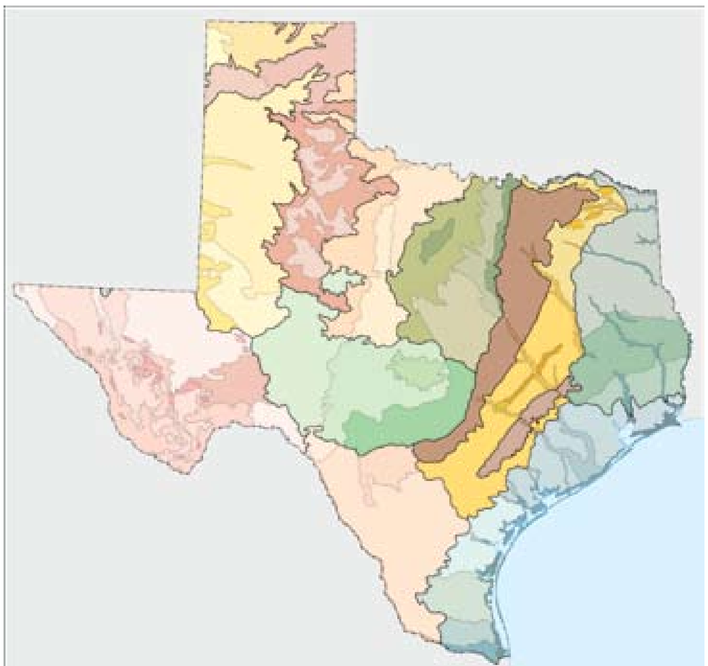
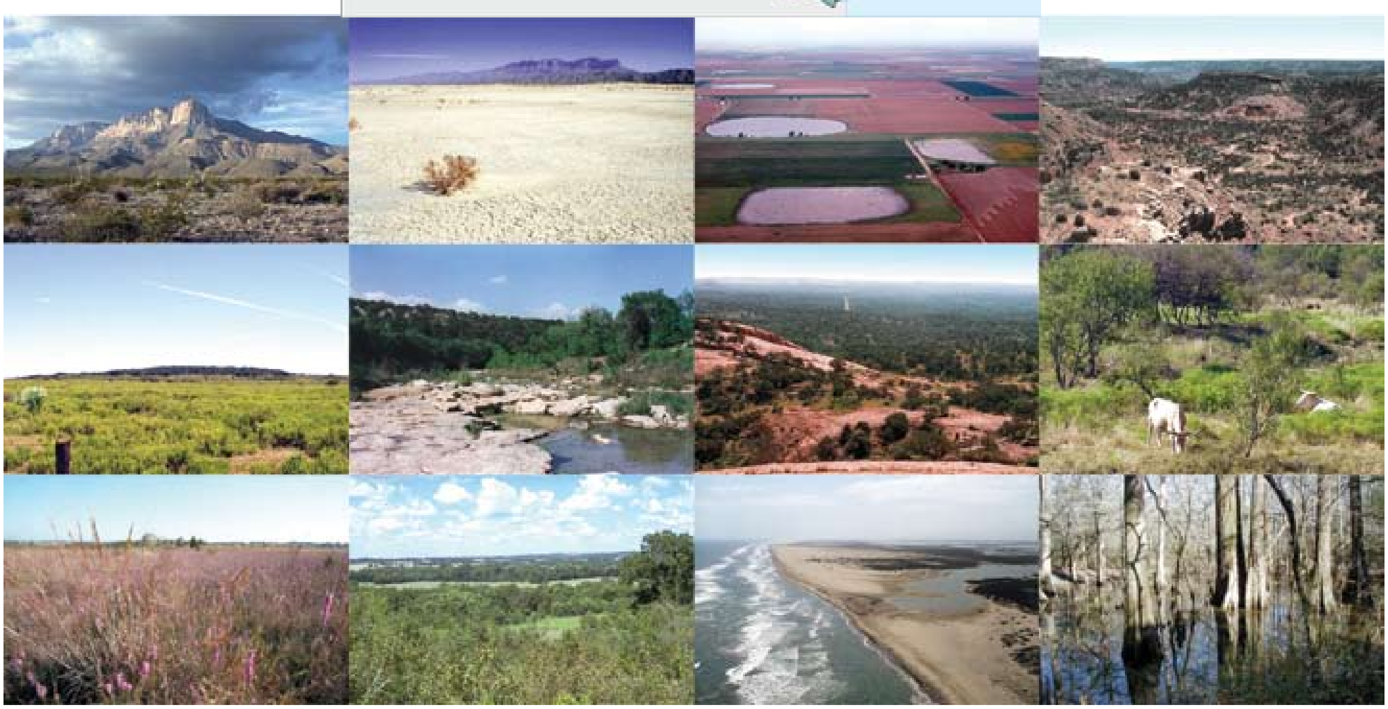
ECOREGIONS OF TEXAS





Glenn Griffith, Sandy Bryce, James Omernik, and Anne Rogers

ECOREGIONS OF TEXAS

Glenn Griffith[1], Sandy Bryce[2], James Omernik[3], and Anne Rogers[4]

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[1]Dynamac Corporation
200 SW 35th Street, Corvallis, OR 97333
(541) 754-4465; email: griffith.glenn@epa.gov

[2]Dynamac Corporation
200 SW 35th Street, Corvallis, OR 97333
(541) 754-4788; email: bryce.sandy@epa.gov

[3]U.S. Geological Survey
c/o U.S. Environmental Protection Agency
National Health and Environmental Effects Research Laboratory
200 SW 35th Street, Corvallis, OR 97333
(541) 754-4458; email: omernik.james@epa.gov

[4]Texas Commission on Environmental Quality
Surface Water Quality Monitoring Program
12100 Park 35 Circle, Building B, Austin, TX 78753
(512) 239-4597; email anrogers@tceq.state.tx.us

Project report to
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ABSTRACT

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. Ecoregion frameworks are valuable tools for environmental research, assessment, management, and monitoring of ecosystems and ecosystem components. They have been used for setting resource management goals, developing biological criteria and establishing water quality standards. In a cooperative project with the Texas Commission on Environmental Quality, the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, and other interested state and federal agencies, we have defined ecological regions of Texas at two hierarchical levels that are consistent and compatible with the U.S. EPA ecoregion framework. Twelve level III ecoregions and 56 level IV ecoregions have been mapped for Texas. These general purpose regions are useful to help structure and implement ecosystem management strategies across federal agencies, state agencies, and nongovernmental organizations that are responsible for different types of resources within the same geographical areas. Aquatic biologists in Texas have a long history of analyzing streams and potential reference conditions within a variety of Texas regional frameworks. This ecoregion framework was the result of input from a variety of disciplines, both terrestrial and aquatic based, and takes a broader ecological perspective than just water quality or aquatic macroinvertebrates. We believe that this new ecoregion framework still provides a valuable tool for the State's water quality assessments. Streams that are representative of an ecoregion and are minimally disturbed and least impacted from point and nonpoint source pollution can serve as suitable reference streams. Ecoregions and reference watersheds can be used together to better understand regional variations in stream quality, assess attainable conditions, develop biological criteria, and augment the watershed management approach.

ACKNOWLEDGEMENTS

Many people contributed to the organization of this project and to the development of the Texas ecoregion framework. For their collaboration and contributions, special thanks are given to Anne Rogers (TCEQ), Bill Harrison (TCEQ), Stephen Hatch (Texas A&M University), David Bezanson (Natural Area Preservation Association), Jeffrey Comstock (Indus Corporation), Philip Crocker (USEPA), Art Crowe (TCEQ), Michael Golden (NRCS), Susan Casby-Horton (NRCS), James Greenwade (NRCS), Conrad Neitsch (NRCS), Shannen Chapman (Dynamac Corporation), Augie De La Cruz (TCEQ), Kevin Wagner (Texas State Soil and Water Conservation Board [TSSWCB]), Richard Egg (TSSWCB), Alan Woods (Oregon State University), Clark Hubbs (University of Texas), David Certain (The Nature Conservancy) and Thomas Loveland (USGS). These people were authors or collaborators of the multi-agency Texas ecoregion poster published by the USGS (Griffith *et al.*, 2004). Thanks are also given to the reviewers of the ecoregion poster, including Charles Hallmark (Texas A&M University), Gordon Linam (TPWD), Milo Pyne (NatureServe), and Raymond Telfair, II (TPWD).

To obtain larger, color maps of the Level III and IV ecoregions of Texas or for an ARC/INFO export file of the ecoregion boundaries, contact the authors or see www.epa.gov/wed/pages/ecoregions/tx_eco.htm.

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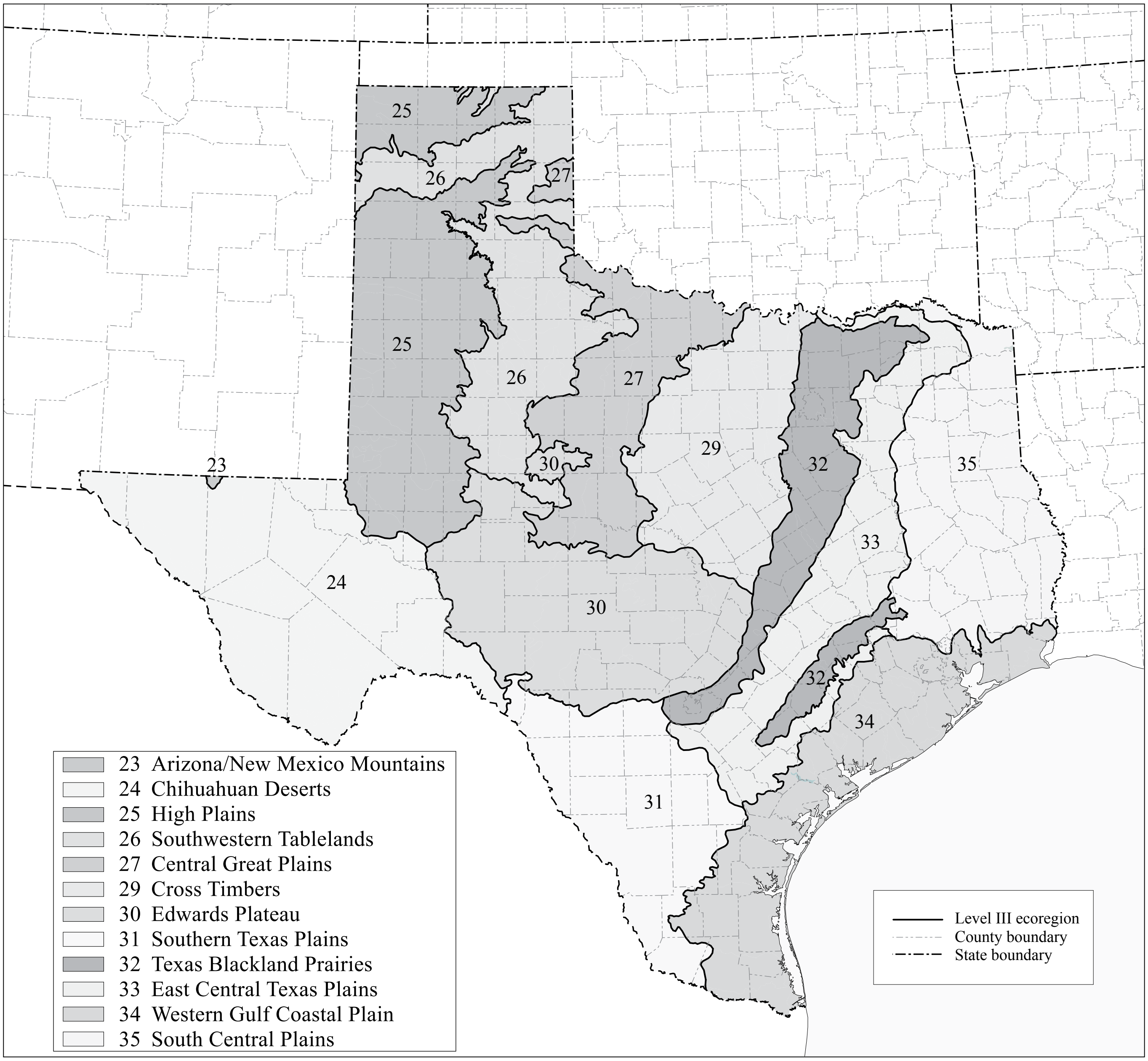


Figure 1. Level III Ecoregions of Texas

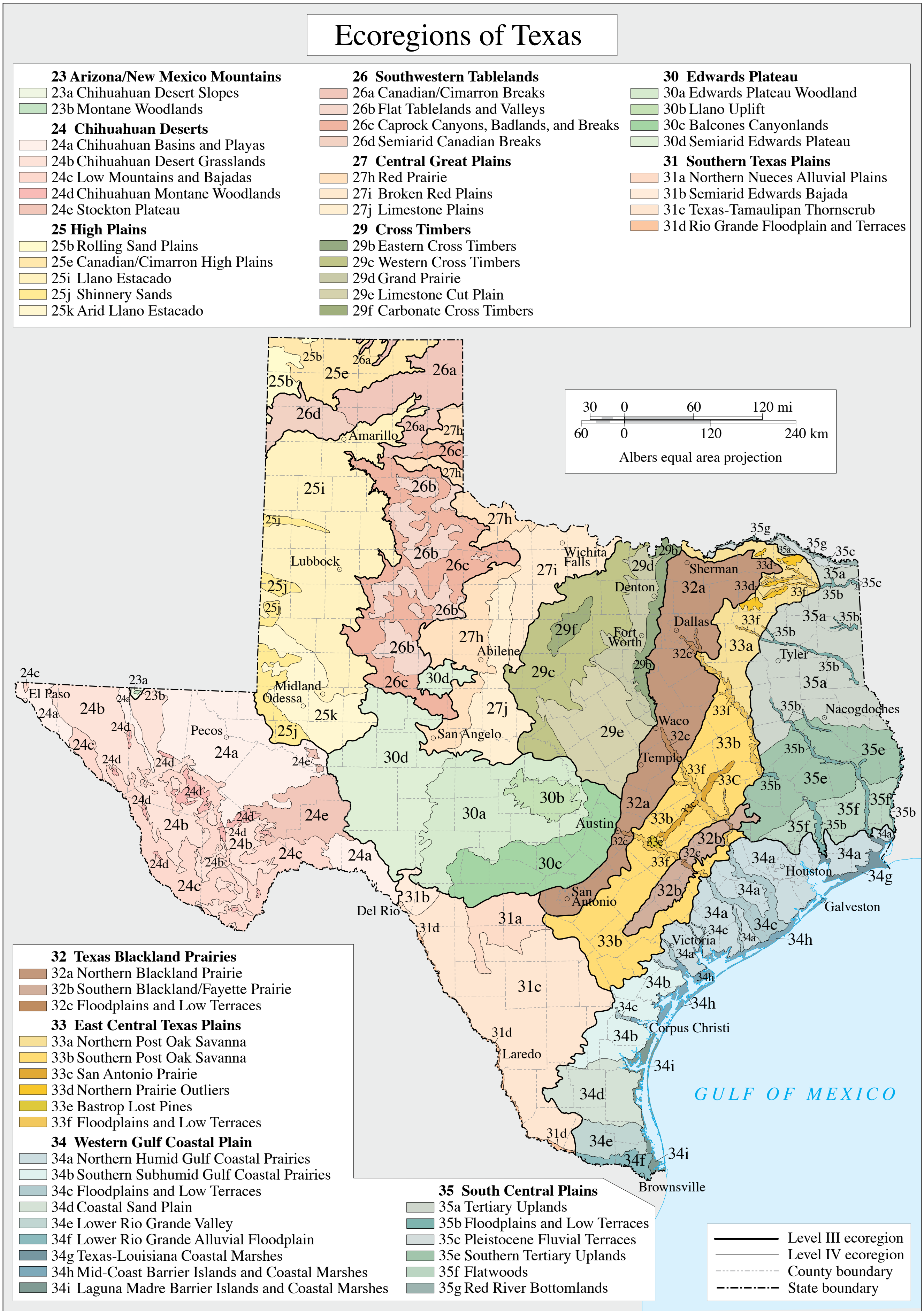


Figure 2. Level III and IV Ecoregions of Texas

INTRODUCTION

Spatial frameworks are necessary to structure the research, assessment, monitoring, and management of environmental resources. Ecological region (or ecoregion) frameworks designed to meet these needs have been developed in the United States (Bailey 1976, 1983, 1995; Bailey *et al.*, 1994; Omernik 1987, 1995), Canada (Wiken 1986; Ecological Stratification Working Group 1995), New Zealand (Biggs *et al.*, 1990), Australia (Thackway and Cresswell 1995), the Netherlands (Klijn 1994), Austria, (Moog *et al.*, 2004), Finland (Heino *et al.*, 2002), and many other countries. We define ecoregions as areas of relative homogeneity in ecological systems and their components. They portray areas within which there is similarity in the mosaic of biotic and abiotic components of both terrestrial and aquatic ecosystems. Factors associated with spatial differences in the quality and quantity of ecosystem components, including soils, vegetation, climate, geology, and physiography, are relatively homogeneous from place to place within an ecoregion. Various patterns in human stresses on ecosystems and in the existing and attainable quality of environmental resources are also evident among different ecological regions. Ecoregion classifications are effective for inventorying and assessing national and regional environmental resources, for setting regional resource management goals, and for developing biological criteria and water quality standards (Gallant *et al.*, 1989; Hughes *et al.*, 1990, 1994; Hughes 1989; Environment Canada 1989; U.S. Environmental Protection Agency, Science Advisory Board 1991; Warry and Hanau 1993, Stoddard 2004).

The development of ecoregion frameworks in North America has evolved considerably in recent years (Bailey *et al.*, 1985; Omernik and Gallant 1990; Omernik 1995, 2004). The U.S. Environmental Protection Agency's (EPA) first compilation of ecoregions of the conterminous United States was performed at a relatively cursory scale, 1:3,168,000, and was published at a smaller scale, 1:7,500,000 (Omernik 1987). The approach recognized that the combination and relative importance of characteristics that explain ecosystem regionality vary from one place to another and from one hierarchical level to another. This is similar to the approach used by Environment Canada (Wiken 1986). In describing ecoregionalization in Canada, Wiken (1986) stated:

> "Ecological land classification is a process of delineating and classifying ecologically distinctive areas of the earth's surface. Each area can be viewed as a discrete system which has resulted from the mesh and interplay of the geologic, landform, soil, vegetative, climatic, wildlife, water and human factors which may be present. The dominance of any one or a number of these factors varies with the given ecological land unit. This holistic approach to land classification can be applied incrementally on a scale-related basis from very site specific ecosystems to very broad ecosystems."

The EPA's ecoregion framework has been revised and made hierarchical. It has been expanded to include Alaska (Gallant *et al.*, 1995), and joined with Canadian and Mexican regional frameworks to create ecological regions for all of North America (Commission for Environmental Cooperation 1997, maps revised 2006). A Roman numeral classification scheme has been adopted for the hierarchical levels of ecoregions. This numbering is used, in part, to avoid confusion over different usage of terms such as ecozones, ecodistricts, ecoprovinces, subregions, etc. Level I is the coarsest level, dividing North America into 15 ecological regions. At level II, the continent is subdivided into 50 ecoregions, and at level III the continental United States contains 104 ecoregions (U.S. EPA 2006).

The goal of the U.S. EPA ecoregion work that began nearly 20 years ago was to develop a spatial framework for states to structure their regulatory programs more effectively, and to more closely match the natural potential and resilience of the regional landscape (Omernik 1987). It was initially suspected and subsequently confirmed that the quantity and quality of water tended to be similar within these ecological regions. The level III ecoregions defined initially by Omernik (1987) were shown to be useful for stratifying streams in Arkansas (Rohm *et al.*, 1987), Ohio (Larsen *et al.*, 1988), and Oregon (Hughes *et al.*, 1987; Whittier *et al.*, 1988), as well as in several other states (Hughes *et al.*, 1994, Davis *et al.*, 1996, Feminella 2000). They were used to identify lake management goals in Minnesota (Heiskary *et al.*, 1987; Heiskary and Wilson 1989), and to develop biological criteria in Ohio (Yoder and Rankin 1995).

Many state agencies, however, have found that the resolution of the level III ecoregions does not provide enough detail to meet their needs. This has led to several collaborative projects, with states, EPA regional offices, and the EPA's National Health and Environmental Effects Research Laboratory in Corvallis, OR, to refine level III ecoregions and define level IV ecoregions at a larger (1:250,000) scale. These level IV ecoregion projects have been completed or are in process in forty-one of the fifty U.S. states as of 2006, and are largely in response to requests from EPA regional offices or state water resource management agencies. Many of these state projects are also associated with interagency efforts to develop a common framework of ecological regions (McMahon *et al.*, 2001).

Water quality legislation and regulations, with a mandate to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," depend on some model of attainable conditions, that is, on some measurable objectives towards which cleanup efforts are striving (Hughes *et al.*, 1986). States are adopting biological criteria for surface waters to improve water quality standards. Biological criteria are defined as numeric values or narrative expressions that describe the reference biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use (U.S. EPA 1990). Biological integrity has been defined as, " the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats of a region," (Karr and Dudley 1981). Regional reference sites within an ecoregion can give managers and scientists a better understanding of attainable water body conditions. The biota and physical and chemical habitats characteristic of these regional reference sites serve as benchmarks for comparison to more disturbed streams, lakes, and wetlands in the same region (Hughes *et al.*, 1986; Hughes 1995). Along with other information, these sites help indicate the range of conditions that could reasonably be expected in an ecoregion, given natural limits and present or possible land use practices.

The Surface Water Quality Monitoring Program of the Texas Commission on Environmental Quality (TCEQ) has been examining regional influences on water quality for many years (Twidwell and Davis 1986, Hornig *et al.*, 1995). To facilitate ecological assessments and the continued development of biological criteria for streams and rivers in Texas, the TCEQ, U.S. EPA Region VI, U.S. EPA-Corvallis, U.S. Department of Agriculture-Natural Resources Conservation Service (USDA NRCS), and other agencies collaborated to define level III and level IV ecoregions. This type of framework can be useful for assessing nonpoint source pollution problems, determining the effectivenes of best management practices, identifying high quality or outstanding resource waters, establishing ecoregion-specific chemical and biological water quality standards, putting basin or statewide 305(b) water quality reports in an ecological context, and for managing areas to preserve biological diversity. In this report, we discuss the method and materials used to refine level III ecoregions and define level IV ecoregions in Texas, and provide descriptions of the significant characteristics of these regions. It expands on the published map poster of the ecoregions of Texas (Griffith *et al.*, 2004).

METHODS

Our regionalization process includes compiling and reviewing relevant materials, maps, and data; outlining the regional characteristics; drafting the ecoregion boundaries; creating digital coverages and cartographic products; and revising as needed after review by national, state, and local experts. In the regionalization process, we use primarily a qualitative, weight-of-evidence analysis of relevant data and information. Expert judgment is applied throughout the selection, analysis, and classification of data to form the regions, basing judgments on the quantity and quality of source data and on interpretation of the relationships between the data and other environmental factors. The analysis accounts for differences in map accuracy, scale, and generalization, as well as for differences in the relative importance of any one factor as it relates to ecological classification at any particular location. More detailed descriptions on the U.S. EPA's methods, materials, rationale, and philosophy for regionalization can be found in Omernik (1987, 1995, 2004), Omernik *et al.*, (2000), Gallant *et al.*, (1989), and Omernik and Gallant (1990). The regionalization process used for Texas was similar to that of surrounding states (Daigle *et al.*, 2006, Griffith *et al.*, 2006, Woods *et al.*, 2004, 2005) and other state-level EPA ecoregion projects (e.g., Bryce *et al.*, 2003; Griffith *et al.*, 1994a,b,c, 1997, 2001, 2002; Omernik *et al.*, 2000; Woods *et al.*, 1996, 1998).

Maps of environmental characteristics and other documents were collected from the state of Texas, U.S. EPA-Corvallis, USGS, and from other sources. The most important of these are listed in the References section. The most useful map types for our ecoregion delineation generally include physiography or land surface form, geology, soils, climate, vegetation, and land cover/land use. There are several different small-scale physiographic maps of Texas that can be found in a variety of publications. Statewide physiographic and land surface-form descriptions and maps were gathered from sources including the Bureau of Economic Geology (1996), Raisz (1957), Bayer (1983), Hammond (1970), Hunt (1967, 1974) and Fenneman (1931, 1938). Topography and land-form features were also discerned from 1:250,000, 1:100,000, and larger scale topographic maps, and from a variety of digital elevation models (e.g., Thelin and Pike 1991). Geologic information was gathered from maps such as the 1:500,000-scale state map (Barnes 1992) and other state and regional maps (Kier *et al.*, 1977; Renfro 1973); from surrounding state geology maps for New Mexico (Dane and Bachman 1965, New Mexico Bureau of Geology and Mineral Resources 2003), Louisiana (Snead and McCulloh 1984), and Oklahoma; from the 1:1,000,000-scale Quaternary geology series (Moore *et al.*, 1993, Richmond *et al.*, 1990, Richmond and Christiansen 1994, Fullerton *et al.*, 2003); from state, regional, or local geology descriptions (e.g., Spearing 1991, Ryder 1996); and from national scale maps such as Hunt (1979), Bayer (1983), and King and Biekman (1974).

Soils information was obtained from the USDA county soil surveys, the 1:250,000-scale STATSGO soil data base (USDA NRCS 1994), and state and regional publications (e.g., Godfrey *et al.*, 1973). Because soil taxonomy and interpretations are dynamic, and current soil series names may be different from those in earlier publications, soil information and ecological aggregations of STATSGO or other soil data were also obtained from state soil experts (Micheal Golden, Susan Casby-Horton, James Greenwade, USDA NRCS, personal communications).

Climate information and summaries were based on a variety of data and sources. These included 1971-2000 and 1961-1990 data summaries from the Southern Regional Climate Center (http://www.srcc.lsu.edu/) information from the Texas state climatologist (http://www.met.tamu.edu/met/osc/osc.html), from precipitation and temperature information based on the PRISM model (Daly *et al.*, 1997; http://www.ocs.orst.edu/prism/prism_new.html), from state summaries (Larkin and Bomar 1983, Orton 1974, Russell 1945), from data in Koss *et al.*, (1988), and from climate information listed in the county soil surveys.

Statewide vegetation information for Texas includes that from sources such as McMahan *et al.*, (1984), Bezanson (2000), Gould (1975), and Tharp (1939). Regional vegetation information came from sources such as Diggs *et al.*, (1999), NatureServe (2002), and Brown (1994). Vegetation and forest type information were also obtained from Braun (1950), Kuchler (1964), the forest atlas of the South (USDA, Forest Service 1969), the national atlas (Kuchler 1970; U.S. Forest Service 1970), USDA Forest Service (1997), from numerous journal manuscripts listed in the references, from in-state personnel with botanical expertise (e.g., Steven Hatch, Texas A&M; David Bezanson, Natural Area Preservation Association; Raymond Telfair (TPWD, Retired) personal communications), and from web pages such as “A Checklist of the Vascular Plants of Texas” (http://www.csdl.tamu.edu/FLORA/taes/tracy/regeco.html).

For land use/land cover we used primarily the National Land Cover Data set (NLCD), part of the Multi-Resolution Land Characterization (MRLC) consortium activities. This data is based on early to mid-1990’s Landsat Thematic Mapper satellite data of 30 meter resolution (Vogelmann *et al.*, 2001). We also used the 1:250,000 scale land use/land cover maps from the U.S. Geological Survey (USGS 1986), and the general land use classification of Anderson (1970). For assessing variations in the mix of agriculture activities as an expression of land potential, maps from the 1987, 1992 and 1997 Census of Agriculture were analyzed (U.S. Department of Commerce 1990, 1995; U.S. Department of Agriculture NASS 1999). In addition, a map produced from composited multi-temporal Advanced Very High Resolution Radiometer (AVHRR) satellite data was also used to assess boundaries and regional differences. This AVHRR NDVI (Normalized Difference Vegetation Index) data is also used by the USGS Center for Earth Resources Observation and Science (EROS) Data Center to characterize land cover of the conterminous United States (Loveland *et al.*, 1991, 1995).

In addition to the component information listed above, other existing ecological, biological, or physical frameworks were examined. These include the Texas ecoregions of the LBJ School of Public Affairs (1978), Texas ecological areas shown by McMahan *et al.*, (1984), Bezanson (2000), and Telfair (1999), the USFS sections and subsections (Keys *et al.*, 1995), ecoregions of the Nature Conservancy (The Nature Conservancy Ecoregional Working Group 1997, The Nature Conservancy 2003), Major Land Resource Areas (USDA SCS 1981) and later derivatives developed by NRCS, and the natural land-use regions of Barnes and Marschner (1933), among others. Also of major importance in our process of regionalization were the mental maps that local experts brought to discussion meetings, reviews, or field reconnaissance trips.

We used USGS 1:250,000-scale topographic maps as the base for delineating and digitizing the ecoregion boundaries. Although this map series is dated, it does provide quality in terms of the relative consistency and comparability of the series, in the accuracy of the topographic information portrayed, and in the locational control. It is also a very convenient scale. Fifty one of these maps give complete coverage of Texas.

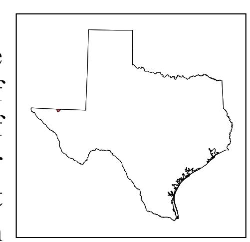
RESULTS AND REGIONAL DESCRIPTIONS

We have divided Texas into twelve level III ecoregions (Figure 1, p. v) and 56 level IV ecoregions (Figure 2, p. vi). Although these level IV ecoregions still contain some heterogeneity in factors that can affect water quality and biotic characteristics, they provide a more detailed framework and more precise ecoregion boundaries than the earlier national-scale ecoregions (Omernik 1987). The ecoregion framework also provides more homogeneous units for inventorying, monitoring, and assessing surface waters than the commonly used hydrologic unit frameworks or political unit frameworks (Omernik and Bailey 1997, Omernik and Griffith 1991, Griffith *et al.*, 1999, Omernik 2003). Major river basins drain strikingly different ecological regions. A map poster of the ecoregions of Texas has been published by USGS (Griffith *et al.*, 2004).

23 ARIZONA/NEW MEXICO MOUNTAINS

The Arizona/New Mexico Mountains are distinguished from neighboring mountainous ecoregions by lower elevations and an associated vegetation indicative of drier, warmer environments, due in part to the region's more southerly location. Chaparral is common at lower elevations; pinyon-juniper, and oak woodlands are found at lower and middle elevations; and the higher elevations are mostly covered with open to dense ponderosa pine forests. Forests of spruce, fir, and Douglas-fir are common in the Southern Rockies (21) and the Wasatch and Uinta Mountains (19), but they are found only in limited areas at the highest elevations in this region. Only a small portion of Ecoregion 23 occurs in Texas. The Guadalupe Mountains on the Texas-New Mexico border comprise the southernmost peaks of the Arizona/New Mexico Mountains ecoregion.

23a Chihuahuan Desert Slopes



The Chihuahuan Desert Slopes of the Guadalupe Mountains in Texas form the leading edge of a giant uplifted Permian reef created from the accumulated remains of algae, sponges, and marine bivalves (Spearing 1991). The white, 2000 foot high cliff face dominates the landscape of the northern Trans-Pecos region of Texas. The lower slopes of the mountains, composed of eroded limestone, shale, and sandstone, represent a continuation of the Chihuahuan Desert ecosystem; soils and vegetation in much of Ecoregion 23a are similar to those in the Low Mountains and Bajadas (24c) of the Chihuahuan Desert ecoregion (24). Water is scarce; the few streams that originate from springs at higher elevations do not persist beyond the mouths of major canyons.

The lower elevation boundary of the Chihuahuan Desert Slopes ecoregion (23a) coincides with the base of the Guadalupe Mountains at about 4500 to 5000 feet. Climate, vegetation, and soil do not differ significantly on either side of the mapped boundary, but the line marks a physiographic and geological transition to the mountainous ecosystem with its cliffs and canyons. The upper boundary of Ecoregion 23a is very generalized; it indicates the passage of desert shrubs and grassland to woodland and surrounds the core of the forested area of the Texas Guadalupe Mountains. The scale of mapping is not detailed enough to represent strips of riparian vegetation or small areas of woodland growing on north-facing slopes.

There is some evidence that grassland once covered the lower slopes of the Guadalupe Mountains as well as the higher elevations up to 7500 feet, and that desert shrubs invaded the area after it was overgrazed in the late 19th century (Gehlbach 1979, Northington and Burgess 1979, Schmidley 2002). Today, yucca (*Yucca* spp.), sotol (*Dasylirion* spp.), lechuguilla (*Agave lechuguilla*), ocotillo (*Fouquieria splendens*) and cacti (*Opuntia* spp.) dominate rocky slopes below 5500 feet, but up to 6500 feet on exposed southern exposures and on the steeper western escarpment. These shrub species are sometimes called succulent desert shrubs to distinguish them from woody desert shrubs, such as creosotebush (*Larrea tridentata*) and tarbush (*Flourensia cernua*), typically found in the drier Chihuahuan Basins and Playas (24a) (Gehlbach 1979). Grasslands dominated by threeawns (*Aristida* spp.), muhly (*Muhlenbergia* spp.), and gramas (*Bouteloua* spp.) persist near alluvial fans and on benches and gentle slopes with deeper soils (Northington and Burgess 1979).

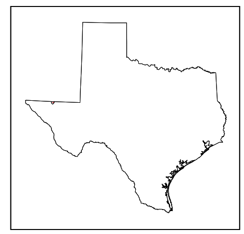
Several lizard species that are adapted to the exposed, sun-baked landscape of west Texas are indicative of the succulent desert shrubland: the round-tailed horned lizard (*Phrynosoma modestum*), the checkered whiptail (*Cnemidophorus tesselatus*), and the greater earless lizard (*Cophosaurus texanus*) (Gehlbach 1979). Other characteristic desert fauna are common, such as rattlesnake (*Crotalus* spp.), kangaroo rat (*Dipodomys* spp.), tarantula (*Aphonopelma* spp.), roadrunner (*Geococcyx californianus*), and, perhaps unexpectedly, mule deer (*Odocoileus hemionus*), a large mammal that is also well-adapted to desert life. In fact, in 1905 Vernon Bailey reported in his Biological Survey of Texas that the mule deer was more numerous in the dry foothills of the western Guadalupe Mountains than it was in the wooded regions at higher elevations (Schmidley 2002). The mule deer can survive without water for extended periods by getting moisture from the plants that it eats, such as the pulpy heart of the sotol plant. The heart of the sotol, or mescal, was also a staple in the diet of the Mescalero Apaches, who mastered the art of survival in the desert (Phelan 1976).

The round-tailed horned lizard (*Phrynosoma modestum*) is a reptilian indicator of the succulent desert shrubland in the Chihuahuan Desert.
Photo: Erik Enderson, Tucson Herpetological Society

Level IV Ecoregion	**23a. Chihuahuan Desert Slopes**
Area (sq. mi.)	69
Physiography	Lower slopes of Guadalupe Mountains; very steep on west and south sides of range, more gradual on the east; cut by steep canyons. Moderate gradient ephemeral streams that carry water only after periodic storms.
Elevation / Local Relief (feet)	4500-6500 / 800-2000
Surficial Geology; Bedrock Geology	Pleistocene to Holocene clay loam colluvium and residuum mixed with limestone and sandstone fragments, gypsum deposits; Pleistocene to Holocene gravels and sands in drainages. Permian limestones, sandstones, and claystones.
Soil Order (Great Groups)	Mollisols (Calciustolls), Aridisols (Haplocalcids, Petrocalcids), Entisols (Torriorthents)
Common Soil Series	Limestone foothills, flat benches, and erosional slopes: Ector, Lozier, Rock outcrop. Alluvial terraces and fans: Tencee, Tome.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Aridic
Mean Annual Precipitation (in.)	15-18
Mean Annual Frost Free Days	180-210
Mean Temperature (F) (Jan. min/max; July min/max)	29/52; 62/85
Vegetation	On benches and slopes with deeper soil: grasses such as blue, black, and sideoats gramas, purple threeawn, mourning lovegrass, curlyleaf muhly. On rocky slopes and in disturbed grasslands: succulent desert shrubs such as sotol, lechuguilla, yucca, ocotillo, and cacti.
Land Cover and Land Use	Shrubland and grassland. Rangeland where not protected in Guadalupe Mountains National Park.

Perennial streams are rare in the Guadalupe Mountains of Ecoregion 23; stream channels generally carry water only after storm events. Sparse vegetation, typical of the Chihuahuan Desert, grows on lower mountain slopes.
Photo Phil Gavenda.

23b Montane Woodlands



The Montane Woodlands ecoregion occurs above 5000 feet on the Guadalupe Mountains on north slopes and in stream riparian zones and above 6500 feet on south facing slopes and on the steep western escarpment. This portion of Ecoregion 23b is at the southernmost tip of the Arizona/New Mexico Mountains (23), surrounded by desert on three sides. Compared to other mountain ranges in Ecoregion 23, the extent of pinyon-juniper woodland, oak woodland, and coniferous forest is much reduced (Johnston 1979). The mapped polygon for Ecoregion 23b is generalized and does not convey the patchy nature of the woodland cover. Densities of juniper (*Juniperus* spp.), pinyon pine (*Pinus edulis*), and oak (*Quercus* spp.) vary according to aspect. At middle elevations, a chaparral community occurs beneath the trees, composed of shrubs such as desert ceanothus (*Ceanothus greggii*), alderleaf mountain mahogany (*Cercocarpus montanus*), and catclaw mimosa (*Mimosa aculeaticarpa*). The top of the plateau is grassy and park-like with scattered juniper, pinyon pine, and oak. Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), and ponderosa pine (*Pinus ponderosa*) grow in limited areas at the highest elevations (above 7000 feet) where more moisture is available (Northington and Burgess 1979). These areas of high elevation conifers form a distinct level IV ecoregion elsewhere in the Arizona/New Mexico Mountains (23), but in the Guadalupe Mountains the coniferous area is too small to map at the 1:250,000 scale.

The east and west faces of the Guadalupe Mountains are cut by a series of canyons. Surface water is scarce; infiltrating rainfall percolates through the limestone, creating caverns throughout the range and a few springs that emerge from sandstone layers at 6000 feet or below. In the canyons, Chihuahuan desert shrubs and higher elevation conifers mix with deciduous riparian trees such as chinkapin oak (*Quercus muehlenbergii*), wavyleaf oak (*Quercus pauciloba*), and bigtooth maple (*Acer grandidentatum*). The canyons support a high number of endemic plant species due in part to their isolation as relics of a wetter climate; they also provide valuable habitat for songbirds that are characteristic of more northerly regions.

