio and El Paso. This expedition is of special interest because the Smithsonian's $150 contribution to defray Wright's expenses was, according to some, one of the early steps taken by that institution toward the formation of a national herbarium (Winkler 1915). It was also noteworthy because Wright covered the 637 mile distance to El Paso on foot (Morrell 1996). Wright is commemorated by such plants as *Datura wrightii*, angel-trumpet, and *Ipomoea wrightii*, Wright's morning-glory. Further information on Wright's Texas travels can be found in Shaw (1987).

John Leonard Riddell (1807–1865) (Fig. 140), a botanist and geologist, visited Texas briefly in 1839 and contributed to early knowledge about the plants of the state. He traveled across the southern portion of East Texas, from Columbus to Gonzales, Seguin, and San Antonio (Breeden 1994). Riddell worked more extensively in Louisiana, and in 1852 published a list of about 1,800 plants growing in that state. Remarkably, this was the most thorough compilation of the plants of Louisiana available until 1982 (MacRoberts 1984). His name can be seen in *Aphanostephus riddellii*, Riddell's lazy daisy, and *Selaginella arenicola* subsp. *riddellii*, Riddell's selaginella. Detailed information about his travels in Texas is given in Breeden (1994), and a brief synopsis of his life in MacRoberts (1984).

A devoted student of Texas natural history was Gideon Lincecum (1793–1874), a Georgia-born frontier naturalist and pioneer physician who lived and worked in Texas (and later Mexico) from 1848 to 1874 (Fig. 141). During his career he corresponded with such eminent scientists as Charles Darwin, Spencer Baird, and Joseph Henry. Though self-taught, he published at least two dozen scientific articles and was elected a corresponding member of the Philadelphia Academy of Natural Sciences. Lincecum sent botanical specimens to such prestigious museums as the Academy of Natural Sciences of Philadelphia, the British Museum, and the Smithsonian Institution. Some of his collections are still available for study today at the Barker Texas History Collection, part of the University of Texas at Austin Library. Lincecum was also one of the earliest voices in Texas expressing a conservation ethic. In 1861, he wrote about the importance of conserving native pasture grasses and lamented the decline in prairie vegetation (Doughty 1987). In fact, Lincecum became an authority on Texas grasses and early on stressed the use of native grasses. He objected vehemently to recommendations for importing grasses from foreign lands or from states in the north and east ("a Yankee trick!") in order to improve Texas pastures (Doughty 1983). According to Lincecum (1861b), "The grasses best suited for meadows in Texas are already here." Additionally, he made extensive observations of the Texas agricultural (harvester) ant. His work with ants was eventually read by Darwin before the Linnaean Society in London and published in the Society's journal in 1862 (Lincecum 1861a, 1862; Geiser 1948a; Burkhalter 1965; Lincecum & Phillips 1994; Lincecum et al. 1997). His name is remembered in *Vitis aestivalis* var. *lincecumii*, the pinewoods grape, of East Texas. Detailed information and much of his correspondence can be found in Lincecum and Phillips (1994) and Lincecum et al. (1997).

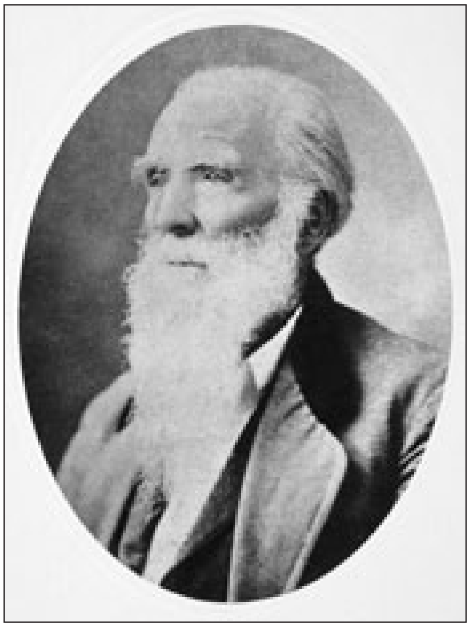


FIG. 141/ GIDEON LINCECUM (1793–1874). FROM PRINTS AND PHOTOGRAPHS (CN00151), THE CENTER FOR AMERICAN HISTORY, THE UNIVERSITY OF TEXAS AT AUSTIN.

Important Texas collections were made in 1849–1850 by the French botanist Auguste Adolph Lucien Trécul (1818–1896). According to Geiser (1948a), he visited Texas on his scientific mission to North America to study and collect plants used for food by Native Americans. *Stillingia treculeana*, Trecul's stillingia, and *Yucca treculeana*, Trecul's yucca or Spanish-dagger, are both named in his honor. McKelvey (1955, 1991) gave detailed information about Trécul's travels in southern and central Texas, including an outline of his route and some collection numbers. Further information on Trécul can be found in Jovet and Willmann (1957).

In 1852, George G. Shumard (1825–1867), surgeon on R.B. Marcy's expedition to explore the Red River (Marcy 1853), collected 200 plant species (Winkler 1915). Torrey (1853) published a list of species from this expedition, along with 20 excellent illustrations, some of which are reproduced in this flora.

Another interesting early contributor to Texas botany was Samuel Botsford Buckley (1809–1884). He first came to Texas in 1859, twice served as State Geologist of Texas, and collected plants in various parts of the state. He also served at one time as the official State Botanist (Studhalter 1931). According to L. Dorr (pers. comm.), "… it should be noted that Buckley was the first botanist to collect in Texas who then described new taxa from his own collections. Asa Gray took great exception to this infringement upon his virtual monopoly on publishing on Texas plants and Gray published several scathing reviews of Buckley's work. Buckley published in excess of 100 taxa of Texas plants, a number of which are recognized today." Several of Buckley's scientific papers were published in the *Proceedings of the Academy of Natural Sciences of Philadelphia* (e.g., Buckley 1861 [1862]), including his rebuttal to Gray's criticisms (Buckley 1870). One of the best known species described by Buckley is *Quercus shumardii*, Shumard's red oak, which he named for B.F. Shumard, a geologist under whose direction he once worked. Buckley's name is remembered in *Quercus buckleyi*, Texas red oak (Dorr & Nixon 1985). Detailed information about Buckley's life and work can be found in Dorr and Nixon (1985) and Dorr (1997).

It should be noted that early Texas plant collectors often encountered great difficulties. They endured conditions hardly imaginable today, and often made great sacrifices (Hatter 1991). For example, both Berlandier and Lindheimer are reported to have contracted malaria while in Texas, and Julien Reverchon "lost both of his sons to typhoid fever while he was away collecting in West Texas" (Hatter 1991). Further, large numbers of specimens were often lost during shipment or through various types of damage. To work today with herbarium specimens from these early botanists or to read their first-hand accounts is to look through important windows back in time to a Texas very different than we know today.

Botany was also being taught in Texas schools prior to the Civil War. According to Studhalter (1931), in "the various institutions of higher learning in the state, the subject of botany, together with many other sciences, received a surprising amount of attention." Charles Wright taught at Rutersville College in Fayette County in 1845–46, and his work there "represents some of the first science field-work done in the schools of Texas" (Geiser 1948a). Also among the earliest schools in the state teaching botany, physics, and chemistry was Austin College, established in 1849 (Studhalter 1931).

After the Civil War to the End of World War II / 1865–1945

While much of the post-Civil War botanical history is covered in the section on Modern Centers of Botanical Research in Texas, a number of important contributions warrant mention here.

One of the earliest significant collections of East Texas plants was by Elihu Hall (1822–1882). Hall collected for a variety of subscribers, including Asa Gray, and in 1873 he published *Plantae Texanae: A List of the Plants Collected in Eastern Texas in 1872, and Distributed to Subscribers*. This was a compilation of the 861 species that he had collected in the eastern part of the state and as such represented one of the earliest plant inventories of that part of Texas. A number of specific epithets honor Hall, including those of *Dalea hallii*, Hall's dalea, *Panicum hallii*, Hall's witch grass, and *Schoenoplectus hallii*, Hall's bulrush.

Maude Jeannie Young (1826–1882), the first woman botanist in Texas, taught botany in Houston, collected plants, and in 1873 published *Familiar Lessons in Botany with Flora of Texas*. This extensive work (646 pages) is reported to be "the first text in any science written within the state" (Studhalter 1931; Todzia 1998). According to Dorr and Nixon (1985), "It is a curious book. The major portion of the Flora was copied verbatim from Chapman's *Flora of the Southern United States* (1860), Mrs. Young's editorial contribution consisting of the deletion of taxa not present or expected to be present in Texas, occasional notes on the distribution of species within Texas and the description of one new species of plant." Nonetheless, according to Studhalter (1931), "too much emphasis cannot be directed toward the courage which Mrs. Young showed throughout her work on this, the first science text for Texas. With almost no formal education, with no opportunities for travel or study in herbaria, she nevertheless accomplished the herculean task of publishing a 646 page text and flora. . . ." Studhalter (1931) also noted that Young held the position of State Botanist for two or three years around 1872–1873. Her herbarium was lost in the disastrous hurricane and flood at Galveston in 1900.

FIG. 142/ JOHN KUNKEL SMALL (1869–1938). USED WITH PERMISSION OF THE HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION, CARNEGIE MELLON UNIV., PITTSBURGH, PA; PHOTOGRAPH BY GEORGE F. WEBER.

Other relatively early (pre-1945) contributions to the understanding of Texas botany were those by T.V. Munson (1883), *Forests and Forest Trees of Texas*; V. Havard (1885), *Report on the Flora of Western and Southern Texas*; J.M. Coulter (1891–1894), *Botany of Western Texas*; J.E. Gow (1905), *An Ecological Study of the Sabine and Neches Valleys, Texas*; J.W. Blankinship (1907), *Plantae Lindheimerianae, Part III*; I.M. Lewis (1915), *The Trees of Texas* (the first guide to Texas trees); C.H. Winkler (1915), *The Botany of Texas*; R.M. Harper (1920), *A Week in Eastern Texas*; E.D. Schulz (1922), *500 Wild Flowers of San Antonio and Vicinity* and (1928), *Texas Wild Flowers*; W.A. Silveus (1933), *Texas Grasses*; and M.C. Metz (1934), *A Flora of Bexar County, Texas*. While neither done in Texas nor focusing primarily on Texas plants, J.K. Small's (Fig. 142) *Flora of the Southeastern United States* (1903 and subsequent editions), did include the eastern portion of Texas within its range. This huge work (1370 pages) was a landmark in the study of plants of the entire southeastern United States and was the standard used by generations of southern botanists. Unfortunately, its long use in parts of Texas not intended to be covered by the work resulted in the misidentification of hundreds of herbarium specimens, some of which were later found to represent new species.

HISTORY OF TEXAS BOTANICAL SPECIMENS

While a great deal of work was conducted in the 1800s on Texas plants, most of the research was accomplished by non-residents or was funded by outside sources. The result was that few of the estimated 125,000–150,000 (B. Lipscomb, unpublished) early collections remained in the state. According to Shinners (1949),

> Pioneer collectors [in Texas] were either sent from Europe, or were patronized by botanists in the older parts of the United States. Not until the late 1890s did a Texas institution begin serious study of the flora of the state. Just fifty years ago [now about 110 years ago], W.L. Bray made collections more or less incidentally to ecological studies of the vegetation. These were the earliest collections to remain permanently in Texas and were the beginning of what is now the largest herbarium in the state, that of the University of Texas [at Austin].

Over the past century this situation has changed greatly. As a result of various state and local floristic projects and the collecting efforts of numerous individuals, well over two million herbarium specimens are now kept in Texas. Nearly 40 herbaria are active in the state. The three largest are the Plant Resources Center at the University of Texas at Austin, with about 1,100,000 specimens (including the University of Texas and Lundell Herbaria), which make it the 12th largest in the U.S.—Morin & Spellenberg 1993); the Botanical Research Institute of Texas in Fort Worth, with approximately 1,000,000 specimens (including the Southern Methodist University, Vanderbilt University, and Southeastern Oklahoma State University collections), the 13th largest in the U.S. (Morin & Spellenberg 1993); and the S.M. Tracy Herbarium of the Department of Rangeland Ecology and Management of Texas A&M University, with over 217,000 specimens (Simpson 1996; Holmgren et al. 2004). A substantial number of very early Texas collections have been returned to the state through the efforts of Lloyd Shinners and exchanges with the Milwaukee Public Museum and the Missouri Botanical Garden. For example, slightly less than 1,400 early Texas specimens (dating back to 1839) collected by Ferdinand Lindheimer, Julien Reverchon, Charles Wright, and others are now in the collection at the Botanical Research Institute of Texas (Shinners 1949).

Further information on the history of botany in Texas can be obtained from Winkler (1915), Geiser (1936, 1939, 1945a, 1948a, 1948b), Shinners (1949, 1958), and McKelvey (1955, 1991).

Modern State-Wide or Regional Floras

Fig. 143/ Donovan Stewart Correll (1908–1983). Reprinted by permission from Economic Botany 38:135, Bernice G. Schubert, copyright 1984, the New York Botanical Garden, Bronx, NY.

The first attempt at a comprehensive statewide flora was the three volume *Flora of Texas* by C.L. Lundell (1961, 1966, 1969). While never completed, this project of the Texas Research Foundation at Renner (near Dallas) was a valuable contribution to the knowledge of Texas plants. The Texas Research Foundation subsequently published the *Manual of the Vascular Plants of Texas* (Correll & Johnston 1970), which after nearly four decades is still the only comprehensive flora (including keys and descriptions) that treats the entire state. Donovan Stewart Correll (1908–1983) (Fig. 143) was born in North Carolina and trained at Duke University. After serving at Harvard University and the United States Department of Agriculture, he came to the Texas Research Foundation in 1956. There his most important contribution was to direct and complete the *Manual* project. His research specialties included potatoes (*Solanum*), ferns, the Orchidaceae, and economic botany (Schubert 1984). With his wife, Helen B. Correll, he authored the influential and still widely used *Aquatic and Wetland Plants of Southwestern United States* (1972, 2002). Subsequent to his work at the Texas Research Foundation, he served at the National Science Foundation and Fairchild Tropical Garden. Marshall Conring Johnston (1930–) (Fig. 144), a native Texan reared in the brush country of the Rio Grande delta, spent his career in the Botany Department at the University of Texas at Austin. His research specialties include the Euphorbiaceae, Rhamnaceae, and floristics of Texas and Mexico. His contributions are described in more detail below in the section on the University of Texas.

Another floristic treatment that was state-wide in scope was Frank Gould's (1975b) *The Grasses of Texas*. That work covered 523 species of Poaceae and is still considered the standard for the study of Texas grasses. Gould's contributions are discussed further in the section on Texas A&M University.

Another family that has received thorough coverage state-wide and beyond is the Cactaceae. Lyman Benson's work (1982) and books (1970, 1984a) by Del Weniger (1923–-1999) provide detailed information about cacti in the state. Weniger, who spent much of his career at Our Lady of the Lake University in San Antonio, is also well known for his *Explorers' Texas: The Lands and Waters*, published in 1984.

FIG. 144/ MARSHALL CONRING JOHNSTON (1930–). PHOTO FROM DUST JACKET OF *MANUAL OF THE VASCULAR PLANTS OF TEXAS* (CORRELL & JOHNSTON 1970).

At present there are a few long-term state-wide flora projects ongoing in Texas. These include a revision of the *Manual* being undertaken by David E. Lemke of Texas State University-San Marcos and the various projects of the Flora of Texas Consortium (FTC), conceived by the Botanical Research Institute of Texas (BRIT), with founding members including BRIT, Southwest Texas State University (now Texas State University-San Marcos), Texas A&M University, and the University of Texas at Austin. The goal of the FTC's Flora of Texas project is to create an electronic database of information about the more than 5,000 taxa of native and naturalized vascular plants of Texas, to make these data accessible via the internet, and to use the information to support botanical studies, including the production of floras. Extensive online information can be accessed at the Flora of Texas Consortium's homepage (http://www.csdl.tamu.edu/FLORA/ftc/ftchome.htm). An outgrowth of the original FTC project is the Digital Flora of Texas, whose products, including images, prototype web-based keys, bibliographic references, and various checklists, may be found at http://www.texasflora.org. Stephan Hatch (2002) of Texas A&M University is also preparing a state-wide revision of Gould's (1975b) *The Grasses of Texas*.

The publication in 1969 of the two Texas volumes in the *Wildflowers of the United States* series by Harold William Rickett was also a major contribution. Approximately 2,700 species were covered in a total of 553 pages (including descriptions and extensive color photographs). At the time of publication, it was the most thorough and detailed work on the Texas flora ever published.

Another slightly different state-wide effort is the Useful Wild Plants (UWP) Project headed by Scooter Cheatham. This is one of the most extensive botanical projects ever undertaken in the state, and more than two decades of work have already been devoted to the effort. The first goal of the project is "to complete and publish a comprehensive twelve volume encyclopedia that describes over 4,000 Texas plants, discusses in detail their past, present, and future value, and provides color photographs and distribution maps for each species" (Useful Wild Plants 2001). Two volumes (Cheatham & Johnston 1995, 2000) have already been published, with others nearly ready for printing or partially finished. When completed, this landmark multi-volume work, titled *The Useful Wild Plants of Texas, the Southeastern and Southwestern United States, the Southern Plains, and Northern Mexico*, will be the definitive economic botany study of the southern half of the United States and northern Mexico. Information about the project can be obtained online at http://www.usefulwildplants.org.

On a more local scale, the Illustrated Texas Floras Project, a collaboration between BRIT and the Austin College Center for Environmental Studies, is attempting to produce illustrated floras for various parts of the state. This volume is the second in that series. *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999), which covered approximately 46% of the species in Texas, was the first fully illustrated flora for any region of Texas or adjacent states. The current *Illustrated Flora of East Texas* project, when completed, will give detailed coverage of approximately two-thirds of the state's plants.

Floras are also available for some other regions of the state, including South Central Texas (Reeves & Bain 1947), the Big Bend (McDougall & Sperry 1951), North Central Texas (Shinners 1958; Mahler 1984, 1988), the Texas Coastal Bend (Jones et al. 1961; Jones 1975, 1977, 1982), Central Texas (Reeves 1972, 1977), the Edwards Plateau (Stanford 1976), southernmost Texas (Richardson 1990), Brazos and surrounding counties (Reed 1997), and the Rio Grande Delta (Richardson 1995). More specialized works (e.g., treatments of trees and shrubs, grasses, or ferns) are available for some regions of the state (e.g., Austin and the Hill Country (Lynch 1981); East Texas (Nixon 1985, 2000); Lower Rio Grande Valley (Lonard 1993); Trans-Pecos (Powell 1988, 1994, 1998; Yarborough & Powell 2002)).

MODERN CENTERS OF BOTANICAL RESEARCH IN TEXAS

(1900 TO THE PRESENT)

While there has been important botanical work at numerous institutions and locations throughout the state, there are three centers where sustained botanical research, spanning many decades and involving numerous botanists, has been carried out. In addition, the three largest herbaria in the state, located in these centers, reflect this ongoing activity. These centers are North Central Texas, the University of Texas at Austin, and Texas A&M University. Each will be discussed separately, with the understanding that there has been overlap and cooperation. A final section will discuss other important contributions to Texas botany.

North Central Texas

Early Contributions / prior to 1970

Fig. 145/ Julien Reverchon (1837–1905). Image obtained from Shirley Lusk, a descendant of Reverchon (image reported to have been published in "A History of Dallas County").

Fig. 146/ Albert Ruth (1844–1932). From the collection of the Fort Worth Public Library.

Botanical exploration, observation, and collecting in North Central Texas occurred as early as the mid-1800s (e.g., Smythe 1852; Parker 1856; Buckley—See Dorr & Nixon 1985; Munson 1883, 1909—see McLeRoy & Renfro 2004), with the first botanist to collect extensively in the north central part of the state being Julien Reverchon (Fig. 145). Reverchon's botanical work spanned the years 1856–1905, with most of his collecting after 1869. By the time of his death in 1905, Reverchon's collection numbered about 20,000 specimens of more than 2,600 Texas species. It was the best collection of the state's flora then in existence (Geiser 1948a). Reverchon corresponded extensively with Asa Gray, one of the leading American botanists of the nineteenth-century, and was even visited by Gray. Reverchon was a member of the Torrey Botanical Club, published a number of scientific papers (e.g., Reverchon 1879, 1880, 1903), and during the last decade of his life served as Professor of Botany in the Baylor University College of Medicine and Pharmacy at Dallas (Geiser 1948a). Gray named the monotypic genus *Reverchonia* (Euphorbiaceae) in his honor (Geiser 1948a), as well as the Texas endemic *Campanula reverchonii*, basin bellflower.

A number of other botanists were important in the Dallas-Fort Worth area. Albert Ruth (1844–1932) (Fig. 146) was the first active botanist in Fort Worth. He collected primarily in Tarrant County but did some work as far away as Bexar and Garza counties (Shinners 1958). A number of his collections are now in the BRIT herbarium, and BRIT has in its library a lengthy unpublished typescript by Ruth of a *Manual of Texas Flora*. William Larrey McCart was also active in the area, doing extensive and well-organized collecting, particularly from 1937 to 1940. According to Shinners (1958), it was the best organized and most thorough work on the state's flora being carried out during that time. Approximately 4,000 of his specimens are now incorporated into the BRIT herbarium. Yet another early contributor was Norma Stillwell,

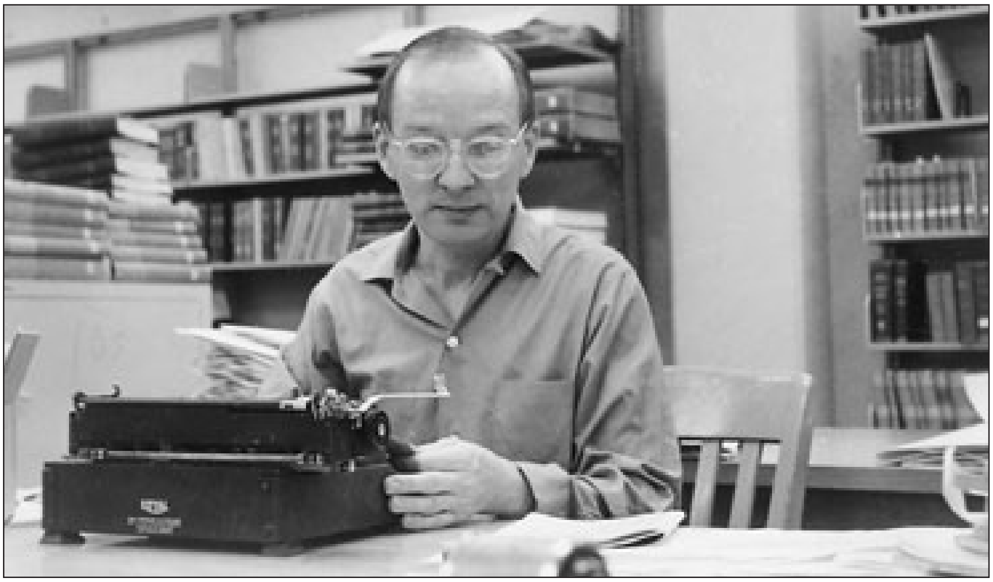


FIG. 147/ LLOYD HERBERT SHINNERS (1918–1971). FROM THE COLLECTION OF THE BOTANICAL RESEARCH INSTITUTE OF TEXAS.

who published her *Key and Guide to the Woody Plants of Dallas County* (1939), a pamphlet treating some 90 species. This publication was, according to Shinners (1958), "the first independent publication dealing with our local flora."