McKittrick Creek Canyon is a center of biotic diversity and a focal point for visitors in Guadalupe Mountains National Park. Several ice-age era woodland species are found here due to water and high, sheltering walls of the canyon. McKittrick Creek is considered a perennial stream, although it often runs underground and ends at the mouth of its canyon. Stream temperatures vary between 59°F near springs to 77°F in open shallow sections. Two species of sunfish (*Lepomis* spp.) and rainbow trout (*Salmo gairdneri*), stocked in McKittrick Creek by previous landowners, are still present. The trout are able to survive and reproduce in the upper sections of the creek at cooler spring sources (Lind 1979). Hanging terraces, or limestone seeps, on the walls of McKittrick Canyon, support maidenhair fern (*Adiantium capillus-veneris*), sawgrass (*Cladium mariscus*), and the rare Chapline columbine (*Aquilegia chrysantha var. chaplinei*), mountain deathcamas (*Zigadenus elegans*), and mountain ninebark (*Physocarpus monogynus*) (Northington and Burgess 1979). The canyon ecosystems are vulnerable communities, even with National Park protection; they are vulnerable to flash flood and drought, browsing and trampling by elk and deer, and trampling by human visitors.

Mule deer (*Odocoileus hemionus*), black bear (*Ursus americanus*), mountain lion (*Puma concolor*), and the only chipmunk in Texas, the gray-footed chipmunk (*Tamias canipes*), are protected within Guadalupe Mountains National Park. Elk (*Cervus elaphus*) were introduced in the 1920's to replace an extinct subspecies, the Merriam elk, which was known in the region only from archeological evidence. The elk introduction was not without some controversy. In a report describing the benefits of adding the McKittrick Canyon area to the National Park System, Wright *et al.*, (1932) observed that the Rocky Mountain elk were an exotic addition to the desert landscape, that they would concentrate their activities in the limited riparian habitats, and have a negative impact on the native vegetation. The report recommended that the elk be greatly reduced in number or extirpated entirely if the area were to become a National Park. The elk population increased to 350 by the mid 1960's, but since then they have declined steadily to their original numbers (Schmidley 2002). Another introduced mammal, the aoudad (Barbary sheep) (*Ammotragus lervia*), has taken over the ecological niche once occupied by desert bighorn sheep (*Ovis canadensis*), which had been eliminated from the Guadalupe Mountains by 1910 (Texas State Historical Association 2002).

Level IV Ecoregion	**23b. Montane Woodland**
Area (sq. mi.)	16
Physiography	Fault block mountain range dissected by deep canyons; Moderate gradient intermittent, flashy streams with mostly cobble, gravel, and sandy substrates.
Elevation / Local Relief (feet)	5,000-8000 / 400-1200
Surficial Geology; Bedrock Geology	Pleistocene to Holocene clay loam colluvium mixed with limestone and sandstone fragments, gypsum deposits; Pleistocene to Holocene gravels and sands in drainages. Permian limestones, sandstones, and claystones.
Soil Order (Great Groups)	Mollisols (Calciustolls)
Common Soil Series	Deama, Rock outcrop.
Soil Temperature / Soil Moisture Regimes	Mesic / Ustic
Mean Annual Precipitation (in.)	18-22
Mean Annual Frost Free Days	110-170
Mean Temperature (F) (Jan. min/max; July min/max)	29/52; 62/85
Vegetation	North-facing canyon slopes and upland locations above 7000 feet: Ponderosa pine, southwestern white pine, Douglas-fir, limited aspen on talus slopes. Montane woodland: pinyon pine, red-berry juniper, gray oak, Emory oak. Montane grassland: little bluestem, gramas, needlegrasses. Canyon riparian woodland: chinkapin oak, alligator juniper, bigtooth maple, Texas madrone, velvet ash.
Land Cover and Land Use	Patches of montane woodland, grassland, riparian woodland. Public land (Guadalupe Mountains National Park), recreation, research.

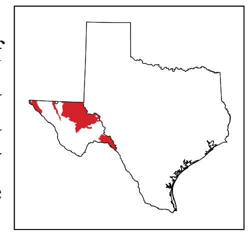
Canyon vegetation includes juniper, ash, oak, Texas madrone, and bigtooth maple, with some ponderosa pine at higher elevations. Mule deer and elk tend to concentrate in riparian areas, stripping the bark off older trees and consuming emerging seedlings. The Texas madrone is particularly vulnerable to browsing pressure. *Photo: George Hosek*

Guadalupe Mountains National Park is one of the few areas in Texas where the cougar has protected status. However, even with unregulated hunting pressure outside the park, cougars are well-established in Ecoregions 23 and 24. *Photo: US Fish and Wildlife Service*

24 CHIHUAHUAN DESERTS

This desert ecoregion extends from the Madrean Archipelago (79) in southeastern Arizona to the Edwards Plateau (30) in south-central Texas. It is the northern portion of the southernmost desert in North America that extends more than 500 miles south into Mexico. In much of the U.S. portion, the physiography of the region is generally a continuation of basin and range terrain (excluding the Stockton Plateau) that is typical of the Mojave Basin and Range (14) and the Central Basin and Range (13) ecoregions to the west and north, although the pattern of alternating mountains and valleys is not as pronounced as it is in Ecoregions 13 and 14. The mountain ranges are a geologic mix of faulted limestone reefs, volcanoes and associated basalt and tuff extrusive rocks, and rhyolitic intrusions. Outside the major river drainages, such as the Rio Grande and Pecos River, the landscape is largely internally drained. Vegetative cover is predominantly semi-desert grassland and arid shrubland, except for high elevation islands of oak, juniper, and pinyon pine woodland. The extent of desert shrubland is increasing across lowlands and mountain foothills due to gradual desertification caused in part by historical grazing pressure.

24a Chihuahuan Basins and Playas



The boundaries for the Chihuahuan Basins and Playas ecoregion surround areas of lowest elevation in west Texas (under 1500 feet near the confluence of the Pecos and Rio Grande rivers), alluvial basins near these rivers, and arid intermountain basins and salt flats under 4500 feet. The boundaries of these disjunct areas are marked climatically by rainfall amounts between 8 and 14 inches, the lowest in the state, by soils that are alkaline or gypsiferous, and by desert shrub vegetation, predominantly creosote bush.

The major Chihuahuan basins in Ecoregion 24a, such as the Hueco, Salt, and Presidio basins, formed during the Basin and Range tectonism when the earth's crust stretched, causing portions of the crust to collapse creating deep depressions or grabens that filled with sediment over time. The sediments consist of clay, silt, sand, and gravel up to 9000 feet thick (such as in the Hueco basin) (Spearing 1991). The flat arid floors of these basins (playas) have saline or alkaline soils and areas of white salt flats (former lake beds), dunes, and windblown sand. Surrounding the playas at low elevations are miles of desert shrubland. These basins often lie in the rainshadow of nearby mountain ranges; they represent the hottest and driest habitats in Texas, with less than 14 inches of precipitation per year. Winter precipitation is relatively sparse; precipitation amounts are highest during the monsoonal rains of July, August, and September.

The desert flora must withstand large diurnal ranges in temperature, low available moisture, and an extremely high evapotranspiration rate. The highly saline portion of the playas at the lowest elevations, may be completely barren, but salt-tolerant plants such as fourwing saltbush (*Atriplex canescens*), pickleweed (*Allenrolfea occidentalis*), and alkali sacaton (*Sporobolus airoides*) do grow in the margins of the dry lake beds where the water table is near the surface (Bezanson 2000). The valleys and rolling alluvial fans above the basin floors support vast areas of desert shrubs dominated by creosote bush (*Larrea tridentata*) and tarbush (*Flourensia cernua*). Land use for grazing has evolved from cattle to sheep and goats as the range has changed from a predominance of grass to desert shrubs.

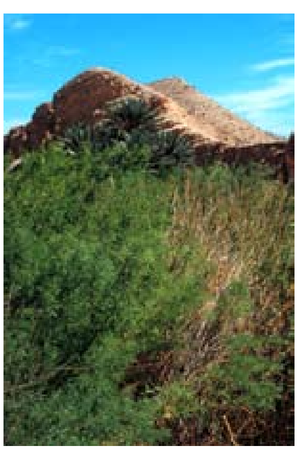
Creosote bushes grow on alkaline flats in evenly spaced rows with their positions relative to one another determined by water availability. These shrubs are also allelopathic, meaning they release toxins into the surrounding soil that discourage competition from neighboring plants. *Photo: Sandy Bryce*

The low elevation desert country of the Pecos River basin and the Rio Grande River basin bound West Texas on the east, south, and west. Both rivers carry water into the region from sources in the Rocky Mountains to the north. There is a high demand for irrigation and industrial water along the length of each river, and the present flow of both the Pecos and the Rio Grande rivers is greatly reduced from historical levels. Early travelers' accounts describe the Pecos, for example, as being wide, deep, and fast (4 to 15 feet deep and up to 100 feet wide), and crossable at only a few safe fording points (Graves 2002).

Riparian areas in the desert lowlands had been highly altered by the late 19th century by the concentration of high numbers of cattle in the more productive areas close to streams. For example, in what is now Big Bend National Park, meadows that once existed along Tornillo and Terlingua Creeks supported 30,000 cattle in 1891 (Gehlbach 1993). In addition, alien saltcedars (*Tamarix spp.*) and river cane (*Phragmites australis*) have invaded most riparian areas, often creating an impenetrable monoculture along the banks. Saltcedars are phreatophytes, plants with deep roots that use significant amounts of ground water through evapotranspiration, transpiring as much as 200 gallons per day (Wuerthner 1989). As a result, besides displacing native riparian plant communities, saltcedars compete for scarce water supplies, and eradication efforts are underway to bulldoze, chain, plow, burn, or apply herbicide to thousands of acres of saltcedar to increase water yield. The paradox to this approach is that the frequent disturbance that is necessary to eliminate the saltcedar also eliminates native riparian plant growth and adds sediment to existing waterways. Burning of riparian areas also occurs along the U.S. side of the Rio Grande, related to border control issues.

Although they may appear to be barren deserts, these sediment-filled basins can hold significant amounts of ground water in underground aquifers. Farmers depend on wells to irrigate cropland near El Paso (Hueco Basin), Pecos (Pecos River valley), and Dell City (Salt Basin) to produce cotton, pecans, alfalfa, tomatoes, onions, and chili peppers. Wells can yield several hundred to over 2000 gallons per minute; however, over-pumping of the aquifers risks infiltration of brackish water as well as earth subsidence caused by drawing down the ground water level. In the El Paso area, ground water levels have declined over 100 feet since the beginning of the 20th century and demand for water there may soon exceed supply (U.S. Geological Survey 2002). Irrigated agriculture may also be curtailed by salt buildup in the soil; large areas of formerly farmed fields have been abandoned in the Pecos River valley.

There are a number of lizard species in the shrub desert ecoregions (23a, 24a, and 24c) that can be considered indicators of a particular ecoregion because their habitat preferences coincide with the physical characteristics defined for that ecoregion. The lizards preferring the shrub desert habitats of Ecoregion 24a are the side-blotched (*Uta stansburiana*), Texas horned (*Phrynosoma cornutum*), and little-striped whiptail (*Cnemidophorus inornatus*). The bird species most closely associated with creosote bush habitats is the black-throated sparrow (*Amphispiza bilineata*); other bird species are present only in proportion to quantities of other types of shrubs (Gehlbach 1979, 1993). The birds and lizards are active in the heat of the day; other species, such as the kangaroo rat (*Dipodomys* spp.) and kit fox (*Vulpes velox macrotis*), cope with the desert environment by spending the day underground and venturing forth at night. The kit fox preys on insects, kangaroo rats, and jackrabbits (*Lepus californicus*) (which weigh the same as this diminutive fox). The number of kit foxes has declined greatly due to poisoning and trapping; it is a candidate species for listing on the U.S. Fish and Wildlife Service's endangered species list (Schmidley 2002).

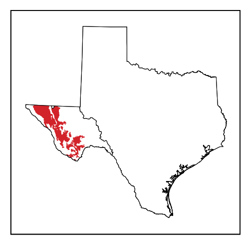


Alien saltcedars (*Tamarix spp.*) and river cane (*Phragmites australis*) have invaded riparian areas in the Chihuahuan Desert and replaced native vegetation. *Photo: Sandy Bryce*

The black-throated sparrow (*Amphispiza bilineata*) is closely associated with creosote bush habitats in Chihuahuan Basins and Playas. It gets all the water it needs from the seeds and insects that it eats. *Photo: National Park Service*

Level IV Ecoregion	24a. Chihuahuan Basins and Playas
Area (sq. mi.)	12,625
Physiography	Deep depressions or grabens filled with sediment to form flat to rolling basins. Basins either alluvial basins surrounding major river (Pecos, Rio Grande) or internally drained (Salt Basin). Streams ephemeral.
Elevation / Local Relief (feet)	1200-4500 / 25-500
Surficial Geology; Bedrock Geology	Upper Pecos, Hueco, and Salt Basins: Holocene, Pleistocene, and late Tertiary alluvium and erosional materials from surrounding mountains, including unconsolidated basin deposits, silt, sand, and gravel. Lower Pecos: Holocene and Pleistocene limestone residuum and colluvium; Upper and Lower Cretaceous limestones.
Soil Order (Great Groups)	Mollisols (Calciustolls), Aridisols (Haplocalcids, Petrocalcids, Calcigypsids), Entisols (Torriorthents, Torripsamments)
Common Soil Series	Basins, fans, and footslopes: Langtry, Zorra, Lozier, Shumla (lower Pecos R. valley), Hueco, Wink (Hueco Basin), Delnorte, Nickel, Reakor, Hoban, Upton (Pecos River basin). Salt Basin alkali flats: Holloman, Reeves. Sand sheets and dunes: Bluepoint.
Soil Temperature / Soil Moisture Regimes	Thermic, Hyperthermic/ Aridic, Ustic Aridic
Mean Annual Precipitation (in.)	8-14
Mean Annual Frost Free Days	220-250
Mean Temperature (F) (Jan. min/max; July min/max)	25/60; 67/97
Vegetation	Saline flats and alkaline playa margins: fourwing saltbush, seepweed, pickleweed, and alkali sacaton. Gypsum land: gyp grama, gyp mentzelia, and Torrey ephedra. Desert shrub land: creosote bush, tarbush, yuccas, sandsage, blackbrush, tasajillo, lechuguilla, and ceniza.
Land Cover and Land Use	Shrubland, remnant grassland, or barren land. Wildlife habitat, limited grazing, some urban and military land, some irrigated cropland.

24b Chihuahuan Desert Grasslands



The Chihuahuan Desert Grasslands occur in areas of fine-textured soils, such as silts and clays, that have a higher water retention capacity than coarse-textured, rocky soil. The grasslands occur in areas of somewhat higher annual precipitation (10 to 18 inches) than the Chihuahuan Basins and Playas (24a); these include elevated basins between mountain ranges, low mountain benches and plateau tops, and north-facing high mountain slopes where natural erosion or the effects of overgrazing have not removed the soil. Desert grasslands also occur at lower elevations in areas of denser clay soil or where the water table is near the surface, for example, in dry lake basins (playas) and alluvial riparian areas. In his 1857 report to Congress, William Emory made regular observations on the grasslands his expedition encountered during the U.S./Mexico Boundary Survey. Since Emory's time, many of these grasslands in West Texas have been replaced by desert shrubland (Gehlbach 1993). The evidence suggests that grazing levels in the late 19th and early 20th centuries were unsustainable, and desert shrubs invaded the fragmented grass cover. Effective management strategies for grasslands take into account their fragile and erosive nature.

The character of grasslands and their species assemblages differ between semidesert, mid-elevation, and mountain grasslands. In low elevation semidesert areas (2000 to 4500 feet) with lower rainfall, the areal coverage of grasses may be sparse, 10% or less. Typical species include black, blue, and sideoats grama (*Bouteloua* spp.), bush muhly (*Muhlenbergia porteri*), beargrass (*Nolina arenicola*), and galleta (*Pleuraphis jamesii*), with scattered creosotebush (*Larrea tridentata*), acacias (*Acacia* spp.) and cacti (*Opuntia* spp.). When the grass cover becomes fragmented, it may be replaced by burrograss (*Scleropogon brevifolius*). Burrograss can only be eaten by cattle when young, and it spreads more aggressively because it can set seed even in the driest weather when other grasses are dormant (Cottle 1931). At the same elevation range, in valley bottoms and ancient lake beds with a high water table and clay soil, gramas are much less prevalent. The taller, coarser tobosa grass (*Pleuraphis mutica*) is dominant, accompanied by tarbush (*Flourensia cernua*). At higher elevations, 4000 to 7000 feet, mountain grasslands tend to be somewhat more intact over wider areas than the semidesert grasslands due to higher precipitation levels and the occasional snowfall, which saturates the soil more thoroughly than intense rain storms. As a result, the incidence of desert shrubs in mountain grasslands is lower as well.

Along ephemeral drainages in the mountain foothills and on alluvial fans, bands of riparian woodland interrupt the grasslands. Gray oak (*Quercus grisea*) predominates, but velvet ash (*Fraxinus velutina*) and little walnut (*Juglans microcarpa*) may also be present. Groves of trees may also spread up north-facing slopes from the riparian areas (Cottle 1931, Bezanson 2000). Typically water only flows in most of these stream channels following a heavy rain, most of which falls between June and October. Runoff is intense and flashy, and it carries heavy loads of sediment along drainages. Riparian woodland helps prevent soil erosion and loss of the thin topsoil cover.

There is some debate whether bison ever inhabited the west Texas grasslands or whether they ever ranged west of the Pecos River (Cottle 1931; Graves 2002), but it is known that the bison's other associate, the pronghorn (*Antilocapra americana*), were once common in west Texas. They were nearly exterminated by the turn of the 20th century, and reintroduced in some areas in the 1930's (Schmidley 2002). Since almost all of these grasslands are privately owned, the future of the pronghorn is dependent on the stewardship of West Texas ranchers.

Pronghorn were once more abundant on desert grasslands. *Photo: USFWS.*

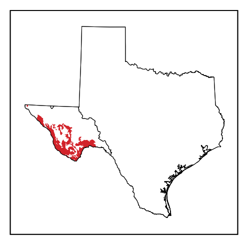
Boundary decisions for Ecoregion 24b were based on vegetation and soil maps, precipitation information, and literature review. When the information was transferred to topographic maps it was checked to ensure that it made sense physiographically, located as expected in intermountain basins, mountain foothills, and bajadas. The Chihuahuan Desert Grasslands ecoregion contains a number of disjunct areas and spans a relatively wide elevational range. The resolution of the level IV ecoregions is not high enough nor is the information about West Texas grasslands detailed enough to distinguish low, mid-, and upper elevation grasslands. At lower elevations, grassland is in general retreat because of a desertification process caused by past and present grazing and natural drought cycles. As a result, some areas that were once grassland, but are now desert shrubland, may not be included in the present ecoregion boundaries.

Few intact areas of desert grassland exist at lower elevations. Even in Big Bend National Park, pictured here, desert grasslands have not fully recovered from past grazing pressure, and they are subject to invasion by desert shrubs. *Photo: Sandy Bryce*

Grasslands tend to be better preserved at higher elevations where there is more available moisture. Grasses there are better able to resist fragmentation under grazing pressure which slows the desertification process by limiting exposed soil, erosion, and the invasion of desert shrubs. Geology plays a role as well; there is better soil development and soil water retention in the volcanically-derived soils of the Davis Mountains than in the droughty calcareous soils of other West Texas mountain ranges underlain by limestone. *Photo: Bruce Young.*

Level IV Ecoregion	24b. Chihuahuan Desert Grasslands
Area (sq. mi.)	10,103
Physiography	Plateaus, high intermountain basins, alluvial fans, and bajadas. Stream segments from occasional spring sources, otherwise ephemeral, flowing only after storm events.
Elevation / Local Relief (feet)	2000-6500 / 150-1000
Surficial Geology; Bedrock Geology	Holocene and Pleistocene alluvium and alluvial fan formations, loamy residuum from limestone bedrock; residuum and colluvium from fractured volcanic and igneous rock. Lower Cretaceous limestone and sandstone; Tertiary igneous and volcaniclastic rocks.
Soil Order (Great Groups)	Aridisols (Haplocalcids, Petrocalcids, Haplocambids), Mollisols (Calciustolls)
Common Soil Series	Alluvial fans and footslopes: Upton; Reakor, Philder, Armesa. Alluvial flats: Reyab, Chamberino, Pajarito. Limestone plateaus: Ector, Lozier. Igneous and volcanic mountain slopes: Chilicotal, Monterosa.
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic, Ustic Aridic
Mean Annual Precipitation (in.)	10-18
Mean Annual Frost Free Days	190-240
Mean Temperature (F) (Jan. min/max; July min/max)	26/60; 62/90
Vegetation	Low elevation semidesert: black, blue, and sideoats grama, bush muhly, beargrass, and galleta, with scattered creosotebush, acacias, and cacti. Ancient lakebeds and alluvial areas: some grama grass, tobosa grass, tarbush. Mountain grassland: blue, hairy, and sideoats grama, little and silver bluestem, threeawns. Scattered yuccas, lechugilla, sotol, and junipers. Riparian areas: gray oak, Emory oak, ash, Texas walnut. Near flowing water, springs: Rio Grande cottonwood, black poplar, black willow, common reed, huisache.
Land Cover and Land Use	Grassland and some shrubland. Grazing, ranching, wildlife habitat, and recreation.

24c Low Mountains and Bajadas



The Low Mountains and Bajadas ecoregion encompasses the mountain ranges scattered across West Texas that separate the broad desert playas and grasslands. The mountains have a mixed geology: Permian-age sandstone, limestone, and shale in the Apache and Delaware mountains; Cretaceous-age limestone along the Rio Grande River in the Sierra del Caballo Muerto; and Tertiary-age volcanic rocks in the Chisos and Davis mountains. Although most of the mountainous areas are not particularly high, mostly below 6000 feet, they are rugged, with exposed bedrock, vertical rimrock cliffs, and steep box canyons. Alluvial fans of rubble, sand, and gravel often bury the base of the mountains and coalesce to form bajadas. These disjunct areas of Ecoregion 24c tend to have somewhat the opposite characteristics of the grassland and basin areas of 24a and 24b: rough topography rather than smooth; rocky substrates rather than fine-textured soils; and desert shrub vegetation rather than grassland.

The Apache and Glass mountains are exposed portions of the same reef complex that forms the headwall of El Capitan in the Guadalupe Mountains to the north. Much of the surface water that falls on these mountains runs off as surface flow, and any moisture that enters the fissures between the limestone layers continues to percolate through the porous rock. As a result, the stony soil on the limestone ranges is generally more droughty than that at similar elevations on other rock types (Bezanson 2000). Upland vegetation, therefore, is extremely depauperate on these limestone ranges. Canyons in the limestone mountains can be just as hostile for plant growth. Santa Elena Canyon, located west of the Chisos Mountains on the Rio Grande River, has sheer vertical walls; it is 1000 feet deep and in places only 25 feet wide. The volcanic mountain ranges also have very little soil, but the pattern of erosion in basaltic canyons provides more diverse aspects and microhabitats for plant life. Volcanic substrates tend to have more springs and ground water available to plants rooted in the fractured rock. The Bofecillos Mountains west of Big Bend National Park, for example, contain moist canyons and more than 80 perennial springs (Parent and Patoski 2001). Other springs, such as Mule Ear Springs and Red Ass Springs, were relied on by Indians and early sheep herders. Cottonwoods are good visual markers of these springs.

There is an abundance of succulent plants in the Chihuahuan Desert, and the sparse upland vegetative cover includes mostly succulent desert shrubs, such as sotol (*Dasylirion* spp.), lechuguilla *(Agave lechuguilla*), ocotillo (*Fouquieria splendens*), lotebush (*Zizyphus obtusifolia*), tarbush (*Flourensia cernua*), and pricklypear (*Opuntia* spp.), with scattered black grama (*Bouteloua eripoda*) or muhly (*Muhlenbergia* spp.). On rocky outcrops, shrubs such as true mountain mahogany (*Cercocarpus montanus*), mock orange (*Philadelphus* spp.), and silktassel (*Garrya wrightii*) are important food sources for browsing animals, e.g., mule deer (*Odocoileus hemionus*), reintroduced elk (*Cervus elaphus*), and desert bighorn sheep (*Ovis canadensis*). At the highest elevations, some scattered juniper (*Juniperus* spp.) and pinyon pine (*Pinus edulis*) cling to the rocks. Several of the mountain ranges above 6000 feet have grassy summits (Bezanson 2000; Parent and Patoski 2001).

The dry mountain habitats provide cover for mule deer (*Odocoileus hemionus*), bobcat (*Lynx rufus*), collared peccary (*Pecari tajacu*), and Montezuma quail (*Cyrtonyx montezumae*); but the animal most emblematic of these mountains is the desert bighorn sheep (*Ovis canadensis mexicana*). In the 1890's Vernon Bailey's Biological Survey found them in several of these mountain ranges. Bailey wrote, "Here the sheep find ideal homes on the open slopes of terraced lime rock or jagged crests of old lava dikes and thanks to the arid and inaccessible nature of the country, they have held their own against the few hunters of the region." Although the bighorn sheep were protected by law in 1903, they continued to decline due to exposure to diseases spread by domestic sheep and goats, and disappeared from Texas in the second half of the 20th century. In the 1970's, the state of Texas began to reintroduce bighorn sheep from a propagation center established on the Black Gap Wildlife Management Area northeast of Big Bend (Schmidley 2002).

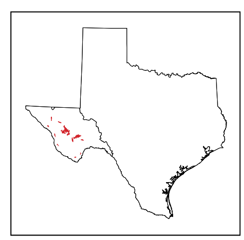
Level IV Ecoregion	**24c. Low Mountains and Bajadas**
Area (sq. mi.)	8199
Physiography	Numerous, mid-elevation mountain ranges separated by basins. Streams ephemeral; scattered springs.
Elevation / Local Relief (feet)	2000-6000 / 300-2800
Surficial Geology; Bedrock Geology	Holocene and Pleistocene loamy residuum over limestone bedrock; Residuum and colluvium from fractured volcanic and igneous rock. Lower Cretaceous limestones (Big Bend region); Permian limestones (Delaware Mountains); Precambrian granite and metamorphic rocks and Paleozoic sedimentary rocks (Franklin Mountains); Tertiary volcanic rocks: basalt, rhyolite, tuff, and breccia (Chinati, Vieja, and Bofecillos Mountains).
Soil Order (Great Groups)	Mollisols (Haplustolls, Calciustolls, and Paleustolls), Aridisols (Haplocalcids, Petrocalcids), Entisols (Torriorthents)
Common Soil Series	Limestone mountains slopes: Lozier, Upton, Mariscal, Ector. Limestone benches, valleys, and fans: Reagan, Delnorte. Igneous and volcanic mountain slopes: Lajitas, Brewster, Liv. Mixed alluvium: Chamberino, Reakor, Tencee. Rock outcrop.
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic, Ustic
Mean Annual Precipitation (in.)	9-17
Mean Annual Frost Free Days	200-250
Mean Temperature (F) (Jan. min/max; July min/max)	29/61; 65/92
Vegetation	Upland slopes: sotol, lechuguilla, yucca, ocotillo, lotebush, tarbush, pricklypear, black grama, gyp grama, muhly. Canyons and north-facing hollows: gray oak, Emory oak, ash, bigtooth maple. Rocky outcrops: widely spaced pinyon pine, redberry and one-seeded juniper, mountain mahogany, Fendler ceanothus.
Land Cover and Land Use	Shrubland, limited woodland. Ranching, wildlife habitat, some mining.

Extremely sparse vegetation grows on layered limestone outcrops in low mountains of Ecoregion 24c near the Rio Grande River, Big Bend National Park. *Photo: Sandy Bryce*

The Low Mountains and Bajadas Ecoregion (24c) was once prime habitat for the desert bighorn sheep. After the desert bighorns' disappearance in the mid-20th century, the state of Texas began a reintroduction effort. *Photo: USFWS*

Ocotillo and pricklypear are members of the succulent desert shrub assemblage; they are pictured here in Ecoregion 24c growing on the broad alluvial fans and terraces extending toward the Rio Grande River from the base of the Chisos Mountains in Big Bend National Park. *Photo: Sandy Bryce*

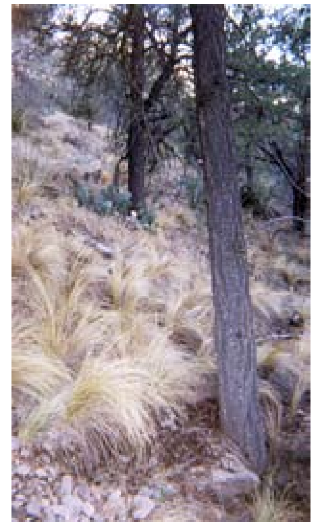
24d Chihuahuan Montane Woodlands



The Chihuahuan Montane Woodlands ecoregion covers disjunct mountainous areas above 5000 feet, mainly in the Chisos, Davis, Glass, and Apache mountains. The lower boundary of the ecoregion begins where upland trees appear as widely spaced individuals with a grass or shrub understory, and the ecoregion polygons extend to include the mountain tops. The larger mountain masses, the Chisos and Davis mountains, having sufficient land area above about 6000 feet, generate increased cloud formation and precipitation in their localized areas in west Texas. Increased precipitation (18 to 20 inches per year) at higher elevations supports woodland, although sunny, exposed slopes may contain grass and chaparral only. There are a few springs, particularly on limestone substrates, and mid-elevation streams may flow only during heavy rains. Although a couple of streams flow for a limited distance in the canyons of the Davis Mountains, the only water in the Chisos Mountains is found in spring seeps and rock basins that collect rainwater.

The Davis and Chisos mountains are products of an extensive Tertiary volcanic episode; they contain eroded lava flows, collapsed calderas, and exposed igneous intrusions. The lava punctured and inundated broad areas of the underlying Cretaceous limestone and sandstone foundation (Spearing 1991). The Davis and Chisos mountains, along with the Guadalupe Mountains (23b), are links in a chain of mountain ranges connecting the southern Rocky Mountains with the Sierra Madre in Mexico. Each range retains some biotic associations to the Rocky Mountains, but existing Rocky Mountain influences, such as isolated patches of aspen (*Populus tremuloides*), are likely relicts of the Pleistocene glaciation when cooler conditions prevailed (Gehlbach 1993). Oak (*Quercus* spp.), juniper (*Juniperus* spp.), and pinyon pine (*Pinus edulis* and *P. cembroides*) woodland, a common vegetation type across the southwestern U.S., is limited in Texas to the upper elevations of the Davis, Chisos, and Guadalupe mountain ranges. Near 5000 feet, these woodland species grow in canyons and shaded hollows, moving upslope to create closed-canopied woodlands with increasing elevation and moisture levels. Trees sometimes grow with a grassy understory, or with a brush cover of bigtooth maple (*Acer grandidentatum*), madrone (*Arbutus xalapensis*), little walnut (*Juglans microcarpa*), white leaf oak chaparral (*Quercus hypoleucoides*), and grapevines (*Vitis* spp.).

Coniferous forests are limited in extent. Ponderosa pine (*Pinus ponderosa*) and some relict Douglas-fir (*Pseudotsuga menziesii*) grow at the highest elevations and on north slopes in the Chisos Mountains. Higher elevation sites in the Davis Mountains also support ponderosa pine and southwestern white pine (*Pinus strobiformis*) forests. Typically, in more extensive mountainous areas, the coniferous forested areas would help define a separate ecoregion, but in Texas these areas are too small and isolated to be mapped separately.



The Chihuahuan Montane Woodland understory includes bunchgrasses and succulent desert shrubs. *Photo: Sandy Bryce*

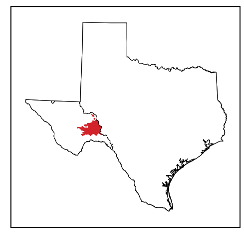
The higher mountainous areas are a refuge for larger ungulates, such as mule deer (*Odocoileus hemionus*) and reintroduced elk (*Cervus elaphus*), and their major predator, the mountain lion (*Puma concolor*). Javelina (*Pecari tajacu*) are common here. The black bear (*Ursus americanus*), formerly extirpated from the Davis Mountains and the Big Bend area, has recolonized the Chisos Mountains from populations in Coahuila, Mexico (Schmidley 2002). A number of northern bird species reach the southernmost extent of their breeding range in the Davis and Chisos mountains, continuing the trend from the Guadalupe Mountains to the north; they are gradually replaced in the Chisos Mountains by northerly recruits from the Sierra Madre in Mexico, such as the Mexican jay (*Aphelocoma ultramarina*), painted redstart (*Myioborus pictus*), and Colima warbler (*Vermivora crissalis*) (Gehlbach 1993).

Level IV Ecoregion	**24d. Chihuahuan Montane Woodlands**
Area (sq. mi.)	978
Physiography	Upper portions of mountain ranges; flat plateau tops and rimrock or steeply sloping pinnacles and canyons. Streams ephemeral; scattered springs.
Elevation / Local Relief (feet)	4800-8378 / 500-2000
Surficial Geology; Bedrock Geology	Chisos, Davis Mountains: Holocene and Pleistocene stony colluvium weathered from igneous bedrock, weathered tuff, trachyte, and rhyolite. Glass, Apache Mountains: Holocene and Pleistocene loamy residuum and colluvium over Permian limestone bedrock. Tertiary volcanic rocks: basalt, rhyolite, and tuff (Chisos and Davis Mountains); Permian limestones (Glass and Apache Mountains).
Soil Order (Great Groups)	Mollisols (Haplustolls, Argiustolls, Calciustolls, and Paleustolls), Alfisols (Paleustalfs)
Common Soil Series	Rolling to steep hills and mountains: Brewster, Liv, Puerta, Madrone, Mainstay (Chisos, Davis Mountains); Ector (Apache, Glass Mountains), Rock outcrop
Soil Temperature / Soil Moisture Regimes	Thermic/ Ustic, Aridic Ustic
Mean Annual Precipitation (in.)	18-26
Mean Annual Frost Free Days	150-230
Mean Temperature (F) (Jan. min/max; July min/max)	26/60; 58/90
Vegetation	Evergreen woodland: Emory oak, gray oak, alligator juniper, Mexican pinyon, bunchgrasses. Riparian deciduous woodland: Little walnut, Texas madrone, bigtooth maple. Coniferous forest: Douglas-fir (Chisos Mts.), Arizona cypress (Chisos Mts.), southwestern white pine (Davis Mts.), ponderosa pine (both ranges). Grasses include gramas, bluestems, muhlys, threeawns, pinyon ricegrass, and lovegrass.
Land Cover and Land Use	Mixed and evergreen woodland and forest. Ranching, grazing, wildlife habitat, some public land (Big Bend National Park).

This view of the upper Chisos Basin in the Chisos Mountains of Big Bend National Park illustrates the diverse and patchy nature of Chihuahuan Montane Woodlands (24d), a mixture of oaks, junipers, and conifers. *Photo: Sandy Bryce*

Relict coniferous forest occurs in the Chihuahuan Montane Woodlands (24d), with ponderosa pine, Douglas-fir, Arizona pine, or southwestern white pine. *Photo: Phil Gavenda*

24e Stockton Plateau



Physiographically, the Stockton Plateau is distinguished as an elevated, dissected landform extending westward into the lower, desert shrub regions of West Texas and the Chihuahuan Desert. The Stockton Plateau differs from the central Edwards Plateau (30) in that the outlines of its mesa topography are more sharply defined than the rounded profiles of hills on the Edwards Plateau due to the lack of precipitation and associated chemical weathering of the limestone substrate (Spearing 1991). Geologically, the Stockton Plateau is composed of the same Cretaceous-age Edwards limestone that forms the karst terrain of the core of the Edwards Plateau (30) to the east. However, ecologically, it is more closely aligned with the more arid West Texas environment, particularly in its arid to semiarid climate, and its landscape of canyons and mesas. The precipitation cycle is also typical of West Texas in that it is relatively dry in the winter, with most of the precipitation (8 to 15 inches per year) falling in June through September. The vegetation of Ecoregion 24e is transitional to the desert shrub habitat of the Chihuahuan Desert that surrounds the plateau on three sides. The eastern boundary of the Stockton Plateau is set at the Pecos River, which provides a suitable break in the limestone substrate to separate it from the Edwards Plateau, as well as a longitudinal marker for the transition to the West Texas landscape. The other boundaries are physiographic, placed at the plateau edges or escarpments.

The Cretaceous-age limestone is fissured with sinkholes and caverns. In fact, the Stockton Plateau is the location of one of the deepest caves in the state, Sorcerer's Cave, a series of vertical drops and chambers emptying into the underground Sirian River at 558 feet below the surface (Elliot 2004). The Sirian River is the source of springs that flow into the Rio Grande River to the south. Another outlet for Stockton Plateau groundwater was Comanche Springs, which poured forth just below the Stockton Plateau north of the present town of Fort Stockton in Ecoregion 24a. It was a large stream that flowed for thirty miles and supported aquatic life in the desert, for example, muskrat (*Ondatra zibethicus*), soft-shelled turtles (*Apalone* spp.), and Comanche Springs pupfish (*Cyprinodon elegans*), but it was pumped dry in the early 1960's. A number of pupfish were transported to Balmorhea State Park in Toyahvale, Texas in Ecoregion 24a, where a recovered population shares the spring pools with the Pecos gambusia (*Gambusia nobilis*), another endangered species (Sneegas 1997).

Historical accounts suggest that the Stockton Plateau was once a grassland and that springs were once more numerous. Grassland turf stores rainwater and allows it to percolate slowly into the groundwater aquifer to be eventually released as springs. Now that the rocky subsoil has been exposed on the surface, rain water tends to run off quickly, no longer recharging the groundwater aquifers. As a result, many springs have dried up, and perennial streams are rare. Independence Creek, a tributary of the Pecos River, is one of the few remaining examples of a large spring-fed creek on the Stockton Plateau; the addition of its clear spring water improves the quality of the Pecos River and increases its volume by over 40 percent (The Nature Conservancy 2004). Independence Creek is an important refugia for several desert springs fish species, such as the proserpine

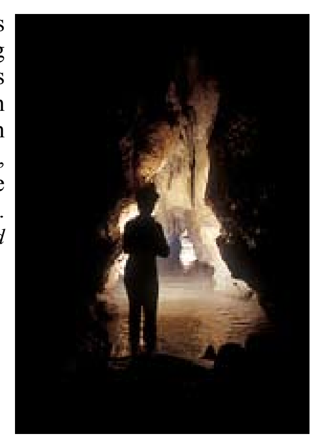
The headwater catfish (*Ictalurus lupus*), found in Independence Creek, is one of several fish species of concern that depend on spring-fed stream systems for their existence. *Photo: Garold Sneegas, Texas Natural History Collections*

shiner (*Cyprinella proserpina*), Rio Grande darter (*Etheostoma grahami*), and headwater catfish (*Ictalurus lupus*) (Bonner *et al.*, 2004; Linam *et al.*, 2002).