From the 1940s to the 1980s, Southern Methodist University was an important center of botanical activity in North Central Texas. Botanists there in the 1940s included Eula Whitehouse (see Flook 1974 for more information), Victor L. Cory, Cyrus L. Lundell, and Lloyd Shinners. While housed in Dallas, these and later botanists focused their research efforts throughout the state. Many of the most important East Texas collections were made by these botanists and their associates.

Without a doubt, the most influential twentieth-century North Central Texas botanist was Lloyd Herbert Shinners (1918–1971) (Fig. 147), a native Canadian who received his botanical training at the University of Wisconsin-Madison. Two genera (*Shinnersia* and *Shinnersoseris*—both in the Asteraceae) are named in his honor. He collected broadly across the whole state, but particularly in the Dallas area, in the extreme northeastern part of the state, and in western Texas. He came to Southern Methodist University in 1945, became the Director of the Herbarium in 1949, and was on the faculty there until his death (Mahler 1971b). Not only did he almost single-handedly develop the herbarium which today forms the core of the collection at BRIT, but he also created one of the best botanical libraries in the United States, did extensive field work, and published a total of 276 articles and a 514-page flora (Flook 1973). His contributions to botanical nomenclature are particularly impressive, totaling 558 new scientific names and combinations (Flook 1973). Among his most lasting achievements are the *Spring Flora of the Dallas-Fort Worth Area Texas* (Shinners 1958) and the journal, *Sida, Contributions to Botany*, which he founded in 1962 (Mahler 1973b). Shinners' *Spring Flora* was the first completed, original, technical book on Texas plants prepared by a resident of the state. It was extensively used by high schools, colleges, and universities as a textbook for classes and is still in use today. For a synopsis of Shinners' life, see Mahler (1971b); for a guide to his botanical contributions, see Flook (1973); for a recently published biography, see Ginsburg (2002). Shinners' appreciation for plants can be seen in the following quote: "…nothing of course can take the place of seeing the plants live, again and again, year after year" (Shinners 1958).

Eula Whitehouse (1892–1974) (Fig. 148) is best known for her *Texas Flowers in Natural Colors* (1936), the first color-illustrated guide to Texas wildflowers (Flook 1974). She worked at the Houston Municipal Hospital, the Texas Memorial Museum in Austin, the University of Texas College of Mines, and Southern Methodist University. She worked on various plant groups (e.g., *Phlox* for her Ph.D. dissertation) and while at SMU studied bryophytes (Whitehouse & McAllister 1954), published taxonomic revisions (e.g., Whitehouse 1945, 1949), and did extensive art work. Some of her illustrations were used in Shinners' *Spring Flora* and are reproduced in this volume.

FIG. 148/ EULA WHITEHOUSE (1892–1974). FROM THE COLLECTION OF THE BOTANICAL RESEARCH INSTITUTE OF TEXAS.

Another important North Central Texas botanist was Cyrus Longworth Lundell (1907–1994) (Fig. 149). While he formally organized the SMU herbarium in 1944, Lundell is best known as founder of the Texas Research Foundation (Renner), author (with collaborators) of the *Flora of Texas*, and a specialist on the Myrsinaceae. His institute was instrumental in establishing Texas as an important center of taxonomic botany. Lundell's herbarium (official abbreviation: LL) is now part of the collection at the University of Texas at Austin. He and his wife, Amelia, are also honored by the name of the journal, *Lundellia*, published by the Plant Resources Center at that institution.

FIG. 149/ CYRUS LONGWORTH LUNDELL (1907–1994). WORKING IN FRONT OF HIS THATCHED HUT HEADQUARTERS AT TIKAL, GUATEMALA. FROM THE COLLECTION OF THE BOTANICAL RESEARCH INSTITUTE OF TEXAS.

Recent Contributions / 1970–2005

Fig. 150/ William Fred "Bill" Mahler (1930–). Photo courtesy of W.F. Mahler.

More recently, William F. "Bill" Mahler (1930–) (Fig. 150), Director Emeritus of BRIT, had an extensive role in the botany of the North Central part of the state. He joined the faculty of Southern Methodist University in 1968, became editor of *Sida* in 1971, and assumed leadership of the herbarium in 1973. Mahler is probably best known for his *Shinners' Manual of the North Central Texas Flora* (1984, 1988), well known for its clarity and ease of use. This manual was a revision of Shinners' (1958) *Spring Flora of the Dallas-Fort Worth Area Texas*, expanded to include the summer and fall flora for North Central Texas. Other notable publications by Mahler were the *Keys to the Plants of Black Gap Wildlife Management Area, Brewster County, Texas* (1971a), *Flora of Taylor County, Texas* (1973a), and *The Mosses of Texas* (1980), an elaboration upon Eula Whitehouse's research on the mosses of the state. Mahler's specialties included Fabaceae, *Baccharis* (Asteraceae), mosses, floristics, and the study of endangered species. He served as the first Director of the Botanical Research Institute of Texas (1987–1992) and along with Barney Lipscomb and Andrea McFadden, was instrumental in its establishment as a free-standing research institution.

The Botanical Research Institute of Texas (BRIT) in Fort Worth is currently the center of botanical activity in North Central Texas, with active research, education, and public outreach programs. Its plant collection (including those formerly at Southern Methodist, Vanderbilt, and Southeastern Oklahoma State universities) includes approximately 1,000,000 specimens and its library has over 75,000 volumes. As such, it represents one of the most important centers of botanical information in the southwestern U.S. It also has one of the largest concentrations of professional taxonomic botanists in the southwestern United States. Four nationally prominent scientists have relocated to BRIT to continue their research. These are Theodore M. Barkley (1934-2004; formerly of Kansas State University), Robert Kral (formerly of Vanderbilt University), Joe F. Hennen (formerly of Purdue University), and Henri Alain Liogier (formerly of the Botany Garden of the University of Puerto Rico-San Juan). Other professional biologists or research associates in residence (full or part time) at BRIT are Justin Allison, George Diggs, Tiana Franklin, Robert George, John Janovec, Helen Jeude, Barney Lipscomb, Caren McLemore, Amy Nare-Trauth, Amanda Neill, Guy Nesom, Robert O'Kennon, Roger Sanders, S.H. Sohmer, and Dora Sylvester. This volume is a product of the Illustrated Texas Floras Project, a collaboration between BRIT and the Austin College Center for Environmental Studies.

Jack Stanford (1935–), of Howard Payne University in Brownwood on the very southwest margin of North Central Texas, made an important contribution to the knowledge of Texas botany with his publication in 1976 of *Keys to the Vascular Plants of the Texas Edwards Plateau and Adjacent Areas*. That work covered portions of the Lampasas Cut Plain, which is included in recent delineations of North Central Texas (e.g., Diggs et al. 1999). Stanford has also done extensive collecting in the Lampasas Cut Plain and Edwards Plateau and has found many important distributional records (see e.g., Stanford & Diggs 1998).

Baylor University in Waco also has a tradition of botanical studies. Fred R. Gehlbach made contributions to knowledge of the Edwards Plateau and the genus *Acer* and co-authored *Edwards Plateau Vegetation: Plant Ecological Studies in Central Texas* (Amos & Gehlbach 1988). More recently, Walter H. Holmes, a specialist on the genus *Mikania* (Asteraceae), has made numerous collections and published extensively on plant distributions in Texas and surrounding areas. His work with Jason R. Singhurst (Texas Parks and Wildlife Department), one of the best field botanists in Texas, has resulted in many significant range extensions and publications (e.g., Singhurst & Holmes 2001a, 2001b; Singhurst et al. 1997, 2002a, 2002b, 2003a, 2003b), including a number of state records. Recently, Holmes provided treatments of *Alstroemeria*, *Crinum*, *Hippeastrum,* and *Smilax* (Holmes 2002a, 2002b, 2002b, 2002d) for the newly published Liliales and Orchidales *Flora of North America* volume.

Nelson Rich and his students at Collin County Community College are actively engaged in an ongoing inventory of the plants of Collin County (Rich 2004).

Another important figure in the history of botany in North Central Texas and the state as a whole is Benny J. Simpson (1928–1996) (Fig. 151) (see Diggs et al. 1999, Appendix 15). Having served for many years with the Texas Research Foundation and later with the Texas A&M Research and Extension Center at Dallas, Simpson is possibly best known as the author of *A Field Guide to Texas Trees* (Simpson 1988). For a full list of his publications see Davis (1997). However, among botanists and native plant enthusiasts, he is correctly best remembered as the "Pioneer of the Native Plant Movement" in Texas (Nokes 1997). Simpson understood that the scarcity of water is one of the biggest challenges facing Texas' future and that native plants, well-adapted to the state's climate, are an important resource (e.g., Simpson & Hipp 1984; Simpson 1993). Through his research, nine superior selections of native plants were released to the nursery industry, including three forms of *Leucophyllum* (Scrophulariaceae), widely known as Texas purple-sage (Nokes 1997; Kiphart 1997). In addition to his other contributions, Simpson was one of the founding members and a former president of the Native Plant Society of Texas and was active in that organization until his death (Nokes 1997; Pickens 1997). Extensive information and photographs of Texas trees (by Benny Simpson) can be found at Benny Simpson's Texas Native Trees website (http://aggie-horticulture.tamu.edu/ornamentals/natives/tamuhort.html) maintained by the Texas Agriculture Experiment Station (Mackay et al. 2003).

FIG. 151/ BENNY J. SIMPSON (1928–1996). USED WITH PERMISSION OF THE NATIVE PLANT SOCIETY OF TEXAS.

In the past, most of the botanical work in North Central Texas has been completed at private institutions, a tradition which continues today. Until the 1970s and 1980s respectively, the Texas Research Foundation and Southern Methodist University were leaders in the field. In recent years, Austin College, Baylor University, the Botanical Research Institute of Texas, Howard Payne University, Texas Christian University, and Texas Wesleyan University have all been actively engaged in botanical research. A number of public colleges and universities in the area also have taxonomic botanists. Among these are Paris Junior College, Tarleton State University, the University of North Texas, and the University of Texas at Arlington.