With the intensive year round grazing and overstocking common at the end of the 19th century, woody shrubs began to increase in density on the Stockton Plateau as they did elsewhere in both east and west Texas. Today, the mesa tops are sparsely covered by honey mesquite brush (*Prosopis glandulosa*), redberry juniper (*Juniperus pinchotii*) in the north and west, and Ashe juniper (*J. ashei*) in the east and south. Mohr oak (*Quercus mohriana*) and Vasey oak (*Q. vaseyana*), both shrubby in growth form, replace plateau live oak (*Q. fusiformis*) that is common on the Edwards Plateau (30) to the east. The lower elevations on the Stockton Plateau are covered with grama grasses (*Bouteloua* spp.) and Chihuahuan Desert shrubs, such as yucca (*Yucca* spp.), sotol (*Dasylirion* spp.), and lechuguilla (*Agave lechuguilla*). Broomweeds (*Amphiachyris* and *Gutierrezia* spp.), tasajillo (*Opuntia leptocaulis*), pricklypear *(Opuntia* spp.), and burrograss *(Scleropogon brevifolius*) are common on overgrazed ranges (Bezanson 2000, Texas A&M Bioformatics Working Group 1996).

Level IV Ecoregion	**24e. Stockton Plateau**
Area (sq. mi.)	3369
Physiography	Plateau with mesa topography. Most streams ephemeral; scattered springs. Stream substrate bedrock, cobble, or gravel.
Elevation / Local Relief (feet)	1700-4900 / 300-700
Surficial Geology; Bedrock Geology	Holocene and Pleistocene clay loam residuum and colluvium mixed with limestone shards and stones; Holocene and Pleistocene gravels and sands in drainages. Lower Cretaceous limestones and dolomite of the Edwards Formation; Upper Cretaceous limestones of the Buda and Boquillas formations cap higher hills and buttes.
Soil Order (Great Groups)	Mollisols (Haplustolls, Calciustolls), Aridisols (Haplocalcids, Haplocambids, Petrocalcids)
Common Soil Series	Limestone plains and plateaus: Ector; Kavett, Tarrant, Valera. Alluvial flats and floodplains: Dev, Reagan, Sanderson, Upton. Rock outcrop.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Aridic
Mean Annual Precipitation (in.)	14-18
Mean Annual Frost Free Days	220-240
Mean Temperature (F) (Jan. min/max; July min/max)	31/60; 70/95
Vegetation	Mesas: Ashe or redberry juniper, Vasey or Mohr oak brush, honey mesquite, lotebush. Lower elevations: yucca, sotol, lechuguilla, tarbush, grama and muhly grasses. Riparian vegetation: plateau live oak, little walnut, desert willow, and alien saltcedar.
Land Cover and Land Use	Mostly shrubland, some grassland. Ranching, grazing, wildlife habitat.

The Pecos River flows along the eastern boundary of the Stockton Plateau ecoregion (24e). *Photo: R.E. Rosiere, Tarleton State University*

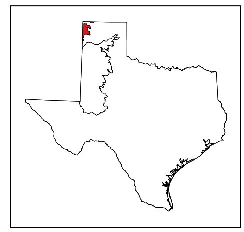


Cave explorers proficient in rappelling down vertical shafts explore the Sirian River at the bottom of Sorcerer's Cave, 500 feet below the Stockton Plateau. *Photo: Chris Vreeland*

25 HIGH PLAINS

The High Plains ecoregion is higher and drier than the Central Great Plains (27) to the east. And, in contrast to the characteristic irregular rangeland of the Northwestern Great Plains (43) to the north in the Dakotas and eastern Montana and Wyoming, much of the High Plains is expressed as smooth to slightly irregular plains with a high percentage of cropland. The potential natural vegetation in this region is grama-buffalo grass compared to mostly wheatgrass-needlegrass to the north, Trans-Pecos shrub savanna to the south, and tallgrass prairie to the east (Kuchler 1964, 1970). The northern boundary of this ecological region is also the approximate northern limit of winter wheat and sorghum and the southern limit of spring wheat. The ecoregion includes the plains area of the Llano Estacado. Thousands of playa lakes (seasonal depressional wetlands) occur in this area, many serving as recharge areas for the important Ogallala Aquifer. These playa lakes are also essential for waterfowl during their yearly migration along the Central Flyway of North America. Oil and gas production occurs in many parts of the region.

25b Rolling Sand Plains



The Rolling Sand Plains expand northward from the lip of the Canadian River trough, and they are topographically expressed as flat sandy plains or rolling dunes. Ecoregion 25b is similar to the Canadian-Cimarron High Plains (25e) in that it has a more northerly climate with colder, more snowy winters than the rest of the Llano Estacado (25i) to the south of the Canadian River. The vegetative cover of the Rolling Sand Plains is transitional between the Shinnery Sands (25j) to the south and the sandsage prairies of Oklahoma and Kansas (northerly disjunct polygons of Ecoregion 25b). Havard shin oak (*Quercus havardii*), the characteristic shrub cover of the Shinnery Sands (Ecoregion 25j), still grows in the Texas portion of Ecoregion 25b, but it is at the northern limit of its distribution. However, both Havard shin oak and sand sagebrush (*Artemisia filifolia*) perform the same important function of stabilizing sandy areas subject to wind erosion.

The sand shinnery (*Quercus mohriana*, *Artemisia filifolia*) community protects the Rolling Sand Plains from wind erosion by vegetating the loose sand substrate. The rolling dune topography is visible in the background. *Photo: R.E. Rosiere, Tarleton State University.*

The boundaries for the Rolling Sand Plains were delineated through a conjunction of the mapped sandsage association on vegetation maps and the soil maps and descriptions that identified typically sandy soil associations (USDA NRCS 1994). These sandy areas were also corroborated on topographical maps as areas that had a more random and irregular road network, rather than the rectangular grid that is common in agricultural areas.

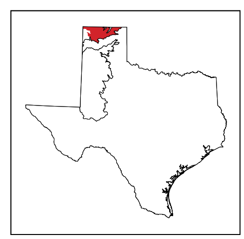
The sandsage association includes grasses such as big sandreed *(Calamovilfa gigantea*), little bluestem (*Schizachyrium scoparium*), sand dropseed (*Sporobolus cryptandrus*), and sand bluestem (*Andropogon gerardii*). Other native range plants are blue grama (*Bouteloua gracilis*), sideoats grama (*Bouteloua curtipendula*), buffalograss *(Buchloe dactyloides*), switchgrass (*Panicum virgatum*), yellow Indiangrass (*Sorghastrum nutans*), and yucca (*Yucca* spp.). The soils of the Rolling Sand Plains have a mesic temperature regime in contrast to the thermic temperature regime of soil in the Llano Estacado (25i) south of the Canadian River. Coarse textured sandy soils typically remain in native rangeland. Soils that are more loamy or clayey may be tilled and planted with wheat or grain sorghum. The goal of both agricultural and grazing management is to keep enough vegetative cover on the land surface to minimize wind erosion.

The sand dropseed (*Sporobolus cryptandrus*) is a bunchgrass that grows in the coarse sands of Ecoregion 25b. *Photo: R.E. Rosiere, Tarleton State University*

The drainage density of the region is low, but the sandy surface serves as a recharge area for a minor groundwater aquifer that feeds a few widely spaced streams. Two sand plains streams, Carrizo and Rita Blanca creeks, have been dammed to create Rita Blanca Lake, which is a major stopover for migrating waterfowl. The sandy native rangeland areas, with a cover of low shrubs and mid- and shortgrass prairie, may also serve as suitable habitat for the threatened lesser prairie chicken (*Tympanuchus pallidicinctus*), a species that is imperiled due to intensive grazing and modern farming practices.

Level IV Ecoregion	**25b. Rolling Sand Plains**
Area (sq. mi.)	1104
Physiography	Flat to rolling sand plain or sand hills and dunes. Low drainage density; occasional intermittent or spring fed streams.
Elevation / Local Relief (feet)	3600-4585 / 25-150
Surficial Geology; Bedrock Geology	Pleistocene sandy and loamy eolian sediments of the Blackwater Draw Formation. Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation.
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs), Mollisols (Paleustolls), Entisols (Ustipsamments)
Common Soil Series	Dallam, Dalhart, Dumas, Vingo, Rickmore, Valentine
Soil Temperature / Soil Moisture Regimes	Mesic / Aridic Ustic, Ustic
Mean Annual Precipitation (in.)	16-18
Mean Annual Frost Free Days	170-185
Mean Temperature (F) (Jan. min/max; July min/max)	18/47; 63/91
Vegetation	Sandsage association: Havard shin oak, big sandreed, little bluestem, sand dropseed, sand bluestem. Short and midgrass prairie: Blue grama, sideoats grama, buffalograss, switchgrass, yellow Indiangrass, yucca.
Land Cover and Land Use	Shrubland and grassland. Ranching, grazing, and some cropland of wheat and grain sorghum.

25e Canadian-Cimarron High Plains



The Canadian-Cimarron High Plains ecoregion includes that portion of the High Plains that lies north of the Canadian River in the Texas Panhandle. The region is bounded on the south in Texas by the edge of the escarpment descending into the Canadian Breaks (26a), and in the west where the region meets the Rolling Sand Plains (25b). The northern boundary occurs in Oklahoma and Kansas. The plains of Ecoregion 25e are somewhat more rolling than the Llano Estacado (25i) to the south; they have fewer playas and are more deeply dissected by stream channels. Winters are more severe than on the Llano Estacado (25i); the increased snow accumulation delays summer drought conditions because the snowmelt saturates the ground in the spring season. There is also relatively more grazing land in Ecoregion 25e than on the main portion of the Llano Estacado to the south; the rougher terrain near the stream incisions tends to be grazed rather than tilled. Overgrazing is less of a danger in Ecoregion 25e than it is in the Arid Llano Estacado (25k) at the southernmost end of the High Plains; drought is more infrequent and the shortgrass prairie sod, which evolved under the grazing and trampling of huge bison herds, remains unbroken under good grazing management (Ricketts *et al.*, 1999). In cultivated areas, corn, winter wheat, and grain sorghum are the principal crops; the region is too far north to grow cotton, which is a principal crop on the Llano Estacado (25i) to the south.

It was the tilling of the land that was most destructive in the uncertain moisture conditions of this part of the High Plains. The soils are calcareous, loamy eolian sediments derived from the Blackwater Draw Formation. They were deposited by prevailing southwest winds during the Pleistocene ice age, and they were carried away by the same prevailing winds during the Dust Bowl of the 1930's. The Rita Blanca National Grassland in the northwest corner of Ecoregion 25e in Texas occupies formerly eroded land purchased for restoration by the U.S. government in the late 1930's. Here a portion of the complex prairie ecosystem still exists minus

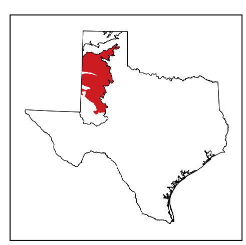
The sandy soils of the Canadian-Cimarron High Plains (25e) formed the core of the Dust Bowl during the drought years of the 1930's. This historic photograph shows the approaching wall of a dust storm about to engulf Stratford, Texas in 1935. *Photo: NOAA*

the central character, the bison (*Bison bison*): the larger ungulates, e.g., pronghorn (*Antilocapra americana*), white-tailed and mule deer (*Odocoileus virginianus* and *O. hemionus*), and the prairie dog and its prairie dog town associates, burrowing owl (*Athene cunicularia*), coyote (*Canis latrans*), swift fox (*Vulpes velox*), and prairie raptors, golden eagle (*Aquila chrysaetos*), Swainson's and ferruginous hawks (*Buteo swainsoni* and *B. regalis*). Although bison no longer graze the shortgrass prairie in this ecoregion, this area remained unsettled until after 1870, and the last of the bison survived here until 1889 (Schmidley 2002).

Black-tailed prairie dogs are a keystone species of North American shortgrass prairies. They are a food source for many predators and their burrows provide homes for many other animal species, such as black-footed ferrets (*Mustela nigripes*), burrowing owls (*Athene cunicularia*), rabbits (*Sylvilagus* spp.), and snakes. *Photo: TPWD*

Level IV Ecoregion	**25e. Canadian-Cimarron High Plains**
Area (sq. mi.)	4587
Physiography	Level to rolling plains, dissected by stream channels. Streams intermittent or spring fed.
Elevation / Local Relief (feet)	2750-4735 / 10-150
Surficial Geology; Bedrock Geology	Pleistocene calcareous eolian sediments of the Blackwater Draw Formation; Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation.
Soil Order (Great Groups)	Mollisols (Paleustolls, Haplustolls, Argiustolls)
Common Soil Series	Gruver, Sherm, Sunray, Ulysses, Darrouzett
Soil Temperature / Soil Moisture Regimes	Mesic / Aridic Ustic
Mean Annual Precipitation (in.)	17-22
Mean Annual Frost Free Days	170-200
Mean Temperature (F) (Jan. min/max; July min/max)	18/47; 63/91
Vegetation	Shortgrass prairie: blue, black, and hairy grama, buffalograss, silver bluestem. Mid-grasses: sideoats grama, western wheatgrass. Forbs: scarlet globe-mallow, sunflowers, stiffstem flax. Invading shrubs: mesquite, narrowleaf yucca, juniper. Playas: Grasses, or willow, rushes, and aquatic plants.
Land Cover and Land Use	Grassland, cropland of wheat and grain sorghum, shrubland. Ranching, grazing, cattle feedlots, oil and gas production.

25i Llano Estacado



The Llano Estacado ecoregion, translated from Spanish as the "Staked Plain", is a level, treeless, elevated plain surrounded by escarpments on three sides It is bounded on the east, west, and north by a clear escarpment descending sometimes hundreds of feet to the plains below. In the south, the boundary is much less distinct; there it is a broader fuzzier boundary, representing the transition to a more arid climate (up to 2 inches less precipitation per year) and a land cover of rangeland typical of the Arid Llano Estacado (25k) rather than the tilled agriculture of the Llano Estacado (25i). Geologically, the Llano Estacado began as an apron of Miocene-Pliocene sediments (Ogallala Formation) eroded from the eastern Rocky Mountains.

Several caliche horizons (calcium carbonate hardpan layers) developed in the Ogallala sediments, including a caprock caliche in the uppermost layer. The caprock was eventually covered by Pleistocene wind-borne sand and silt, the Blackwater Draw Formation (Spearing 1991, Barnes 1992). The caprock makes the High Plains plateau somewhat resistant to erosion, although it is disintegrating slowly through mass wasting and water erosion at the edges of the escarpments. The Pecos River and the Canadian River captured the headwater streams of rivers that once ran across the plain from the Rocky Mountains, isolating the Llano Estacado and truncating the drainage areas of the Red, Brazos, and Colorado rivers of Texas (Flores 1990). As a result, the dry plain, cut off from a mountain surface water source and with little slope to induce runoff, has a very low drainage density. There are very few spring fed creeks, and shallow draws carry water only after heavy rains. The smooth surface of the plain holds seasonal rainfall in myriads of small intermittent ponds or playas.

This is a view of typical shortgrass prairie remaining on the 20% of the Llano Estacado that is not tilled for agriculture. Cholla cacti grow over a turf of blue grama (*Bouteloua gracilis*), with patchy buffalograss (*Buchloe dactyloides*) in the middleground, and galleta (*Hilaria jamesii*) in the right foreground. *Photo: R. Rosiere, Tarleton State University*

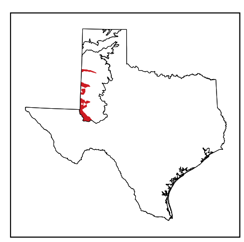
The Llano Estacado was once covered with shortgrass prairie, composed of buffalograss (*Buchloe dactyloides*), blue and sideoats grama (*Bouteloua* spp.), and silver bluestem (*Bothriochloa laguroides ssp. torreyana*) (Bezanson 2000). An estimated 7 million bison once populated the southern High Plains (Flores 1990). They were the most prominent elements of a prairie ecosystem that no longer functions as an interdependent web of bison (*Bison bison*), black-tailed prairie dog (*Cynomys ludovicianus*), black-footed ferret (*Mustela nigripes*), burrowing owl (*Athene cunicularia*) snake, ferruginous hawk (*Buteo regalis*), coyote (*Canis latrans*), swift fox (*Vulpes velox*), deer (*Odocoileus* spp.), pronghorn (*Antilocarpa americana*), mountain lion (*Puma concolor*), and gray wolf (*Canis lupus*). Today, isolated prairie dog towns still exist in public parks or on wildlife refuges and some pronghorn remain on High Plains ranches. The larger playa lakes attract wintering waterfowl such as green-wing teal (*Anas crecca*), widgeon (*Anas americana*), and northern pintail (*Anas acuta*), and sandhill cranes (*Grus canadensis*) on migration. However, few of the playas are protected, and many have been excavated into deep cisterns to store irrigation water, or used as wastewater lagoons for cattle feedlots (Bolen 2004; Sanger and Reed 2000).

About 80% of the Llano Estacado is presently tilled for agriculture (Schmidley 2002). In the era before irrigation, agriculture was not sustainable during drought cycles, and, as a result, the Llano Estacado formed the core of the Dust Bowl during the drought years of the 1930's. Strong winds still mobilize the sandy loam soil to create dust storms; modern tilling practices attempt to configure fields to locally capture some of the airborne soil. Today farmers produce cotton, corn, and wheat under dryland agriculture or irrigated with water pumped from the Ogallala Aquifer. However, the capacity of the Ogallala Aquifer is limited, particularly under drought conditions, emphasizing the need for expansion of ongoing water conservation practices for agricultural and urban water users. The water is literally being mined from the aquifer because it is no longer being recharged from its Rocky Mountain sources, nor is it sufficiently recharged

Much of the surface water in Ecoregion 25 in the Texas Panhandle occurs in seasonal playa lakes that form in small depressions. Playas are key sites of biodiversity and provide important habitat to ducks, geese, sandhill cranes, shorebirds, amphibians, and small mammals. Many of these shallow recharge wetlands have been modified, drained, or converted for cropland or feedlot uses. *Photo: Loren M. Smith, Texas Tech University* from seepage from the playa lakes to replace the water that has been withdrawn. Water withdrawal has increased exponentially throughout the 20th century across 6 million irrigated acres because of the progression from the relatively small output of the windmill to the 1000 gallons per minute of modern centrifugal pumps (Red River Authority of Texas 2004, Leatherwood 2004). In recent years the removal of water from the aquifer has slowed somewhat through changes in the technology of water delivery from the center pivot irrigation systems. However, as the water level has dropped 200 to 300 feet in the Ogallala Aquifer, pumping irrigation water has become prohibitively expensive for many farmers, and up to a million acres of farmland has been returned to dryland farming (Flores 1990).

Level IV Ecoregion	**25i. Llano Estacado**
Area (sq. mi.)	19,072
Physiography	Level, elevated plain, decreasing in elevation from west to east. Few to no streams. Surface water in numerous ephemeral pools or playas.
Elevation / Local Relief (feet)	2480-4400 / 10-100
Surficial Geology; Bedrock Geology	Pleistocene loamy, calcareous, eolian sediments of the Blackwater Draw Formation; Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation.
Soil Order (Great Groups)	Mollisols (Paleustolls, Argiustolls, Haplustolls), Alfisols (Paleustalfs), Vertisols (Epiaquerts), Inceptisols (Calciustepts, Haplustepts)
Common Soil Series	Plains: Olton, Acuff, Amarillo, Estacado, Pullman, Lofton. Playas: Randall. Sandy sites: Patricia, Gomez. Footslope and alluvial soils: Berda, Mansker, Bippus.
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic Ustic
Mean Annual Precipitation (in.)	16-20
Mean Annual Frost Free Days	180-220
Mean Temperature (F) (Jan. min/max; July min/max)	22/51; 65/92
Vegetation	Shortgrass prairie: blue, black, and hairy grama, buffalograss, silver bluestem. Mid-grasses: sideoats grama, western wheatgrass, galleta, yellow Indiangrass, tobosa. Sandy sites: Sand bluestem, sand dropseed. Forbs: dalea, scarlet globe-mallow, sunflower, stiffstem flax. Invading shrubs: mesquite, narrowleaf yucca, juniper. Playas: Grasses, or willow, rushes, and aquatic plants. Riparian woodland: Occasional hackberry, elm, chickasaw plum, sumac.
Land Cover and Land Use	Irrigated and dryland cropland of cotton, corn, grain sorghum, and winter wheat. Ranching, cattle feed lots, oil and gas production.

25j Shinnery Sands



The disjunct areas of the Shinnery Sands ecoregion include sand hills and dunes as well as flat sandy recharge areas. These sand beds lie at the western edge of the High Plains where winds rising onto the plateau drop the heavier sand grains and carry the finer material further east onto the flat expanse of the Llano Estacado (25i). The ecoregion is named for the Havard (shin) oak (*Quercus havardii*) brush that stablizes sandy areas subject to wind erosion. Although the shin oak rarely grows higher than 4 feet, its extensive root system can reach over 50 feet through dune sand to reach water. The largest area of sand dunes, at the southwestern edge of the Llano Estacado (25i), is composed of sands blown out of the Pecos River Basin against the western escarpment of the Llano Estacado by prevailing southwesterly

Havard shin oak (*Quercus havardii*).
Photo: Sandy Bryce

winds (Spearing 1991). These dunes serve as a major recharge area for the Pecos River (Ashworth and Hopkins 1995).

As was done for the Rolling Sand Plains (25b) to the north, the Shinnery Sands were delineated through a conjunction of the mapped Havard shin oak and sandsage associations on vegetation maps (Frye *et al.*, 1984), and the soil maps and descriptions that identified typically sandy soil associations (USDA NRCS 1994). The sand areas included in the Shinnery Sands were more distinct than those in the Rolling Sand Plains (25b) because the sandy soils and dunes of the middle and south Llano Estacado are coarser and more easily distinguished from the finer textured soils surrounding them.

While sand sagebrush (*Artemisia filifolia*) and prairie grasses such as sand dropseed (*Sporobolus cryptandrus*), sand bluestem (*Andropogon gerardii var. paucipilus*), and big sandreed (*Calamovilfa gigantea*) may create a continuous plant cover in portions of Ecoregion 25j, the vegetative cover is vulnerable to overgrazing and subsequent wind blowouts which may begin a cycle of dune formation. Shrub and forb cover may be sparse in dune areas due to the constant motion of the sand base. However, in some dune areas, anchoring shrubs such as Havard oak (*Quercus havardii*), fourwing saltbush (*Atriplex canescens*), and yucca (*Yucca* spp.) stabilize the dune sand for herbaceous grasses and forbs such as sand verbenas (*Abronia* spp.), sunflowers (*Helianthus* spp.), fringed sagewort (*Artemisia frigida*), and hoary rosemary-mint (*Poliomintha incana*). Ephemeral ponds and swales between the dunes support rushes (*Juncus* spp.), sedges (*Carex* spp.), and sandbar willow (*Salix exigua*) (Bezanson 2000).

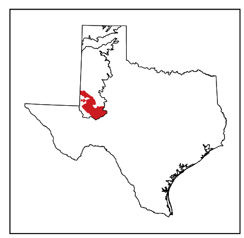
The shinnery sands provide habitat for the lesser prairie chicken (*Tympanuchus pallidicinctus*), a species that is in serious decline. The shrubs offer cover and shade for nesting, and shin oak acorns are a staple food source. The decline of the lesser prairie chicken is linked to the conversion of shinnery to other uses such as agriculture and oil field development. A cooperative study by the Texas Parks and Wildlife Department and Texas A&M University found that, in areas of prairie chicken habitat experiencing population declines between 1940 and 1989, cropland cover had increased from 12-75%, while areas where the number of birds remained stable retained at least 40% of preferred habitat, i.e., brush and native grass cover (Wu *et al.*, 2001). Since many of the flat sandy areas have been converted to irrigated row crops, the last refugia of the lesser prairie chicken tend to be dune areas that have no agricultural value. The dunes at Monahans Sand Dunes State Park protect some lesser prairie chicken habitat as well as that of other wildlife such as mule deer (*Odocoileus hemionus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), and peccary (*Pecari tajacu*), another animal that depends on the shin oak acorns as a major food source (Graham 1992; Schmidley 2002).

Deep-rooted shrubs such as the Havard shin oak (*Quercus havardii)* stabilize shifting sand dunes at Monohan Sand Dunes within Ecoregion 25j.
Photo: Sandy Bryce

The lesser prairie chicken (*Tympanuchus pallidicinctus*) depends on the cover and acorns provided by the Havard shin oak (*Quercus havardii*). *Photo: USFWS*

Level IV Ecoregion	25j. Shinnery Sands
Area (sq. mi.)	2814
Physiography	Flat sand plains, or sand hills and dunes. Low drainage density; occasional intermittent or spring fed streams.
Elevation / Local Relief (feet)	2380-3940 / 10-100
Surficial Geology; Bedrock Geology	Holocene calcareous loamy sediments, Pleistocene sandy eolian sediments of the Blackwater Draw Formation; Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation.
Soil Order (Great Groups)	Entisols (Ustipsamments, Torripsamments), Alfisols (Paleustalfs), Inceptisols (Calciustepts), Aridisols (Haplargids, Petrocalcids)
Common Soil Series	Sand hills: Nutivoli, Springer. Level to rolling sand plains: Arch, Jalmar, Penwell, Triomas, Wickett.
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic Ustic, Ustic Aridic
Mean Annual Precipitation (in.)	13-18
Mean Annual Frost Free Days	180-220
Mean Temperature (F) (Jan. min/max; July min/max)	25/55; 66/94
Vegetation	Shrubs: Havard shin oak, fourwing saltbush, sand sagebrush, yucca. Tall and mid-grasses: Sand dropseed, sand bluestem, big sandreed, little bluestem, switchgrass, sideoats grama. Shortgrass: Buffalograss, alkali sacaton, black grama. Forbs: sand verbena, bush sunflower, hoary rosemary-mint, fringed sagewort.
Land Cover and Land Use	Grassland and shrubland. Ranching, grazing, wildlife habitat, some cropland to the north in flat areas with cotton and grain sorghum. Large oil fields near Andrews, Denver City, and southwest of Odessa.

25k Arid Llano Estacado



The Arid Llano Estacado ecoregion is drier than the main portion of the Llano Estacado (25i) to the north. Its climate is transitional to the arid Trans-Pecos region to the southwest (Ecoregion 24). It has somewhat more broken topography and fewer playas than the plain to the north (Ecoregion 25i). Mean annual precipitation is generally 2 to 3 inches less than that of the Llano Estacado; there is also less winter precipitation and an absence of snow cover to saturate the soil and provide moisture into the summer months. Less moisture in the soil means that the caliche layer is closer to the surface in Ecoregion 25k, increasing the general droughty condition of the soil and making tilled agriculture more difficult than in the Llano Estacado (25i).

In the Arid Llano Estacado, the shortgrass prairie of grama (*Bouteloua* spp.) and buffalo grasses (*Buchloe dactyloides*) is susceptible to overgrazing, and as elsewhere in central and western Texas, a broken grass cover allows the invasion of shrubs such as mesquite (*Prosopis glandulosa*) and lotebush (*Zizyphus obtusifolia)*. The arid conditions also limit agricultural activity, which is dominated by livestock grazing and some irrigated rowcrop agriculture for cotton, sorghum, wheat, and pecans.

The boundary where the Arid Llano Estacado meets the Semiarid Edwards Plateau (30d) is rather indistinct. It was determined geologically by the transition from the Ogallala Formation which underlies the High Plains to the Cretaceous Edwards limestone underlying the Edwards Plateau, and vegetatively by the transition from mesquite-covered shortgrass plains to the mesquite- and juniper-covered, rocky terrain of the Semiarid Edwards Plateau (30d). The soils also change from the silty and sandy soils over caliche in Ecoregion 25k to the thin to nonexistent soil and limestone rock fragments of the Semiarid Edwards Plateau (30d). On the southwest, the Arid Llano Estacado meets the sand dunes of the Shinnery Sands (25j). In the north, the boundary is a broader transition zone to the wetter climate and land cover of tilled agriculture typical of the Llano Estacado (25i) rather than the rangeland of the Arid Llano Estacado (25k).

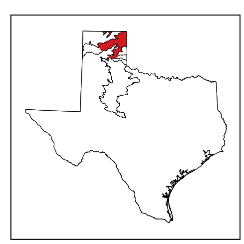
Geology is an important geographical attribute for shaping the present landscape of Ecoregion 25k. The Arid Llano Estacado has roughly the same extent as the Midland Basin, part of the Permian Basin, a structural depression in earth's crust covering much of north central Texas (Spearing 1991). Organic marine sediments from an ancient sea filled the basins over the millennia and were transformed into massive oil reserves. Several large oil fields exist in Ecoregion 25k; surface waters and ground water aquifers are at risk in the region from the movement of contaminating brine through unplugged abandoned oil wells as well as through the disposal of oil industry waste products through deep well injection (Sanger and Reed 2000).

Level IV Ecoregion	**25k. Arid Llano Estacado**
Area (sq. mi.)	4880
Physiography	Level, elevated plain, decreasing in elevation from west to east. Few to no streams. Surface water in numerous ephemeral pools.
Elevation / Local Relief (feet)	2600-3620 / 10-150
Surficial Geology; Bedrock Geology	Pleistocene fine textured, loamy eolian and calcareous sediments of the Blackwater Draw Formation. Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation
Soil Order (Great Groups)	Aridisols (Calciargids, Petrocalcids, Haplargids, Haplocalcids, Petroargids), Mollisols (Paleustolls, Haplustolls)
Common Soil Series	Level to gently rolling plains: Faskin, Douro, Conger, Kimbrough, Stegall, Slaughter,Triomas, Wickett, Upton, Sharvana. Alluvial depressions: Reagan, Bippus
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic Aridic, Aridic Ustic
Mean Annual Precipitation (in.)	13-17
Mean Annual Frost Free Days	210-230
Mean Temperature (F) (Jan. min/max; July min/max)	30/58; 68/95
Vegetation	Shortgrass prairie: blue, black, and hairy grama, buffalograss, silver bluestem, sand dropseed, threeawn, Arizona cottontop, hairy tridens, muhly, bottlebrush squirreltail, sand sagebrush. Increasers with grazing: Burrograss, threeawns, tobosa, broom snakeweed. Forbs: bush sunflower, gray goldaster, dalea, gayfeather. Invading shrubs: mesquite, narrowleaf yucca, juniper, ephedra, catclaw sensitivebriar, tarbush.
Land Cover and Land Use	Shrubland, some grassland, some irrigated cropland of cotton, grain sorghum, wheat, and pecans. Ranching and livestock grazing. Oil fields scattered throughout region.

26 SOUTHWESTERN TABLELANDS

The Southwestern Tablelands flank the High Plains (25) with red hued canyons, mesas, badlands, and dissected river breaks. Unlike most adjacent Great Plains ecological regions, little of the Southwestern Tablelands are in cropland. Much of this region is in sub-humid grassland and semiarid rangeland. The potential natural vegetation in this region is grama-buffalo grass with some mesquite-buffalo grass in the southeast, juniper-scrub oak-midgrass savanna on escarpment bluffs, and shinnery (midgrass prairie with low oak brush) along parts of the Canadian River. Soils in this region include Alfisols, Inceptisols, Entisols, and Mollisols.

26a Canadian/Cimarron Breaks



The Canadian/Cimarron Breaks ecoregion is a broad erosional incision between the High Plains (25) and the Central Great Plains (27). It is also a latitudinal divide that roughly separates the milder climate of the southern plains from the seasonal extremes of the central and northern High Plains. The ecoregion includes the areas in the trough of the Canadian River and the channels of its major tributaries that are incised below the plane of the level Llano Estacado (25i) and Canadian/Cimarron High Plains (25e). The roughened topography of the Canadian/Cimarron Breaks (26a) lies below an escarpment marking the edge of the Llano Estacado (25i), although it is generally not as distinct as the escarpment farther south that breaks more precipitously, exposing deeper geological strata and marking the boundary between the Llano Estacado (25i) and the Caprock Canyons, Badlands, and Breaks (26c). In this case, the escarpment is visible, but the land surface has more of a terraced aspect as it descends to the Canadian River channel.

The creation of the Canadian River trough began during the Pleistocene, when the significantly lowered sea level increased the gradient of rivers like the Canadian. Rivers draining the Rocky Mountains also carried more water during the Pleistocene than they do today because of higher precipitation and glacial melt. These factors combined to increase the river's erosional force and accelerate the headward erosion of the edge of the High Plains (25). There is also evidence that the deep trench of the Canadian River, 500 to 800 feet below the surface of the High Plains (25), may also be partly due to the solution of underlying salt beds and subsequent collapse of overlying rocks (Spearing 1991). Perhaps because of this collapse of the topmost strata, erosion has not penetrated deeply enough in the Texas portion of this region to expose much of the underlying Triassic mudstones or Permian red beds that are prominent in the Cimarron Breaks to the north and east and the caprock canyonlands to the south. The primary deposit is the tan-colored Ogallala Formation and the surficial Blackwater Draw Formation. Thus, the boundaries of the Canadian/Cimarron Breaks ecoregion follow the physiographic break at the escarpment surrounding the edge of the Llano Estacado (25i) and Canadian/Cimarron High Plains (25e) and extend southward along the eastern edge of the Llano Estacado (25i) to where the Ogallala Formation surface meets the red Triassic mudstones and shales of Ecoregion 26c on the south and east.

The Canadian River has a high salt content, and it is turbid from carrying easily eroded sediments. The Ogallala Aquifer feeds springs that flow from exposed strata in the canyons of the Canadian River and its tributaries (Red River Authority 2004). The recent draw down of the Ogallala Aquifer has caused the disappearance of many of the springs, reducing the flow of regional streams (Graves 2002). The loss of springs has also reduced the marshes and wet tallgrass meadows that once flanked the Canadian River (Schmidley 2002). Today, the Canadian River flows through a wide sandy bed flanked by thickets of riparian woodland similar to that found on the eastern Great Plains: black willow (*Salix nigra*), hackberry (*Celtis occidentalis*), skunkbush sumac (*Rhus trilobata*), Chickasaw plum (*Prunus angustifolia*), and a few cottonwoods (*Populus deltoides*) and elms (*Ulmus crassifolia*). Sand sagebrush (*Artemisia filifolia*) also grows on sandy footslopes and creek bottoms. However, this native plant association is presently being displaced by the alien salt cedar (*Tamarix* spp.).

Several declining species of concern depend on the dynamic sandy substrates of rivers and streams in the Canadian River drainage. For example, the interior least tern (*Sterna antillarum*) nests on barren sandbars. The damming of rivers and their tributaries has decreased river channel activity and allowed riparian woodland to cover former sand bars, which decreases tern nesting habitat. In addition, disturbance by off-road vehicle traffic along the margins of the river channel also eliminates tern nesting territory and causes nest abandonment. An active river channel is also important to the Arkansas River shiner (*Notropis girardi*). The fish depends on turbulence and sand movement to continually expose its food supply, and slack water behind dams eliminates Arkansas River shiner habitat (Springer 2000). A reduction in river flow has the same effect. Below Lake Meredith, the flow of the Canadian River has been reduced by 88% from historic levels (Bonner *et al.*, 1997). As a result, today's relative abundance of the Arkansas River shiner, which, along with the plains minnow (*Hybognathus placitus*) composed more than 90% of fish collected in the mid-1950's, is less than 1% of fishes collected in the Canadian River below Lake Meredith (Bonner *et al.*, 1997). These figures are consistent with the fact that the Arkansas River shiner has been extirpated from 75% of its former range in the Arkansas River basin (Echelle *et al.*, 1995).

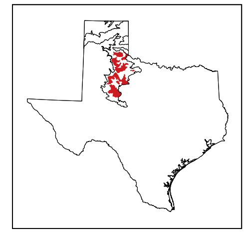
The breaks of the Canadian River and its tributary creeks are important today in terms of wildlife habitat, but they were also important to early Native American groups. The streams and their wooded riparian zones provided water and shelter on the dry and windy High Plains. Archaeologists have excavated stone ruins of the villages of Paleoindians, who hunted bison and farmed the alluvial flats of Wolf Creek, a major stream draining the eastern Canadian/Cimarron High Plains (25e) (Graves 2002, Hughes and Hughes-Jones 1986). These Paleoindian groups and their successors also produced fine projectile points from dolomite exposed on the southern rim of the Canadian River canyon, and visible today at the Alibates Flint Quarries National Monument near Lake Meredith.

Level IV Ecoregion	**26a. Canadian/Cimarron Breaks**
Area (sq. mi.)	5504
Physiography	Tablelands, terraces, and broken topography bordering Canadian River and tributary canyons. Streams intermittent or spring fed, salty and sometimes turbid.
Elevation / Local Relief (feet)	2250-3600 / 50-350
Surficial Geology; Bedrock Geology	Holocene and Pleistocene calcareous loam and sandy loam colluvium and alluvium, Pleistocene loamy eolian sediments of the Blackwater Draw Formation. Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation.
Soil Order (Great Groups)	Inceptisols (Haplustepts, Calciustepts), Mollisols (Calciustolls, Argiustolls), Entisols (Ustipsamments)
Common Soil Series	Mobeetie, Berda, Veal, Conlen, Berthoud, Mansic, Irene, Likes, Circleback
Soil Temperature / Soil Moisture Regimes	Mesic, Thermic / Aridic Ustic
Mean Annual Precipitation (in.)	19-23
Mean Annual Frost Free Days	180-200
Mean Temperature (F) (Jan. min/max; July min/max)	22/48; 66/93
Vegetation	Canyon and hillslope grasses: Little bluestem, sideoats grama, sand bluestem, buffalograss, and blue grama. Riparian trees and shrubs: Cottonwood, elm, black willow, Chickasaw plum, skunkbush sumac, hackberry, sandbar willow, sand sagebrush, alien saltcedars. Riparian grasses: big bluestem, switchgrass, yellow Indiangrass, and alkali sacaton. Sandy areas: Havard shin oak, fourwing saltbush, sand sagebrush, sand dropseed, sand bluestem, big sandreed, yucca.
Land Cover and Land Use	Grassland, some riparian woodland. Grazing, wildlife habitat. In alluvial areas, some cropland with wheat and grain sorghum.

The large trough of the Canadian Breaks north of Amarillo was caused in part by the solution of salt beds beneath the Permian-age geologic layers, creating continual collapse of the upper rocks into the salt chambers. As a result, the Canadian River can have a high salt content. *Photo: Sandy Bryce*

The interior least tern (*Sterna antillarum)* is found along the Canadian and Red rivers in Ecoregion 26. It is in danger of extinction due to the disappearance of clean sand bars below dams as well as the disturbance of nesting habitat by off-road vehicles. *Photo: US Fish and Wildlife Service*

26b Flat Tablelands and Valleys



The Flat Tablelands and Valleys ecoregion includes islands of level land between the prominent buttes, badlands, and escarpments of Ecoregion 26c. Geologically, the surficial composition of these flat areas is composed of Pleistocene-aged sand and gravel or sheets of eolian sand over undissected Triassic or Permian red beds or disjunct portions of the Ogallala caprock that is found on the Llano Estacado (25i) to the west. The soils are predominately fine sandy loams or silt loams derived from Permian sedimentary rocks or the overlying waterborne and airborne sediments. Where the sediments lie thickly on depressions in the poorly permeable Permian red beds, they comprise disjunct recharge areas of the Seymour Aquifer, which provides irrigation, municipal, and industrial water to the region (US Geological Survey 2002). Because of the flat terrain and fine-textured soil, most of Ecoregion 26b has been tilled to produce cotton, sorghum, and wheat.

The boundaries of the Flat Tablelands and Valleys follow the edges of disjunct polygons of undissected red beds of the Dockum, Quartermaster, or Whitehorse Formations or smooth-surfaced sand shields of the Ogallala or Lingos Formation. These areas in Ecoregion 26 are often completely surrounded by the dissected topography and/or badlands of the same geological red bed formations, or, on the eastern side of Ecoregion 26, they may be adjacent to the undissected mudstones and sandstones of the Pease River and Clear Fork Formations that underlie the Red Prairie (27h). Thus the level areas of Ecoregion 26 are distinguished from the level plains of Ecoregion 27 by their geology, but also because the longitudinal break between the two ecoregions represents the transition from subhumid to semiarid climate conditions and a broader transition zone from the Central Great Plains to the western High Plains. These smooth areas of Ecoregion 26b also have a different land use capability than the surrounding lands of Ecoregion 26c; they are more suited to cultivated agriculture than the surrounding badlands and breaks that are generally unproductive and remain in native vegetative cover.

Fragments of remaining native prairie inaccessible to cattle are composed of mid-height grasses, such as sideoats grama (*Bouteloua curtipendula*) and little bluestem (*Schizachyrium scoparium*). Where the land has been intensively grazed, short grasses typical of a drier climate such as buffalo grass (*Buchloe dactyloides*) predominate, and invading cacti (*Opuntia* spp.) and honey mesquite (*Prosopis glandulosa*) are common (Flores 1990). Riparian vegetation is similar to that of the Canadian Breaks ecoregion (26a) with cottonwood, elm, shrub thickets, and mid- and tallgrass meadows. Recently, alien saltcedars (*Tamarix* spp.) have been replacing native vegetation in riparian areas.

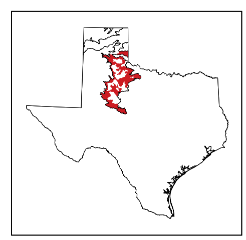
As in many other agricultural ecoregions across the U.S., some of the tilled acreage in Ecoregion 26b has been taken out of production and placed into the Conservation Reserve Program (CRP), in which farmers receive government payment incentives to take idle or erodible land out of production for several years. Typically, grasses are planted on reserve land to slow erosion and to provide habitat for grassland wildlife species. The most common grasses used for CRP plantings are non-native species, such as weeping lovegrass (*Eragrostis curvula*), which is common on CRP parcels in Texas.

Saline soils are common along the Salt Fork of the Brazos River and on nearby low tablelands in ecoregions 26b and 26c. *Photo: Sandy Bryce*

Skunkbush sumac (*Rhus aromatica*) is a common riparian shrub of the subhumid Great Plains, along with other native species such as elm, hackberry, and Chickasaw plum. However, alien shrubs such as saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) are replacing native riparian vegetation. *Photo: National Park Service*

Level IV Ecoregion	26b. Flat Tablelands and Valleys
Area (sq. mi.)	5569
Physiography	Flat to gently rolling valleys and plains. Intermittent streams and meandering rivers in broad sandy channels carry high sediment load.
Elevation / Local Relief (feet)	1400-2925 / 25-200
Surficial Geology; Bedrock Geology	Late Quaternary fossiliferous sand and gravel. Eolian or fluvial sand and silt of the Blackwater Draw Formation. Holocene and Late Wisconsinan sheet sand. Holocene and Illinoisan alluvial, lacustrine, and eolian deposits. Loamy calcareous colluvium and sandstone residuum. Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation; Triassic mudstones, sandstones, and shales of the Dockum Group; Permian red claystone, sandstone, and gypsum beds of the Quartermaster Formation; Late Permian Whitehorse sandstone.
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs), Mollisols (Paleustolls, Argiustolls, Calciustolls)
Common Soil Series	Miles, Mansker, Bukreek, Cobb, Delwin, Carey, Springer, Flomot, Motley, Sagerton, Quanah, Heatley, Nobscot
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	20-25
Mean Annual Frost Free Days	190-220
Mean Temperature (F) (Jan. min/max; July min/max)	26/54; 68/95
Vegetation	Presettlement prairie: Midgrasses such as sideoats grama, little and sand bluestem, yellow Indiangrass, western wheatgrass, switchgrass. Grazed prairie: Buffalograss, blue and hairy grama, tobosa, purple threeawn. Shrubs: Mesquite, lotebush. Riparian vegetation: Elm, cottonwood, hackberry, sandbar willow, skunkbush sumac, sand sagebrush, Chickasaw plum. Alien shrubs: saltcedar and Russian olive.
Land Cover and Land Use	Cropland with cotton, grain sorghum, corn, and wheat; some grassland and shrubland. Livestock grazing, some oil and gas production.

26c Caprock Canyons, Badlands, and Breaks



The Caprock Canyons, Badlands, and Breaks ecoregion covers the broken country extending eastward from the eroded edge of the High Plains (25). The escarpment at the eastern edge of the Llano Estacado (25i) may extend as much as 1100 feet above the Red Prairie (27h) below; it exposes the Ogallala Formation caprock at the surface, slopes of multicolored Triassic shales, mudstones, and sandstones of the Dockum Formation, and Permian red beds at the base. Farther to the east, badlands exposing Lower Permian red beds contain the oldest fossil remains of primitive reptiles and amphibians in the world (Jones and Hentz 1988).

The caprock canyons serve as the headwater basins for several major Texas rivers, such as the Colorado, Brazos, and Red. These rivers once drained the Rocky Mountain snow fields, but once the Pecos River captured their upper watersheds and isolated the Llano Estacado (25i), the rivers' headwaters became the dry draws of the High Plains and canyons below the escarpment. The springs in the tributary canyons beneath the escarpment in Ecoregion 26c were important in contributing perennial flow to local streams and rivers. With the drawdown of the Ogallala Aquifer, many of the springs feeding the upper tributaries have disappeared (Flores 1990). The rains of spring and early summer also contribute to stream flow. The collision of humid air from the Gulf of Mexico and dry air from the high plains along the escarpment creates thunderstorms and infamous tornadoes.

The Triassic shales and mudstones create colorful badland formations along the escarpment and farther to the east on river breaks along river and stream channels. There is little vegetative cover on the badlands and they tend to melt away under wind and water erosion, producing a high sediment load in local rivers and streams. Beneath the Triassic Dockum Formation, the Permian red beds are embedded with white gypsum

The expansion of woodland during years of fire suppression has likely been a factor in the westward expansion of the Mississippi kite, offsetting a decline in native prairie and large riparian cottonwood trees. *Photo: Helen Baines*

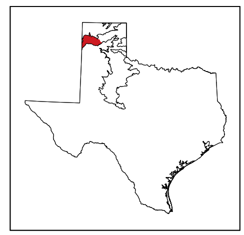
deposits, beds of salts and evaporites left on mudflats during episodes of drying along inlets of a shallow, ancient Permian sea. The gypsum deposits are most visible where they are exposed along river breaks. Gypsum is subject to solution by precipitation and flowing water, and the gypsum beds develop caverns and sinkholes as do the limestone beds in the karstic region of the Edwards Plateau (30). The gypsum beds also serve as aquifers, although the water is not potable for human consumption because of a high concentration of dissolved solids, sulfate, and chloride (Ryder 1996).

Along the escarpments, redberry junipers (*Juniperus pinchotii*) grow on the rimrock and cliff faces, along with skunkbush sumac (*Rhus aromatica*), mountain mahogany (*Cercocarpus montanus*), plum (*Prunus* spp.), grape (*Vitis* spp.), and clematis (*Clematis* spp.). Mohr shin oak (*Quercus mohriana*) and Havard oak (*Q. havardii*) are found on the benches and slopes, and honey mesquite (*Prosopis glandulosa*) on the flat valley floors. Riparian vegetation includes cottonwood (*Populus* spp.), willow (*Salix* spp.), hackberry (*Celtis* spp.), and big bluestem grasses (*Andropogon gerardii*) with elms (*Ulmus* spp.) and alien saltcedars (*Tamarix* spp.). Steep slopes, runoff, and salinity in mudstones and shales of the badland areas limit vegetation to a sparse growth of yucca (*Yucca* spp.), cacti (*Opuntia* spp.), ephedra (*Ephedra* spp.), or sandsage (*Artemisia filifolia*) (Flores 1990, Bezanson 2000). Because the escarpments and badlands are not productive in human development terms, they are centers of wildlife diversity. For example, mule and white-tailed deer (*Odocoileus* spp.), Rio Grande turkey (*Meleagris gallopavo intermedia*), bobcat (*Lynx rufus*), and the occasional pronghorn (*Antilocapra americana*) and mountain lion (*Puma concolor*) are protected in the Matador Wildlife Management Area (WMA) on the Pease River (Phelan 1976). The Caprock Canyons, Badlands, and Breaks are an important area for the Mississippi kite (*Ictinia mississippiensis*), a raptor that has been negatively affected by intensive agricultural development on the High Plains (25) and the Red Prairie (27h), as well as by the invasion of salt cedar in riparian areas and the subsequent disappearance of large cottonwood trees. On the other hand, the kite has expanded its range westward during the 20th century, perhaps because of the shelterbelts planted in the prairie states that provide nest sites on the normally treeless plains (Fantina 2001).

Level IV Ecoregion	**26c. Caprock Canyons, Badlands, and Breaks**
Area (sq. mi.)	9956
Physiography	Steep canyons, escarpments, rounded badlands, and dissected river breaks. Intermittent or springfed streams.
Elevation / Local Relief (feet)	1250-3500 / 50-850
Surficial Geology; Bedrock Geology	Holocene loamy colluvium, sandy loam colluvium, and residuum; Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation; Triassic mudstones, sandstones, and shales of the Dockum Group; Permian red claystone, sandstone, and gypsum of the Quartermaster and Whitehorse formations.
Soil Order (Great Groups)	Entisols (Ustorthents, Torriorthents), Mollisols (Calciustolls), Inceptisols (Haplustepts, Calciustepts), Aridisols (Haplocambids)
Common Soil Series	Knoco, Cottonwood, Lueders, Quinlan, Obaro, Burson, Aspermont, Glenrio
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic Ustic, Ustic, Ustic Aridic
Mean Annual Precipitation (in.)	18-24
Mean Annual Frost Free Days	190-230
Mean Temperature (F) (Jan. min/max; July min/max)	24/51; 67/94
Vegetation	Escarpment: Redberry juniper, skunkbush sumac, mountain mahogany, Chickasawa plum, grape, clematis. Benches: Mohr and Havard shin oak. Riparian woodland: Cottonwood, willow, elm, hackberry, alien saltcedar. Badlands: Cacti, yucca, ephedra, sand sagebrush. Grasslands: Blue grama, buffalo grass.
Land Cover and Land Use	Shrubland and grassland, some woodland. Livestock grazing, wildlife habitat, some oil production in the south.

Tableland topography of Ecoregion 26c is evident in Palo Duro canyon which cuts through the eastern escarpment of the Llano Estacado (25i). Colorful Permian and Triassic-age layers of sandstone, claystone, mudstone, and gypsum are topped by the hard caprock of the Miocene-Pliocene-age Ogallala Formation sandstone, siltstone, and conglomerate. *Photo: Sandy Bryce*

26d Semiarid Canadian Breaks



In Texas, the Semiarid Canadian Breaks ecoregion (26d) covers the western third of the trough of the Canadian River incised below the plane of the level Llano Estacado (25i) and Canadian-Cimarron High Plains (25e). It is distinguished from the Canadian/Cimarron Breaks (26a) by its differences in climate, geology, soil, and vegetation. The Semiarid Canadian Breaks ecoregion is similar to the Canadian/Cimarron Breaks (26a) to the east with its deep valley trough and surrounding moderate-relief tablelands, but it is drier; Ecoregion 26d lies more directly in the rain shadow of the Rocky Mountains and receives just 16 to 18 inches per year of precipitation (2 to 3 inches less than in 26a),. The Semiarid Canadian Breaks ecoregion also has large areas of mudstones and shales of the Triassic Dockum Formation exposed whereas the Texas portion of the Canadian/Cimarron Breaks ecoregion (26a) has a more homogeneous substrate composed of the Ogallala Formation. The mudstones and shales create badlands that are not productive, and plant growth is sparse, increasing the look of aridity on the landscape. Some of the taller grasses and eastern riparian species found in the Canadian/Cimarron Breaks (26a) also tend to disappear towards the west in Ecoregion 26d as conditions become drier and the soils become less productive. The shrub and midgrass prairie vegetation includes juniper (*Juniperus* spp.), sand sagebrush (*Artemisia filifolia*), skunkbush sumac (*Rhus trilobata*), and yucca (*Yucca* spp.), along with sideoats grama (*Bouteloua curtipendula*) and little bluestem (*Schizachyrium scoparium*). Fringes of cottonwood (*Populus deltoides*), willow (*Salix* spp.), and hackberry (*Celtis* spp.) occur along some streams. Invasive saltcedars (*Tamarix* spp.) have become established along many bottomlands, and honey mesquite (*Prosopis glandulosa*) has also increased in the region.

Elevated levels of chloride in this portion of the Canadian River originate from an underlying shallow brine aquifer near Logan, New Mexico. This aquifer is under artesian pressure and contains water almost as salty as seawater (Red River Authority 2003). Construction of Ute Reservoir in New Mexico reduced the flow of the Canadian River in this region by about 50%. The reduced flow has a deleterious effect on the survival of fish such as the Arkansas River shiner (*Notropis girardi*) and the plains minnow (*Hybognathus placitus*); both fish need enough water volume and stream power to keep the sandy substrate actively turning over to expose bits of food. However, in this section of the Canadian River the relative abundance of the endangered Arkansas River shiner has remained more stable than it has further to the east below Lake Meredith in the Canadian/Cimarron Breaks ecoregion (26a) (Bonner *et al.*, 1997).

Human population is sparse in the Semiarid Canadian Breaks, with large ranches and land use devoted primarily to livestock grazing and hunting leases. The exotic aoudad, or Barbary sheep (*Ammotragus lervia*), released in the mid-20th century as a trophy game animal, has increased in the breaks and competes with the native mule deer (*Odocoileus hemionus*) for browse. The aoudad's expansion has slowed somewhat, due to a worm that infects the aoudad but not the native deer (Flores 1990).

The rougher terrain in the Canadian River Breaks provides cover for mule deer (*Odocoileus hemionus*). The exotic aoudad or Barbary sheep (*Ammotragus lervia*), has increased in the breaks and competes with the mule deer for browse. *Photo: Gary Zahm, USFWS*

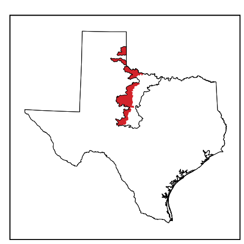
The damming of rivers and streams in Ecoregion 26 affects the Arkansas River shiner (*Notropis girardi*) which depends on flowing water and clean sand to forage for food. The relative abundance of the Arkansas River shiner is more stable in this section of the Canadian River (Ecoregion 26d) than in Ecoregion 26a where the sandy substrate is reduced below Lake Meredith dam. *Photo: Ken Collins, USFWS*

Level IV Ecoregion	**26d. Semiarid Canadian Breaks**
Area (sq. mi.)	2209
Physiography	Tablelands, terraces, and broken topography bordering Canadian River and tributary canyons. Streams intermittent or spring fed, salty, and sometimes turbid.
Elevation / Local Relief (feet)	3100-4300 / 100-350
Surficial Geology; Bedrock Geology	Holocene and Pleistocene colluvium and alluvium;. Miocene-Pliocene siltstone, conglomerate, sandstone, and limey caprock of the Ogallala Formation; Triassic mudstones, sandstones, and shales of the Dockum Group.
Soil Order (Great Groups)	Mollisols (Calciustolls), Inceptisols (Haplustepts, Calciustepts; Aridisols(Haplocalcids, Haplocambids)
Common Soil Series	Mansic, Mobeetie, Berda, Veal, Quay, Glenrio, Tascosa
Soil Temperature / Soil Moisture Regimes	Thermic / Aridic Ustic, Ustic Aridic
Mean Annual Precipitation (in.)	16-18
Mean Annual Frost Free Days	180-200
Mean Temperature (F) (Jan. min/max; July min/max)	22/48; 66/93
Vegetation	Short and midgrasses: Sideoats, black, and blue grama, sand dropseed, buffalograss, western wheatgrass, galleta, alkali sacaton, and fringed sagewort. Brushy overstory: Juniper, sand sagebrush, skunkbush sumac, four-wing saltbush, yucca, honey mesquite, cholla cactus. Riparian: Cottonwood, willow, hackberry, alien saltcedar.
Land Cover and Land Use	Shrubland and grassland. Livestock grazing, hunting leases, wildlife habitat.

27 CENTRAL GREAT PLAINS

The Central Great Plains are slightly lower, receive more precipitation, and are more irregular than the High Plains (25) to the west. The ecological region was once grassland, a mixed or transitional prairie from the tallgrass in the east to shortgrass farther west. Scattered low trees and shrubs occur in the south. Most of the ecoregion is now cropland. The eastern boundary of the region marks the eastern limits of the major winter wheat growing area of the United States. Soils in this region are generally deep with shallow soils on ridges and breaks.

27h Red Prairie



The broken tablelands of Ecoregion 26c flatten out to form the gently rolling Red Prairie ecoregion (27h). The extent of the ecoregion is determined largely by topography, soil capability, and underlying geology. The Central Great Plains ecoregion (27) forms a shallow trough between the High Plains (25) to the west, the more rugged topography of the Cross Timbers (29) to the east, and the Edwards Plateau (30) to the south. Erosion by the Brazos and Colorado rivers has removed the overlying Cretaceous limestones to expose 250 million year old Permian sedimentary rocks (Spearing 1991). Today, these rivers are colored by the red sediments that they carry through these prairie ecoregions. The parallel bands of Permian rocks underlying the Red Prairie and the Broken Red Plains (27i) are reddish-brown sandstones and mudstones from thick deposits, up to 5000 feet thick, built up at the edge of a Permian sea. These are the same strata that are the source of oil in the Midland Basin, the structural depression that underlies the Permian sediments in north-central Texas (Jones and Hentz 1988). The bands of Permian rocks, the Cisco-Bowie, Wichita, Clear Fork, and Pease River formations, decrease in age from east to west across the Central Great Plains (27) (Spearing 1991).

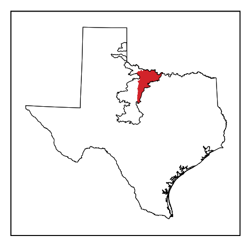
Precipitation amounts are greater in Ecoregion 27h than on the High Plains (25), although they are not high enough to support forest vegetation. The prairie type in the Central Great Plains (27) may be midgrass or shortgrass depending upon soil type, moisture availability, and grazing pressure. Typical grasses under less disturbed conditions include little bluestem (*Schizachyrium scoparium*), Texas wintergrass (*Stipa leucotricha*), white tridens (*Tridens albescens*), Texas cupgrass (*Eriochloa sericea*), and sideoats grama (*Bouteloua curtipendula*). Tobosa (*Pleuraphis mutica*) and curlymesquite (*Hilaria belangeri*) increase in swales and flats with clay soils. Buffalograss (*Buchloe dactyloides*), hairy tridens (*Erioneuron pilosum*) and purple threeawn (*Aristida purpurea*) increase with grazing. Today, much of Ecoregion 27h is cultivated, in contrast to the neighboring Broken Red Plains (27i) that are predominately grazed.

In the riparian zones of perennial streams, pecan (*Carya illinoensis*) is the most prominent tree, mixed with American elm (*Ulmus americana*), black willow (*Salix nigra*), and little walnut (*Juglans microcarpa*). Farther west and along intermittent channels, riparian vegetation becomes patchy and brushy, with thickets of netleaf hackberry (*Celtis reticulata*), bumelia (*Bumelia lanuginosa)*, and western soapberry (*Sapindus saponaria*) or mesquite and grass. Riparian woodlands along streams and rivers in the prairie ecoregions allow eastern bird species to penetrate the Great Plains to the west of characteristically wooded terrain like the Western Cross Timbers (29c). Shrubland and woodland has increased on large portions of the plains to the point where the predominate bird species assemblages are not from typical Great Plains groups. A breeding bird survey in the Concho Valley conducted by Maxwell (1979) found few endemic Great Plains species. Increased shrubby vegetation is just one of many interacting effects that cause grassland birds to have declined more than birds of other North American ecosystems (Knopf 1995).

Herds of bison were once common on the rolling Central Great Plains landscapes and were important to the Comanche and Kiowa Indians who inhabited these lands until the 1870's. *Photo: Texas Parks and Wildlife Department.*

Level IV Ecoregion	27h. Red Prairie
Area (sq. mi.)	8218
Physiography	Level to gently rolling plain. Streams largely intermittent. Larger rivers may be braided and carry heavy sediment load.
Elevation / Local Relief (feet)	1300-2950 / 20-100
Surficial Geology; Bedrock Geology	Holocene red silty clay residuum and quartz sand residuum, Pleistocene alluvial sand and gravel. Middle and Upper Permian red-brown shale, siltstone, sandstone, dolomite, and gypsum.
Soil Order (Great Groups)	Mollisols (Calciustolls, Argiustolls, Haplustolls, Paleustolls), Alfisols (Paleustalfs, Haplustalfs), Vertisols (Haplusterts)
Common Soil Series	Alluvial fans, plains, and ancient stream terraces: Mereta, Sagerton, Miles, Winters, Angelo, Cho, Rioconcho, Tillman, Wichita. Upland plains: Paducah, Rowena, Hollister, Rotan. Depressions: Tobosa, Roscoe. Stream terrace sands and sand sheets: Springer, Delwin
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	20-28
Mean Annual Frost Free Days	210-230
Mean Temperature (F) (Jan. min/max; July min/max)	31/55; 71/95
Vegetation	Short and midgrass prairie. Minimally disturbed grasslands: sideoats grama, Texas wintergrass, Texas cupgrass, white tridens, little bluestem. Intensively grazed grasslands: buffalograss, purple threeawn, red and blue grama, hairy tridens, pricklypear, tasajillo, mesquite, lotebush. Riparian vegetation: pecan, elm, black willow, little walnut, cat-briar. Intermittent channels: mesquite, hackberry, bumelia, western soapberry, alien saltcedar.
Land Cover and Land Use	Cropland and grassland. Dryland and some irrigated farming for cotton, wheat, and grain sorghum. Grazing for cattle, sheep, and goats. Oil, gas, and coal production. Gypsum mined from Whitehorse Formation.

27i Broken Red Plains



The soils of the Broken Red Plains ecoregion are red and tan clay and sand, similar to that on the Red Prairie (27h). However, the topography of the sandstone surface of the Wichita Formation in Ecoregion 27i is more irregular and even more shrub-covered; it is a cuesta topography of alternating low ridges and shallow depressions that foreshadows the topography of the Western Cross Timbers (29c) just to the east (Spearing 1991). The prevalence of honey mesquite (*Prosopis glandulosa*) in Ecoregion 27i has been attributed to fire suppression, intense grazing pressure, and 19th century cattle drives. Early and mid-19th century reports record the presence of open mesquite groves, confined mostly to low areas along streams and floodplains. By 1892, Vernon Bailey reported that mesquite occurred "over much of the prairie" near Wichita Falls. Smith and Rechenthin (1964) later reported that the distribution of mesquite had increased by 1.3 million acres between 1948 and 1963 (Maxwell 1979, Schmidley 2000). The eastern boundary of Ecoregion 27i is marked by the line of 30 inches annual precipitation (at about the 98th meridian) that generally denotes the eastern limit of the distribution of mesquite (although occasional mesquite occur in the Grand Prairie (29d) and Limestone Cut Plain (29e) ecoregions). This boundary also coincides with the western edge of the Western Cross Timbers (29c) oak

Today, brushy species such as mesquite and lotebush have invaded the Central Great Plains. Brush tends to increase with overgrazing, fire suppression, soil erosion, declining ground water levels, and the fragmentation of native grassland cover.

savannah ecosystem. On the west, the Broken Red Plains meet the smooth topography of the Red Prairie (27h), the broken badlands of the easternmost portions of the Caprock Canyons, Badlands and Breaks (26c), recognized as the Pease River Formation, and the more finely dissected, thinly soiled, remnant erosional ridges of the Limestone Plains (27j) composed of Cretaceous, Permian, and Pennsylvanian limestones.

As in Ecoregion 27h, the prairie type is transitional between tallgrass and shortgrass growth forms. Besides honey mesquite, lotebush (*Zizyphus obtusifolia*), wolfberry (*Lycium berlandieri*), sand sagebrush (*Artemisia filifolia*), yucca (*Yucca* spp.), and pricklypear cacti (*Opuntia* spp.) may be mixed with the grasses. Riparian vegetation includes cottonwood (*Populus* spp.), hackberry (*Celtis* spp.), cedar elm (*Ulmus crassifolia*), pecan (*Carya illinoensis*), and little walnut (*Juglans microcarpa*). In contrast to the predominance of cultivation in Ecoregion 27h, the Broken Red Plains are used mainly for grazing.

Rivers flowing across the Broken Red Plains are meandering and generally turbid except near the outflow of regional dams. River levels follow drought and rainy cycles, but flow may be particularly reduced in river segments below dams, depending on the timing of regulated water releases. Particularly during low flow episodes, rivers and their tributaries may experience problems with high total dissolved solids, low dissolved oxygen, algal growth, and bacteria due to the proximity of oil fields and livestock grazing (Red River Authority 2003).

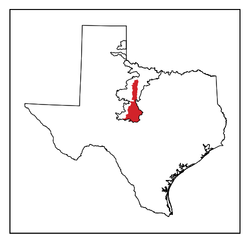
The prairie dog town was once the ecological focus of the prairie ecoregions (26b, 26c, 27h, 27i, 27j); colonies once covered tens of thousands of square miles of prairie in Texas and ranged east as far as the western boundary of the Western Cross Timbers (29c) (Schmidley 2002). Black-tailed prairie dogs (*Cynomys ludovicianus*) were a plentiful food source for predators, such as the black-footed ferret (*Mustela nigripes*), rattlesnake (*Crotalus* spp.), badger (*Taxidea taxus*), and ferruginous and Swainson's hawks (*Buteo regalis, B. swainsoni*). Their extensive system of underground burrows housed other animals, such as kit fox (*Vulpes velox macrotis*), burrowing owl (*Athene cunicularia*), and horned lizard (*Phrynosoma cornutum*). Grassland birds, such as the mountain plover (*Charadrius montanus*), that today are in serious decline, depended on the manicured short grass areas near prairie dog towns for foraging (Doughty 2004). Ranchers saw the prairie dog as a competitor for cattle forage, and poisoning crews used strychnine during the 20th century to reduce the prairie dog population by 98% (Schmidley 2002). Many associated species were poisoned as well, and other species dependent on the prairie dog for food have disappeared along with the prairie dog. There is some debate about whether the reduction in competition for forage by the elimination of the prairie dog, is balanced today by the reduction in forage area caused by the expansion of brush which was controlled in part by the prairie dog (Doughty 2004).

Riparian vegetation in Ecoregion 27i can include hackberry, cottonwood, elms, and willows. Tree density is sometimes greater to the east near the Cross Timbers (29), as shown here along the Clear Fork of the Brazos River near Ft. Griffin.
Photo: Texas Archeological Research Laboratory, University of Texas

The burrowing owl uses prairie dog burrows for nesting and shelter. Burrowing owl numbers are seriously declining with the destruction of prairie dog towns as well as the conversion of their south Texas wintering ground to rowcrop agriculture. *Photo: TPWD*

Level IV Ecoregion	27i. Broken Red Plains
Area (sq. mi.)	5178
Physiography	Dissected plain, cuesta topography. Streams largely intermittent; larger rivers meandering, turbid.
Elevation / Local Relief (feet)	750-1600 / 20-150
Surficial Geology; Bedrock Geology	Quaternary, sandy clay loam and smectitic clay decomposition residuum, calcareous clay and red silty clay disintegration residuum; Permian tan and red shales and sandstones.
Soil Order (Great Groups)	Mollisols (Argiustolls, Paleustolls), Alfisols (Haplustalfs, Paleustalfs), Vertisols (Haplusterts), Entisols (Ustifluvents)
Common Soil Series	Rolling plains: Bluegrove, Jolly, Weswind, Kamay, Deandale, Hollister, Stoneburg, Kirkland. Alluvial plains: Tillman, Anocon. Floodplains: Clairemont, Yomont, Mangum
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	26-32
Mean Annual Frost Free Days	210-230
Mean Temperature (F) (Jan. min/max; July min/max)	28/54; 71/96
Vegetation	Short and midgrass prairie. Sideoats and blue grama, Texas wintergrass, buffalograss, sand and little bluestem, vine-mesquite, Wright's threeawn. Invasive shrubs: pricklypear, sand sagebrush, wolfberry, mesquite, lotebush. Riparian vegetation: pecan, cedar elm, black willow, little walnut, tobosa grass.
Land Cover and Land Use	Grassland, shrubland. Grazing for cattle, sheep, and goats. Cropland of cotton, wheat, and grain sorghum. Oil and gas production.

27j Limestone Plains



The Limestone Plains ecoregion is composed of thin strata of Permian-age limestone, sandy limestones, mudstones, and shales, perched on top of the Permian red beds in a north-south band between the Red Prairie (27h) and the Broken Red Plains (27i). The boundaries of the Limestone Plains are generalized around groups of erosional remnants of Cretaceous, Permian, and Pennsylvanian limestone formations as indicated on geology maps. The limestone beds are gray and tan in contrast to the red beds of the neighboring ecoregions; the rock strata are also embedded with fossilized shells of brachiopods and clams (Spearing 1991). Sections of the Limestone Plains have a rougher topography than the smooth, flat Red Prairie (27h) to the west. Just south of Abilene, the west edge of the Limestone Plains forms the eastern gateway of the Callahan Divide, forming a ridge 120 feet above the Red Prairie (27h) surface. The gap in the ridgeline at this point was named Buffalo Gap because herds of buffalo were forced to file through the narrow gap during their migrations (Nix 2002).

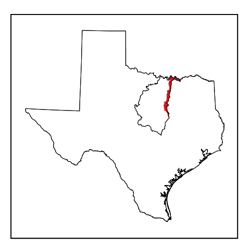
The Limestone Plains are covered by mixed grass prairie of little bluestem (*Schizachyrium scoparium*), yellow Indiangrass (*Sorghastrum nutans*), and buffalograss (*Buchloe dactyloides*), with scattered honey mesquite (*Prosopis glandulosa*). However, upland soils are often thin, rocky, and droughty in the vicinity of limestone outcrops. Drier (or eroded) areas support desert shrubs such as lotebush (*Ziziphus obtusifolia*), agarita (*Mahonia trifoliolata*), tree cholla *(Opuntia imbricata*), and ephedra (*Ephedra* spp.). And, although the Central Great Plains (27) are typically treeless except in riparian areas, on the Cretaceous limestone erosional remnants of Ecoregion 27j, scattered plateau live oak *(Quercus fusiformis*) and Ashe juniper (*Juniperus asheii*) grow with mesquite shrub, in transition to the live oak-mesquite-Ashe juniper woodland of the adjacent Edwards Plateau (30). As in some other limestone-based ecoregions in Texas (such as 29d, 29e, 30a), land use is dominated by grazing rather than cultivated agriculture. A minor amount of wheat or sorghum may be grown in deeper alluvial soils.

Level IV Ecoregion	27j. Limestone Plains
Area (sq. mi.)	4633
Physiography	Rolling plains with some low hills or ridges. Most streams intermittent.
Elevation / Local Relief (feet)	1230-2300 / 50-300
Surficial Geology; Bedrock Geology	Quaternary shale and limestone clast disintegration residuum, calcareous clay disintegration residuum, limestone clast stony colluvium; Erosional remnants of Lower Cretaceous limestones; Lower Permian limestones and shales, Middle Permian limestones, Upper Pennsylvanian limestones.
Soil Order (Great Groups)	Mollisols (Argiustolls, Calciustolls, Haplustolls), Inceptisols (Haplustepts), Vertisols (Haplusterts)
Common Soil Series	Level to rolling uplands: Speck, Kavett, Valera, Rowena. Footslopes: Throck. Ridgetops and breaks: Lueders, Talpa, Owens. Stream terraces and alluvial fans: Cho, Nuvalde, Mereta. Valley depressions and alluvium: Leeray, Nukrum, Abilene.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	25-28
Mean Annual Frost Free Days	210-230
Mean Temperature (F) (Jan. min/max; July min/max)	29/55; 70/96
Vegetation	Short and midgrass prairie grassland: buffalograss, little and silver bluestem, sideoats grama, Texas wintergrass, yellow Indiangrass, threeawn, curlymesquite, vine-mesquite, tasajillo, honey mesquite. Introduced coastal Bermudagrass and Kleingrass. Rocky outcrops: lotebush, agarita, tree cholla, ephedra. On Cretaceous limestone outcrops: Plateau live oak and juniper with mesquite.
Land Cover and Land Use	Grassland and shrubland. Grazing for cattle, sheep, and goats. Some cropland with cotton, wheat, and grain sorghum. Oil and gas production.

29 CROSS TIMBERS

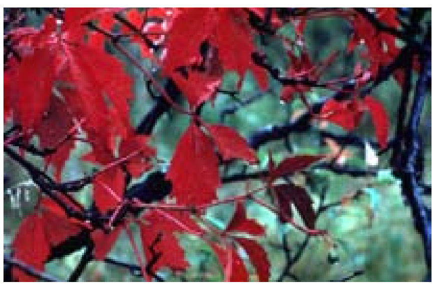
The Cross Timbers ecoregion is a transitional area between the once prairie, now winter wheat growing regions to the west, and the forested low mountains or hills of eastern Oklahoma and Texas. The region stretches from southern Kansas into central Texas, and contains irregular plains with some low hills and tablelands. It is a mosaic of forest, woodland, savanna, and prairie. The Cross Timbers ecoregion is not as arable or as suitable for growing corn and soybeans as the Central Irregular Plains (40) to the northeast. The transitional natural vegetation of little bluestem grassland with scattered blackjack oak and post oak trees is used mostly for rangeland and pastureland, with some areas of woody plant invasion and closed forest. Oil production has been a major activity in this region for over eighty years.

29b Eastern Cross Timbers



The Eastern Cross Timbers ecoregion occurs on a narrow band of Upper Cretaceous sandstone, the Woodbine Sand, that lies between the Grand Prairie (29d) and Texas Blackland Prairies (32) in eastern Texas. The region's boundaries were influenced by patterns of vegetation, geology (i.e., the extent of the Woodbine Formation), and soils (i.e., sandy soils having a potential to support oak woodland). To the west, the Grand Prairie (29d) separates the Eastern and Western Cross Timbers (29c); it is a limestone region that sustains a prairie plant community different from the oak savanna found on sandstone-derived substrates. The Eastern Cross Timbers differs from the Western Cross Timbers (29c) in having higher yearly precipitation amounts, deeper, somewhat more fertile sandy soil, and, as a result, taller trees. These connections between geology, soils, and the resultant land cover of the Cross Timbers and surrounding regions were discussed as early as 1887 by geologist R.T. Hill in his publication "The Topography and Geology of the Cross Timbers" (Francaviglia 2000).

Post oaks (*Quercus stellata*) and blackjack oaks (*Q. marilandica*) have adapted to life in sandy soils that have been leached of nutrients, and they dominate the overstory. Black hickory (*Carya texana*) may be present, especially in the Eastern Cross Timbers, along with occasional plateau live oak (*Quercus fusiformis)*, eastern redcedar (*Juniperus virginiana*), and sumac (*Rhus* spp.). Honey mesquite (*Prosopis glandulosa*) and pricklypear (*Opuntia* spp.) occur in disturbed areas, although they are not as prevalent in Ecoregion 29b as they are in the Western Cross Timbers (29c). The prairie inclusions and understory, if not overgrazed, include mid- and tall grasses, such as big and little bluestem (*Schizachyrium* spp.), yellow Indiangrass (*Sorghastrum nutans*), and tall dropseed (*Sporobolus asper*) (Bezanson 2000). The savanna character of the Cross Timbers (29) has been reduced by fire suppression and heavy grazing, just as the area of true oak savanna has been reduced on the Edwards Plateau (30). The savanna of widely-spaced oaks growing over prairie grass has been replaced by thickets of young trees, shrubs, and vines with occasional prairie openings. Although the rural land use in the Eastern Cross Timbers is predominantly cattle grazing, oak woods in areas of flatter topography have been cleared for agriculture and there is some farming for peanuts, grain sorghum, pecans, peaches, and vegetables. Urban and suburban development also occurs within this region, particularly near Dallas-Fort Worth, which continually fragments the remaining oak forest and prairie inclusions.