Other notable individual contributors to the botany of North Central Texas include Robert Adams (Baylor University), Geyata Ajilvsgi (Austin), John Bacon (University of Texas at Arlington), Bruce Benz (Texas Wesleyan University), Lewis Bragg (University of Texas at Arlington), M.D. "Bud" Bryant (Austin College), William Carr (The Nature Conservancy of Texas), Wayne Clark (Fort Worth Nature Center), Sally Crosthwaite (Austin College), Arnold Davis (Native Prairies Association of Texas), Charles Finsley (Dallas Museum of Natural History), Hugh Garnett (Austin College), Harold Gentry (Grayson County), Glenn Kroh (Texas Christian University), George High (Austin), Harold Keller (Central Missouri State University), Joe Kuban (Nolan High School, Fort Worth), Shirley Lusk (Denton), David Montgomery (Paris Junior College), Jeff Quayle (Fort Worth), Elray Nixon (Las Vegas, Nevada), Donald Smith (University of North Texas), David Riskind (Texas Parks and Wildlife Department), John Steele (BRIT), Connie and John Taylor (Southeastern Oklahoma State University), Geoffrey Stanford (Dallas Nature Center), Jerry Vertrees (Texas Wesleyan University), and Sally Wasowski (Taos, New Mexico).

A number of scientific journals originated in North Central Texas, including *Field & Laboratory*; *Wrightia*; *Sida, Contributions to Botany*; and *Sida, Botanical Miscellany. The Southwestern Naturalist*, a prominent regional natural history journal, also has close ties to North Central Texas, with Lloyd Shinners having served as its co-founder and first editor.

More information about the history of botany in North Central Texas can be found in Shinners (1958) and Diggs et al. (1999).

FIG. 152/ MARY SOPHIE YOUNG (1872–1919) AND HER MULE, NEBUCHADNEZZAR. FROM *SOUTHWESTERN HISTORICAL QUARTERLY* 65:366–393, 512–538, EDITED BY B.C. THARP & C.V. KIELMAN, ©1962. COURTESY TEXAS STATE HISTORICAL ASSOCIATION, AUSTIN.

UNIVERSITY OF TEXAS AT AUSTIN

In the 1890s, Professor Frederick W. Simonds, though interested mainly in geology, began to prepare a few botanical specimens at the new state university in Austin. Soon thereafter (1898), William L. Bray was installed as the first Professor of Botany at the University of Texas. Bray, who was active in the study of Texas vegetation, and his students (e.g., A.M. Ferguson and W.H. Long) added to the small herbarium begun by Simonds. Among the various works published by Bray were *Ecological Relations of the Vegetation of Western Texas* (Bray 1901a) and *Distribution and Adaptation of the Vegetation of Texas* (Bray 1906). Following Bray, Professor Frederick DeForest Heald made additional collections, but it was not until Mary Sophie Young (1872–1919) (Fig. 152) that the herbarium at the University of Texas expanded dramatically, from 2,500 to more than 16,000 specimens (Turner & Johnston 1971). Young made important plant collections in various parts of the state, including the Panhandle and Trans-Pecos, until her untimely death. Her publications included *A Key to the Families and Genera of the Wild Plants of Austin Texas* (Young 1917) and *The Seed Plants, Ferns, and Fern Allies of the Austin Region* (Young 1920).

Benjamin Carroll Tharp, one of Young's students, replaced her and made major contributions to Texas botany during a career spanning 45 years (1919–1964). Possibly his most lasting contribution was the building of the University of Texas herbarium from 16,000 to 200,000 specimens, in the process raising it from "regional obscurity to wide recognition" (Turner & Johnston 1971). His published contributions include the landmark *Structure of Texas Vegetation East of the 98th Meridian* (1926), *The Vegetation of Texas* (1939), and *Texas Range Grasses* (1952a). Among Tharp's students were L.C. Hinckley (working mostly in the Trans-Pecos), C.H. Muller (well known for his study of oaks and Mexican plants), and B.H. Warnock (who was to become the recognized authority on the plants of the Trans-Pecos). From 1942 to 1947, F.A. Barkley did taxonomic research at the University of Texas, working with Tharp and eventually contributing to the herbarium in the capacity of curator. Botany was established as a separate department at the University of Texas in 1949, and the new chair, W. Gordon Whaley, was charged with developing an excellent department (Turner 1999a).

In 1954, Billie Lee Turner (1925–) (Fig. 153), a student of L.H. Shinners (M.S.) and M. Ownbey (Ph.D.), arrived at the University of Texas to begin a career that would span nearly half a century. Among his contributions were *The Legumes of Texas* (Turner 1959) and extensive work with colleague Ralph E. Alston on the "*Baptisia* project," a series of studies on hybridization in that genus. Turner supervised the doctoral programs of over 60 students, including such stellar individuals as H.S. Irwin (co-author of *Roadside Flowers of Texas*). Turner was also one of the individuals responsible for developing the Botany Department at the University of Texas at Austin into one of the best known and most respected departments in the United States. Turner is still actively contributing to Texas botany, having recently co-authored the landmark *Atlas of the Vascular Plants of Texas* (2 volumes) (Turner et al. 2003). This work, incorporating the knowledge gained from a lifetime of study of Texas plants, is the first work providing distribution maps for all the native and naturalized plants of the state. Turner is also engaged in publishing the multi-volume *The Comps of Mexico: A Systematic Account of the Family Asteraceae* (e.g., Turner 1996, 1997), and is writing *The Comps of Texas* with co-author Guy Nesom. In addition, the University of Texas herbarium grew tremendously under the leadership of Turner, resulting in its current size of more than a million specimens.

FIG. 153/ BILLIE LEE TURNER (1925–). PHOTO COURTESY OF BILLIE LEE TURNER.

With the addition of T.J. Mabry in 1961, phytochemical research at the University of Texas expanded, eventually resulting in such publications as *Biochemical Systematics* (Alston & Turner 1963), *The Systematic Identification of Flavonoids* (Mabry et al. 1970), and *Plant Chemosystematics* (Harborne & Turner 1984).

In 1967, Marshall C. Johnston (Fig. 144) was officially appointed as a faculty member at the University of Texas. His most important contributions include co-authoring the *Manual of the Vascular Plants of Texas* (Correll & Johnston 1970), authoring two lists (Johnston 1988, 1990) updating that work, and co-authoring volumes produced by the Useful Wild Plants Project (Cheatham & Johnston 1995, 2000).

By the 1970s and early 1980s, the University of Texas Department of Botany was ranked as the number one botany department in the U.S., if not the world (Turner 1999a). Numerous highly respected scientists had been assembled and were actively producing research. In addition to those mentioned above were such well known figures as C.J. Alexopoulos, H.C. Bold, and R. Starr. Four University of Texas botanists, Harold Bold, Verne Grant, Jack Myers, and Richard Starr, were elected to the National Academy of Sciences (B.L. Turner, pers. comm.). Verne Grant, the author of numerous books and articles (e.g., Grant & Grant 1965; Grant 1971, 1975), though retired, continues to publish actively (e.g., Grant 2001a, 2001b, 2004) and to assist and encourage other botanists in their research.

Since the early 1980s, many additional botanists have made major botanical contributions at the University of Texas, with recent research focused primarily on tropical regions (particularly Mexican) and biochemical/molecular topics. Botanists recently associated with the University of Texas include Bill Carr, Barbara Ertter, Paul Fryxell, Larry Gilbert, Jim Henrickson (working on the Chihuahuan Desert Region flora project), Robert Janzen, Karen Clary, Blanco Leon, Don Levin, Guy Nesom, José Pinero, Jackie Poole, Beryl Simpson, Carol Todzia, Tom Wendt, and Lindsay Woodruff. In addition, there have been numerous graduate students who have done important research.

The herbarium has continued to grow to the present. Through the last half of the 1970s and the 1980s, Dr. Cyrus Lundell (Fig. 149) transferred the 450,000 sheet herbarium of the Texas Research Foundation (at Renner near Dallas) to the University of Texas. Other important components of the University of Texas collection include the 8,750 specimen Robert Runyon herbarium (made by this early student of South Texas botany who began collecting there in 1909), as well as the W.A. Silveus grass collection which served as the basis for the first book on *Texas Grasses* (Silveus 1933). As a result of these and other acquisitions and continued collecting, the Plant Resources Center, including LL (Lundell Herbarium), RUNYON (Robert Runyon Herbarium), and TEX, now houses approximately 1.1 million specimens of vascular plants (Morin & Spellenberg 1993). In 1998, a new journal of botanical systematics, *Lundellia* (named in honor of Dr. and Mrs. Cyrus Lundell) was begun by the Plant Resources Center. Extensive botanical data are currently being put online and can be accessed through the Plant Resources Center website (http://www.biosci.utexas.edu/prc/).

In 1999, in a reorganization of biology at the University of Texas, the Botany Department was split between the Cellular and Developmental Biology and the Integrative Biology departments of the newly structured School of Biological Sciences (Turner 1999b).

TEXAS A&M UNIVERSITY

Numerous botanical contributions have been made by scientists working at and associated with Texas A&M University. As a land grant institution, A&M has always had an emphasis on plant sciences. Possibly the earliest botanist at Texas A&M was Greenleaf C. Nealley (1846–1896) (Fig. 154), who arrived on the young campus of Texas A&M College in the year 1882, apparently hired directly by College President John Garland James "to make plant collections" (McVaugh 1946; Geiser 1947). Nealley published an early paper, "*Report of Botany of Brazos County*," according to Geiser (1947), "in the *Sixth Annual Catalogue* of the A. & M. College of Texas, 1883." Nealley also published (March 1883) a "*Report on Texas Grasses*" in the "*Seventh Annual Report* of the college," with his "List of grasses in the college herbarium" at College Station including some 162 species (Geiser 1947). These collections apparently represent the first herbarium at Texas A&M. While only associated with Texas A&M from 1882–1883, Neally collected widely in Texas until 1893, particularly in the Trans-Pecos (McVaugh 1946; Geiser 1947). Formal work in botany began at Texas A&M in 1888 with the appointment of Thomas L. Brunk, a graduate of Cornell University, as Professor of Botany and Horticulture (Geiser 1948b). During 1889–1890, Herbert Spencer Jennings, later of Johns

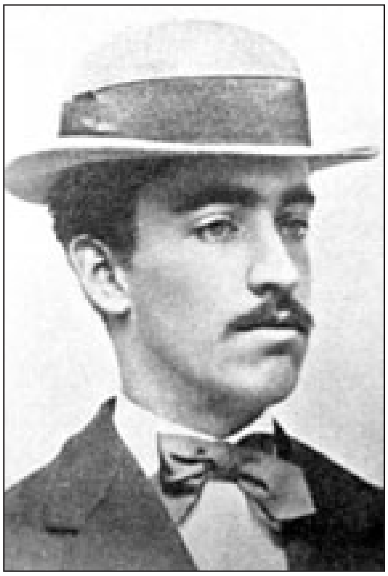


FIG. 154/ GREENLEAF C. NEALLEY (1846–1896) (FROM GEISER 1947).

Hopkins, taught botany and investigated plant diseases in Brazos County. He was succeeded by Helge Ness, who for many years did research on botany and plant breeding (Geiser 1948b).