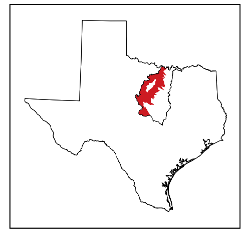


Virginia creeper or woodbine (*Parthenocissus quinquefolia*) is a common plant in the understory of the Eastern Cross Timbers. It is a ground cover as well as a climber on tree trunks; Virginia creeper vines (as well as thorny greenbriar (*Smilax bona-nox*) contribute to the impenetrability of some Cross Timber woodland.
Photo: National Park Service

The Cross Timbers wooded areas consist primarily of post oaks, blackjack oaks, and hickories, along with tall and midgrasses. A denser woody understory forms in the absence of fire.
Photo: R.E. Rosiere, Tarleton State University

Level IV Ecoregion	**29b. Eastern Cross Timbers**
Area (sq. mi.)	1555
Physiography	Gently rolling plains and low hills.
Elevation / Local Relief (feet)	500-1042 / 50-200
Surficial Geology; Bedrock Geology	Quaternary and Tertiary quartz sand decomposition residuum; Cretaceous Woodbine Sandstone
Soil Order (Great Groups)	Alfisols (Paleustalfs); Ultisols (Haplustults)
Common Soil Series	Level to gently rolling uplands: Callisburg, Gasil, Konsil, Crosstel. Slopes: Aubrey
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Udic Ustic
Mean Annual Precipitation (in.)	32-38
Mean Annual Frost Free Days	220-250
Mean Temperature (F) (Jan. min/max; July min/max)	33/55; 73/96
Vegetation	Upland forest (oak savanna): post oak, blackjack oak, cedar elm, black hickory, plateau live oak, eastern redcedar, sumac. Riparian forest: pecan, black willow, eastern cottonwood, sycamore, boxelder. Grassy understory - relatively undisturbed: big bluestem, little bluestem, yellow Indiangrass, tall dropseed. Grassy understory - heavily grazed: buffalograss, purple threeawn. Understory shrubs and vines: persimmon, sassafras, Virginia creeper, greenbriar.
Land Cover and Land Use	Woodland, grassland, cropland, urban. Grazing, some farming for peanuts, grain sorghum, pecans, peaches, and vegetables.

29c Western Cross Timbers



The Western Cross Timbers ecoregion covers the wooded areas west of the Grand Prairie (29d) on sandstone and shale beds of Pennsylvanian, Permian, and Lower Cretaceous age. The Eastern and Western Cross Timbers (Ecoregions 29b and 29c) in Texas are the southern portion of a larger area (Ecoregion 29) that extends into Oklahoma and Kansas. The entire region is a mosaic of oak woodland and prairie that forms the transition between the eastern deciduous forest and the Great Plains. The oak woodland is concentrated on sandstone substrates while prairie grasses dominate on surrounding limestone formations or interior limestone inclusions. Trees in the Western Cross Timbers are drought-stressed; they experience erratic precipitation and seasonal extremes in temperature. Trees growing under such conditions may be several hundred years old and no taller than 20 to 30 feet (Stahle *et al.*, 2003).

The landscape has cuesta topography that is expressed as lines of sandstone ridges with a gentle dip slope on one side and a steeper scarp on the other (Spearing 1991). The soils are mostly fine sandy loams with clay subsoils that retain water. Some researchers contend that these woodland areas would be savanna-like if they experienced fire, although one early account described the Cross Timbers as "an immense natural hedge" or belt of thick impenetrable forest. It is likely that with more frequent fire there were more prairie openings between the belts of forest, and that closed canopy woodland and park-like savannas were both present.

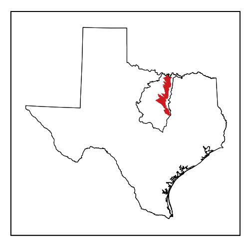
As in the Eastern Cross Timbers (29b), the dominant trees are post oak and blackjack oak with an understory of shrubs and grasses. The prairie openings historically contained taller grasses such as big bluestem (*Andropogon gerardii*), yellow Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*) growing on deeper soil, and shorter grasses such as sideoats grama (*Bouteloua curtipendula*), buffalograss (*Buchloe dactyloides*), and silver bluestem (*Bothriochloa laguroides ssp. torreyana*) growing on shallow soil. The grassy understory is better developed on the red, gravelly soils of Pennsylvanian age (Francaviglia 2000). The riparian vegetation in the eastern portion of Ecoregion 29c resembles that of the Grand Prairie (29d) and Eastern Cross Timbers (29b), but, farther to the west, eastern riparian species are gradually replaced by typically western species such as little walnut (*Juglans microcarpa*), netleaf hackberry (*Celtis reticulata*), and mesquite (*Prosopis glandulosa*) (Bezanson 2000). The variety of ecosystems in the Cross Timbers, i.e., prairie, open woodland, and thicket, provide diverse habitats for wildlife. In addition, the abundant acorns are a staple food source for wild turkeys (*Meleagris gallopavo*), prairie chickens (*Tympanuchus* spp.), raccoons (*Procyon lotor*), squirrels (*Sciurus* spp.), and deer (*Odocoileus* spp.). The area has a long history of coal, oil, and natural gas production from the Pennsylvanian sandstone, limestone, and shale beds. Deeper soils in the eastern part of this ecoregion support a dairy industry, pastureland, and cultivation of forage sorghum, silage, corn, and peanuts.

The height of oak trees in the Cross Timbers is affected by the depth of soil. Here, stunted oaks grow at the edge of a sandstone outcrop covered with lichen. *Photo: R.E. Rosiere, Tarleton State University*

The yearly acorn crop from Cross Timbers oaks is an important food source for the wild turkey (*Meleagris gallopavo*). *Photo: Albert Lavalle, National Wild Turkey Foundation*

Level IV Ecoregion	29c. Western Cross Timbers
Area (sq. mi.)	8274
Physiography	Rolling plains, low rimrock or ridges, and cuesta topography.
Elevation / Local Relief (feet)	650-1845 / 50-300
Surficial Geology; Bedrock Geology	Quaternary and Tertiary quartz sand to smectitic clay decomposition residuum, sandy clay and clay loam colluvium; Lower Cretaceous sandstone and claystone; Upper Pennsylvanian sandstone, mudstone, claystone.
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs)
Common Soil Series	Convex surfaces: Bonti, Exray, Truce, Bluegrove, Windthorst. Erosional footslopes: Callahan, Nocken, Duffau. Rolling plains: Chaney, Demona, Patilo, Nimrod, Cisco.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Udic Ustic
Mean Annual Precipitation (in.)	27-35
Mean Annual Frost Free Days	220-240
Mean Temperature (F) (Jan. min/max; July min/max)	30/56; 70/96
Vegetation	Oak savanna and prairie. Upland forest: post oak, blackjack oak, cedar elm, black hickory, plateau live oak, eastern redcedar, sumac. Riparian forest-east: pecan, black willow, eastern cottonwood, sycamore, boxelder. Riparian forest - west: honey mesquite, netleaf hackberry, little walnut. Grassy understory - relatively undisturbed: big bluestem, little bluestem, yellow Indiangrass, switchgrass, sideoats grama. Grassy understory - grazed: buffalograss, purple threeawn, curlymesquite, honey mesquite, lotebush. Understory shrubs and vines: persimmon, sassafras, Virginia creeper, greenbriar.
Land Cover and Land Use	Woodland, grassland, shrubland. Grazing, some dairy, some cropland of peanuts, grain sorghum, silage, corn, and peaches. Hunting leases. Coal, oil, and natural gas production. Some urban and residential, particularly in the eastern portion.

29d Grand Prairie



The Grand Prairie ecoregion is an undulating plain underlain by Lower Cretaceous limestones with interbedded marl and clay. It is bounded on the east and west by the sandstones of the Cross Timbers, and its open plains contrast with the Cross Timbers oak woodlands. On the south, the generally smoother surface of the Grand Prairie meets the mesa or stairstep topography of the Limestone Cut Plain (29e).Although the vegetation of the Grand Prairie is similar to the Northern Blackland Prairie (32a), the limestone of the Grand Prairie is more resistant to weathering, which gives the topography a rougher appearance than 32a. Ecoregion 29d also has thinner soil and less precipitation than Ecoregion 32a; its location is transitional between the more moist climate of east Texas and the drier climate of the Great Plains. Meandering streams deeply incise the limestone surface.

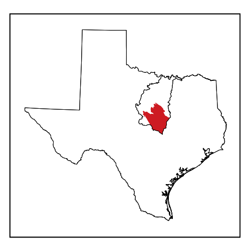
The original vegetation was tallgrass prairie in the upland areas and elm (*Ulmus* spp.), pecan (*Carya illinoensis*), and hackberry (*Celtis* spp.) in riparian areas where deeper soils have developed in floodplain deposits or where the underlying clays have been exposed by limestone erosion. The invasive species Ashe juniper (*Juniperus ashei*) and, to a lesser extent, honey mesquite (*Prosopis glandulosa*) have increased since European settlement. Grand Prairie grasses under minimally disturbed conditions include big bluestem (*Andropogon gerardii*), yellow Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*B. curtipendula*), and Texas cupgrass (*Eriochloa sericea*). Buffalograss (*Buchloe dactyloides*), Texas wintergrass (*Stipa leucotricha*), and gramas (*Bouteloua* spp.) tend to increase with intensive grazing (Bezanson 2000). In the spring, abundant forbs create a showy display of flowers, as they do on Edwards Plateau (30) grasslands to the south and west.

The red wolf once inhabited the Grand Prairie (29d). It is intermediate in size between the gray wolf and the coyote. *Photo: Greg Koch, USFWS*

Some common Great Plains animals, such as black-tailed jackrabbits (*Lepus californicus*) and the scissortail flycatcher (*Tyrannus forficatus*), range farther east through the Grand Prairie, creating an overlap in Great Plains and eastern forest species. The Grand Prairie was once also the home of bison (*Bison bison*), red wolf (*Canis rufus*), and black bear (*Ursus americanus*). Red wolf numbers were decimated along with gray wolves (*Canis lupus monstrabilis*) under predator control programs in the late 19th and early 20th centuries; the last of the red wolves in the wild in Texas hybridized with coyotes (Schmidley 2002).

Level IV Ecoregion	**29d. Grand Prairie**
Area (sq. mi.)	3298
Physiography	Rolling plains with some bedrock exposure. Meandering, incised streams.
Elevation / Local Relief (feet)	450-1170 / 50-300
Surficial Geology; Bedrock Geology	Quaternary and Tertiary stony calcareous clay solution residuum and silty clay decomposition residuum; Lower Cretaceous limestone, marl, and claystone.
Soil Order (Great Groups)	Mollisols (Calciustolls, Haplustolls), Inceptisols (Haplustepts), Entisols (Ustorthents), Alfisols (Paleustalfs, Haplustalfs), Vertisols (Haplusterts)
Common Soil Series	Convex uplands and slopes: Aledo, Bolar, Eckrant, Purves, Dugout, Maloterre. Level uplands: Denton, Crockett. Erosional footslopes: Cranfill. Stream terraces: Wilson, Burleson.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Udic Ustic
Mean Annual Precipitation (in.)	33-37
Mean Annual Frost Free Days	220-245
Mean Temperature (F) (Jan. min/max; July min/max)	31/55; 72/96
Vegetation	Upland tall to midgrass prairie. Minimally disturbed grasslands: big bluestem, yellow Indiangrass, sideoats grama, little bluestem, switchgrass, tall dropseed, Texas cupgrass. Grazed grasslands: silver bluestem, grama grasses, Texas wintergrass, purple threeawn, seep muhly, buffalograss, mesquite, introduced bermudagrass and Kleingrass. Escarpments: plateau live oak, juniper, sumac, Texas persimmon. Riparian woodland: elm, hackberry, bur oak, pecan.
Land Cover and Land Use	Pasture, grassland, shrubland, urban. Grazing, dairy farming, some cropland of corn, grain sorghum, and wheat.

29e Limestone Cut Plain



The Limestone Cut Plain is similar to the Edwards Plateau (30) in its woodland vegetation, but the Edwards Limestone substrate preferred by this vegetation type is more restricted in the Limestone Cut Plain. Ecoregion 29e has a more varied geology than Ecoregion 30, and it is more highly eroded. It has higher precipitation amounts than the Edwards Plateau, and its grasslands have elements of the eastern tallgrass prairie. The Limestone Cut Plain is bounded on the west by the sandstones and clays that support Cross Timbers oak woodland, on the east by the remnant Balcones Escarpment marking the boundary with the Blackland Prairie (32), and on the north by the transition to the smoother topography of the Grand Prairie. The southern boundary is a transition to the Balcones Canyonlands (30c), with its characteristic oak motte/ Ashe juniper woodland, dissected canyon topography, and spring-fed streams.

Mesas alternate with broad intervening valleys in the stairstep topography of the Limestone Cut Plain ecoregion. Although Edwards Limestone caps the highest buttes, the Limestone Cut Plain is distinguished by other Lower Cretaceous limestones, predominately the Glen Rose Formation and Walnut Clay, that are older than the limestone of the Edwards Plateau (30). The Glen Rose Formation has alternating layers of limestone, chert, and marl that erode differentially and generally more easily than the Edwards Limestone. The effects of increased precipitation and runoff are also apparent in the increased erosion and dissolution of the limestone layer. The Limestone Cut Plain has flatter topography, lower drainage density, and a more open woodland character than the Balcones Canyonlands (30c).

The soils over the limestone substrate are shallow. The broad lowlands generally contain grasslands growing on the Walnut Clay. The narrow mesa divides, capped by Edwards Limestone, support oak savanna, and uncapped mesas may also support prairie. The woodland vegetation of Ecoregion 29e is similar to that of the Balcones Canyonlands, but less diverse; it includes plateau live oak (*Q. fusiformis*), cedar elm (*Ulmus crassifolia*), Texas ash (*Fraxinus texensis*), big tooth maple (*Acer grandidentatum*), and bur oak (*Q. macrocarpa*). Other endemic Edwards Plateau (30) floral species are prevalent. The dry rocky slopes have little soil, but they may have a sparse cover of white shin oak (*Q. sinuata var. breviloba*), sumac (*Rhus* spp.), and Ashe juniper (*Juniperus asheii*). Although the grasslands of the Limestone Cut Plain are a mix of tall, mid, and short grasses, some consider it a westernmost extension of the tallgrass prairie, which distinguishes this ecoregion from the Edwards Plateau Woodland (30a). Presettlement grasslands included species such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), yellow Indiangrass (*Sorghastrum nutans*), tall dropseed (*Sporobolus asper var. asper*), and sideoats grama (*Bouteloua curtipendula*). These tallgrass prairies once supported herds of bison. With concentrated grazing these grasses have been replaced by species such as silver bluestem (*Bothriochloa laguroides ssp. torreyana*), Texas wintergrass (*Stipa leucotricha*), and purple threeawn (*Aristida purpurea*). As in some other limestone regions (e.g., Ecoregions 30a, 30c, 29f), fire suppression and grazing have changed the nature of the oak savanna and grassland through the expansion of shrubs such as Ashe juniper and mesquite. Where they are present, mature Ashe juniper stands have value as nesting habitat for the endangered golden-cheeked warbler (*Dendroica chrysoparia*) that nests in low numbers in this ecoregion.

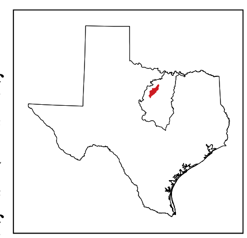
The Cross Timbers ecoregion is a "crossroads" of landscapes and vegetation types with its prairies and woodlands. The pale yucca (*Yucca pallida*) in bloom here is endemic to a six-county area of central Texas where the southern part of the Cross Timbers (29) meets Ecoregions 30 and 32. *Photo: Clarence Rechenthin*

The Paluxy River is deeply incised into the soluble Lower Cretaceous limestones of Ecoregion 29e. *Photo: John Crossley*

The Glen Rose Formation, exposed at the surface of the Limestone Cut Plain (29e), contains dinosaur tracks of both carnivorous theropods (pictured here) and herbivorous sauropods. *Photo: Keith Minor*

Level IV Ecoregion	29e. Limestone Cut Plain
Area (sq. mi.)	6107
Physiography	Benched or stairstep topography with capped mesas, eroded sideslopes, and broad flat valleys. Headwater streams in narrow canyons, lower reaches in broader valleys. Springs common.
Elevation / Local Relief (feet)	550-1800 / 50-350
Surficial Geology; Bedrock Geology	Quaternary and Tertiary calcareous clay solution residuum, limestone-clast loamy colluvium, silty clay decomposition residuum; Lower Cretaceous limestone and claystone.
Soil Order (Great Groups)	Inceptisols (Haplustepts), Mollisols (Calciustolls, Haplustolls, Argiustolls), Vertisols (Haplusterts), Entisols (Ustorthents)
Common Soil Series	Slopes: Brackett, Purves, Real, Bolar, Eckrant, Maloterre, Topsey. Terraces and footslopes: Sunev, Cranfill, Krum. Ridgetops and level stream divides: Nuff, Doss, Georgetown, Denton, San Saba, Dugout. Floodplains: Oakalla, Bosque
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Udic Ustic
Mean Annual Precipitation (in.)	30-34
Mean Annual Frost Free Days	230-260
Mean Temperature (F) (Jan. min/max; July min/max)	32/57; 71/94
Vegetation	Oak savanna. Ridgetop woodland: Plateau live oak, post oak, Texas ash, bur oak, Texas persimmon. Erosional slopes: white shin oak, sumac, Ashe juniper. Mid- and tall grassland: big bluestem, little bluestem, yellow Indiangrass, tall dropseed, sideoats grama. Grazed grasslands: silver bluestem, Texas wintergrass, red grama, hairy tridens, curlymesquite, purple threeawn, pricklypear, Ashe juniper.
Land Cover and Land Use	Shrubland, grassland, and woodland. Grazing for cattle, sheep, and goats. Some cropland of cotton, corn, small grains, and sorghum.

29f Carbonate Cross Timbers



The Carbonate Cross Timbers ecoregion is that portion of the Western Cross Timbers (29c) that has mostly Pennsylvanian limestone substrate. The boundary delineation of the Carbonate Cross Timbers was guided by the extent of the underlying limestone geology, the overlying vegetation pattern, and the topography of the region. This area is not included on some maps of the Cross Timbers because it does not support the typical oak woodland of the sandstone-based territory surrounding it. The topography of Ecoregion 29f is also somewhat different from that of the Western Cross Timbers (29c) in that it is expressed as low, rounded mountains (the Palo Pinto Mountains) rather than alternating ridges and shallow basins.

The limestone substrate is apparent in the vegetation cover, that is reminiscent of the vegetation of the Edwards Plateau (30) to the south. There is more plateau live oak (*Quercus fusiformis*), honey mesquite (*Prosopis glandulosa*), and pure Ashe juniper (Juniperus ashei) woodland than in other surrounding Cross Timber areas. The juniper woodlands are particularly dense; it is presumed that before widespread fire suppression, the area was less wooded and more savanna-like.

The Brazos River cuts through the middle of Ecoregion 29f; its meandering channel was etched into place as it eroded down through the limestone substrate. The river supports a typical warmwater fishery with largemouth, spotted, and striped bass (*Micropterus salmoides, Micropterus punctulatus, and Morone saxatilis*), red-breasted sunfish (*Lepomis auritis*), and channel catfish (*Ictalurus punctatus*). Trout are released in the winter in the tailrace of the dam below Possum Kingdom Lake; 10,000 rainbow trout (*Onchorhynchus mykiss*) were released there in the winter of 2003-2004 for put-and-take fishing (Texas Parks and Wildlife 2004). Until recently, this portion of the river basin was relatively undeveloped, but recent quarrying for the sandstone rock capping many hills in the region has released surges of clay and silt particles from the mudstones underlying the sandstone. This has muddied the river as well as the sandbars, changing the geomorphology and sediment carrying capacity of the river in some areas below Possum Kingdom Lake (Traylor 2004).

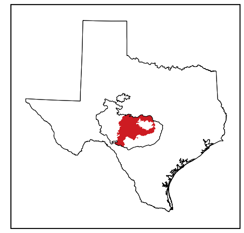
The Carbonate Cross Timbers (29f) is that portion of Ecoregion 29 that is underlain by Pennsylvanian- or Cretaceous-age limestones and shales. The Pennsylvanian strata pictured here in a roadcut in Palo Pinto County contain pink and white limestones over gray shale.

Level IV Ecoregion	29f. Carbonate Cross Timbers
Area (sq. mi.)	813
Physiography	Rounded low hills and mountains. Low to moderate gradient, turbid streams and rivers.
Elevation / Local Relief (feet)	900-1560 / 50-400
Surficial Geology; Bedrock Geology	Quaternary limestone-clast loamy colluvium, smectitic clay decomposition residuum; Pennsylvanian limestones.
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs, Rhodustalfs), Vertisols (Haplusterts), Mollisols (Haplustolls, Calciustolls)
Common Soil Series	Upland plains, benches, and ridgetops: Palopinto, Bonti, Exray, Leeray, Lindy, Hensley. Slopes: Set, Truce. Alluvial and flood plains: Bosque, Minwells
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Udic Ustic
Mean Annual Precipitation (in.)	28-32
Mean Annual Frost Free Days	220-235
Mean Temperature (F) (Jan. min/max; July min/max)	30/55; 72/95
Vegetation	Oak mottes and juniper brakes. Upland forest: plateau live oak, Texas oak, post oak, cedar elm, Ashe juniper. Understory: Texas persimmon, elbowbush, skunkbush sumac, mesquite, lotebush, tasajillo, pricklypear. Riparian forest: post oak savanna, pecan, black willow, eastern cottonwood, hackberry, sycamore, boxelder. Grassy understory: sideoats grama, Texas grama, big and little bluestem, silver bluestem, switchgrass, sand lovegrass, threeawn, yellow Indiangrass, sand dropseed. Forbs: Engelmann daisy, gayfeather, prairie clover, bush sunflower.
Land Cover and Land Use	Woodland, shrubland, and grassland. Mostly grazing for cattle, sheep, and goats; some cropland with small grains, grain sorghum, pecans, and peaches. Coal, oil, and natural gas production.

30 EDWARDS PLATEAU

This ecoregion is largely a dissected limestone plateau that is hillier to the south and east where it is easily distinguished from bordering ecological regions by a sharp fault line. The region contains a sparse network of perennial streams. Due to karst topography (related to dissolution of limestone substrate) and resulting underground drainage, streams are relatively clear and cool in temperature compared to those of surrounding areas. Soils in this region are mostly Mollisols with shallow and moderately deep soils on plateaus and hills, and deeper soils on plains and valley floors. Covered by juniper-oak savanna and mesquite-oak savanna, most of the region is used for grazing beef cattle, sheep, goats, exotic game mammals, and wildlife. Hunting leases are a major source of income. Combined with topographic gradients, fire was once an important factor controlling vegetation patterns on the Edwards Plateau. It is a region of many endemic vascular plants. With its rapid seed dispersal, low palatability to browsers, and in the absence of fire, Ashe juniper has increased in some areas, reducing the extent of grassy savannas.

30a Edwards Plateau Woodland



The Edwards Plateau Woodland ecoregion encompasses the central portion of the elevated Edwards Plateau, which is composed of flat beds of limestone deposited in a shallow Cretaceous age sea about 100 million years ago. The landscape of the central plateau is characterized by rolling hills and intervening broad flat valleys in contrast to the greater relief and higher dissection of the Balcones Canyonlands (30c) to the south and east where the edge of the uplifted limestone shield has been eroded. The Edwards Plateau is situated in a transition zone between eastern mesic and western arid climates; it is subject to periodic drought and drying west winds as well as moist humid weather from the Gulf of Mexico. The north central portion of the Edwards Plateau receives enough rainfall to support oak savanna. In contrast, the western end of the plateau (Ecoregion 30d) is too dry to sustain full-sized trees. The rounded profile of the hills in Ecoregion 30a is a result of solution and chemical weathering of the limestone substrate by precipitation and stream erosion (Spearing 1991).

The eastern and southern boundary of 30a is determined by the beginning of the highly dissected topography and exposure of Glen Rose limestone in the Balcones Canyonlands (30c). The northern boundary is marked physiographically by the perceptible drop in elevation at the edge of the Edwards Plateau; geologically, by the change from lower Cretaceous Edwards limestone to sandstone, shale, and upper Cretaceous limestone and marl; and vegetationally, by a transition from a plateau live oak/mesquite/Ashe juniper association to the post oak/blackjack oak savanna of the Cross Timbers (29) and the mixed grasslands of the Central Great Plains (27). The transition in climate from subhumid to semiarid marks the western boundary between Ecoregion 30a and 30d (Semiarid Edwards Plateau); where live oak, juniper, and mesquite take on a shrubby growth form.

The solution and chemical weathering of the limestone foundation of the Edwards Plateau forms karst, a system of sinkholes and underground fissures and caverns that fill with groundwater to create aquifers. The Edwards-Trinity Aquifer, located in Ecoregion 30a, has not been as depleted as those in neighboring regions, such as the urbanizing fringe of the Balcones Canyonlands (30c) and the Grand Prairie (29d), because municipal and agricultural groundwater demands are not as high in the central Edwards Plateau. Major spring-fed rivers (e.g., the San Saba, Llano, and Pedernales) in this region flowing over limestone substrate are clear and cool, except in midsummer when water temperatures can exceed 80°F (Lower Colorado Water Authority, 2005). These rivers support sunfish *(Lepomis spp.*), channel catfish (*Ictalurus punctatus*), Guadalupe bass *(Micropterus treculi*), and largemouth bass (*Micropterus salmoides*).

Historically, parts of the Edwards Plateau consisted of a savanna of grassland with scattered groves of plateau live oak (*Quercus fusiformis*), Texas oak (*Q. buckleyi*), and Ashe juniper (*Juniperus ashei*). Frequent fires, started by lightning or by Native American hunters, limited woody growth and helped maintain open grasslands. Following these burns, oak trees that burned above ground sprouted from the root to create dense groves, or oak mottes, scattered across the grasslands. The mottes provide a shaded nursery for shrubs such as juniper, Texas persimmon (*Diospyros texana*), and agarita (*Mahonia trifoliolata*) (Fowler 1988). The grasslands of the Edwards Plateau Woodland may be considered mixed grass prairie, expressed as midgrass or shortgrass depending on local soil type, moisture availability, and grazing pressure. Prairie grasses such as little bluestem (*Schizachyrium scoparium*), yellow Indiangrass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*), and Texas cupgrass (*Eriochloa sericea*), once common in Edwards Plateau grasslands, decrease with intensive grazing, and have been largely replaced by species such as curlymesquite (*Hilaria belangeri*) and Texas wintergrass (*Stipa leucotricha*) in grazed areas. Blue grama (*Bouteloua gracilis*), buffalograss, and tobosa (*Hilaria mutica*), typical of more arid regions to the west, tend to dominate overgrazed areas (Riskind and Diamond 1988). Wildflowers, such as Texas bluebonnets (*Lupinus texensis*), Indian blankets (*Gaillardia aestivalus*), coreopsis (*Coreopsis basalis*), and winecups (*Callirhoe digitata*), brighten the Texas landscape in the spring.

Since settlement, many wildlife species once found on the Edwards Plateau (e.g., red and gray wolf, black bear, mountain lion, prairie dog) are much reduced or locally extinct after years of hunting, trapping, and poisoning, but some have adapted. The badger (*Taxidea taxus*), once dependent on prairie dog towns (as was the not so adaptable black-footed ferret (*Mustela nigripes*)), has widened its range eastward to include the Edwards Plateau, partly by concentrating its foraging efforts on more prolific ground squirrels and woodrats. The porcupine (*Erithizon dorsatum*) is also more widespread than it was a century ago, likely due to the expansion of woodland, and the coyote (*Canis latrans*) has returned with the decline in the use of poisons (Schmidley 2002).

As in other limestone-based ecoregions in Texas (29d, 29e, 27j), most of the land area of Ecoregion 30a is dedicated to livestock grazing, since most soils outside of alluvial valleys are rocky and shallow, with bedrock often at or near the surface. Some farming for hay and grain sorghum occurs in alluvial valleys and areas of deeper soil, but high summer temperatures, high evapotranspiration rates, and little water available for irrigation limit crop production. In addition to cattle ranching, the Edwards Plateau is also a center of sheep and goat production. Angora goat production has declined in recent years with decreasing demand for wool; in the last decade the Boer goat, raised for meat, has outnumbered angora goats and sheep. Goats are particularly suited to areas having steeper slopes, eroded soils, or poor forage, such as parts of the Balcones Canyonlands (30c) and Semiarid Edwards Plateau (30d); however, with more of the ranches of the central Edwards Plateau (30a) being subdivided at the outskirts of expanding urban centers, meat goats have become the livestock-of-choice for small acreages (Byrns 2003).

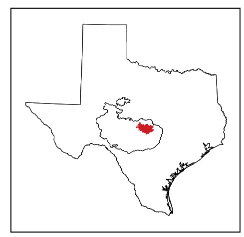
Level IV Ecoregion	**30a. Edwards Plateau Woodland**
Area (sq. mi.)	9394
Physiography	Elevated plateau with rolling terrain, rounded hills and ridges, and intervening broad valleys; low to moderate gradient streams with mostly bedrock, cobble, gravel, and sandy substrates.
Elevation / Local Relief (feet)	800-2500 / 50-400
Surficial Geology; Bedrock Geology	Quaternary limestone-clast loamy colluvium, cemented alluvial sand, silt, clay, and gravel in drainages. Lower Cretaceous limestone and dolomite of the Edwards Formation; interbedded dolomite, chalk, marl, and mudstone of the Glen Rose Formation; Hensell Sand exposed in valleys and floodplains; Upper Cretaceous Buda Formation limestone caps higher hills and buttes.
Soil Order (Great Groups)	Mollisols (Calciustolls, Haplustolls, Argiustolls) on hills and plateaus; Alfisols (Paleustalfs, Haplustalfs, Rhodustalfs) on floodplains and in valleys; Entisols on slopes (Ustorthents).
Common Soil Series	Uplands and stream divides: Tarrant, Kavett, Eckrant, Yates, Roughcreek, Rumple, Purves, Hensley, Tarpley, Eckert, Oplin. Deeper valley soils: Pedernales, Luckenbach.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	22-34, declining westward
Mean Annual Frost Free Days	215-240
Mean Temperature (F) (Jan. min/max; July min/max)	33/60; 70/95
Vegetation	Plateau live oak, Texas oak, Texas persimmon, and some Ashe juniper in groves or oak mottes scattered over open grassland (or juniper invaded grassland). In minimally disturbed areas, grasses such as little bluestem, yellow Indiangrass, sideoats grama, and Texas cupgrass. In grazed areas, grasses include Texas wintergrass and curlymesquite. Riparian trees include sycamore, ash, black willow, little walnut, and eastern cottonwood, with pecan, American elm, and plateau live oak growing in the floodplains of larger rivers.
Land Cover and Land Use	Woodland, grassland, pasture, cattle ranching, some cropland in alluvial valleys, hunting leases.

The Edwards Plateau grasslands are well known for their spring wild flowers. Although known for fields of Texas bluebonnets *(Lupinus texensis)*, there are many other showy species, such as these winecups (*Callirhoe digitata*). *Photo: Sandy Bryce*

The Edwards Plateau Woodland (30a) in Gillespie County.
Photo: J.R. Manhart, Texas A&M University

The South Llano River flows through the Edwards Plateau Woodland (30a).
Photo: Earl Nottingham, TPWD

30b Llano Uplift



The Llano Uplift ecoregion is actually a basin; in some places, it is 1000 feet below the level of the surrounding Cretaceous and Paleozoic limestone escarpments of 30a. The region has distinctive geology and accompanying soils that influence the types of vegetation growing there as well as water quality. The ecoregion boundaries were generalized primarily from a congruence of physiography, geology, and soil patterns. Ecoregion 30b gets its name from a mass of magma pushed upward in the Tertiary period that hardened into granite. The granite was subsequently exposed when the overlying limestones were eroded away. The granitic intrusions, surrounded by a matrix of metamorphic quartz-feldspar gneisses and schists, are some of the oldest rocks in Texas at more than one billion years old (Barnes 1992, Spearing 1991). The largest mass of granite, Enchanted Rock, is a 400 foot high exfoliation dome that has sheets of granite peeling off the central exposed mass of the dome.

Between the rose-colored granite and gneiss outcrops, the vegetated land surface is flat or gently rolling. The soils over granite, gneiss, and schist are shallow, reddish-brown, stony, sandy loams (Inceptisols); valley soils, composed of deeper sandy loams (Alfisols) are more acidic in contrast to the alkaline soils of the Edwards Plateau Woodland ecoregion (30a) that surrounds Ecoregion 30b. The woody vegetation of the Llano Uplift has elements of both Ecoregion 30a and the Cross Timbers to the north (29b and 29c), with savanna woodland of plateau live oak (*Quercus fusiformis*), post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), cedar elm (*Ulmus crassifolia*), and some black hickory (*Carya texana*) present depending on aspect and habitat. Honey mesquite (*Prosopis glandulosa*) dominates the intervening grassy openings. Two prominent Edwards Plateau species, Ashe juniper *(Juniperus ashei*) and Texas oak (*Quercus buckleyi*), are generally absent from the granitic areas of the Llano Uplift; they may be found on the slopes of the limestone escarpment surrounding the basin or on limestone inclusions within it. Shrubs normally occurring in the deserts of West Texas, such as catclaw mimosa (*Mimosa aculeaticarpa*) and soaptree yucca (*Yucca elata*) grow on dry, exposed sites. Grasses include little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), yellow Indiangrass (*Sorghastrum nutans*), sand lovegrass (*Eragrostis trichodes*), and silver bluestem (*Bothriochloa laguroides var. torreyana*) (Riskind and Diamond 1988). Heavily grazed areas may be dominated by honey mesquite, purple threeawn (*Aristida purpurea*), Texas bluebonnet (*Lupinus texensis*), Texas pricklypear (*Opuntia lindheimeri*), and short grasses more typical of drier ecoregions (Bezanson, 2000). Crevices and patches of shallow soil between bare granite boulders and outcrops contain localized and uncommon plant communities containing plants such as spikemoss (*Selaginella apoda*), cliffbrake ferns

(*Pellaeae* spp.), Nuttall's stonecrop (*Sedum nuttallianum*), and quillworts (*Isoetes* spp.) and bladderworts (*Utricularia* spp.) in seasonal vernal pools (Bezanson 2000).

Because the rough, rocky country of the Llano Uplift ecoregion has not been intensively farmed, it supports a diverse collection of wildlife species, both native and exotic. Besides the native wildlife species of interest to hunters, i.e., white-tailed deer, Rio Grande turkey, and mourning dove, the Llano Uplift harbors nongame wildlife such as armadillo (*Dasypus novemcinctus*), badger (*Taxidea taxus*), civet cat (*Bassariscus astutus*), the westernmost representatives of the large brown mink (*Lutreola lutreocephala*), and the endemic Llano pocket gopher (*Geomys texensis*), a resident of the sandy loams of the region's valleys and stream bottoms (Schmidley 2002). The Llano River bisects Ecoregion 30b from east to west. Before it becomes submerged under Lake Lyndon B. Johnson, the river meanders with multiple channels, granite boulders, and sandy shoals. Elm (*Ulmus* spp.), willow (*Salix* spp.), American sycamore (*Plantanus americanus*), and alien salt-cedars (*Tamarix* spp.) line the banks (Belisle and Josselet 1999). Llano River fish include Guadalupe and largemouth bass (*Micropterus treculi* and *M. salmoides*), channel catfish (*Ictalurus punctatus*), and Rio Grande perch (*Cichlasoma cyanoguttatum*), species that prefer clear water over a sand and/or cobble substrates.

Before European settlers arrived in the Llano basin in the mid-1800's, the area was home to the Tonkawa, Apache, and Comanche Indians, respectively. Earlier in the mid-1700's the Comanches had repelled the advance of Spanish settlers, but the Comanches were eventually removed by U.S. cavalry to Indian Territory during the early 1870's. The vacated land was settled by German immigrants. Today, as then, ranching remains the major land use, and hunting leases on private land are a mainstay of the local economy. Farms in level areas of sandy loam produce some wheat, grain sorghum, and peaches. Limited amounts of gold, talc, graphite, granite, and iron ore have been extracted from the Llano region over the years, but none of these mining operations, except quarrying granite for building material, are presently economically viable (Garner 2002, Spearing 1991).

The Llano Uplift (30b) contains rocks that are distinctly different from surrounding areas on the Edwards Plateau. Exposed pink crystalline granite, such as Enchanted Rock, forms domelike hills that often contain unique plant communities.

The spring-fed Llano River bisects the Llano Uplift (30b) ecoregion and flows among pink granite boulders and cobbles. *Photo Billy Moore, Lower Colorado River Authority*

Level IV Ecoregion	30b. Llano Uplift
Area (sq. mi.)	1673
Physiography	Basin consisting of flat to rolling terrain punctuated by ridges and bare rock outcrops; low to moderate gradient streams with cobble, boulder, and sandy substrates.
Elevation / Local Relief (feet)	800-1900 / 50-600
Surficial Geology; Bedrock Geology	Quaternary and Tertiary weathered residuum or grus of quartz, feldspar, and biotite crystals; Precambrian granitic intrusions in a metamorphic gneiss and schist matrix.
Soil Order (Great Groups)	Inceptisols (Haplustepts) near granitic outcrops and on steep slopes; Alfisols (Paleustalfs, Haplustalfs, Rhodustalfs) in floodplains, valleys, convex slopes; Rock outcrops
Common Soil Series	Keese, Castell, Lou, Katemcy, Ligon
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	27-32
Mean Annual Frost Free Days	220-230
Mean Temperature (F) (Jan. min/max; July min/max)	32/60 70/95
Vegetation	Post oak and blackjack oak with cedar elm, black hickory and plateau live oak in some areas, mixed with mesquite grassland. Minimally disturbed grassland dominated by little bluestem and sideoats grama. Grasses in grazed areas include Texas wintergrass , purple threeawn, silver bluestem, sand lovegrass, and short grasses typical of drier ecoregions.
Land Use and Land Cover	Woodland, shrubland, grassland or pasture, and rock outcrops. Cattle ranching, some cropland in alluvial valleys, hunting leases, quarries, recreation and residential development.