One of the first major botanical works produced at Texas A&M that is still widely cited today was *The Fauna and Flora of the Big Thicket Area*, published by H.B. Parks (Fig. 109) and V.L. Cory in 1936. This work focused attention on the biologically rich area of the Big Thicket and was the basis of much future work. Cory and Parks collected in many parts of Texas, and some of their specimens remain the only records of some species from certain counties. These two highly productive individuals had numerous other publications (e.g., Cory 1940, 1948, 1949, 1950a, 1950b; Parks 1937), including the *Catalogue of the Flora of the State of Texas* (V.L. Cory & H.B. Parks 1937). This latter work was the earliest attempt to compile a complete list of the vascular plants of the state. Following Cory and Parks' first list, a number of subsequent checklists have been produced by botanists associated with or trained at Texas A&M University. These include *Texas Plants—A Checklist and Ecological Summary* (Gould 1962, 1969, 1975a), *Checklist of the Vascular Plants of Texas* (Hatch et al. 1990), and *Vascular Plants of Texas: A Comprehensive Checklist including Synonymy, Bibliography, and Index* (Jones et al. 1997).

Because of the diverse nature of Texas A&M University, two herbaria currently exist there: the S.M. Tracy Herbarium (TAES), maintained and developed as part of the Department of Rangeland Ecology and Management, and the Biology Department Herbarium (TAMU), initially founded as a departmental facility. A third herbarium, Paul Fryxell's extensive collection of Malvaceae, was present at Texas A&M but is currently at the University of Texas at Austin. The Tracy Herbarium was begun in the early 1930s and was based on early collections of several individuals, among them the outstanding botanist-agriculturist, Samuel M. Tracy (1847–1920) (Fig. 155), for whom the herbarium is named (S.M. Tracy Herbarium 2002a), and possibly G.C. Nealley as well. Tracy's collections of Gulf Coast plants, particularly grasses, provided the nucleus for the development of the present-day herbarium (S.M. Tracy Herbarium 2002b). The herbarium currently has over 200,000 specimens, making it the third largest in the state, exceeded only by those at the University of Texas at Austin and the Botanical Research Institute of Texas. The Tracy Herbarium was listed in 1974 as one of only 105 herbaria in the U. S. designated as National Resource Collections (out of a total of 1,127 U. S. herbaria). The grass collection, possibly the finest in the state, and regarded by many as one of the best in the southwestern U.S., now numbers about 70,000 sheets. (S.M. Tracy Herbarium 2002a).

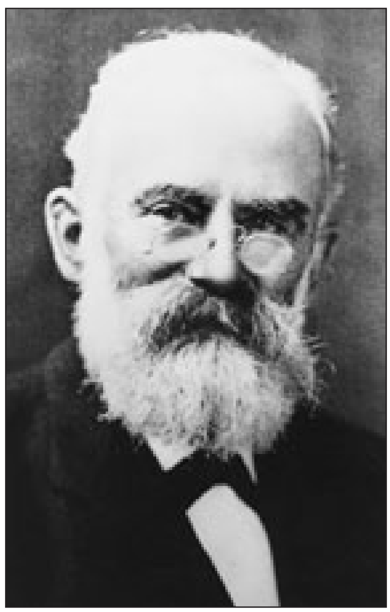


FIG. 155/ SAMUEL MILLS TRACY (1847–1920). PHOTO COURTESY OF S.M. TRACY HERBARIUM.

Frank W. Gould (1913–1981) (Fig. 156), curator at TAES from 1949 to 1979, is without doubt one of the most important figures in the history of botany at Texas A&M University and in the state as a whole. Born in Mayville, North Dakota, he came to Texas in 1949 with a Ph.D. in botany from the University of California at Berkeley. As a professor in the Range Science Department at what was then Texas Agricultural and Mechanical College, he influenced Texas botany in numerous ways. Though his doctoral dissertation was on a *Camassia* (Hyacinthaceae, formerly Liliaceae), he went on to become *the* expert on the grasses of Texas, publishing numerous scientific papers and several books on the subject. To this day, the most used and comprehensive of these is *The Grasses of Texas* published in 1975. That treatment of the more than 500 grasses of the state includes numerous illustrations and is still one of the most usable publications in the country for the identification of grasses. Many of the illustrations in that volume are reprinted here thanks to the generosity of Lucile Gould Bridges, widow of Dr. Gould. Other important works by Gould include *Grasses of the Southwestern United States* (Gould 1951), *Texas Plants—A Checklist and Ecological Summary* (Gould 1962, 1969, 1975a), *Grasses of the Texas Coastal Bend* with Thadis Box (1965), a textbook, *Grass Systematics* (Gould 1968a), and *Common Texas Grasses* (Gould 1978). Besides producing very helpful and practical books, he was also one of the pioneers in using cytotaxonomy (the study of chromosome number, type, and behavior) in his research on the systematics of the grass family. Gould's extensive work received national and even international recognition. Under his leadership, the Tracy Herbarium increased in size from 4,000 to 150,000 specimens (McCarley 1986). The Mexican grass genus *Gouldochloa* (Valdés-Reyna et al. 1986) is named in his honor.

FIG. 156/ FRANK W. GOULD (1913–1981). PHOTO COURTESY OF LUCILE GOULD BRIDGES.

Stephan L. Hatch, now director of the TAES collection, is widely recognized as the foremost current authority on Texas grasses. He and his numerous students have continued the TAES tradition of excellence in grass research with numerous publications, including *Grasses (Poaceae) of the Texas Cross Timbers and Prairies* (Hignight, Wipff, & Hatch 1988), *Texas Range Plants* (Hatch & Pluhar 1993), *Grasses of the Texas Gulf Prairies and Marshes* (Hatch et al. 1999), and a book in preparation updating Gould's (1975b) *Grasses of Texas* (classroom teaching version—Hatch 2002). The publication of *Checklist of the Vascular Plants of Texas* (Hatch et al. 1990 and online at http://www.csdl.tamu.edu-/FLORA/taes/tracy/coverNF.html) was another major achievement. Hatch has also made major contributions to the S.M. Tracy Herbarium, which is currently curated by Dale Kruse. Further, Hatch and colleagues, including Eddy Dawson, have provided extensive online information about grasses, including a list of Texas species, a key to Texas species, extensive floral dissection images, and numerous grass illustrations, etc. (S.M. Tracy Herbarium 2003). One of Hatch's students, Stanley D. Jones, has been very active in Texas botany, particularly through his studies of the genus *Carex* (Cyperaceae). He has numerous publications, often co-authored with Gretchen D. Jones and J.K. Wipff (e.g., Jones 1994a, 1994b, 1999; Jones & Hatch 1990; Jones & Reznicek 1991; Jones & Jones 1992; Jones & Wipff 1992a, 1992b, Jones et al. 1990a, 1990b, 1996, 1997). Also associated with TAES is Ed McWilliams of the Texas A&M Department of Horticultural Sciences. McWilliams is an expert on Texas Bromeliaceae (e.g., McWilliams 1992, 1995) and, though retired, continues to do research on invasive exotics.

The Texas A&M Biology Department Herbarium (TAMU) was founded in 1975. The original plan was for it to focus on cryptogams, but events conspired to shape it as a primarily Texas-focused collection. While relatively small (approximately 50,000 specimens), it is the only Texas herbarium with fully computerized specimen data. Scientists associated with the herbarium include Hugh Wilson (curator), James Manhart, Alan Pepper, and Monique Reed. Manhart has used molecular characters to study phylogenetic relationships of green algae and land plants, including Cyperaceae (e.g., Manhart 1990, 1995; Rettig, Wilson, & Manhart 1992) and is currently, along with Alan Pepper, focusing on conservation genetics, studying the population genetics of rare and endangered species and invasive plants. Wilson studies crop/weed gene flow and systematics of *Cucurbita* and *Chenopodium* and works with endangered *Spiranthes* (e.g., Wilson 1993; Wilson & Manhart 1993; Wang, Tsuchiya, & Wilson 1993; Wilson et al. 1994), and Reed concentrates on floristics (e.g., Canne-Hilliker & Dubrule [Reed] 1993; Reed 1997, 2004; Reed & Ketchersid 1998). Texas A&M graduate students whose works are relevant to this book include Thomas J. Starbuck (flora of Robertson Co.—Starbuck 1984) and Amanda K. Neill (flora of Madison Co.—Neill & Wilson 2001). As a group, the TAMU botanists work with local flora, particularly bog and outcrop plants. Geyata Ajilvsgi spent considerable time at TAMU working on her *Wildflowers of Texas* (Ajilvsgi 1984, 2002). One of the first detailed floras covering a portion of East Texas was the *Manual of the Dicot Flora of Brazos and Surrounding Counties* by Monique Dubrule Reed (1997).

Extensive botanical data can be accessed through TAMU-supported web pages, including the TAMU homepage (http://www.csdl.tamu.edu/FLORA/biolherb/tamuhome.htm), its teaching page (http://www.csdl.tamu.edu/FLORA/tfp/tfphome1.html), the Digital Flora of Texas Herbarium Specimen Browser (http://www.csdl.tamu.edu/FLORA/tracy2/main1.html), and the Vascular Plant Image Gallery (http://www.csdl.tamu.edu/FLORA/bwgpros.htm).

Fred E. Smeins, Department of Rangeland Ecology and Managerment at Texas A&M, has done extensive ecological research on Texas prairies and on the influence of large herbivores, fire, and climatic fluctuations on rangeland ecosystem composition, structure, and function. His numerous publications (e.g., Smeins 1984, 1988, 2004; Smeins & Diamond 1983, 1986; Smeins et al. 1982; Diamond & Smeins 1985, 1993) have been particularly valuable in understanding Texas vegetation.

Other Important Contributions to Texas Botany

Extensive botanical research, particularly of an ecological nature, has been carried out at Stephen F. Austin State University (SFASU) in Nacogdoches. The herbarium there (abbreviation ASTC) houses one of the best collections of East Texas plants outside the three major herbaria in the state. The work of Elray S. Nixon (1931–) (dedication on page XII; Fig. 157) ranks among the most important of the study of East Texas plants. While at SFASU from 1965–1993, Nixon worked extensively on the ecology of East Texas (see Appendix 24 for a bibliography) and produced three books—*Trees, Shrubs and Woody Vines of East Texas* (Nixon 1985, 2000), *Plant Characteristics, Aids to Plant Identification* (Nixon & Anderson 1989), *Ferns and Herbaceous Flowering Plants of East Texas* (Nixon & Kell 1993)—and numerous articles (e.g., Sullivan & Nixon 1971; Nixon et al. 1977; Nixon et al. 1990). This plant ecology tradition is being ably continued today by James Van Kley, who specializes in the vegetation of the Pineywoods, particularly the Caddo Lake ecosystem (e.g., Van Kley & Hine 1998). An example of Van Kley's work can be seen in the introduction of this book—he contributed the section on the Pineywoods.

Robert A. Vines (1907–1978), of the Museum of Natural History of Texas, the Houston Arboretum and Botanical Garden, and the Robert A. Vines Environmental Science Center (SBSC) of the Spring Branch Independent School District in Houston, made important contributions to the understanding of woody plants in Texas. His publications include *Native East Texas Trees* (1953), *Trees, Shrubs and Woody Vines of the Southwest* (1960), and

FIG. 157/ ELRAY NIXON (1931–), WITH BOB O'KENNON (LEFT) BESIDE AN INDIVIDUAL OF *CRATAEGUS NANANIXONII* (ROSACEAE), AN EAST TEXAS ENDEMIC NAMED FOR NIXON (PHOTO BY RJO).