30c Balcones Canyonlands

The southern Edwards Plateau was shaped through uplift and subsidence along the Balcones Fault Zone during the Miocene epoch, separating central Texas from the coastal plain by over 1000 feet in elevation (Spearing 1991). The Balcones Canyonlands form the eroded southern border of the Edwards Plateau (30), where stream activity has exposed the more erodible Glen Rose Limestone Formation. The Balcones Canyonlands are highly dissected through the solution of springs, streams, and rivers working both above and below ground to create canyons, sinkholes, and caverns (karst). The ecoregion is largely defined by the extent of the escarpment; the intervening canyons and surrounding stairstep topography are evident on topographic maps of the region. The underlying geology also helps define the boundaries of the region: the fractured nature of the escarpment, and the presence of both Edwards and Glen Rose limestone formations contrast to the more homogeneous horizontal strata of the central Edwards Plateau (30a).

This escarpment ecoregion is distinctive because its broken topography discourages intensive human development and supports diverse habitats, high species diversity and wildlife numbers, and refugia for endemics and endangered species. Assemblages of both plant and animal species have evolved to specific conditions characteristic of the limestone substrate. Moist caves support endemic species of fish (e.g., widemouth blindcat (*Satan eurystomus*)) and salamanders (e.g., Comal blind salamander (*Eurycea tridentifera*) and Blanco blind salamander (*Typhlomolge robusta*)). Millions of Mexican free-tailed bats (*Tadarida brasiliensis*) also use the caves as maternity roosts (Ricketts *et al.*, 1999).

A distinguishing characteristic of the Balcones Canyonlands is the relative abundance of running water. Where the overlying Edwards Formation has been eroded, the central Edwards Plateau (30a) aquifer, the

Trinity-Edwards aquifer, discharges toward the south and east through springs to contribute to the surface water flow in the canyons of Ecoregion 30c. Regional stream flow and annual precipitation infiltrate the sinkholes, fissures, and caverns of the limestone substrate to recharge the Balcones Canyonlands' portion of the Edwards aquifer. Agriculture and urban development at the base of the Balcones escarpment and on the neighboring Blackland Prairie (32) depend on the continuing supply of surface and ground water. The intimate connection between surface water and ground water in a karstic region underscores the importance of water resource management. The groundwater reservoir responds quickly to yearly climate change, and regional conservation measures are implemented when prolonged drought lowers the groundwater level to unsustainable levels. (Ashworth and Hopkins 1995; US Geological Survey 2002).

The dissected southeast portion of the Edwards Plateau is an area of canyonlands with a diversity of flora and fauna. The Cretaceous-age Glen Rose Limestone provides abundant water through seeps, springs, and cool, clear streams that support the deciduous woodland and associated wildlife. *Photo Carlo Abbruzzese*

Plant associations in the Balcones Canyonlands ecoregion grow along soil and moisture gradients from mesic riparian forest, to deciduous north-slope forest, to drought tolerant evergreen woodland on exposed slopes (Van Auken 1988). There are a number of endemic and rare plant species in this ecoregion that have evolved to grow in limestone habitats, such as crevice seeps and springs, where maidenhair fern (*Adiantium capillus-veneris*), tuber anemone (*Anemone edwardsiana*), and southern shield fern (*Thelypteris kunthii*) may be found (Bezanson 2000; Amos and Rowell 1988). The sheltered canyons of Ecoregion 30c have a generally southeastern orientation, and support the westernmost distribution of many eastern deciduous woody species, such as slippery elm (*Ulmus rubra*), Ohio buckeye (*Aesculus glabra*), boxelder (*Acer negundo*), bigtooth maple (*Acer grandidentatum*), Carolina basswood (*Tilia caroliniana*), and escarpment black cherry (*Prunus serotina var. exima*). Some relicts of eastern swamp communities, such as baldcypress (*Taxodium distichum*), American sycamore (*Platanus americanus*), and black willow (*Salix nigra)*, occur along major stream courses. It is likely that these trees, now stranded far from others of their kind in eastern Texas, have persisted as remnant assemblages from moister, cooler climates following the Pleistocene glacial epoch (Amos and Rowell 1988). Toward the west the vegetation in the canyons changes gradually as the climate becomes more arid. Plateau live oak woodland is eventually restricted to north and east facing slopes and floodplains, and drier south and west-facing slopes are covered with open shrublands of Ashe juniper (*Juniperus ashei*), sumac (*Rhus* spp.), sotol (*Dasylirion texanum*), acacia (*Acacia* spp.), honey mesquite (*Prosopis glandulosa*), and ceniza (*Leucophyllum frutescens*) (Riskind and Diamond 1988).

In the wild, the endangered canyon mock-orange (*Philadelphus ernestii*) generally grows on steep cliffs out of range of browsing animals.

Outside of riparian areas, oak savanna covers topographic divides between drainages, as well as mid-slope benches and alluvial valleys. Woodland vegetation in oak groves or mottes and in slope assemblages includes plateau live oak (*Quercus fusiformis*), Texas oak (*Quercus buckleyi*), Ashe juniper (*Juniperus asheii*), cedar elm (*Ulmus crassifolia*), and escarpment black cherry (*Prunus serotina var. exima*) (Bezanson 2000). As in the Edwards Plateau Woodland ecoregion (30a), fire was once much more prevalent in the Balcones Canyonlands than it is today. Summer lightning fires were common, and Native Americans regularly set hunting fires. Ashe juniper (*Juniperus asheii*) is killed outright by fire, while Texas oak and plateau live oak send up root sprouts after burning (Fonteyn *et al.*, 1988). With more frequent fire, Ashe juniper (*Juniperus asheii*) was confined to the understory of oak mottes or to escarpment areas that escaped burning. Today, it has invaded former grasslands on ridgetops and benches in the Balcones Canyonlands. Other upland deciduous

Oak mottes or scattered groves, rather than continuous woodland, were typical on plateaus and topographic divides in the Balcones Canyonlands before fire suppression led to the widespread expansion of Ashe juniper. *Photo: Sandy Bryce*

Mid-slope areas are cleared of Ashe juniper and returned to grassland on this restored portion of the Bamberger Ranch near Johnson City. Trees remain in escarpment areas, on hilltops and divides, as well as in riparian areas. At this location, the restoration of grassland areas has resulted in the rejuvenation of formerly dry springs and streams, in part because grass acts as a sponge to soak up precipitation which then percolates into the underlying perforated limestone. *Photo: Sandy Bryce*

species such as Texas oak *(Quercus buckleyi)*, Lacey oak (*Quercus laceyi*), and Texas ash (*Fraxinus texensis*), are not reproducing due to competition from juniper and the preferential browsing of hardwood seedlings by livestock and deer (Van Auken 1988). Where grasslands still exist, short grass species such as threeawns (*Aristida* spp.) and gramas (*Bouteloua* spp.) grow on ridge tops and heavily grazed areas while taller species cover slopes and moist depressions (Riskind and Diamond 1988). Ranchers have conducted juniper eradication efforts for decades in an attempt to reclaim land and create more forage for livestock. However, in many areas, soil has been lost from steep hill slopes, making it difficult to provide a seed bed for grasses. In some areas, where restoration of grassland has been successful, dry springs have begun to flow again. Rain water percolates slowly through grass cover and then through the limestone substrate. In contrast, precipitation runs off the bare rocky soil under juniper thickets.

A century of fire suppression, as well as habitat loss and fragmentation from intensive agriculture and urbanization, have threatened wildlife species that were adapted to presettlement ecosystems. There is intensive development pressure from expanding urban areas, particularly in the eastern portion of the Edwards Plateau. Elsewhere in the Balcones Canyonlands, land is often managed to include wildlife because hunting leases provide income for land owners. The primary native game animals are white-tailed deer and Rio Grande wild turkey. In addition, ranchers raise exotic game animals such as axis, fallow, and sika deer (*Cervus axis, C. dama, and C. nippon*), blackbuck antelope (*Antelope cervicapra*), and wild boar (*Sus scrofa*). Game ranching subjects native wildlife to competition for forage and cover, and exposes it to introduced parasites and disease. A recent study of interspecific competition between native and exotic species suggests that axis and sika deer compete directly with white-tailed deer for browse, and outcompete native deer by surviving on lower quality forage than white-tailed deer (Feldhamer and Armstrong 1993, in Schmidley 2002).

The high incidence of browsers (i.e., native deer, exotic ungulates, domestic goats and cattle) in Ecoregion 30c also has a direct impact on the vegetation of the region, particularly shrub species. Shrub species, such as the rare canyon mockorange (*Philadelphus ernestii*) and nearly extinct Texas snowbell (*Styrax texana*) are only found on limestone bluffs and escarpments that are inaccessible to the browsing animals. The San Antonio Botanical Garden has begun a formal effort to collect Texas snowbell seed and replant live specimens behind protective cages (Center for Plant Conservation 2004).

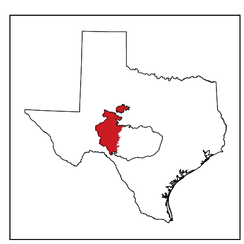
The Balcones Canyonlands contain important remnant habitat for two bird species, the golden-cheeked warbler (*Dendroica chrysoparia*) and the black-capped vireo (*Vireo atricapillus*), both of which are in serious decline. In addition to the physical limitations of shrinking habitat, both species experience low nesting success caused by increasing populations of the brown-headed cowbird (*Molothrus ater*), a nest parasite that benefits from human development and fragmented landscapes. Local groups have implemented cowbird trapping efforts on public land and private landowner incentives to preserve or restore appropriate habitat (Riparian Habitat Joint Venture 2004). Ironically, other efforts to increase grassland area and to restore the

Edwards Plateau to savanna-like conditions can be detrimental to the survival of golden-cheeked warblers because the wholesale removal of Ashe juniper destroys the mature juniper groves that the birds prefer for nesting.

The endangered golden-cheeked warbler depends on habitat of mature Ashe juniper, plus a mix of oaks and other hardwoods.
Photo: Earl Nottingham, TPWD

Level IV Ecoregion	**30c. Balcones Canyonlands**
Area (sq. mi.)	6795
Physiography	Dissected plateau and escarpment with stair step topography; moderate to high gradient streams with bedrock, cobble, and gravel substrates.
Elevation / Local Relief (feet)	650-2400 / 150-700
Surficial Geology; Bedrock Geology	Holocene to Pleistocene clay and loam colluvium mixed with limestone fragments, Quaternary and Tertiary cherty calcareous clay solution residuum. Lower Cretaceous limestone and dolomite of the Edwards Formation; interbedded dolomite, chalk, marl, and mudstone of the Glen Rose Formation; Hensell Sand exposed in valleys and floodplains; Buda Formation limestone caps higher hills and buttes.
Soil Order (Great Groups)	Inceptisols (Haplustepts) on gradual to steep slopes; Mollisolls (Calciustolls, Haplustolls, Argiustolls) on flat or convex surfaces; Rock outcrops
Common Soil Series	Upland benches and slopes: Brackett, Purvis, Real, Eckrant, Rumple. Deep valley, terrace, floodplain, and alluvial fan soils: Frio, Krum, Nuvalde, Mereta, Oakalla
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	26-34
Mean Annual Frost Free Days	230-260
Mean Temperature (F) (Jan. min/max; July min/max)	34/59 70/94
Vegetation	Upland woodland: Texas oak, plateau live oak, Vasey oak, Texas persimmon, Ashe juniper, cedar elm. Minimally disturbed grasslands: little bluestem, yellow Indiangrass, and sideoats grama. Grazed areas: Texas wintergrass, threeawns. Riparian areas: baldcypress, American sycamore, black willow, slippery elm, Ohio buckeye, boxelder, bigtooth maple, Carolina basswood.
Land Use and Land Cover	Woodland and forest, some shrubland and grassland. Cattle ranching, pasture, some cropland of cotton, grain sorghum, and small grains in alluvial valleys; hunting leases; quarries for building stone and aggregate; urban, suburban, and recreational development.

30d Semiarid Edwards Plateau



The Semiarid Edwards Plateau lies in a transition zone between the live oak savannas of central Texas and the arid west Texas desert. It also parallels the mid-grass to short-grass prairie transition between the Central Great Plains (27) and the High Plains (25) to the north. Ecoregion 30d lies west of the 100th meridian, where annual precipitation amounts (16 to 22 inches) are too low to support closed canopy forest. More precipitation falls in summer than in winter, with rainfall peaking in May/June and again in August through October. The Semiarid Edwards Plateau ecoregion is underlain by the same Cretaceous limestone as the rest of the Edwards Plateau and has soils as shallow and stony as the rolling hills of the Edwards Plateau Woodland (30a) to the east. However, the character of the landscape differs from that further east due to the drier climate. The hills are more mesa-like, their profiles sharp, rather than rounded, because erosion occurs mainly through rock fall rather than through limestone dissolution as it does in the wetter climate of Ecoregion 30a (Spearing 1991).

The eastern boundary of Ecoregion 30d is wide and "fuzzy", covering a swath of rangeland receiving 20 to 22 inches of annual precipitation, which is the minimum amount of precipitation to support full-sized trees. Thus, the boundary generally corresponds to the shift from live oak, mesquite, and juniper trees to brush or chaparral. The western boundary is similar in that it represents a transition to arid Chihuahuan Desert; it follows the Pecos River in part because there the land surface drops off the central portion of the Edwards Limestone Formation into the Pecos River valley. Ecologically, the west side of the Pecos River (in Ecoregion 24e) has more of the character of west Texas and the Chihuahuan Desert. In the south and southwest, the boundary marks a change in elevation, topography, geology, and vegetation where the land surface descends to the brush country of the Southern Texas Plains (31) and the hot, arid Pecos River basin at its confluence with the Rio Grande River. The northern boundary is fairly sharp; it follows the escarpment composing the edge of the Edwards Plateau and the northernmost extent of the Cretaceous limestone geology. At the base of the northern escarpment lie the red beds of Permian Age and the Central Great Plains (27). In the northwest part of Ecoregion 30d, the transition to the High Plains (25) is physiographically more gradual; it occurs where the Edwards limestone substrate changes to the Ogallala and Blackwater Draw formations, and the soils lose their rocky texture to become finer-grained sand and windblown loess.

Grasslands were once the predominant land cover as they were in other portions of the Edwards Plateau. The shift to shrubland occurred with the suspension of frequent grass fires, and the intensive year round grazing practiced in the late 19th and early 20th centuries. The loss of grassland to soil erosion and subsequent desertification led to the disappearance of the Montezuma quail (*Cyrtonyx montezumae*), which requires grasses for food and cover (Gehlbach 1993). Today, open savanna groves of Ashe and redberry juniper (*Juniperus asheii* and *pinchotii*), Vasey shin oak (*Quercus vaseyana*), mesquite (*Prosopis glandulosa*), and papershell pinyon (*Pinus remota*) grow on rocky mesa tops or as closed woodland in canyons. Grasslands contain scattered shrubs: mesquite (*Prosopis glandulosa*), lotebush (*Zizyphus obtusifolia*), and agarito (*Mahonia trifoliata*). Arid land shrubs and harbingers of the Chihuahuan Desert such as lechuguilla (*Agave lechuguilla*), ocotillo (*Fouquieria splendens*), and sotol (*Dasylirion* spp.) also start to appear in rangeland areas in the west end of the region; and short grasses, such as buffalograss (*Buchloe dactyloides*), tobosa (*Pleuraphis mutica*), and black grama (*Bouteloua eriopoda*) become more common in the west and northwest portions of Ecoregion 30d as the climate becomes more arid (Bezanson 2000, Schmidley 2002).

The decline in grassland cover in the Semiarid Edwards Plateau (30d) led to the disappearance of the Montezuma Quail. The bird may still be found at higher elevations, for example in the grasslands of the Davis Mountains in Ecoregion 24. *Photo:Robert Shantz*

A system of tributary canyons dissects the western portion of the Semiarid Edwards Plateau east of the Pecos River. Most streams are intermittent or ephemeral in Ecoregion 30d; many stream channels carry water only after a rainfall. Perennial streams, however, such as the lower reaches of the Devil's River have characteristics of those in the wetter central Edwards Plateau Woodland (30a) to the east, with clear, cool spring sources providing a more constant flow, and a riparian fringe of plateau live oak (*Quercus fusiformis*), huisache (*Acacia smallii*), sycamore (*Plantanus americanus*) and pecan (*Carya illinoensis*). As in other desert areas, conditions are very limiting for fish life: perennial waters are geographically restricted, populations become isolated from each other, and even spring-fed systems are susceptible to drought and flooding. Any human disturbances added to the list of natural disturbances can tip the balance toward extinction for a species with low numbers. The Devil's River minnow (*Dionda diaboli*), presently a candidate for the endangered species list, prefers fast moving water; it lost habitat with the filling of Amistad Reservoir, which flooded the lower Devil's River. The proserpine shiner (*Notropis proserpinus*), on the other hand, has a similarly restricted distribution in the Devil's River and lower Pecos River, but it is more flexible in its habitat requirements and its numbers are more stable. It is able to live in riffles as well as pools, and it reproduces quickly following floods (Lee *et al.*, 1980).

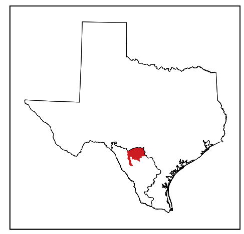
The water level in the Devil's River is sustained by headwater spring sources. The river is an oasis of fresh water in an arid landscape, benefitting aquatic and terrestrial riparian wildlife.
Photo: Earl Nottingham, TPWD

Level IV Ecoregion	**30d. Semiarid Edwards Plateau**
Area (sq. mi.)	11,081
Physiography	Flat to gently rolling plateau dissected by canyons; streams mostly ephemeral or intermittent.
Elevation / Local Relief (feet)	1400-3068 / 50-500
Surficial Geology / Bedrock Geology	Quaternary limestone-clast loamy colluvium, cemented alluvial sand, silt, clay, and gravel in drainages; Lower Cretaceous limestone and dolomite of the Edwards Formation on plateau surface and canyons, Buda Formation limestone capping higher hills and buttes.
Soil Order (Great Groups)	Mollisolls (Calciustolls, Haplustolls) and Vertisols (Haplusterts) on flat plains and stream terraces, Aridisols (Haplocalcids, Haplocambids) on dry flats and alluvial fans.
Common Soil Series	Upland benches and erosional slopes: Ector, Kavett., Tarrant; Deeper valley, terrace, floodplain, and alluvial fan soils: Dev, Reagan, Tobosa, Iraan, Cho, Mereta; Rock outcrops
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic, Aridic Ustic, Ustic Aridic
Mean Annual Precipitation (in.)	16-22
Mean Annual Frost Free Days	220-240
Mean Temperature (F) (Jan. min/max; July min/max)	31/59 69/95
Vegetation	Minimally disturbed grassland: little bluestem, buffalograss, forbs. Grazed grassland: Texas wintergrass, green sprangletop, threeawns, buffalograss, tobosa, black grama. Grassland shrubs: Mesquite, lotebush, agarita. Mesa tops: plateau live oak, Ashe and redberry juniper, Vasey shin oak, mesquite, papershell pinyon. Desert shrubs (west): Sotol, ocotillo, lechuguilla, yucca, pricklypear. Riparian woodland: plateau live oak, sycamore, pecan, huisache.
Land Use and Land Cover	Shrubland and woodland on mesa tops and in canyons; grassland with brushy overstory. Cattle ranching, pasture, some farming for cotton, grain sorghum, and small grains in alluvial valleys.

31 SOUTHERN TEXAS PLAINS

These rolling to moderately dissected plains were once covered in many areas with grassland and savanna vegetation that varied during wet and dry cycles. Following long continued grazing and fire suppression, thorny brush, such as mesquite, is now the predominant vegetation type. Ceniza and blackbrush occur on caliche soils. Also known as the Tamualipan Thornscrub, or the "brush country" as it is called locally, the region has its greatest extent in Mexico. The subhumid to dry region contains a diverse mosaic of soils, mostly clay, clay loam, and sandy clay loam surface textures, and ranging from alkaline to slightly acid. The ecoregion also contains a high and distinct diversity of plant and animal life. It is generally lower in elevation with warmer winters than the Chihuahuan Deserts (24) to the northwest. Oil and natural gas production activities are widespread.

31a Northern Nueces Alluvial Plains



The Northern Nueces Alluvial Plains ecoregion differs from much of Ecoregion 31 due to greater annual precipitation (22 to 28 inches), numerous streams that flow from the Balcones Canyonlands (30c), transitional vegetation patterns, different mosaic of soils and surficial materials, and land cover that includes more cropland and pasture. Broad Holocene and Pleistocene-age alluvial fans and other alluvial plain deposits characterize the region. The region has a hyperthermic soil temperature regime with aridic ustic and typic ustic soil moisture regimes. Soils are mostly very deep, moderately fine-textured and medium-textured. Mollisols are typical, with some Alfisols and Inceptisols.

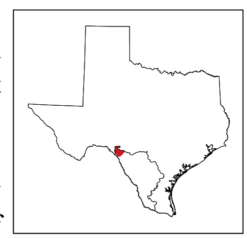
Vegetation, soils, geology, and especially topography help define the relatively distinct northern boundary of the region,where it meets the more rugged, dissected, and wooded terrain of the Balcones Canyonlands (30c) at about 1100 to 1200 feet in elevation. The eastern boundary with the Northern Blackland Prairie (32a) and Southern Post Oak Savanna (33b) is transitional and less distinct, as the Blackland soils and post oak woods fade to the drier, thorny brush covered plains of Ecoregion 31. The southern and western boundaries are influenced by the combination of patterns of soils, surficial geology, and agricultural land use.

General vegetation types include some mesquite-live oak-bluewood parks in the north, and mesquite-granjeno parks in the south (McMahan *et al.*, 1984). Some open grassland with scattered honey mesquite (*Prosopis glandulosa*), plateau live oak (*Quercus fusiformis*), and other trees occur. Little bluestem (*Schizachyrium scoparium)*, sideoats grama (*Bouteloua curtipendula*), lovegrass tridens (*Tridens eragrostoides*), multiflowered false rhodesgrass (*Trichloris pluriflora*), Arizona cottontop (*Digitaria california*), plains bristlegrass (*Setaria macrostachya*), and other mid grasses are dominant on deeper soils. Open grassland with scattered low-growing brush, such as guajillo (*Acacia berlandieri*), blackbrush (*Acacia ridigula*), elbowbush (*Forestiera pubescens*), and kidneywood (*Eysenhardtia texana*), characterize shallower soils. Arizona cottontop, sideoats grama, green sprangletop (*Leptochloa dubia*), and false rhodesgrass (*Trichloris crinita*) are dominant mid grasses on these soils. Some floodplain forests may have hackberry (*Celtis* spp.), plateau live oak, pecan (*Carya illinoensis*), and cedar elm (*Ulmus crassifolia*), with black willow (*Salix nigra*) and eastern cottonwood (*Populus deltoides*) along the banks.

As an agricultural area, this is also known as part of the Winter Garden region of Texas. Cropland is common, but large areas are also used as rangeland. The main crops are corn, cotton, small grains, and vegetables. Most cropland areas are irrigated. Winter vegetables were important in the early 1900's and continue to occupy some current cropland. Historically, honey, Angora goats and mohair, and pecans also were important products in parts of the region. Hunting leases for white-tailed deer (*Odocoileus virginianus*), northern bobwhite (*Colinus virginianus*), and mourning dove (*Zenaida macroura*) are an important source of income for many ranchers in the region today.

Level IV Ecoregion	**31a. Northern Nueces Alluvial Plains**
Area (sq. mi.)	2742
Physiography	Lightly to moderately dissected irregular plains, broad, gently sloping alluvial fans.
Elevation / Local Relief (feet)	460-1250 / 100-250
Surficial Geology; Bedrock Geology	Quaternary alluvial fan gravelly loam, silty clay decomposition residuum, alluvial gravel and sand; Cretaceous limestone in north, Paleocene and Eocene sandstone and claystone in the south.
Soil Order (Great Groups)	Mollisols (Calciustolls, Haplustolls, Paleustolls, Argiustolls), Alfisols (Haplustalfs, Paleustalfs), Inceptisols (Haplustepts), Vertisols (Haplusterts)
Common Soil Series	Knippa, Uvalde, Castroville, Montell, Winterhaven, Bigfoot, Bookout, Yologo, Hindes, Olmos, Duval, Webb, Brystal
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic, Aridic Ustic
Mean Annual Precipitation (in.)	22-28
Mean Annual Frost Free Days	250-280
Mean Temperature (F) (Jan. min/max; July min/max)	37/63; 72/96
Vegetation	Mesquite-acacia savanna: Scattered honey mesquite, granjeno, blackbrush, guajillo, some plateau live oak, with grasses of little bluestem, sideoats grama, plains bristlegrass, multiflowered false rhodesgrass, and lovegrass tridens. On riparian areas of streams originating from the Edwards Plateau, some sugar hackberry, plateau live oak, pecan, cedar elm, black willow, and eastern cottonwood.
Land Use and Land Cover	Rangeland; cropland with wheat, corn, cotton, small grains, and vegetables; pasture.

31b Semiarid Edwards Bajada



The Semiarid Edwards Bajada ecoregion is composed primarily of alluvial fan and slope wash deposits below the escarpment of the Edwards Plateau (30). Although not composed of karstic Edwards Limestone nor physiographically part of Ecoregion 30, Ecoregion 31b contains springs and streams that show some similarities to those of the Edwards Plateau (30) because they flow over a limey substrate (Austin Chalk) and likely originate from cool water aquifers beneath the Edwards Plateau. The very presence of perennial streams in such an arid region is distinctive. Elevations are lower and the climate is warmer than on the Edwards Plateau (30), and the vegetation, primarily blackbrush (*Acacia rigidula*) and honey mesquite (*Prosopis glandulosa*), is more typical of the rest of the Southern Texas Plains (31).

With influences from both the Edwards Plateau (30) and South Texas Plains (31), Pinto Creek and Sycamore Creek are both high quality, spring-influenced streams with diverse assemblages of invertebrates, reptiles, fish, and birds (Bayer 1992, El-Hage and Moulton 2001). The riparian gallery forests are dominated by sycamore (*Plantanus americanus*), willows (*Salix* spp.), sugar hackberry (*Celtis laevigata*), cottonwood (*Populus* spp.), pecan (*Carya illinoensis*), and huisache (*Acacia minuata*). Some rare aquatic and terrestrial fauna possibly associated with these riparian areas include the proserpine shiner (*Cyprinella proserpina*), Devils River minnow (*Dionda diaboli*), Rio Grande darter (*Etheostoma grahami*), common black-hawk

Cool, spring-fed Pinto Creek flows over limestone bedrock and contains aquatic fauna similar to that in streams of the Edwards Plateau ecoregion (30) to the north and east. *Photo: Sandy Bryce*

(*Buteogallus anthracinus*), golden-cheeked warbler (*Dendroica chrysoparia*), black-capped vireo *(Vireo atricapillus)*, and Texas indigo snake (*Drymarchon corais erebennus*) (Hubbs *et al.*, 1991, Bayer *et al.*, 1992, El-Hage and Moulton 2001).

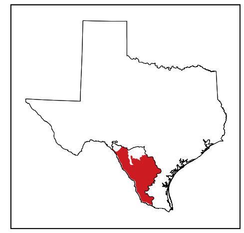
Most of the ecoregion is used as rangeland, with large ranches occupying the landscape. Native grasses included slim tridens (*Tridens muticus var. muticus*), plains bristlegrass (*Setaria macrostachya*), sideoats grama (*Bouteloua curtipendula*), pink pappusgrass (*Pappophorum bicolor*), silver bluestem (*Bothriochloa laguroides ssp. torreyana*), purple threeawn (*Aristida purpurea)*, red grama (*Bouteloua trifida*), curleymesquite (*Hilaria belangeri*), and lovegrasses (*Eragrostis* spp.). With overgrazing or range deterioration, woody shrubs, such as honey mesquite (*Prosopis glandulosa*), whitebrush (*Aloysia gratissima*), tarbush (*Flourensia cernua*), ceniza (*Leucophyllum frutescens)*, blackbrush (*Acacia rigidula*), agarita (*Mahonia trifoliolata*), yuccas (*Yucca* spp.), and pricklypear *(Opuntia* spp.), are common increasers or invaders.

Mexican pricklypoppy (*Argemone mexicana*) grows in limestone colluvium typical of stony west Texas soils. *Photo: Sandy Bryce*

The northern boundary with the Edwards Plateau is based on the apparent coincidence of change in both vegetation and physiography, as shown on the vegetation types map (Frye *et al.*, 1984) and topographic maps. The boundary between ecoregions 31 and 24, between Del Rio and Amistad Reservoir, is similar to the vegetation breaks shown by Frye *et al.*, (1984) and Kuchler (1964, 1970) and generally similar to the eastern boundary placement of West Texas (Chihuahuan Desert) of other natural region frameworks of Texas (Gould *et al*., 1960, LBJ School of Public Affairs 1978, Telfair 1999, Bezanson 2000). The eastern boundary with Ecoregion 31c is transitional. Portions of Las Moras Creek, for example, just east of the boundary in Ecoregion 31c, are also influenced by springs from the Edwards Aquifer and have similarities to Pinto and Sycamore creeks to the west in Ecoregion 31b.

Level IV Ecoregion	**31b. Semiarid Edwards Bajada**
Area (sq. mi.)	855
Physiography	Lightly to moderately dissected irregular plains, with alluvial fans; springs and some perennial streams.
Elevation / Local Relief (feet)	880-1780 / 50-250
Surficial Geology; Bedrock Geology	Quaternary limestone-clast loamy colluvium, alluvial gravel and sand, stony calcareous clay solution residuum; Cretaceous limestone and clay.
Soil Order (Great Groups)	Mollisols (Calciustolls), Aridisols (Haplocalcids)
Common Soil Series	Olmos, Acuna, Coahuila, Amistad, Elindio
Soil Temperature / Soil Moisture Regimes	Thermic, Hyperthermic / Ustic, Aridic Ustic, Ustic Aridic
Mean Annual Precipitation (in.)	19-22
Mean Annual Frost Free Days	280-290
Mean Temperature (F) (Jan. min/max; July min/max)	38/62; 74/96
Vegetation	Mesquite-acacia-savanna. Honey mesquite, blackbrush, granjeno, guajillo, yucca, with grassses of slim tridens, red grama, purple threeawn, plains bristlegrass, pink pappusgrass, curleymesquite, and lovegrasses.
Land Use and Land Cover	Shrub and grass rangeland.

31c Texas-Tamaulipan Thornscrub



Covering a large portion of the Southern Texas Plains, and extending into Mexico, the Texas-Tamaulipan Thornscrub ecoregion encompasses a mosaic of vegetation assemblages and a variety of soils. This South Texas region owes its diversity to the convergence of the Chihuahuan Desert to the west, the Tamaulipan thornscrub and subtropical woodlands along the Rio Grande to the south, and coastal grasslands to the east. Composed of mostly gently rolling or irregular plains, the region is cut by arroyos and streams, and covered with low-growing vegetation. The thorn woodland and thorn shrubland vegetation is distinctive, and these Rio Grande Plains are commonly called the "brush country". Three centuries of grazing, suppression of fire, and droughts have contributed to the spread of brush and the decrease of grasses (Archer 1995, Brown and Archer 1987, Hanselka and Archer 1998, Johnston 1963).

The region in Texas is bounded on the south by the narrow Rio Grande Floodplain and Terraces (31d) before extending southward in Mexico. Boundaries with ecoregions 31a, 31b, and 33b tend to be transitional. Some frameworks, such as the "Natural Subregions of Texas" (LBJ School of Public Affairs 1978), extend the Brush Country closer to the San Antonio River, but that area appears to have more agriculture, pasture, grassland, and post oaks more typical of Ecoregion 33b. Areas of of brushy species typical of 31c, however, have long been present in that transition. The boundary with Ecoregion 34 on the east occurs mostly at the physiographic and geologic breaks where it meets the Quaternary sediments of the coastal prairies or coastal sand plain.

Hot, dry summers and mild winters characterize the subtropical climate of this ecoregion. Precipitation is bimodal, with peak rainfall occurring in spring and fall. Spring rains are the result of frontal activity, while fall precipitation is usually tropical in origin. Typically, transpiration and evaporation far exceed input from precipitation. Precipitation is erratic, with extreme year-to-year moisture variation. Droughts are common and frequently severe (Hanselka and Archer 1998, Orton 1974).

Soils of the region include hyperthermic Alfisols, Aridisols, Mollisols, and Vertisols. They are varied and complex, highly alkaline to slightly acidic, ranging from deep sands to clays and clay loams. Caliche outcroppings and gravel ridges are common.

The vegetation is dominated by drought-tolerant, mostly small-leaved, and often thorn-laden small trees and shrubs, especially legumes. The most important woody species is honey mesquite (*Prosopis glandulosa*). Where conditions are suitable, there is a dense understory of smaller trees and shrubs such as brasil (*Condalia hookeri*), colima or lime pricklyash (*Zanthoxylum fagara*), Texas persimmon (*Diospyros texana*), lotebush (*Ziziphus obtusifolia*), granjeno (*Celtis pallida*), kidneywood (*Eysenhardtia texana*), coyotillo (*Karwinskia humboldtiana*), Texas paloverde (*Parkinsonia texana*), anacahuita (*Cordia boissieri*), and various species of cacti. Xerophytic brush species, such as blackbrush (*Acacia rigidula*), guajillo (*Acacia berlandieri*), and ceniza (*Leucophyllum frutescens*), are typical on the rocky, gravelly ridges and uplands. The brush communities also tend to grade into desert scrub near the Rio Grande. Mid and short grasses are common, including cane bluestem (*Bothriochloa barbinodis*), silver

The composition of the thornscrub and shrub savannas is variable across Ecoregion 31, influenced by substrate and grazing practices. Typical brush on the caliche ridge shown here includes cenizo, blackbrush, guajillo, and mesquite. Common plants in other areas are huisache and other acacias, along with guayacan, amargosa, yuccas, and Texas prickly pear. Typical grasses are silver bluestem, multi-flower trichloris, plains bristlegrass, purple threeawn, and several grama species.
Photo: David Bezanson

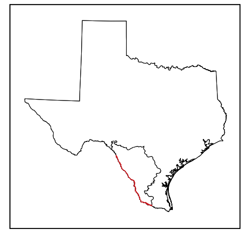
bluestem (*Bothriochloa laguroides*), multiflowered false rhodesgrass (*Trichloris pluriflora*), sideoats grama (*Bouteloua curtipendula*), pink pappusgrass (*Pappophorum bicolor*), bristlegrasses (*Setaria* spp.), lovegrasses (*Eragrostis* spp.), and tobosa (*Hilaria mutica*). On overgrazed sites or drier sites to the west, red grama (*Bouteloua trifida*), Texas grama (*Bouteloua rigidiseta*), buffalograss (*Buchloe dactyloides*), and curleymesquite (*Hilaria belangeri*) occur (Bezanson 2000).

Most of the ecoregion's land use is rangeland. Ranches that raise beef cattle tend to be large due to the low livestock carrying capacities. In the late 1800's, many south Texas counties had more sheep than cattle. During the peak decade, 1880 to 1890, at times there were more than 2 million sheep in south Texas. Sheep were an important ecological factor in changing the landscape, and literally grazed themselves out of the region (TPWD 2006). Ranching income is supplemented with hunting leases. Game species are diverse and relatively abundant compared to some other regions of Texas (Telfair 1999). Northern bobwhite (*Colinus virginianus*) and white-tailed deer (*Odocoileus virginianus*) are important game species. Hunting also occurs for mourning doves (*Zenaida macroura*), wild turkey (*Meleagris gallopavo*), and collared peccary (*Pecari tajacu*). Cultivated land is minimal, with mostly grain sorghum, small grains, cotton, and watermelons.

Texas longhorns. a hardy, adaptable, and aggressive breed of cattle, were suited to many harsh range conditions, such as those found in South Texas. Its resistance to disease and ability to survive on marginal pasture has revived the breed as beef stock, although some ranchers keep longhorn herds only because of their role in Texas history.
Photo: Texas Archeological Research Laboratory, University of Texas.

Level IV Ecoregion	**31c. Texas-Tamaulipan Thornscrub**
Area (sq. mi.)	16729
Physiography	Lightly to moderately dissected irregular plains.
Elevation / Local Relief (feet)	95-1800 / 100-300
Surficial Geology; Bedrock Geology	Quaternary calcareous clay disintegration residuum, fine sandy loam disintegration residuum, quartz sand disintegration residuum, massive clay decompostion residuum; Miocene, Oligocene, and Eocene sands, silts, and clays of various induration.
Soil Order (Great Groups)	Vertisols (Haplusterts), Alfisols (Paleustalfs, Haplustalfs), Inceptisols (Haplustepts, Calciustepts), Mollisols (Calciustolls), Aridisols (Haplargids, Calciargids)
Common Soil Series	Catarina, Montell, Maverick, Aguilares, Zapata, Copita, Ramadero, Moglia, Randado, Brennan, Duval, Webb, Delmita, Olmos, Houla, Mavco, Pryor, Tonio
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Aridic Ustic, Ustic Aridic, Ustic
Mean Annual Precipitation (in.)	20-26
Mean Annual Frost Free Days	280-300
Mean Temperature (F) (Jan. min/max; July min/max)	39-45/63-69; 73/99
Vegetation	Historically, a mix of shrublands and grasslands, some parklands and narrow woodlands; now mostly brushy shrubland. Mesquite-acacia-savanna, some mesquite-live oak savanna near northern and eastern boundaries, post oak-live oak woodlands in northeast, ceniza shrub near Rio Grande, scattered mid and short grasses.
Land Use and Land Cover	Shrubland and rangeland, ranching, hunting leases, some oil and gas production.