Trees of East Texas (1977). The collections of Larry E. Brown at the Vines Environmental Science Center are particularly important for the study of East Texas plants. Brown's work, including efforts at the Big Thicket National Preserve and the Trinity River National Wildlife Refuge, has resulted in numerous distributional records and extensive publications (e.g., Brown 1993; Brown & Peterson 1984; Brown & Gandhi 1989; Brown & Marcus 1998; Brown & Elsik 2002; Brown et al. 2002a; Brown et al. 2002b; Evans & Brown 2002; Hatch, et al. 1990). He is widely regarded as one of the finest field botanists in East Texas.

Michael H. and Barbara R. MacRoberts, of Bog Research and Louisiana State University, Shreveport, while not residents of the state, are two of the most prolific researchers on the plants of East Texas. Their numerous publications (e.g., MacRoberts & MacRoberts 1991, 1992, 1993a, 1993b, 1995a, 1995b, 1997a, 1997b, 1997c, 1998a, 1998b, 1998c, 1998d, 1998e, 1999, 2001, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d, etc.), with particular emphasis on bogs, xeric sandylands, Big Thicket floristics, and the flora of the West Gulf Coastal Plain, have been a major contribution to Texas botany.

The collections and publications of Stanley D. and Gretchen D. Jones of the Botanical Research Center Herbarium (BRCH) in Bryan are important for the study of East Texas. The collection is particularly strong in Cyperaceae, reflecting Stanley Jones' expertise in that family. In addition, the *Vascular Plants of Texas: A Comprehensive Checklist Including Synonymy, Bibliography, and Index* (Jones et al. 1997), is a particularly valuable resource for nomenclatural work state-wide. Stanley Jones contributed the *Carex* (Cyperaceae) treatment for this volume.

The ecological studies of Paul Harcombe at Rice University (e.g., Marks & Harcombe 1975, 1981; Harcombe & Marks 1977; Schafale & Harcombe 1983; Harcombe et al. 1993) in Houston have contributed much to the understanding of the plant communities of the Big Thicket and surrounding areas. Sandra Elsik, also at Rice, has been active in inventory and ecological research (e.g., Brown & Elsik 2002).

David Riskind and David Diamond, often in collaboration, have also carried out ecological research (e.g., Diamond et al. 1987, 1997; Poole & Riskind 1987; Riskind & Collins 1975; Riskind & Moreland 1973) and have contributed significantly to the understanding of plant communities in Texas.

Another East Texas herbarium (SHST), at Sam Houston State University in Huntsville, though relatively small, has the distinction of being the oldest herbarium in the state (founded 1899—one year before the University of Texas herbarium—Holmgren et al. 1990). Justin Williams, who specializes in the Apocynaceae and the flora of the Texas Panhandle, is at SHST and has recently taken over the editorship of the botanical journal *Phytologia* (Turner & Williams 2004).

Glenn Kroh of Texas Christian University in Fort Worth and his students have done research on the plant ecology of various areas in East Texas, including Caddo Lake (e.g., Cross 1996).

There are numerous Texas institutions and locations outside East Texas where important botanical contributions have been made. One of the most significant of these is Sul Ross State University in Alpine, where the emphasis is on plants of the Trans-Pecos. The herbarium there (SRSC) houses one of the most complete plant collections covering the Trans-Pecos (Warnock 1970). Early students in the region included Charles Wright (collected in the area in 1849), G.C. Nealley (collected in the area 1887–1893—McVaugh 1946), W.L. Bray (made observations prior to 1905), and M.S. Young (who visited the region about 1914). Later, Leon C. Hinckley did work in the region, including an extensive survey of the vegetation of Mt. Livermore in 1934–1939 (Warnock 1977). *Aquilegia chrysantha* var. *hinckleyana*, endemic to the Trans-Pecos, and *Quercus hinckleyi* are both named in his honor. One of the earliest widely available publications on the plants of the area was *Plants of Big Bend National Park* (McDougall & Sperry 1951).

FIG. 158/ BARTON H. WARNOCK (1911–1998) IN THE FIELD IN WEST TEXAS IN 1947. PHOTO BY ROGERS MCVAUGH. COURTESY OF THE HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION, CARNEGIE MELLON UNIVERSITY, PITTSBURGH, PA.

While significant collecting and limited publication had been done on the Big Bend area previous to his arrival at SRSC, it was with Barton H. Warnock (1911–1998) (Fig. 158), a student of Tharp, that work on the botany of the Trans-Pecos expanded dramatically. Among his books on the region are *Wildflowers of the Big Bend Country, Texas* (Warnock 1970), *Wildflowers of the Guadalupe Mountains and the Sand Dune Country, Texas* (Warnock 1974), and *Wildflowers of the Davis Mountains and Marathon Basin, Texas* (Warnock 1977). More than a dozen species have been named in his honor including *Hexalectris warnockii*, Texas purple-spike. For additional details on Warnock see Turner (1998) and McVaugh (1999). Subsequently, and continuing to the present, Michael A. Powell and his numerous students have conducted extensive research in the region. His most noteworthy publications include *Trees and Shrubs of Trans-Pecos Texas including Big Bend and Guadalupe Mountains National Parks* (Powell 1988), *Trees and Shrubs of the Trans-Pecos and Adjacent Areas* (Powell 1998), *Grasses of the Trans-Pecos and Adjacent Areas* (Powell 1994), and *Ferns and Fern Allies of the Trans-Pecos and Adjacent Areas* (Yarborough & Powell 2002). Other contributors at SRSC have included Sharon Yarborough and James C. Zech.

Botanical research on the Trans-Pecos is also being carried out by Richard Worthington at the University of Texas at El Paso (UTEP).

An important botanical project now underway, that is state-wide in scope, is a joint effort between botanists at the Nature Conservancy of Texas and Texas Parks and Wildlife. The product will be an illustrated book titled *The Rare Plants of Texas,* which is currently in preparation by William Carr, Jackie Poole, Dana Price, and Jason Singhurst, with illustrations by Linny Heagy. This work will be a major contribution to raising public awareness about the many plant species of conservation concern in the state.

Texas State University-San Marcos (SWT) has been active in botanical research through the efforts of David E. Lemke and his colleagues and students. These studies have included research on aquatic plants and an effort to update the Correll and Johnston *Manual*.

Angelo State University (SAT) in San Angelo is known for the work of Chester Rowell and Bonnie Amos. Rowell (1925–2003) specialized in systematic and ecological botany, including early work on bog communities (e.g., Rowell 1949), and is particularly remembered as a teacher and mentor (Blassingame 2003). Many of his students did county floras and made significant contributions of plant distribution data. More recently, Amos has worked on Texas endemics, pollination ecology, and the plants of the Edwards Plateau. She co-authored *Edwards Plateau Vegetation: Plant Ecological Studies in Central Texas* (Amos & Gehlbach 1988).

Plant ecology research has been carried out at the University of Texas at San Antonio by O.W. van Auken (e.g., van Auken 2000).

The E.L. Reed Herbarium at Texas Tech University (TTC) in Lubbock is perhaps best known botanically for the works of R.C. Jackson, David K. Northington, and Charles Werth.

A number of institutions have been involved in botanical research on southern Texas. The University of Texas Pan American (PAUH) in Edinburgh has been a center of research on the plants of Padre Island and the southern part of the state, largely through the work of Robert Lonard (e.g., Lonard 1993; Lonard & Judd, 1980, 1981, 1985, 1991, 1993, 2002; Lonard et al. 1991; Everitt et al. 2002), often in association with Frank Judd. Other work on these areas has been carried out by Allan Nelson of Tarleton State University, Stephenville (TAC), I.G. Negrete of Texas A&M Univ.-Kingsville (TAIC), and their colleagues (e.g., Negrete et al. 1999, 2002; Nelson et al. 2000, 2001) and by Alfred Richardson (Univ. of Texas at Brownsville) (e.g., Richardson 1995, 2002).

Other active Texas herbaria, listed in Index Herbariorum (Holmgren et al. 2004) but not mentioned elsewhere in this section, include ETST (Texas A&M-Commerce), HABAYC (University of Mary Hardin-Baylor, Belton), HSU (Hardin-Simmons University, Abilene), LAMU (Lamar University, Beaumont), LLC (Our Lady of the Lake University, San Antonio), NTSC (University of North Texas, Denton), SPLT (South Plains College, Levelland, particularly strong in ferns due to work by Jim Blassingame), TCSW (Texas Woman's University, Denton), UVST (Toney Keeney Herbarium at Southwest Texas Junior College, Uvalde), WTS (West Texas A&M University, Canyon), and WWF (Rob & Bessie Welder Wildlife Foundation, Sinton).

Current Botanical Activity

Botanical efforts are under way currently in East Texas at the institutions listed above, through the Texas Parks and Wildlife Department, by various conservation organizations (e.g., Lady Bird Johnson Wildflower Center, Native Prairies Association, Native Plant Society of Texas, Natural Area Preservation Association, Nature Conservancy of Texas), and by other interested professional and lay botanists. Surprising and exciting discoveries are constantly being made. Species new to science are still being described (Ertter 2000), and numerous species, both native and introduced, are found for the first time in Texas each year. From 1990 to 2000, 48

Texas taxa new to science were described, and an additional 86 new state records were discovered (27 native, 59 introduced) (B. Lipscomb, unpublished data). Examples of East Texas native species new to science include *Agalinis navasotensis* (Canne-Hilliker & Dubrule 1993), *Carex perdentata* (Jones 1994b), *Calopogon oklahomensis* (Goldman 1995), *Carex ozarkana* (Rothrock & Reznicek 1996a), *Baptisia* ×*variicolor* (Kosnik et al. 1996), *Crataegus nananixonii* (named for Elray Nixon—Phipps & O'Kennon 1997), *Spiranthes eatonii* (Brown 1999), *Carex shinnersii* (named for the late Lloyd Shinners—Rothrock & Reznicek 2001), *Liatris aestivalis* (Nesom & O'Kennon 2001), *Liatris glandulosa* (Nesom & O'Kennon 2001), *Nemophila sayerensis* (endemic to the "fossil beach sand areas" in east central Texas—Simpson et al. 2001), *Pseudognaphalium austrotexanum* (Nesom 2001), *Spiranthes sylvatica* (Brown 2001), *Carex kraliana* (named in honor of Robert "Bob" Kral "in recognition of his contributions to the knowledge of the flora of the southeastern United States, particularly its great diversity of sedges"—Naczi et al. 2002), and most recently, *Yucca cernua* (a striking Texas endemic with inflorescences to 4 m tall—Keith 2003). Native species recently discovered for the first time in Texas (all in East Texas) include *Triosteum perfoliatum* (Holmes et al. 1999), *Houstonia longifolia* (Singhurst & Holmes 2001b), *Verbesina walteri* (Singhurst & Holmes 2001a), *Bidens alba* (Brown & Elsik 2002), *Calycanthus floridus* (Brown & Elsik 2002), *Cuphea viscosissima* (Brown & Elsik 2002), *Iris fulva* (Singhurst et al. 2002a), *Lyonia lucida* (Brown & Elsik 2002), *Rhynchosia tomentosa* (Brown & Elsik 2002), *Silene virginica* (Singhurst et al. 2002a), *Agalinis harperi* (Keith & Hays 2003), *Geocarpon minimum* (Keith et al. 2004; J. Singhurst & E. Keith, pers. comm.; a federally threatened species), *Ctenium aromaticum* (J. Singhurst, pers. comm. 2003), and *Decumaria barbara* (J. Singhurst, pers. comm. 2004). This continuing discovery of species new to science and new to the state emphasizes the need for additional collecting and habitat conservation in East Texas and Texas as a whole.