31d Rio Grande Floodplain and Terraces

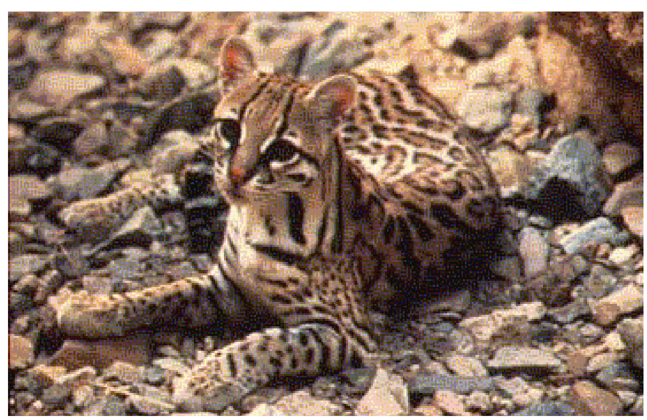


The Rio Grande Floodplain and Terraces are relatively narrow in Texas, but this region is an important natural and cultural feature of the state. Draining more than 182,000 square miles in eight states of Mexico and the United States, the Rio Grande Basin is one of the largest in North America. The river, called the Rio Bravo del Norte in Mexico, is generally sluggish and its water flow in this section is controlled in part by two large dams, Amistad above Del Rio, and Falcon below Laredo. The region consists of mostly Holocene alluvium or Holocene and Pleistocene terrace deposits, with a mix of ustic to aridic, hyperthermic soils. Boundaries for the alluvial floodplain and low terraces were based on a combination of topographic, soils and geology maps to help distinguish the narrow riverine region from the adjacent upland portions of Ecoregion 31c.

Some floodplain forests occurred, especially in the lower portion of the region, with species such as sugar hackberry (*Celtis laevigata*), cedar elm (*Ulmus crassifolia*), and Mexican ash (*Fraxinus berlandieriana*). These species are generally more typical downstream in Ecoregion 34f. Riparian forests have declined as natural floods have been restricted by flood-controlling dams and water diversions. Brushy species from adjacent dry uplands occur at the margins, such as honey mesquite (*Prosopis glandulosa*), huisache (*Acacia smallii*), blackbrush (*Acacia rigidula*), and lotebush (*Ziziphus obtusifolia*), with some grasses such as multiflowered false rhodesgrass (*Trichloris pluriflora*), sacaton (*Sporobolus wrightii*), cottontop (*Digitaria* spp.), and plains bristlegrass (*Setaria macrostachya*). Wetter areas near the river may have black willow (*Salix nigra*), black mimosa (*Mimosa pigra*), common reed (*Phragmites australis*), the introduced giant reed (*Arundo donax*), and hydrophytes such as cattails (*Typha* spp.), bulrushes (*Scirpus* spp.), and sedges (*Carex* spp.).

Many of the wider alluvial areas of the floodplain and terraces are now in cropland, mostly with cotton, grain sorghum, and cool-season vegetables. The arid or semi-arid climate of the Rio Grande Basin, the over-allocation of actual water, and the difficulties of bi-national management contribute to serious water resource, environmental, and economic issues. Water withdrawals and pollution from agricultural, urban, and industrial sources have degraded water quality. Salinity, nutrients, fecal coliform bacteria, heavy metals, and toxic chemicals are concerns for river uses such as irrigation and drinking water. In the Laredo area, US EPA and others in a binational, multiagency study in the mid 1990's identified elevated levels of arsenic, mercury, chlordane, and DDE in edible fish tissue (Governments of Mexico and the United States of America 1997).

The Rio Grande-Falcon thorn woodland in the lower portion of Ecoregion 31d, below Falcon Dam, contains many rare plants and animals, including the only known grove of Montezuma bald cypresses in the United States.
Photo: TPWD



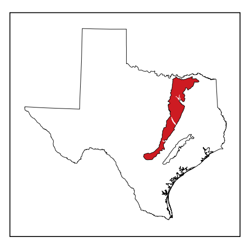
The ocelot is a neotropical cat that once ranged over the southern part of Texas. It occurs now only in a few small patches of remaining habitat near the lower Rio Grande and is on the verge of disappearing from the state.
Photo: Tom Smylie, USFWS

Level IV Ecoregion	**31d. Rio Grande Floodplain and Terraces**
Area (sq. mi.)	328
Physiography	Floodplain and narrow terraces
Elevation / Local Relief (feet)	115-790 / 20-80
Surficial Geology; Bedrock Geology	Holocene and Pleistocene sand, silt, and clay; Miocene, Oligocene, and Eocene sandstone and claystone.
Soil Order (Great Groups)	Entisols (Ustifluvents), Inceptisols (Haplustepts), Mollisols (Haplustolls)
Common Soil Series	Rio Grande, Camargo, LaGloria, Reynosa, Laredo
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic, Aridic Ustic
Mean Annual Precipitation (in.)	19-23
Mean Annual Frost Free Days	290-330
Mean Temperature (F) (Jan. min/max; July min/max)	43/67; 74/99
Vegetation	Woody riparian plants of hackberry, Mexican ash, and cedar elm. In the low parts of the floodplain, black willow, black mimosa, and giant reedgrass. Some honey mesquite, huisache, blackbrush, and lotebush, with grasses such as multiflowered false rhodesgrass, sacaton, cottontop, and plains bristlegrass.
Land Use and Land Cover	Shrub and grass rangeland, irrigated cropland with cotton, grain sorghum, vegetables.

32 TEXAS BLACKLAND PRAIRIES

The Texas Blackland Prairies form a disjunct ecological region, distinguished from surrounding regions by fine-textured, clayey soils and predominantly prairie potential natural vegetation. The predominance of Vertisols in this area is related to soil formation in Cretaceous shale, chalk, and marl parent materials. Unlike tallgrass prairie soils that are mostly Mollisols in states to the north, this region contains Vertisols, Alfisols, and Mollisols. Dominant grasses included little bluestem, big bluestem, yellow Indiangrass, and switchgrass. This region now contains a higher percentage of cropland than adjacent regions; pasture and forage production for livestock is common. Large areas of the region are being converted to urban and industrial uses. Before Anglo settlement, animal species included bison, pronghorn antelope, mountain lion, bobcat, ocelot, black bear, collared peccary, deer, coyote, fox, badger, and river otter among others (Schmidley 2002, Diggs *et al.*, 1999). Typical game species today include mourning dove and northern bobwhite on uplands and eastern fox squirrel along stream bottomlands.

32a Northern Blackland Prairie



The rolling to nearly level plains of the Northern Blackland Prairie ecoregion stretches over 300 miles from Sherman in the north to San Antonio in the south. The ecoregion generally coincides with a belt of Upper Cretaceous chalks, marls, limestones, and shales. Boundaries of the ecoregion were determined primarily by a coincidence of the soils, vegetation, land cover, and geology patterns. Historically, the distinctive element of the Northern Blackland Prairie was the vast expanse of tallgrass prairie vegetation. Frequent fire and the grazing of bison were important factors in shaping the tallgrass vegetation in the Blackland Prairie landscape. The prairie fires burned intensely hot and extensively, stopped only by a river or creek break, change in topography or soils, or lack of dry fuel. The fire suppressed invading woody species and stimulated the growth of grass and forbs. Bison consumed the prairie grass, trampled organic matter, and spread seed in the disturbed soil.

Soils formed on the Cretaceous deposits are mostly fine-textured, dark, calcareous, and productive Vertisols. These "black waxy" soils are characterized by abundant smectitic, or shrink/swell, clays that

Houston Black, recognized as the State Soil of Texas, is a Vertisol developed on the Texas Blackland Prairie. These clayey soils shrink when dry and swell when wet, and formed in calcareous clays and marls of Cretaceous age. These prime farmland soils are important agriculturally, supporting crops of grain sorghum, cotton, corn, small grains, and forage grasses. *Photo: NRCS*

shrink when dry and swell when wet, causing cracks and significant soil movement (Hallmark 1993). These soil features can shift or crack roads and building foundations, and are also difficult for certain agricultural practices. The soils are easily compacted by farm machinery when wet and can form large clods when plowed dry. Some Alfisols also occur in the region. These Alfisols developed on bedrocks that are higher in sand and lower in calcium carbonate than the Vertisols, and are found mainly on the eastern and northern margins of the ecoregion. Mollisols are found on rocks of the Austin Group. On these soils, bedrock is often just below the surface, limiting rooting depth and soil water storage. The Mollisols are usually less useful for agriculture than the Vertisols and today are primarily in pasture or residential land uses.

Small microhabitats with knolls and shallow depressions influence the composition of plant communities. Gilgai microtopography occurs on Vertisols, and mima mounds or pimple mounds are found on many Alfisols. Gilgai are shallow depressions formed by pedoturbation of montmorillonitic clays. Mima mounds are small circular hills, variable in size, composed of sandy loam that is often coarser than surrounding soil. Both gilgai and mima mounds increase microhabitat diversity and thus cause vegetational differences over small distances.

The region was dominated by little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), yellow Indiangrass (*Sorghastrum nutans*), and tall dropseed (*Sporobolus asper*) (Diamond and Smeins 1993). In lowlands and more mesic sites, such as on some of the clayey Vertisol soils in the higher precipitation areas to the northeast, dominant grasses were eastern gamagrass (*Tripsacum dactyloides*) and switchgrass (*Panicum virgatum*). Also in the northeast, over loamy Alfisols, were grass communities dominated by Silveanus dropseed (*Sporobolus silveanus*), Mead's sedge (*Carex meadii*), bluestems, and long-spike tridens (*Tridens strictus*). Common forbs included asters (*Aster* spp.), prairie bluet (*Hedyotis nigricans*), prairie clovers (*Dalea* spp.), and coneflowers (*Rudbeckia* spp.).

A few areas within the ecoregion were historically forested and some places continue to be in forest or woodland today. These include near riparian areas, on some mesic slope forests particularly in the north, and on areas such as the Austin Chalk escarpment (Diggs *et al.*, 1999, Bezanson 2000). Stream bottoms were often wooded with bur oak (*Quercus macrocarpa*), Shumard oak (*Q. shumardii*), sugar hackberry (*Celtis laevigata*), elm (*Ulmus* spp.), ash (*Fraxinus* spp.), eastern cottonwood (*Populus deltoides*), and pecan (*Carya illinoinensis*).

When farming of the Blackland Prairies replaced ranching, in the late 1800's and early 1900's, more extensive "breaking of the prairie" took place, signaling the end of the tallgrass prairie communities. Cotton production was widespread, and the wooded bottomlands were cleared to the stream banks (Schmidley 2002). A few small remnants and hay meadows remain, but virtually all of the native Blackland Prairie communities are gone (Hatch et al., 1990, Burleson 1993). Most all of the prairie has been converted to cropland and non-native pasture of introduced grasses such as Johnson grass (*Sorghum halepense*), Bermuda grass (*Cynodon dactylon*), or King Ranch bluestem (*Bothriochloa ischaemum*). Also transforming the region are the expanding urban and suburban uses, especially around Dallas, Waco, Austin, and San Antonio. The Blackland Prairies that once supported bison, pronghorn, wolves, and greater prairie chickens, now have little habitat to support a diversity of wildlife.

Major urban centers are expanding and transforming land uses in the Northern Blackland Prairie (32a). *Photo: Jim Lyle, Texas Transportation Institute*

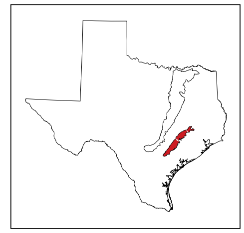
Historically, soil erosion on the native Blackland Prairie was low because of the dense tallgrass community, and also because of the water-trapping capacity of gilgai (Diggs *et* *al.*, 1999). At some times of the year during wet weather, the Blackland Prairies were nearly impassable due to the thousands of gilgai and the resultant pools of standing water (Hayward and Yelderman 1991). Clear streams and clear runoff were in contrast to today's stream conditions. With current agricultural and land use practices, little plant cover during parts of the year, and the reduction of gilgai by plowing, erosion rates in the region can be high. Thompson (1993) notes that the Blacklands have one of the highest rates of soil loss on cropland of any major area in Texas.

Cropland and pasture along with more urban uses have altered the Texas Blackland Prairies (32). The former tallgrass prairies, once dominated by Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), and big bluestem (*Andropogon gerardii*), now grow grain sorghum, corn, wheat, and hay crops. *Photo: Department of Soil and Crop Sciences, Texas A&M University*

Less than one percent of the original vegetation remains in the Texas Blackland Prairies, scattered in several small parcels across the region. A transitional prairie type at the western edge of the region is shown here. These remnant prairies contain imperiled plant communities and provide habit for many bird species and other fauna. Restoration activities in some of the protected prairies include prescribed burning, haying, and bison grazing. *Photo: Lee Stone, City of Austin*

Level IV Ecoregion	**32a. Northern Blackland Prairie**
Area (sq. mi.)	13827
Physiography	Irregular plains, lightly to moderately dissected; low to moderate gradient streams with silty, clayey, and sandy substrates.
Elevation / Local Relief (feet)	300-1050 / 100-300
Surficial Geology; Bedrock Geology	Quaternary to Tertiary silty clay decomposition residuum; Cretaceous chalk, marl, limestone, and shale.
Soil Order (Great Groups)	Vertisols (Haplusterts, Hapluderts), Alfisols (Haplustalfs), Mollisols (Haplustolls, Calciustolls)
Common Soil Series	Houston Black, Austin, Heiden, Crockett, Fairlee, Ferris, Dalco, Leson, Wilson, Lewisville, Branyon; on stream floodplains, Tinn, Ovan, Gowan, Pursley
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic/ some Udic
Mean Annual Precipitation (in.)	28 in south to 42 in north
Mean Annual Frost Free Days	230-270
Mean Temperature (F) (Jan. min/max; July min/max)	30/52 north, 40/61 south; 72/94
Vegetation	Historically, tallgrass prairie of little bluestem, big bluestem, yellow Indiangrass, and tall dropseed. In more mesic areas, eastern gamagrass, and switchgrass. Forbs of asters, prairie bluet, prairie clovers, and black-eyed susan. Riparian forests of bur oak, Shumard oak, sugar hackberry, elm, ash, eastern cottonwood, and pecan.
Land Use and Land Cover	Cropland with grain sorghum, cotton, wheat, and corn; pasture and hayland; urban, suburban, and industrial.

32b Southern Blackland Prairie



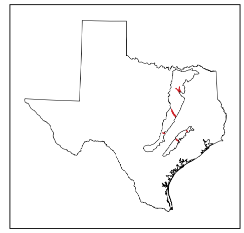
The Southern Blackland Prairie ecoregion, also known as the Fayette Prairie, has similarities to 32a, although there are some geologic, soil, vegetation, and land use differences. The Miocene-age Fleming Formation and to the west the Oakville Sandstone have some calcareous clays and marls, but differ some from the Cretaceous-age formations of Ecoregion 32a. Soils are mostly Vertisols (Calciusterts and Haplusterts), Mollisols (Calciustolls and Paleustolls), and Alfisols (Paleustalfs and Haplustalfs). The region appears more dissected than most of 32a, elevations are lower, and there are less extensive areas of cropland. Land cover is a more complex mosaic than in 32a, with more post oak woods and pasture. Historical grassland differences between 32b and 32a are not well known. Although they were likely to be generally similar, 32b may have had some subdominant species more similar to those of the Northern Humid Gulf Coastal Prairies (34a). Big bluestem (*Andropogon gerardii*) was a likely dominant on the Blackland Prairie Mollisols, and little bluestem-brownseed paspalum (*Schizachyrium scoparium-Paspalum plicatulum*) prairie often occurred on the Fayette Prairie Alfisols. Similar to Ecoregion 32a, the shrink-swell clays contain gilgai microtopography with small knolls and shallow depressions that can influence the composition of plant communities.

Yellow Indiangrass (*Sorghastrum nutans*).
Photo: R.E. Rosiere, Tarleton State University

Big bluestem (*Andropogon gerardii*).
Photo: Texas A&M University

Level IV Ecoregion	**32b. Southern Blackland Prairie**
Area (sq. mi.)	2553
Physiography	Irregular plains, lightly to moderately dissected; low to moderate gradient streams with silty, clayey, and sandy substrates.
Elevation / Local Relief (feet)	190-550 / 100-300
Surficial Geology; Bedrock Geology	Quaternary to Tertiary massive clay decomposition residuum and quartz sand decomposition residuum; Miocene sands, silts, and clays of various induration (Fleming Formation, Oakville Sandstone).
Soil Order (Great Groups)	Vertisols (Calciusterts, Haplusterts, Hapluderts), Mollisols (Calciustolls, Paleustolls, Alfisols (Paleustalfs, Haplustalfs), Inceptisols (Calciustepts)
Common Soil Series	Frelsburg, Latium, Bleiblerville, Carbengle, Brenham, Hallettsville, Crockett, Shiner; on stream floodplains, Gowen, Bosque, Trinity.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	32-44
Mean Annual Frost Free Days	260-280
Mean Temperature (F) (Jan. min/max; July min/max)	41/62; 73/95
Vegetation	Historically, tallgrass prairie with little bluestem, brownseed paspalum, big bluestem, yellow Indiangrass, and tall dropseed. In more mesic areas, eastern gamagrass, and switchgrass. Forbs of asters, prairie bluet, prairie clovers, and black-eyed susan. Some wooded areas of post oak, blackjack oak, and eastern red cedar. Riparian forests of bur oak, Shumard oak, sugar hackberry, elm, ash, eastern cottonwood, and pecan.
Land Use and Land Cover	Woodland, pasture, and some cropland with corn, grain sorghum, small grains, and hay.

32c Floodplains and Low Terraces



The Floodplains and Low Terraces ecoregion of the Texas Blackland Prairies includes only the broadest floodplains, i.e., those of the Trinity, Brazos, and Colorado rivers. It covers primarily the Holocene deposits and not the older, high terraces. The ecoregion boundaries are based on the delineations of this Holocene alluvium and of the floodplain soils, along with topographic landform. The alluvial soils include Vertisols, Mollisols, and Inceptisols. Similar ecological characteristics may continue up or downstream in Ecoregion 33f. As these mainstem rivers cross the Level III ecoregions, however, the surrounding characteristics of Ecoregion 32 can be quite different from those of Ecoregion 33.

The bottomland forests contained bur oak (*Quercus macrocarpa*), Shumard oak (*Q. shumardii*), sugar hackberry (*Celtis* laevigata), elm (*Ulmus* spp.), ash (*Fraxinus* spp.), eastern cottonwood (*Populus deltoides*), and pecan (*Carya illinoinensis*), but most have been converted to cropland and pasture. The remaining fragments of riverine forest provide some habitat for deer, squirrels, raccoons, foxes, opossums, and a variety of birds.

In the north, the ecoregion includes the lower portion of the East Fork Trinity River below Lake Ray Hubbard and the main stem of the Trinity below Dallas. Water quality is greatly affected by the urban and suburban environment that these rivers flow through. Water quality problems throughout the ecoregion typically include high levels of fecal coliform bacteria and nutrients. Below Waco, Ecoregion 32c covers the Brazos River floodplain in McClennan and Falls counties, and again downstream as the Brazos crosses the Southern Blackland/Fayette Prairie (32b) near Navasota in Washington and Grimes counties.

The third major floodplain covered by Ecoregion 32c is the Colorado River below Austin, and again downstream between La Grange in Fayette County and Columbus in Colorado County. The Colorado River watershed begins in New Mexico and drains 39,900 square miles. It flows across Texas for 600 miles before eventually reaching Matagorda Bay. Water availability and instream flows are a concern for both wildlife needs and human uses. The blue sucker (*Cycleptus elongatus*), listed as a threatened species of fish in Texas, occurs in the lower parts of the Colorado and the Brazos rivers. This sensitive species is one indicator of the ecological condition of these rivers, and instream flows are needed especially during the spawning period March through May.

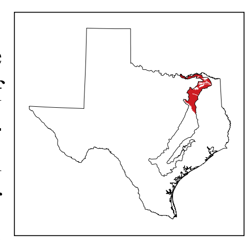
Level IV Ecoregion	**32c. Floodplains and Low Terraces**
Area (sq. mi.)	369
Physiography	Flat floodplains with sloughs, natural levees, and associated alluvial low terraces. Low gradient streams with sand, silt, clay, and gravel substrates.
Elevation / Local Relief (feet)	150-450 / 10-25
Surficial Geology; Bedrock Geology	Holocene alluvium and Holocene and Pleistocene terrace deposits of sand, silt, clay and gravel.
Soil Order (Great Groups)	Vertisols (Hapluderts), Mollisols (Haplustolls), Inceptisols (Haplustepts)
Common Soil Series	Ships, Trinity, Roetex, Bergstrom, Weswood, Highbank
Soil Temperature / Soil Moisture Regimes	Thermic / Udic, Ustic
Mean Annual Precipitation (in.)	32-40
Mean Annual Frost Free Days	250-280
Mean Temperature (F) (Jan. min/max; July min/max)	38/59; 73/95
Vegetation	Bottomland hardwood forests of bur oak, Shumard oak, post oak, green ash, pecan, cedar elm, American elm, sweetgum, sugar hackberry, and eastern cottonwood.
Land Use and Land Cover	Cropland of cotton, grain sorghum, and corn; pasture; deciduous forest and woodlands.

33 EAST CENTRAL TEXAS PLAINS

Also called the Post Oak Savanna or the Claypan Area, this region of irregular plains was originally covered by post oak savanna vegetation, in contrast to the more open prairie-type regions to the north, south, and west, and the pine forests to the east. The boundary with Ecoregion 35 is a subtle transition of soils and vegetation. Soils are variable among the parallel ridges and valleys, but tend to be acidic, with sands and sandy loams on the uplands and clay to clay loams in low-lying areas. Many areas have a dense, underlying clay pan affecting water movement and available moisture for plant growth. The bulk of this region is now used for pasture and range.

Alternating bands of post oak woods or savanna on areas of sandy soil and blackland prairies on more clayey soils typify the landscape pattern of the East Central Texas Plains (33). *Photo: James R. Manhart, Texas A&M University*

33a Northern Post Oak Savanna



The landscapes of the Northern Post Oak Savanna ecoregion are generally more level and gently rolling compared to the more dissected and irregular topography of much of Ecoregion 33b to the south. It is underlain by mostly Eocene and Paleocene-age formations with some Cretaceous rocks to the north. The soils have an udic soil moisture regime compared to ustic in Ecoregion 33b to the south, and are generally finer textured loams. Annual precipitation averages 40-48 inches compared to 28-40 inches in Ecoregion 33b.

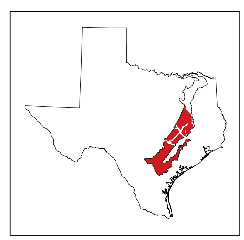
The deciduous forest or woodland is composed mostly of post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), eastern redcedar (*Juniperus virginiana*), and black hickory (*Carya texana*). The understory can include yaupon (*Ilex vomitoria*), farkleberry (*Vaccinium arboreum*), winged elm (*Ulmus alata*), and American beautyberry (*Callicarpa americana*). Prairie openings contained little bluestem (*Schizachyrium scoparium*) and other grasses and forbs. The land cover currently has more improved pasture and less post oak woods and forest than 33b. Some coniferous trees occur, especially on the transitional boundary with Ecoregion 35a. Loblolly pine (*Pinus taeda*) has been planted in several areas. Typical wildlife species include white-tailed deer (*Odocoileus virginianus*), eastern wild turkey (*Meleagris gallopavo silvestris*), northern bobwhite (*Colinus virginianus*), eastern fox squirrel (*Sciurus niger*), and eastern gray squirrel (*Sciurus carolinensis*).

The boundary of the Northern Post Oak Savanna with the Southern Post Oak Savanna (33b) is transitional.

We defined the 33a/33b break near the Trinity River, similar to where the USDA-NRCS delineates the MLRA 87a/87b boundary. The NLCD land cover data (Vogelmann *et al*., 2001) and AVHRR seasonal landcover data (Loveland *et al*., 1995), however, appear to show a change slightly more to the south, closer to the Navasota River. The boundary with Ecoregion 35 is also transitional, as the pines of the Tertiary Uplands (35a) gradually give way to the oaks and hardwoods of the post oak savannas of Ecoregion 33. Planted pines can complicate the nature of the transition. The boundary with Ecoregion 32 is generally more distinct, with a sharper change in soils, geology, and land use.

Level IV Ecoregion	**33a. Northern Post Oak Savanna**
Area (sq. mi.)	4789
Physiography	Level to rolling irregular plains, moderately dissected. Low to moderate gradient streams with sandy substrates.
Elevation / Local Relief (feet)	250-850 / 100-200
Surficial Geology; Bedrock Geology	Quaternary to Tertiary clay and sand decomposition residuum; Eocene, Paleocene, and Cretaceous sands, silts, and clays of various induration.
Soil Order (Great Groups)	Alfisols (Hapludalfs, Paleudalfs, Glossudalfs, Glossaqualfs)
Common Soil Series	Woodtell, Freestone, Annona, Raino, Derly, Pickton, Wolfpen
Soil Temperature / Soil Moisture Regimes	Thermic / Udic
Mean Annual Precipitation (in.)	40-48
Mean Annual Frost Free Days	220-240
Mean Temperature (F) (Jan. min/max; July min/max)	31/53; 71/94
Vegetation	Oak savannas or oak-hickory forest with post oak, blackjack oak, black hickory, and grasses of little bluestem, purpletop, curly threeawn, and yellow Indiangrass. Understory of yaupon, eastern red cedar, winged elm, American beautyberry, and farkleberry.
Land Use and Land Cover	Open deciduous forest and woodland, pasture, shrub and grass rangeland, cattle production, some minor cropland with hay, grain sorghum, corn, and wheat, some pine plantations.

33b Southern Post Oak Savanna



The Southern Post Oak Savanna ecoregion has more woods and forest than the adjacent prairie ecoregions (32 and 34), and consists of mostly hardwoods compared to the pines to the east in Ecoregion 35. Historically a post oak savanna, current land cover is a mix of post oak woods, improved pasture, and rangeland, with some invasive mesquite to the south. A thick understory of yaupon and eastern redcedar occurs in some parts, more characteristic of this southern region (Telfair 1999). Many areas of this ecoregion have more dissected and irregular topography than the Northern Post Oak Savanna (33a) to the north. The soils are generally acidic and have an ustic soil moisture regime compared to udic in Ecoregion 33a, and more sand and sandy loam surface textures. Some clay to clay loams occur on lower areas, and a dense clay pan is usually underlying all soil types. The region's geologic base is composed of Miocene, Oligocene, Eocene, and Paleocene sediments. Sand exposures within these Tertiary deposits have a distinctive sandyland flora, and in a few areas unique bogs occur with their own unique vegetation.

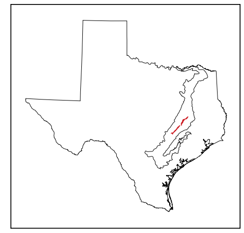
The endangered Navasota Ladies'-Tresses orchid *(Spiranthes parksii)* occurs in this region, especially in Brazos and Grimes counties, mostly along the margins of post oak woodlands in sandy loams along intermittent tributaries of the Brazos and Navasota Rivers. With a limited range and low population numbers, the orchid has been impacted by habitat loss and degradation from urban development (primarily in the Bryan/College Station area), road construction, lignite mining, and oil and gas development. The orchids do appear to be adapted to some of the rangeland management practices used in the Southern Post Oak Savanna ecoregion, and need some patchy distubances and canopy openings.

The southwestern boundary adjoining Ecoregion 31c is transitional. In the ecoregion review meetings and on the field verification trip, there were many debates about where the southern boundary of Ecoregion 33b should be delineated. Certainly, there are transitional features that need to be considered such as soil temperatures (thermic vs. hyperthermic), landcover, natural vegetation, and others, but there do not appear to be sharp breaks. In addition, mesquite and other brushy vegetation typical of Ecoregion 31c have been invading the southern portion of the Southern Post Oak Savanna. Several other natural regions or ecoregion frameworks (e.g., LBJ School of Public Affairs 1978, McMahan *et al.,* 1984, Bezanson 2000, Telfair 1999, Keys *et al.*, 1995, The Nature Conservancy Ecoregional Working Group 1997), or the various MLRA regions delineated by USDA-NRCS tend to define a southern boundary for the post oak savanna further to the northeast. These are generally north of the San Antonio River, putting most all of Karnes County into Ecoregion 31c. Our boundary is similar to that drawn by Omernik and Gallant (1987) and used by Ricketts et al., (1999), while the natural land-use regions of Barnes and Marschner (1933) define a "San Antonio Plains" in the transitional zone. This is one more example that some ecoregion boundaries are "fuzzier" than others.

A small prairie opening within some post oak woods in the northern part of Ecoregion 33b. Although post oaks (*Quercus stellata*) predominate, the woods can contain other trees, such as blackjack oak (*Quercus marilandica*), black hickory (*Carya texana*), and eastern redcedar (*Juniperus virginiana*). *Photo: James R. Manhart, Texas A&M University*

Level IV Ecoregion	**33b. Southern Post Oak Savanna**
Area (sq. mi.)	13947
Physiography	Level to rolling irregular plains, moderately dissected. Low to moderate gradient streams with sandy substrates.
Elevation / Local Relief (feet)	95-800 / 100-300
Surficial Geology; Bedrock Geology	Quaternary to Tertiary clay and sand decomposition residuum; Miocene, Oligocene, Eocene, and Paleocene sands, silts, and clays of various induration.
Soil Order (Great Groups)	Alfisols (Paleustalfs), Mollisols (Argiustolls, Hapludolls, Haplustolls); on stream floodplains, Inceptisols (Haplustepts), Vertisols (Haplusterts, Hapluderts)
Common Soil Series	Edge, Tabor, Gredge, Padina, Silstid, Rader, Burlewash, Singleton, Chazos, Zack, Arol, Straber, Tremona, Catilla, Hitilo, Elmendorf, Weesatche; on stream floodplains, Sandow, Uhland, Trinity, Gowan, Gowker, Buchel.
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	28 south to 40 north
Mean Annual Frost Free Days	260-280
Mean Temperature (F) (Jan. min/max; July min/max)	35/57 north, 40/63 south; 72/95
Vegetation	Oak savannas or oak-hickory forest with post oak, blackjack oak, black hickory, and grasses of little bluestem, purpletop, curly threeawn, and yellow Indiangrass. Understory of yaupon, eastern red cedar, winged elm, American beautyberry, and farkleberry.
Land Use and Land Cover	Open deciduous forest and woodland, pasture, shrub and grass rangeland, cattle and some poultry production, some cropland, especially to the south, with crops of hay, grain sorghum, corn, wheat, and pecans.

33c San Antonio Prairie



The San Antonio Prairie is a narrow, 100-mile long region occurring primarily on the Eocene Cook Mountain Formation. Its name came from the belt of blackland prairie extending from southwest to northeast along either side of the Old San Antonio Road. This mostly treeless belt of grassland contrasted with the post oak savanna of the surrounding Ecoregion 33b.

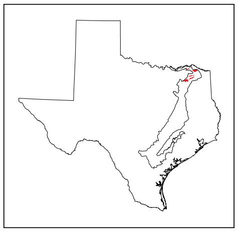
The Eocene Cook Mountain Formation is composed mostly of marine muds and mudstones, with minor interbeds of sand and limestone. Soils of the San Antonio Prairie are generally dark, loamy to clayey, blackland soils with stiff clayey subsoils. These are mostly Alfisols, with some Vertisols, and Mollisols. Generally, there are fewer Vertisols compared to the Northern Blackland Prairie ecoregion (32a) to the west. Upland Alfisol prairies were dominated by little bluestem (*Schizachyrium scoparium*) and yellow Indiangrass (*Sorghastrum nutans*) and contained a different mix of grasses and forbs than the dark, clayey, more calcareous Vertisols of Ecoregion 32a.

Since the 1830's, settlement clustered along the Old San Antonio Road (State Highway 21 in the south, Old San Antonio Road in the north) within this narrow belt of prairie land. Cotton, corn, and small grains were once commonly grown (Launchbaugh 1955). Currrently, land cover is a mosaic of woodland, improved pasture, rangeland, and some cropland.

Level IV Ecoregion	**33c. San Antonio Prairie**
Area (sq. mi.)	429
Physiography	Irregular plains, lightly to moderately dissected; some low gradient streams with sandy and silty substrates.
Elevation / Local Relief (feet)	250-570 / 100-150
Surficial Geology; Bedrock Geology	Quaternary to Tertiary limonitic sandy decomposition residuum; Eocene clays and sands (Cook Mountain Formation).
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs), Vertisols (Haplusterts), Mollisols (Argiustolls)
Common Soil Series	Crockett, Wilson, Luling, Benchley
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	36-39
Mean Annual Frost Free Days	230-240
Mean Temperature (F) (Jan. min/max; July min/max)	38/58; 73/94
Vegetation	Tallgrass prairies of little bluestem, yellow Indiangrass, switchgrass, purpletop, sunflowers, coreopsis, goldenrods, phloxes, and other forbs and grasses.
Land Use and Land Cover	Woodland, pasture, rangeland, some cropland of grain sorghum, cattle production, some oil production.

Cultivated dark prairie soils and oil production in the San Antonio Prairie (33c) near Caldwell.
Photo: Glenn Griffith

33d Northern Prairie Outliers

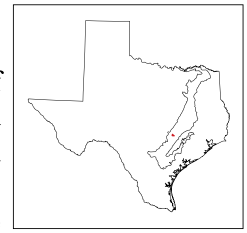


The small, disjunct areas of the Northern Prairie Outliers ecoregion have a blend of characteristics from Ecoregions 32 and 33. These interfluvial prairies occur between the Red River and branches of the Sulphur River. The northern two outliers, north of the Sulphur River, occur on Cretaceous sediments, while south of the river, Paleocene and Eocene formations predominate. A mosaic of forest and prairie occurred historically in this and adjacent regions. The natural vegetation boundaries between forest and prairie in this area were complex in the early to mid 1800's when an open-range Anglo cattle herding economy developed (Jordan 1977). Vegetational influences from Ecoregions 32, 33, and 35 come together, allowing dense pine and hardwood forests to surround disjunct patches of open blackland prairie. Burning was important in maintaining grassy openings, and woody invasions have taken place in parts of the region in the absence of fire. The tallgrass prairies included little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), yellow Indiangrass (*Sorghastrum nutans*), and tall dropseed (*Sporobolus asper*). Some prairie areas in this region and in the northeast portion of Ecoregion 32a where precipitation is relatively high, may have had a distinct grassland type dominated by Silveanus dropseed (*Sporobolus silveanus*), longspike tridens (*Tridens strictus*), and Mead's sedge (*Carex meadii*), along with bluestems, yellow Indiangrass and other grasses (Bezanson 2000). Current land cover of the region is mostly pasture, with some cropland.

Woody plants can become more abundant when wildfires are suppressed in the Northern Prairie Outliers (33c).
Photo: Jim Omernik

Level IV Ecoregion	**33d. Northern Prairie Outliers**
Area (sq. mi.)	421
Physiography	Smooth to irregular plains; small, low gradient streams, mostly intermittent, with silty substrates.
Elevation / Local Relief (feet)	300-570 / 50-100
Surficial Geology; Bedrock Geology	Quaternary to Tertiary fine silty clay, smectitic clay, and sandy clay decomposition residuum; Eocene and Paleocene sands, silts, and clays in the south, Cretaceous marl, chalk, and sandstone in the north.
Soil Order (Great Groups)	Alfisols (Paleustalfs, Haplustalfs), Vertisols (Haplusterts)
Common Soil Series	Crockett, Wilson, Burleson, Houston Black, Deport, Heiden, Leson, Mabank
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	42-46
Mean Annual Frost Free Days	220-230
Mean Temperature (F) (Jan. min/max; July min/max)	31/53; 71/94
Vegetation	Tallgrass prairies with little bluestem, big bluestem, yellow Indiangrass, switchgrass, tall dropseed, coneflowers, asters, phloxes, sunflowers and other forbs and grasses. Some scattered elm and hackberry.
Land Use and Land Cover	Pasture, cropland with wheat and grain sorghum, cattle production.

33e Bastrop Lost Pines



The Bastrop Lost Pines ecoregion is an outlier of relict loblolly pine (*Pinus taeda*) and hardwood upland forest occurring on some dissected hills just east of the city of Bastrop in Bastrop County. It is the westernmost tract of southern pine in the United States. The Lost Pines are about 100 miles west of the Texas pine belt of Ecoregion 35 and occur in a drier environment with 36 inches of average annual precipitation. In this area, the deep, acidic, sandy soils and the additional moisture provided by the Colorado River contribute to the occurrence of pines, which are thought to be a relict population predating the last glacial period. The ecoregion boundary generally encompasses the pine-hardwood vegetation class of McMahan *et al.*, (1984), with the southern boundary at the topographic and soil break to the Colorado floodplain. The northern boundary extends into the post oak woods and forest of McMahan *et al.*, (1984), although field inspection showed some pine in this area. Other scattered areas of loblolly pines appear within parts of 33b, but are mostly too small to map at this scale.

The loblolly pines mostly occur on gravelly soils that formed in Pleistocene high gravel, fluvial terrace deposits associated with the ancestral Colorado River, and sandy soils that formed in Eocene sandstones (Sparta Sand, Weches Formation, Queen City Sand, Recklaw Formation, and Carrizo Sand). The hardwood component is dominated by post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*), along with eastern red cedar (*Juniperus virginiana*) elm species (*Ulmus* spp.), and an understory of yaupon (*Ilex vomitoria*), and other species. This region also has some small areas of sphagnum bogs containing ferns and carnivorous pitcher plants.

As a nearby source of pine lumber, logging and lumber mills began in the mid 1800's, supplying lumber to Austin, San Antonio, and other cities and towns. Lumber operations revived again briefly in the early 1930's. Today, Bastrop and Buescher state parks cover part of the region. Recent decades of fire suppression have allowed thick layers of pine needles and oak leaves to accumulate, inhibiting germination of grasses and forbs. Encroachment of oak, yaupon and other understory brush occurs in some areas. Some prescribed fire treatments occur in Bastrop State Park.

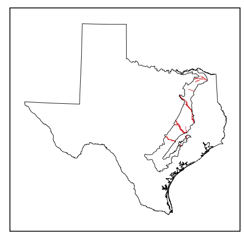
The largest population of the endangered Houston toad (*Bufo houstonensis*) occurs in this ecoregion, as well as in a few small areas of Ecoregion 33 and near the boundary of Ecoregion 34. The amphibian is associated with the deep sandy soils; they burrow into the sand for protection from cold winter weather and hot summer weather. Efforts to protect the toad from extinction have been difficult and controversial among government agencies, environmental groups, land developers, and property owners. Mammals of the region include white-tailed deer, raccoons, opossums, bobcats and armadillos along with rabbits, squirrels and small rodents. The Bastrop Lost Pines ecoregion is also the southwestern most range of the pileated woodpecker (*Dryocupus pileatus*) and pine warbler (*Dendroica pinus*), and the western extension of the range of several other warblers.