Popular Guides to Texas Plants

In addition to the numerous technical works on Texas plants, a large number of popular guides and references have been published, giving a wide audience access to information about the state's flora. Material on plant identification, landscaping with native plants, horticulture, edibility and, other uses can be obtained from these sources. Many contain material (e.g., photographs, landscaping information) not available in the more technical works and are thus of great value. A list of such publications is given in Appendix 14.

FIG. 159/ PAINTING OF *LUPINUS TEXENSIS* (TEXAS BLUEBONNET, FABACEAE) PUBLISHED IN 1836 IN *CURTIS' BOTANICAL MAGAZINE*; PROBABLY BY WALTER HOOD FITCH. USED WITH PERMISSION OF ROYAL BOTANICAL GARDENS, KEW.

Botanical Art in East Texas

Botanical art has a rich history stretching back thousands of years to the early Egyptians and even before. Since plants were such an important contributor to the development of human civilization, it is not surprising that they were among the earliest subjects of artistic expression. After the invention of the printing press, the first books concerning plants were the herbals, which were works primarily about medicinal plants. While the earliest herbals were merely copies of ancient manuscripts from the early Greeks (e.g., Dioscorides' *De Materia Medica*, written about 60 A.D.), by the sixteenth century, botanists had begun to study living plants, and the illustrations in herbals had become increasingly accurate. The oldest illustration included in the *Illustrated Flora of East Texas* (of *Zea mays*, corn, in the Poaceae; see p. 1105) is from such an herbal, *De Historia Stirpium*. This work was published in 1542 by Leonhard Fuchs, who used living plants for his illustrations (Snyder 2001). Since that time, a wealth of excellent botanical art has been produced, including the category frequently referred to as botanical illustration (for further information see Holmgren & Angell 1986; Blunt 1994; West 1996; Saunders 1995; de Bray 2001). According to Snyder (2001), "The primary goal of botanical illustration is not art, but scientific accuracy. It must portray a plant with the precision and level of detail for it to be recognized and distinguished from another species." Thus, botanical "art" and botanical "illustration," while in many ways synonymous or overlapping, can have quite different goals. Nonetheless, botanical illustration is indeed art in the best sense of that word.

Numerous botanical artists and illustrators have used the rich flora of East Texas in their works of art. Beginning with the earliest collections of East Texas plants by European botanists (Jean Louis Berlandier, Thomas Drummond) in the late 1820s and early 1830s, artists had access to East Texas plants. Most of the early collections were sent to European botanists, such as Alphonse de Candolle and Sir William Jackson Hooker, who commissioned paintings and illustrations for their scientific publications. A good example of an East Texas plant drawn for a scientific work is the painting of *Lupinus texensis* (Texas bluebonnet) (Fig. 159) published by W.J. Hooker in 1836 in *Curtis' Botanical Magazine*. While the identity of the artist is not absolutely certain, the bluebonnet painting was probably by Walter Hood Fitch (Hemsley 1915), one of the finest and most prolific botanical illustrators of all time. Fitch drew over 2,700 illustrations for *Curtis' Botanical Magazine* and during his lifetime produced a total of about 12,000 drawings and diagrams (Hemsley 1915; Desmond 1992; Lewis 1992).

While it is beyond the scope of this work to fully cover botanical art in East Texas, a few of the Texas artists and illustrators with which we are familiar are mentioned below, and examples of their art are provided if available. Those still working in Texas are listed first, followed by those of the past.

Probably the two best known contemporary botanical artists/illustrators depicting East Texas plants are Linny Heagy and Bruce Lyndon Cunningham.

Linny Heagy (commercial arts degree, John Herron Art Institute of Indiana University) (see Fig. 160), professional artist, illustrator, and graphic designer, has worked extensively on Texas plants. For *Shinners & Mahler's Illustrated Flora of North Central Texas* she created 226 original line drawings, painted the art for the dust jacket and the frontispiece, and served as creative director/art director for the whole volume. Likewise, for this *Illustrated Flora of*

FIG. 160/ PAINTING OF *DODECATHEON MEADIA* (COMMON SHOOTING-STAR, PRIMULACEAE) BY LINNY HEAGY. USED WITH PERMISSION OF THE ARTIST.

East Texas, she has produced 28 original illustrations, painted the frontispiece, designed the cover, and served as creative director/art director. In addition, Ms. Heagy has depicted a number of new plant species published in the botanical journal *Sida*. Currently, she is illustrating a book on rare and endangered Texas plants in conjunction with the Texas Parks and Wildlife Department (Carr et al., in preparation), and recently she was commissioned as one of the illustrators for the Flora of North America project.

BRUCE LYNDON CUNNINGHAM (see Fig. 161) of Nacogdoches, formally trained as both an artist and a forester, is probably most widely known for illustrating *Trees, Shrubs, & Woody Vines of East Texas* (Nixon 1985, 2000). That work, which included hundreds of line drawings, is the most extensively illustrated treatment of the woody plants of East Texas ever published. An example of his line drawings can be seen in the illustration of *Yucca louisianensis* on page 419. He has produced a wealth of other botanical art using the plants of East Texas and the Pineywoods ecosystem as subjects, including wood carvings and paintings of trees and wildflowers.

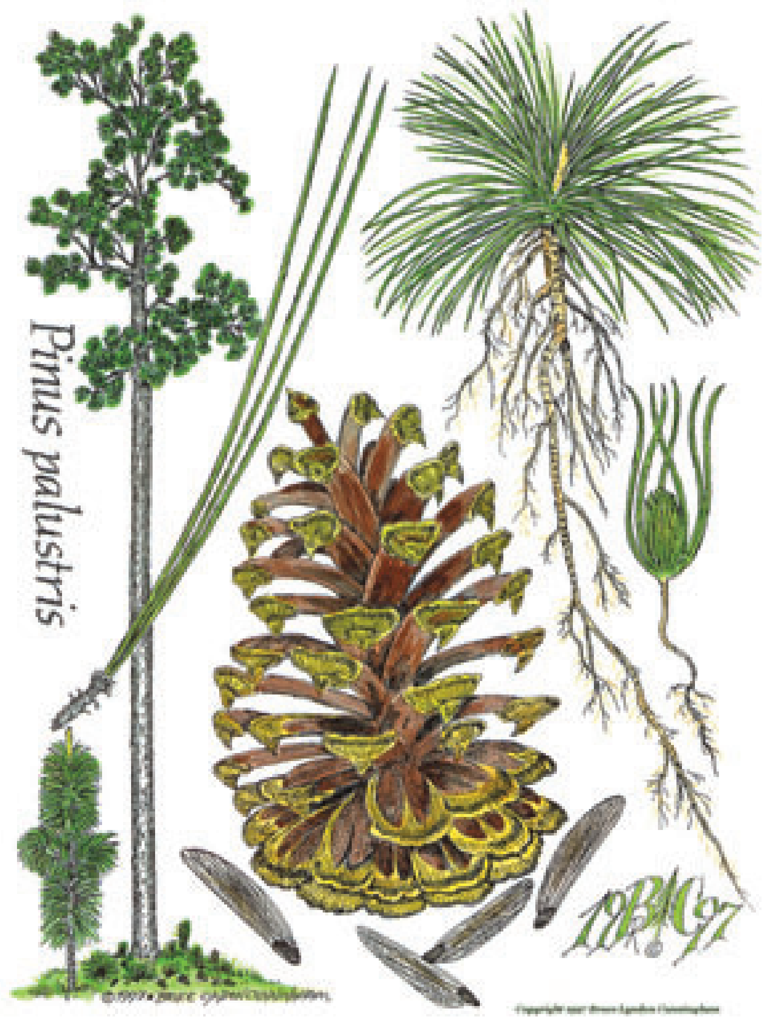


FIG. 161/ PAINTING OF *PINUS PALUSTRIS* (LONGLEAF PINE, PINACEAE) BY BRUCE LYNDON CUNNINGHAM. USED WITH PERMISSION OF THE ARTIST.

FIG. 162/ PAINTING OF *LUPINUS TEXENSIS* (TEXAS BLUEBONNET, FABACEAE), STATE FLOWER OF TEXAS (ALONG WITH THE OTHER FIVE SPECIES OF *LUPINUS* IN TEXAS). ILLUSTRATION BY JEAN ANDREWS FROM *THE TEXAS BLUEBONNET*, REVISED EDITION BY JEAN ANDREWS, COPYRIGHT © 1993. BY PERMISSION OF THE AUTHOR AND THE UNIVERSITY OF TEXAS PRESS.

DR. JEAN ANDREWS (doctorate in art from the University of North Texas), of Austin, has depicted a number of East Texas plants, including the bluebonnet (Andrews 1986) (Fig. 162). Sometimes affectionately known as "The Pepper Lady" for her work on peppers, she has authored and illustrated three books on the subject, *Peppers: The Domesticated Capsicums* (1984, 1995), *The Pepper Lady's Pocket Pepper Primer* (1998), and *The Pepper Trail: History and Recipes from Around the World* (1999). She also authored and illustrated the highly acclaimed *American Wildflower Florilegium* (1992) and co-authored a scientific work on the bluebonnet (Turner & Andrews 1986).

SCOTT AND STUART GENTLING of Fort Worth are professional artists, authors, and lecturers. Perhaps best known for their remarkable *Of Birds and Texas* (boxed elephant folio 1986; hardcover 2001), these twin brothers have been widely recognized and have received various honors, including being named official artists for the Texas Audubon Society's centennial celebration. In addition to their work with birds, they have painted portraits, still lifes, and landscapes, all done in the difficult dry-brush watercolor style. While not generally considered botanical artists, many of their bird and landscape paintings incorporate plants as important components (Fig. 163). The figures of the passenger pigeon, ivory-billed woodpecker, and Carolina parakeet (Fig. 97, 98, and 99) in this volume are from paintings by the Gentlings. These paintings were produced specifically for this flora through the generosity of the Gentlings and are here published for the first time. Further, the dust jacket of this volume, depicting an East Texas scene including pine, bald-cypress, and flowering dogwood, is from an original by Stuart Gentling, also created for this flora.

ROBERT "BOB" KRAL is widely known for his numerous contributions to the taxonomy of Cyperaceae, Eriocaulaceae, Melastomataceae, Pinaceae, and Xyridaceae (e.g., Kral 1966a, 1992, 2000a, 2002d) and for developing the Vanderbilt University herbarium (approximately 300,000 specimens now housed at BRIT). While primarily recognized as a botanist, he is also a respected botanical illustrator. Many of his illustrations of species of Cyperaceae (see Fig. 164), Eriocaulaceae, and Xyridaceae are used in this flora.

FIG. 163/ PAINTING OF BARN SWALLOW AND *NYMPHAEA* (WATER LILY, NYMPHAEACEAE) BY SCOTT AND STUART GENTLING. FROM GENTLING AND GENTLING (2001), USED WITH PERMISSION OF THE ARTISTS.

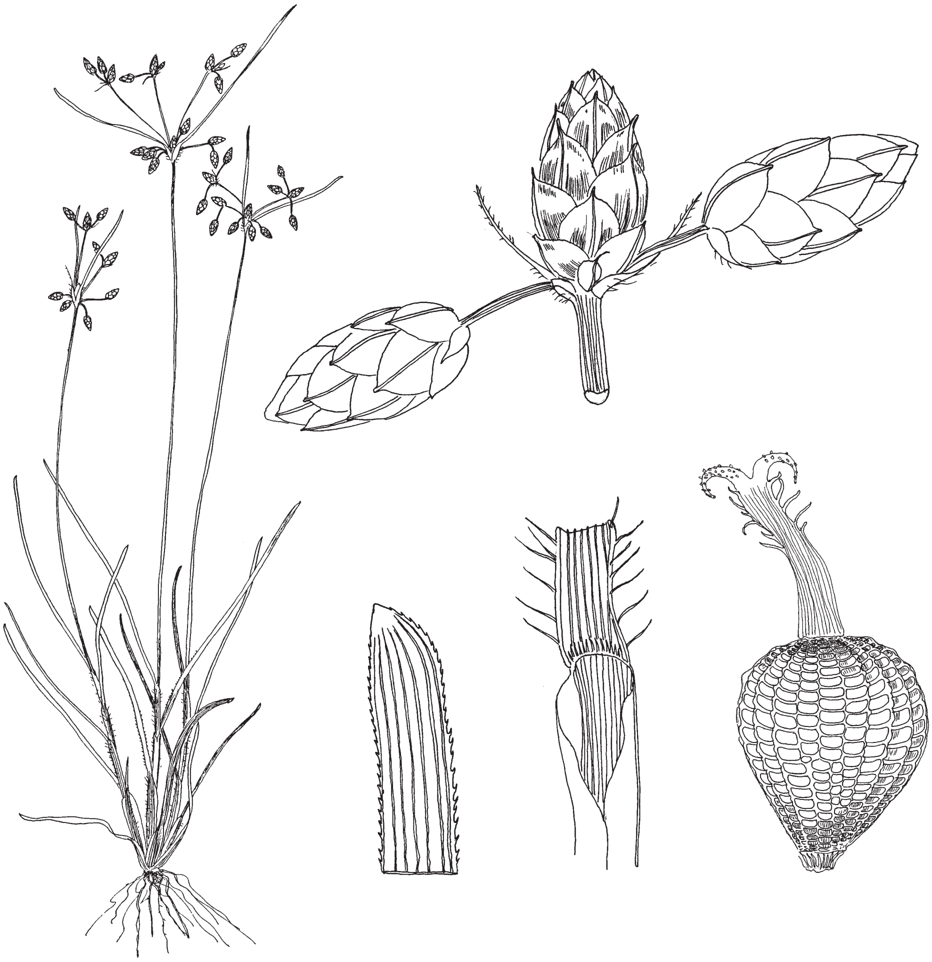


FIG. 164/ LINE DRAWING ILLUSTRATION OF *FIMBRISTYLIS DECIPIENS* (CYPERACEAE) BY ROBERT "BOB" KRAL. USED WITH PERMISSION OF THE ARTIST.

RUTH ANDERSSON MAY, of Dallas, is an artist and conservationist who has painted over 500 watercolors of wildflowers, including many from East Texas (Fig. 165). With formal training in both natural history and art and a love for wildflowers, she brings a special perspective to her art. Her work has been exhibited at numerous places, including the Rancho Santa Ana Botanic Garden, the National Tropical Botanical Garden, and the San Antonio Botanical Center and is on permanent display at the Lady Bird Johnson Wildflower Center and the Botanical Research Institute of Texas. She has been a prime force in maintaining and protecting Harry S. Moss Park in Dallas and has received awards for the implementation of educational programs at Moss Park through which children learn about native wildflowers.

JANE MOLPUS, an artist residing in Fort Worth, has produced numerous paintings of botanical subjects (Fig. 166). As a board member of the Botanical Research Institute of Texas, she has contributed a variety of botanical art for use by the Institute.

GERALDINE WATSON, botanist, writer, and conservationist, is a native of the Big Thicket. She lives near Silsbee and maintains the Watson Pinelands Preserve, which is dedicated to preserving a portion of the diversity of the Big Thicket. Watson has devoted much of her life to protecting the Big Thicket, with efforts ranging from identifying and collecting plants for the University of Texas at Austin and the National Park Service to her many publications

Fig. 165/ Painting of *Ipomopsis rubra* (standing-cypress, Polemoniaceae) by Ruth Andersson May. From the collection at the Botanical Research Institute of Texas.

FIG. 166/ PAINTING OF A COLLECTION OF TEXAS WILDFLOWERS BY JANE MOLPUS. USED WITH PERMISSION OF THE ARTIST.

(e.g., Watson 1975, 2003), to her political involvement with the Big Thicket Association for the creation of a federal preserve, and her work restoring a portion of the Thicket on the Watson Pinelands Preserve. Ms. Watson is also a prolific artist, having produced numerous paintings featuring plant subjects from the Big Thicket (Fig. 167). The sale of her art helps support the preserve. The frontispiece to the taxonomic treatments of this volume, depicting *Cypripedium kentuckiense,* (southern lady's-slipper; Orchidaceae; page 320), is from a painting by Watson, published here for the first time.

ELIZA GRIFFIN JOHNSTON (1821-1896) (see Fig. 168), who lived and worked in Texas during the 1840s and 1850s, produced the earliest known paintings of Texas wildflowers by a Texas artist. Originally given as a gift to her husband, her collection was first published in 1972 (Johnston 1972), as was her biography (Mayhall 1972). She was the wife of General Albert Sidney Johnston, who served in the armies of Texas, the U.S., and the Confederacy, and she traveled extensively with him both in Texas and elsewhere in the U.S. Her early art of Texas plants influenced various future artists, including Ruth Andersson May.

FIG. 167/ PAINTING OF ALOPHIA DRUMMONDII (PURPLE PLEAT-LEAF, IRIDACEAE) BY GERALDINE WATSON. USED WITH PERMISSION OF THE ARTIST.

FIG. 168/PAINTING OF *NEMASTYLIS GEMINIFLORA* (PRAIRIE-CELESTIAL, IRIDACEAE) BY ELIZA GRIFFIN JOHNSTON. FROM JOHNSTON (1972), WITH PERMISSION OF THE DAUGHTERS OF THE REPUBLIC OF TEXAS, TRAVIS COUNTY CHAPTER.

The late MARY JO LAUGHLIN (1932–1986), who lived and painted for many years in McKinney, Texas, had a deep love of wildflowers and a strong drive to portray them in watercolors (Fig. 169). Her "botanically accurate style" is said to have been influenced by the famous Luxembourg-born artist Pierre Joseph Redouté and other botanical artists, as well as by antique botanical prints in the collection of the Heard Natural Science Museum (Fairchild 1989). "Her extensive reading and studying transformed Mary Jo into a knowledgeable amateur botanist with a deep concern for the preservation and perpetuation of wildflowers" (Fairchild 1989). She was a prolific painter, and during a career spanning nearly three decades Laughlin produced more than 1,500 wildflower paintings (Fairchild 1989). Her work can be seen in Grimmer (1982) and Fairchild (1989), and a number of her paintings are permanently preserved and displayed at the Botanical Research Institute of Texas through the generosity of her husband, Harold Laughlin.

Fig. 169/ Painting of *Sarracenia alata* (yellow-trumpets, pitcher plant, Sarraceniaceae) by Mary Jo Laughlin. From the collection at the Botanical Research Institute of Texas, through the generosity of Harold Laughlin.

FIG. 170/ PAINTING OF *RHODODENDRON CANESCENS* VAR. *SUBGLABRUM* (WILD AZALEA, ERICACEAE) BY MARIE WESBY. FROM THE COLLECTION AT THE BOTANICAL RESEARCH INSTITUTE OF TEXAS THROUGH THE GENEROSITY OF VERNE WESBY.

THE LATE MARIE WESBY (1912–1999) (see Fig. 170) created art and illustrations for both the Field Museum of Natural History and the Morton Arboretum. She also produced extensive watercolors of the plants of Texas, which can be seen in Wesby and Sander (2001). Many of her works are permanently preserved and displayed at the Botanical Research Institute of Texas through the generosity of her husband, Vern Wesby.

THE LATE EULA WHITEHOUSE (1892–1974) (see Fig. 171), mentioned earlier for her botanical contributions, is probably best known for her *Texas Flowers in Natural Colors* (1936), the first color-illustrated guide to Texas wildflowers (Flook 1974). During her career, she painted and illustrated extensively. Some of her illustrations were originally published in Shinners' *Spring Flora of the Dallas-Fort Worth Area Texas* (1958a) and were used again in *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999) and in this volume.

FIG. 171/ PAINTING OF THE TEXAS ENDEMIC *SPHAERALCEA LINDHEIMERI* (WOOLLY GLOBEMALLOW, MALVACEAE) BY EULA WHITEHOUSE. FROM THE COLLECTION AT THE BOTANICAL RESEARCH INSTITUTE OF TEXAS.

FIG. 172/ PAINTING OF *IBERVILLEA LINDHEIMERI* (BALSAM GOURD, CUCURBITACEAE) BY MARY MOTZ WILLS. FROM *ROADSIDE FLOWERS OF TEXAS*, PAINTINGS BY MARY MOTZ WILLS, TEXT BY HOWARD S. IRWIN, COPYRIGHT © 1961, RENEWED 1989. BY PERMISSION OF THE UNIVERSITY OF TEXAS PRESS.

WILDFLOWER ARTIST MARY MOTZ WILLS (1875–1961) is best known for illustrating *Roadside Flowers of Texas* (Wills & Irwin 1961). She lived in Abilene for many years and painted Texas wildflowers extensively, producing a total of over 2,000 paintings (Fig. 172). Her work was exhibited in a number of locations, including the Witte Museum in San Antonio (Seeber 1996), and 450 of her paintings are in the Texas Memorial Museum of Science and History Collection of Botanical Watercolor Paintings (University of Texas-Austin).

PAT MUELLER, DAVID WAGNON, and several unknown SMU students did a significant number of botanical illustrations for Lloyd Shinners, in preparation for an early flora of North Central Texas. While Shinners' untimely death prevented the culmination of this project, years later many of the early illustrations were eventually published in *Shinners & Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999). The late David Wagnon had begun to do a number of illustrations for this volume, but that work was cut short by his death in 2001.

VALOO KAPADIA illustrated many of the grasses in the landmark *The Grasses of Texas* (Gould 1975b). Because of the excellent illustrations and Gould's thorough, accurate, and clear keys and descriptions, that work set a new standard for treatments of the grass family. A number of Kapadia's illustrations are reused in the grass treatment of this book through the generosity of Lucile Gould Bridges. Numerous illustrations of grasses, including many by Kapadia, are available online through the Bioinformatics Working Group (1997) at Texas A&M University.