Loblolly pine and oak forest of the Bastrop Lost Pines ecoregion (33e). *Photo: Brian Greenstone*

The endangered Houston toad is associated with deep, sandy soils in the Southern Post Oak Savanna ecoregion (33b). The largest remaining population occurs in the Bastrop Lost Pines (33e). *Photo: Robert Thomas*

Level IV Ecoregion	**33e. Bastrop Lost Pines**
Area (sq. mi.)	88
Physiography	Irregular plains, some dissected hills, gently sloping ridgetops with gently to strongly sloping side slopes.
Elevation / Local Relief (feet)	330-600 / 100-250
Surficial Geology; Bedrock Geology	Quaternary.terrace gravels, quartz sand decomposition residuum, and silty clay decomposition residuum; Eocene sands, silts, and clays of various induration.
Soil Order (Great Groups)	Alfisols (Paleustalfs)
Common Soil Series	Axtell, Patilo, Silstid, Demona, Tabor
Soil Temperature / Soil Moisture Regimes	Thermic / Ustic
Mean Annual Precipitation (in.)	36
Mean Annual Frost Free Days	260-270
Mean Temperature (F) (Jan. min/max; July min/max)	38/60; 72/95
Vegetation	Loblolly pine, post oak, blackjack oak, eastern red cedar, elms, American beautyberry, farkleberry, little bluestem.
Land Use and Land Cover	Evergreen and mixed forest, pine plantations, pasture, public park land.

33f Floodplains and Low Terraces



The Floodplains and Low Terraces ecoregion contains floodplain and low terrace deposits downstream from Ecoregion 32 and upstream from Ecoregions 34 and 35. It includes only the wider floodplains of major streams, such as the Sulphur, Trinity, Brazos, and Colorado rivers. In addition, it covers primarily Holocene deposits and not all of the Pleistocene deposits on older, high terraces. The coincidence of geology, soils, and physiography patterns helped to delineate these floodplain areas.

The bottomland forests contain water oak (*Quercus nigra*), post oak (*Quercus stellata*), elms (*Ulmus* spp.), green ash (*Fraxinus caroliniana*), pecan (*Carya illinoensis*), willow oak (*Quercus phellos*) to the east, and to the west some sugar hackberry (*Celtis laevigata*) and eastern cottonwoods (*Populus deltoides*). Understory vegetation includes flowering dogwood (*Cornus florida*) in the northeast, vines of grape (*Vitis* spp.) and poison ivy (*Toxicodendron* spp.), dewberry (*Rubus* spp.), Virginia wildrye (*Elymus virginicus*), switchgrass (*Panicum virgatum*) and other grasses and forbs (McMahan *et al.*, 1984, Bezanson 2000). Reflecting the east-west moisture gradient, the floodplain areas closest to Ecoregion 35 have some Southeastern U.S. species. On the Trinity River near the boundary with Ecoregion 35 at Big Lake Bottom Wildlife Management Area, Fleming *et al.*, (2002) found eight distinct forest alliances: overcup oak-water hickory, willow oak, planer tree, cottonwood, sugarberry-cedar elm, bur oak-shumard oak, post oak-blackjack oak, and sand post oak-bluejack oak. They found 459 species in the flora of the Wildlife Management Area (Fleming *et al.*, 2002).

Land cover of the ecoregion is mostly forest and woodland in the north, while in the south, the Brazos and Colorado River floodplains are characterized by more cropland and pasture. The ecoregion provides habitat for white-tailed deer, waterfowl, migratory song birds and game birds, fox squirrels, gray squirrels, raccoons, skunks, armadillos, rabbits, bobcats, gray foxes, coyotes, and many species of reptiles and fish.

The Trinity River in Ecoregion 33f after high rainfall event.
Photo: Ray Drenner

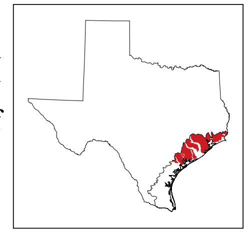
Level IV Ecoregion	**33f. Floodplains and Low Terraces**
Area (sq. mi.)	1489
Physiography	Flat floodplains with sloughs, natural levees, and associated alluvial low terraces. Low gradient streams with sandy, silty, and clayey substrates.
Elevation / Local Relief (feet)	160-420 / 10-30
Surficial Geology; Bedrock Geology	Holocene alluvium and Holocene and Pleistocene terrace deposits of sand, silt, clay and gravel.
Soil Order (Great Groups)	Vertisols (Hapluderts, Endoaquerts, Dystraquerts, Haplusterts), Entisols (Fluvaquents, Ustifluvents), Inceptisols (Haplustepts), Mollisols (Haplustolls)
Common Soil Series	In north: Kaufman, Gladewater, Texark, Estes, Tinn, Nahatche, Trinity, Ovan. In south: Ships, Weswood, Coarsewood, Bergstrom
Soil Temperature / Soil Moisture Regimes	Thermic / Aquic, some Ustic and Udic
Mean Annual Precipitation (in.)	42-45 in north, 34-38 in south.
Mean Annual Frost Free Days	220-240 in north, 260-280 in south.
Mean Temperature (F) (Jan. min/max; July min/max)	30/53 north, 37/60 south; 71/93
Vegetation	Bottomland hardwood forests of water oak, willow oak, post oak, green ash, pecan, cedar elm, American elm, and sweetgum, with more hackberry and eastern cottonwood to the south and west.
Land Use and Land Cover	Deciduous forest and woodlands; cropland of cotton, grain sorghum, and corn; pasture.

34 WESTERN GULF COASTAL PLAIN

The Western Gulf Coastal Plain is a relatively flat strip of land, generally 50 to 90 miles wide, adjacent to the Gulf of Mexico. The principal distinguishing characteristics of this ecoregion are its relatively flat topography and mainly grassland potential natural vegetation. Inland from this region the plains are older, more irregular, and have mostly forest or savanna-type vegetation potentials. Largely because of these characteristics, a higher percentage of the land is in cropland than in bordering ecological regions. Rice, grain sorghum, cotton, and soybeans are the principal crops. Urban and industrial land uses have expanded greatly in recent decades, and oil and gas production is common.

Barrier islands, peninsulas, bays, lagoons, marshes, estuaries, and flat plains characterize Ecoregion 34. The region has been greatly modified. About 35 percent of the state's population and a large part of its industrial base, commerce, and jobs are located within 100 miles of the coastline. More than half of the United States' chemical and petroleum production is located on the Texas coast. *Photo: U.S. Army Corps of Engineers*

34a Northern Humid Gulf Coastal Prairies



Quaternary-age deltaic sands, silts, and clays underlie much of the Northern Humid Gulf Coastal Prairies on this gently sloping, mostly flat, coastal plain. Due to the low relief and clay subsoils, drainage is generally poor and soils remain wet for parts of the year. The historical vegetation was mostly tallgrass grasslands with a few clusters of oaks, known as oak mottes or maritime woodlands. Little bluestem (*Schizachyrium scoparium*), yellow Indiangrass (*Sorghastrum nutans*), brownseed paspalum *(Paspalum plicatulum*), gulf muhly (*Muhlenbergia capillaris*), and switchgrass (*Panicum virgatum*) were the dominant grassland species in a mixture with hundreds of other herbaceous species across these prairies. These coastal prairies had some similarities to the grasslands of Ecoregion 32, the Texas Blackland Prairies. Some post oak savannas (*Quercus stellata*) occurred along the boundary with Ecoregion 33, where coastal prairie and inland savannas intergrade. Some loblolly pine (*Pinus taeda*) occurs in the northern part of the region in the transition to Ecoregion 35. Riparian area vegetation begins a change from the north part of the region, where it is generally similar to the floodplain forests of Ecoregion 35, to the south where fewer bottomland oaks and hickories occur, and pecan (*Carya illinoensis*), sugar hackberry (*Celtis laevigata*), ash (*Fraxinus* sp.), southern live oak (*Quercus virginiana*), and cedar elm (*Ulmus crassifolia*) become the important overstory species. Cane brakes (*Arundinaria gigantea*) may also have occurred along some creeks and rivers in this region (Smeins *et al.*, 1992).

Soil surface texture of the region varies but tends to be fine-textured, with clay, clay loam, or sandy clay loam. Within the region, there are some differences from the higher Lissie Formation to the lower Beaumont Formation, both of Pleistocene age. The Lissie Formation has lighter colored soils, mostly Alfisols, typically with sandy loam, silt loam and sandy clay loam surface textures. The surface horizons tend to dry more quickly than the Vertisols. Small, circular sandy mounds, called mima mounds or pimple mounds are found on some Alfisols, and these can provide micro-habitat variation and affect plant distributions (Smeins *et al.*, 1992). The Beaumont Formation typically has the darker, clayey soils associated with Vertisols. Similar to the Vertisols of Ecoregion 32, gilgai micro-relief features are found in this region as well. Annual precipitation here varies from 37 inches in the southwest portion to 58 inches in the northeast, with a summer maximum.

Some small areas of more natural grassland occur, but almost all of the coastal prairies of Ecoregion 34a have been converted to other uses. *Photo: Sandy Bryce*

The Northern Humid Gulf Coastal Prairies have a long history of alteration, from several hundred years of Amerindian occupance and use of fire (Lehmann 1965), to the grazing of large herds of feral cattle and horses from the Spanish by the early 1800's, to domesticated livestock grazing, agriculture, and urban alteration in more recent times. Today, almost all of the coastal prairies have been converted to cropland, rangeland, pasture, or urban and industrial land uses. Extensive networks of drainage canals and stream channelization have occurred in many areas. Other regional concerns relate to invasive species such as the exotic Chinese

Rice production occurs in many areas of Ecoregion 34a, although harvested acres have declined over the past two decades. Some migratory birds use the rice fields for winter feeding grounds. *Photo: Department of Soil and Crop Sciences, Texas A&M University* tallow tree (*Sapium sebiferum*) and Chinese privet (*Ligustrum sinense*) that have spread across many areas in this region. Chinese tallow has the capacity to convert native prairie into a closed-canopy monoculture within 20 to 30 years. Imported fire ants (*Solenopsis invicta*) can affect biodiversity by reducing or eliminating populations of some small mammals, prairie birds, amphibians, reptiles, and some insects.

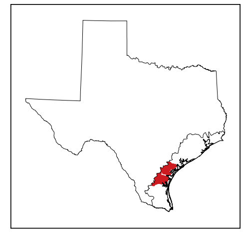
Historically, the diverse animal populations of the region included bison (*Bison bison*), pronghorn (*Antilocarpa americana*), and white-tailed deer (*Odocoileus virginianus*), although apparently in fewer numbers than in grasslands to the west and north (Smeins *et al.*, 1992). Red wolves (*Canis rufus*) were once found along the riverine forests that crossed the prairie region (Grafe 1999). Birds and waterfowl are relatively abundant today, despite the region's altered habitat.

The status of Attwater's prairie chicken (*Tympanuchus cupido attwateri*), a federally-listed endangered species since 1967, is indicative of the changes to this ecoregion. Historically, an estimated one million Attwater's prairie chickens occupied the coastal prairie grasslands from southwestern Louisiana to the Nueces River in Texas (Lehmann 1968). It was an important food source for early settlers in Texas and later an important game bird for sport. By 1919, the bird had disappeared from Louisiana, and by 1937 only about 8700 birds remained in Texas. Agriculture, urban and industrial expansion, invasion of prairie habitat by woody species, and overgrazing have resulted in a dramatic decline in the tallgrass prairie habitat. This decline represents at least a 97% loss of habitat within Attwater's prairie chickens historic range (USFWS 1992). Although listed as an endangered species in 1967, the prairie chicken population continued it's decline during the 1990's, from an estimated 456 birds in 1993 to 42 birds in 1996 (TPWD, www.tpwd.state.tx.us/huntwild/wild/species/endang/animals/birds/apc.phtml). So few birds are left that a captive breeding program is now in place to try and save this species.

Attwater's prairie chickens, a valuable part of Texas' heritage, are an important symbol of the changes that have occurred on the Texas coastal prairies. *Photo: USFWS*

Level IV Ecoregion	**34a. Northern Humid Gulf Coastal Prairies**
Area (sq. mi.)	9009
Physiography	Low, flat plains, low gradient rivers and streams (some channelized) with sandy, silty, and clayey substrates.
Elevation / Local Relief (feet)	0-300 / 5-35
Surficial Geology; Bedrock Geology	Late Pleistocene marine sand, silt, and clay. Some salt domes.
Soil Order (Great Groups)	Vertisols (Dystraquerts, Hapluderts), Mollisols (Argiudolls, Argiaquolls, Hapludolls), Alfisols (Epiaqualfs, Hapludalfs, Glossaqualfs, Glossudalfs, Vermaqualfs)
Common Soil Series	Beaumont, Morey, Mocarey, Bernard, Lake Charles, Verland, Edna, Aris, Anahuac, Clodine, Cieno, Nada, Telferner, Dacosta
Soil Temperature / Soil Moisture Regimes	Hyperthermic, Thermic / Aquic, Udic
Mean Annual Precipitation (in.)	37-58
Mean Annual Frost Free Days	260-300
Mean Temperature (F) (Jan. min/max; July min/max)	42/62; 74/92
Vegetation	Prairie grasslands with little bluestem, yellow Indiangrass, brownseed paspalum, gulf muhly, and switchgrass, with some clusters of southern live oak. Riparian forests of water oak, pecan, southern live oak, American elm, cedar elm, and sugar hackberry, as well as some cane brakes.
Land Use and Land Cover	Cropland with rice, soybeans, grain sorghum, cotton, corn; hay and pastureland, urban and industrial, rangeland, oil and gas production, waterfowl hunting.

34b Southern Subhumid Gulf Coastal Prairies



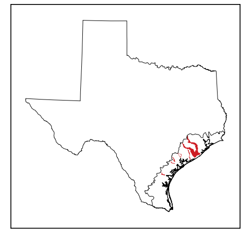
The Southern Subhumid Gulf Coastal Prairies ecoregion is drier than the Northern Humid Gulf Coastal Prairies (34a) to the north, not only receiving less annual precipitation, but also typically experiencing summer drought. Annual precipitation ranges from 26 inches in the southwest to 37 inches in the northeast, with May and September peaks. Soil temperatures are all hyperthermic, compared to mostly thermic soil temperatures in Ecoregion 34a. Within the region, there are some differences from the higher Lissie Formation to the lower Beaumont Formation, both of Pleistocene age. The Lissie Formation has lighter colored soils, mostly Alfisols with sandy clay loam surface texture, while darker, clayey Vertisols are more typical of the Beaumont Formation. Almost all of the coastal prairies have been converted to other land uses: cropland, pasture, urban and industrial.

Little bluestem (*Schizachyrium scoparium)*, yellow Indiangrass *(Sorghastrum nutans)*, and tall dropseed *(Sporobolus asper)* were once dominant grasses. Silver bluestem (*Bothriochloa laguroides*), common curleymesquite (*Hilaria belangeri*), and plains bristlegrass (*Setaria leucopila*, *S. macrostachya*), while considered increaser species due to disturbance, were also thought to be minor parts of the climax grasslands (Smeins *et al.*, 1992). Eragrostoid grasses, including the genera *Bouteloua*, *Buchloe*, *Eragrostis*, *Hilaria*, and *Setaria* increase in importance in Ecoregion 34b compared to 34a (Smeins *et al.*, 1992). Due to fire suppression, overgrazing, and other disturbances, woody or thorn-shrub species such as honey mesquite (*Prosopis glandulosa*), huisache (*Acacia smallii*), blackbrush (*Acacia rigidula*), and granjeno (*Celtis pallida*) have invaded.

Channelized streams and irrigation ditches occur in the agricultural areas of Ecoregions 34a and 34b.
Photo: Texas State Soil and Water Conservation Board

Level IV Ecoregion	**34b. Southern Subhumid Gulf Coastal Prairies**
Area (sq. mi.)	3907
Physiography	Low, flat plains, some low gradient entrenched streams with sandy, silty, and clayey substrates.
Elevation / Local Relief (feet)	0-360 / 5-35
Surficial Geology; Bedrock Geology	Late Pleistocene delta sand, silt, and clay (Beaumont Formation), and Middle Pleistocene sand, silt, and clay (Lissie Formation).
Soil Order (Great Groups)	Vertisols (Haplusterts, Epiaquerts), Alfisols (Haplustalfs, Paleustalfs, Albaqualfs)
Common Soil Series	Victoria, Lattas, Orelia, Papalote, Victine, Wyick, Vidauri, Edroy, Delfina
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic, some Aquic
Mean Annual Precipitation (in.)	26-37
Mean Annual Frost Free Days	280-310
Mean Temperature (F) (Jan. min/max; July min/max)	45/65; 74/94
Vegetation	Prairie grasslands with little bluestem, yellow Indiangrass, and tall dropseed; some silver bluestem, common curleymesquite, and plains bristlegrass that increase with disturbance; some scattered live oak, and in the south, some honey mesquite.
Land Use and Land Cover	Cropland with grain sorghum, cotton, and corn; rangeland, pastureland, urban and industrial. Some oil and gas production.

34c Floodplains and Low Terraces



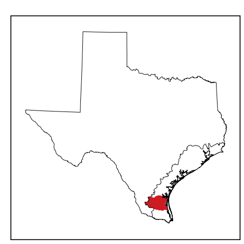
Covering primarily the Holocene floodplain and low terrace deposits, the Floodplains and Low Terraces ecoregion, especially to the southwest, has a different and less diverse bottomland forest than the floodplains of Ecoregion 35. Bottomland forests of pecan (*Carya illinoensis*), water oak (*Quercus nigra*), southern live oak (*Q. virginiana*), and elm (*Ulmus* spp.), are typical, with some baldcypress (*Taxodium distichum*) on larger streams. On some of the terraces, black hickory (*Carya texana*), post oak (*Quercus stellata*) and winged elm (*Ulmus alata*) are found. The Brazos and Colorado River floodplains are a broad expanse of alluvial sediments, while floodplains to the south, including the Navidad, Lavaca, Guadalupe, San Antonio, and Nueces, are more narrow. Soils are variable and include Vertisols, Mollisols, and Entisols. Large portions of floodplain forest have been removed and land cover is now a mix of forest, cropland, and pasture.

The Brazos River in Ecoregion 34c.
Photo: Houston Geological Society

Freshwater flows through Ecoregion 34c remain an important issue as increasing demands for surface water by municipal, industrial, and agricultural interests compete with the freshwater needs of estuaries and bays and their associated aquatic life downstream in Ecoregion 34h. The Nueces River, for example, for a variety of reasons including upstream impoundments, has experienced greatly diminished flows through this ecoregion and into Corpus Christie Bay over the past few decades.

Level IV Ecoregion	**34c. Floodplains and Low Terraces**
Area (sq. mi.)	1743
Physiography	Large river floodplains with sloughs, natural levees, and associated alluvial low terraces. Low gradient streams with sandy, silty, and clayey substrates.
Elevation / Local Relief (feet)	5-200 / 5-25
Surficial Geology; Bedrock Geology	Holocene alluvium and Holocene and Pleistocene terrace deposits of sand, silt, and clay.
Soil Order (Great Groups)	Vertisols (Hapluderts), Entisols (Fluvaquents), Mollisols (Haplustolls, Hapludolls), Inceptisols (Eutrudepts)
Common Soil Series	Pledger, Brazoria, Norwood, Asa, Ganado, Rydolph, Navaca, Navidad, Mequin, Sinton
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Udic, Ustic, Aquic
Mean Annual Precipitation (in.)	31-48
Mean Annual Frost Free Days	260-300
Mean Temperature (F) (Jan. min/max; July min/max)	42/63; 74/93
Vegetation	Bottomland forests of pecan, American elm, cedar elm, live oak, water oak, ash, sugar hackberry, cottonwood, black willow, and some bald cypress on larger rivers and streams.
Land Use and Land Cover	Deciduous forest and woodland; cropland with corn, cotton, grain sorghum, and some pecan orchards; pasture and hayland; forested wetlands.

34d Coastal Sand Plain



The Coastal Sand Plain ecoregion provides a distinct break in both vegetation and surficial materials from the fine-textured soil grasslands of Ecoregion 34b to the north. This sand sheet landscape consists of active and (mostly) stabilized sand dune deposits with lesser amounts of silt sheet deposits (silt and fine sand) to the north. Soils developed on these parent sediments are Entisols and Alfisols with thick sand surfaces. This depositional plain is characterized by a closed internal drainage system with only occasional discontinuous drainage remnants due to sand movement. Although water is generally scarce in this semi-arid region, a complex wetland ecosystem exists. Closed depressions pond water in response to seasonal and tropical storm precipitation. Clayey or restrictive layers keep some water from percolating too deep, and the water comes to or near the surface in some interdune swales.

The dominant grasses on the coastal sand ridges and islands of the adjacent Ecoregion 34i extend inland covering parts of the Coastal Sand Plain. Vegetation is mostly mid and tall grasses such as seacoast bluestem (*Schizachyrium scoparium var. littorale*), switchgrass (*Panicum virgatum*), gulfdune paspalum (*Paspalum monostachyum*), fringeleaf paspalum (*Paspalum ciliatifolium*), sandbur (*Cenchrus* spp.), purple threeawn (*Aristida purpurea*), pricklypear (*Opuntia* spp.), and catclaw (*Acacia greggii*) with an overstory of live oak (*Quercus virginiana*) and honey mesquite trees (*Prosopis glandulosa*). The potholes support plant assemblages that reflect the range of salinity found in these depressions. Some wetland soils are fairly saline due to sea spray blown inland and evaporation concentrating the salts in soils. The fresher ponds generally have a variety of bulrushes and sedges. California bulrush (*Scirpus californicus*), Olney bulrush (*Scirpus americanus*), American bulrush (*Scirpus pungens*) spikerushes (*Eleocharis* spp.), flatsedges (*Cyperus* spp.), cattails (*Typha* spp.), white-topped sedges (*Rhynchospora* spp.), paspalums (*Paspalum* spp.), Gulf cordgrass (*Spartina spartinae*), and other water-tolerant grasses are typical. The more saline wetlands have more salt-tolerant species like saltgrass (*Distichalis spicata*), sea oxeye (*Borrichia frutescens*), Carolina wolfberry (*Lycium carolinianum*), and Gulf cordgrass (*Spartina spartinae*). The wetlands support nesting birds and waterfowl and provide important water to other wildlife as well as for livestock.

Most of the Coastal Sand Plain has been moderately to heavily grazed, and large areas have been converted to non-native range or pasture grasses. The region has little cropland compared to Ecoregion 34b to the north. Hunting leases and birding and wildlife tourism are important for some ranches. Large private land holdings, such as the King and Kenedy ranches, own a large part of this region.

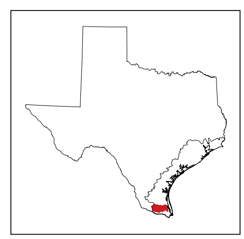
The Coastal Sand Plain has some transitional characteristics between Gulf Coast and South Texas ecoregions. In our draft ecoregion review meetings, there was some debate about including the Coastal Sand Plain within Ecoregion 34 or to classify it within Ecoregion 31, the Southern Texas Plains. Some participants argued for putting ecoregions 34d, 34e, and 34f in with the Southern Texas Plains (31), while others countered that these three ecoregions were more appropriate as part of the Western Gulf Coastal Plain (34). The fauna and freshwater biology are more similar to that found in Ecoregion 31 to the west, some contended. Grasses of 34d are like those on the Gulf barrier islands. Soil and geology are more typical of Ecoregion 34. For the present vegetation, the case could be made either way, but the brushy species from Ecoregion 31 are invasive. The majority or our review groups appeared to agree to map 34d, 34e, and 34f as part of Ecoregion 34, but the debate illustrates the transitional nature of some ecoregions and some of the difficulties in the mapping process.

Gulfdune paspalum (*Paspalum monostachyum*) is one of the more common native grasses on coastal and inland sand dunes in Ecoregion 34d.
Photo: R.E. Rosiere, Tarleton State University

Live oak mottes and introduced grasses on the King Ranch.
Photo: R.E. Rosiere, Tarleton State University

Level IV Ecoregion	**34d. Coastal Sand Plain**
Area (sq. mi.)	3552
Physiography	Flat plains, smooth plains, and some irregular plains, with active dune complexes, and depressional wetlands or potholes. Mostly internal drainage with few perennial streams.
Elevation / Local Relief (feet)	5-760 / 20-100
Surficial Geology; Bedrock Geology	Holocene sand sheet, dune sand sheet, and silt sheet.
Soil Order (Great Groups)	Entisols (Ustipsamments), Alfisols (Paleustalfs, Natrustalfs)
Common Soil Series	Falfurrias, Nueces, Sarita, Padrones
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic
Mean Annual Precipitation (in.)	24-27
Mean Annual Frost Free Days	300-330
Mean Temperature (F) (Jan. min/max; July min/max)	44/67; 73/97
Vegetation	Mesquite-live oak savanna with honey mesquite, southern live oak, Texas persimmon, colima, granjeno, seacoast bluestem, little bluestem, paspalums, yellow Indiangrass, switchgrass, purple threeawn, balsamscale, common sandbur, sand dropseed. In depressional wetlands, giant bulrush, Olney bulrush, spikesedges, arrowheads, burheads, with saltrass, green sprangletop, and spike dropseed along margins.
Land Use and Land Cover	Grass and shrub rangeland, pasture land, some evergreen woodland.

34e Lower Rio Grande Valley

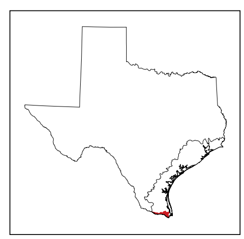


The Lower Rio Grande Valley ecoregion once supported dense, diverse grassland and shrub communities and low woodlands. However, mesquite (*Prosopis* spp.), granjeno (*Celtis pallida*), and a variety of other brush and shrub species invaded the landscape. Now, it is almost all in cropland, pasture, and urban land cover. Much of the Rio Grande's water that is withdrawn for irrigation flows through this region within the Arroyo Colorado, North Floodway, and Raymondville Drain into the Laguna Madre (Buckler *et al.*, 2002). The region is underlain by a mix of Quaternary clays and sands with some Miocene-age sediments of the Goliad Formation at the western edge. Mollisols are extensive, and the soils are deep, mostly clay loams and sandy clay loams. The freeze-free growing season is often over 320 days compared to 250-260 days along the northern Texas coastal area of Ecoregion 34a. Along with Ecoregion 34f to the south, the Lower Rio Grande Valley contains important nesting grounds for the white-winged dove, a favored hunting species in southern Texas.

The northern ecoregion boundary is based on the coincidence of soils, geology, land cover, and vegetation information that illustrate the southern end of the sand sheet of Ecoregion 34d. The eastern boundary generally occurs at the division between Texas STATSGO soils 608 (Willamar-Latina-Lyford) and 505 (Saucel-Latina-Jarron), and is close to where there is the beginning of coastal marsh influence of Ecoregion 34i. This boundary was moved about 3 to 4 miles east from earlier drafts of the boundary at the request of NRCS soil scientists. The southern boundary occurs approximately where the Rio Grande's Holocene alluvial sands and clays begin according to soils and geology information. The western boundary near the Hidalgo/Starr county line is transitional. In the area around McCook, the current boundary is 4 to 5 miles further west than the earlier draft boundary. This was moved after a multi-agency group field inspection and at the suggestion of NRCS personnel. Although the western edge of the region moves into older lithology of slightly greater relief and with more brushy vegetation, cropland has also expanded to the west, making it more similar to Ecoregion 34e, less like Ecoregion 31c, and possibly obscuring a natural division. Another consideration with the western boundary was the ability to match the level III ecoregion boundary at its position on the Rio Grande in order to join with the ecoregions of Mexico (CEC 1997).

Level IV Ecoregion	**34e. Lower Rio Grande Valley**
Area (sq. mi.)	1639
Physiography	Flat plains with slightly more relief to the west; many drainage canals and some channelized streams.
Elevation / Local Relief (feet)	5-350 / 10-50
Surficial Geology; Bedrock Geology	Quaternary (mid to late Pleistocene) alluvial delta deposits, mostly sand and clay veneer over meanderbelt sand; to the west some Quaternary clays, dune sand sheets, and Miocene clay, sand, caliche, and conglomerate (Goliad Formation).
Soil Order (Great Groups)	Mollisols (Argiustolls, Calciustolls)
Common Soil Series	Willacy, Raymondville, Racombes, Hidalgo
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic
Mean Annual Precipitation (in.)	23-27
Mean Annual Frost Free Days	320-340
Mean Temperature (F) (Jan. min/max; July min/max)	48/69; 74/95
Vegetation	Mesquite-acacia-savanna. Grasses of seacoast bluestem, plains bristlegrass, paspalums, buffalograss, windmillgrass, common curleymesquite, Arizona cottontop, and threeawn, with scattered honey mesquite, blackbrush, granjeno, guajillo, and ceniza.
Land Use and Land Cover	Cropland with grain sorghum, cotton, vegetables, melons, hay, corn, milo, sugarcane, sweetpotatoes and some citrus; some pasture and rangeland, urban, oil and gas production.

34f Lower Rio Grande Alluvial Floodplain



The Lower Rio Grande Alluvial Floodplain ecoregion includes the Holocene-age alluvial sands and clays of the Rio Grande floodplain that are now almost completely in cropland or urban land cover. Crops include cotton, citrus, grain sorghum, sugar cane, vegetables, and melons. The soils, mostly Vertisols and Mollisols, are deep, loamy and clayey, and tend to be finer-textured than in Ecoregion 34e to the north. Some Entisols and Inceptisols occur near the river. In the lower portions of the river, the floodplain ridges once had abundant palm trees (*Sabal mexicana*), and early Spanish explorers called it the "Rio de las Palmas." Most large palm trees and floodplain forests had been cleared by the early 1900's.

In some areas, subtropical upland forests, broadleaved and mostly evergreen, occurred. These evergreen low forests formed landscape mosaics with related floodplain hardwood forests that were dominated by deciduous species (Diamond 1998). A few small pieces of these unique forests remain, including Texas ebony (*Pithecellobium flexicaule*), Texas palmetto (*Sabal mexicana*), and sugar hackberry-cedar elm (*Celtis laevigata-Ulmus crassifolia*) floodplain forests. These riparian woodlands are some of the rarest natural communities in Texas (Bezanson 2000, NatureServe 2002).

The hydrology and natural cycles of flooding have been highly altered in this ecoregion. This has decreased the quality and number of wetlands, especially the oxbow lakes known as resacas, an important wildlife habitat. The altered flood cycles in the Lower Rio Grande valley also contribute to the replacement of mesic riparian woodland trees with more xeric species such as mesquite (Jahrsdoerfer and Leslie 1988). The Rio Grande's water is mostly diverted from its channel for irrigation and urban use, and little or no flow reaches the Gulf of Mexico. Return irrigation water generally does not return to the main river, but instead passes through the drainage structures of the Arroyo Colorado and the North Floodway. Agricultural chemicals, along with municipal and industrial discharges are added to the Arroyo Colorado, often causing pollution-induced oxygen depletions (Jahrsdoerfer and Leslie 1988). These contaminants then flow into the Laguna Madre in Ecoregion 34i (White et al. 1983; Chapman et al., 1998).

Salinity is another water-quality issue in this ecoregion. Increasing salinity levels in the Rio Grande negatively affect native fishes, and encourage non-native invasions, such as the salt-tolerant blue tilapia. As groundwater in this region tends to be saline and unusable, increasing surface water salinity also threatens the use of Rio Grande water for irrigation and for human consumption (Edwards and Contreras-Balderas 1991 Chapman *et al.*, 1998). Human population in the region has increased rapidly in the past 30 years. Many unincorporated communities along the river lack adequate water supply and wastewater disposal systems, while larger cities such as Brownsville and Harlingen are close to exceeding their permitted rights to surface water.

Along with the water quantity concerns, a related issue is the invasion of non-native aquatic plants, specifically hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*). Water shortages in the Lower Rio Grande Valley can be intensified by the invasion of these aquatic weeds. Not only do they transpire water into the atmosphere, but the plants clog the flow of the river as well as water distribution pipelines and aqueducts. The plants grow and reproduce rapidly, forming dense surface mats that block sunlight and inhibit the exchange of oxygen. Mechanical harvesting, herbicides, and introduction of grass carp (*Ctenopharyngodon idella*) as a biological agent have been used to control these plant populations.

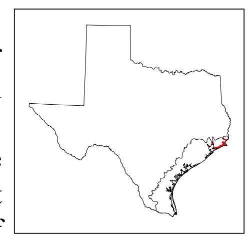
The region has the most subtropical climate of Texas, but hard freezes occasionally occur, affecting plants and animals that are at the northern limit of their range. Subtropical, temperate, coastal, and desert influences converge here, allowing for great species diversity, and the ecoregion harbors many rare species of plants and animals. A few wild tropical cats such as ocelots (*Leopardus pardalis*) and jaguarundis (*Felis yagouaroundi*), are known to occur here. Other special animals include the ferruginous pygmy-owl (*Glaucidium brasilianum*), green jay (*Cyanocorax yncas*), Altimira oriole (*Icterus gularis*), plain chachalaca (*Ortalis vetula*), Texas tortoise (*Gopherus berlandieri*), indigo snake (*Drymarchon corais*), and Mexican burrowing toad (*Rhinophrynus dorsalis)*. Both the Central and Mississippi flyways funnel through the southern tip of Texas and many species of birds reach their extreme northernmost range in this region. Nearly 500 bird species, including neotropical migratory birds, shorebirds, raptors, and waterfowl, can be found here, making the Lower Rio Grande Valley a popular area for birding.

Cropland and riparian zone of the lower Rio Grande.
Photo: Bob Parvin, Texas Department of Transportation

Resacas or oxbow lakes along the lower Rio Grande provide important wildlife habitat. *Photo: TPWD*

Level IV Ecoregion	**34f. Lower Rio Grande Alluvial Floodplain**
Area (sq. mi.)	690
Physiography	Flat, alluvial floodplain and delta; drainage canals, small reservoirs, and some channelized streams.
Elevation / Local Relief (feet)	10-120 / 5-25
Surficial Geology; Bedrock Geology	Holocene alluvial sands and clays.
Soil Order (Great Groups)	Vertisols (Haplusterts), Mollisols (Calciustolls, Haplustolls), Entisols (Ustifluvents), Inceptisols (Haplustepts)
Common Soil Series	Harlingen, Benito, Olmito, Laredo, Rio Grande, Matamoros, Camargo
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Ustic
Mean Annual Precipitation (in.)	23-27
Mean Annual Frost Free Days	320-350
Mean Temperature (F) (Jan. min/max; July min/max)	50/69; 74/94
Vegetation	Floodplain forests of Texas ebony, tepeguaje, anacua, sugar hackberry, Texas palmetto, cedar elm, and Mexican ash. Some mesquite-mixed shrub savanna with mesquite, granjeno, Texas ebony, and snake eyes.
Land Use and Land Cover	Cropland with citrus, cotton, grain sorghum, sugar cane, vegetables, melons, and hay; urban and industrial.

34g Texas-Louisiana Coastal Marshes



The Texas-Louisiana Coastal Marshes region is distinguished from the other Texas coastal ecoregions 34h and 34i by its extensive freshwater and saltwater coastal marshes, lack of barrier islands and fewer bays, and its wetter, more humid climate. Annual precipitation is 48 to 54 inches in Texas and up to 60 inches in Louisiana. There are many rivers, lakes, bayous, tidal channels, and canals. The streams and rivers that supply nutrients and sediments to this region are primarily from the humid pine belt of Ecoregion 35. Extensive cordgrass marshes occur (both *Spartina alternaflora* and *S. patens*). The estuarine and marsh complex supports marine life, supplies wintering grounds for ducks and geese, and provides habitat for small mammals and American alligators. Brown shrimp (*Penaeus aztecus*), the most commercially important marine species in Texas, is common along the whole coast, but in this northern coastal zone white shrimp (*P. setiferus*) are also commercially important. Eastern oysters (*Crassostrea virginica*) and blue crabs (*Callinectes sapidus*) are also common and commercially important in the region. Sport fishery species such as red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), southern flounder (*Paralichthys lethostigma*), and spotted seatrout (*Cynoscion nebulosus*) occur throughout the coastal bays of this region and Ecoregion 34h.

The highest elevation in the region occurs at High Island, a small town located on a salt dome that is more than 30 feet above sea level. This is one of the highest points directly on the Gulf of Mexico between Mobile, Alabama,

The Western Gulf Coastal Plain is one of the most ecologically complex and biologically diverse regions of Texas. With nearly 500 recorded species of resident and migratory birds, the Texas coastal region is one of the richest birding areas in North America. *Photo: U.S. Army Corps of Engineers*

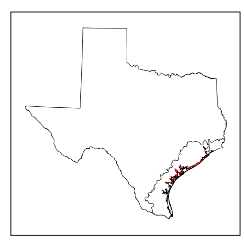
Extensive economic activity along the northern Texas Gulf Coast affects coastal natural resources. *Photo: U.S. Army Corps of Engineers*

and the Yucatán Peninsula. High Island is also a well-known birding location, famous for "fallouts" of warblers during their spring migration across the Gulf of Mexico. When flying against strong north headwinds, large numbers of neotropical migrant songbirds stop to rest in this small "island of trees" on the coastal plain.

Other salt domes occur in this region. Some have huge underground caverns created by salt dissolution that are used to store large volumes of oil in the nation's Strategic Petroleum Reserve.

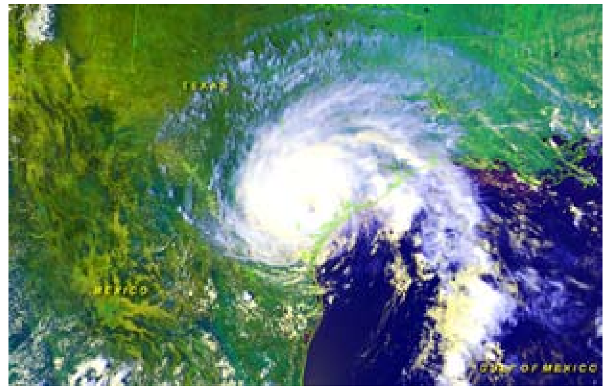
Level IV Ecoregion	**34g. Texas-Louisiana Coastal Marshes**
Area (sq. mi.)	539
Physiography	Flat plains with most of area covered by standing water; tidal marshes with bayous, lakes, canals, and cheniers or beach ridges.
Elevation / Local Relief (feet)	0-30 / 2-10
Surficial Geology; Bedrock Geology	Quaternary (Holocene) clay and silt, sand and shell fragments on cheniers or beach ridges
Soil Order (Great Groups)	Entisols (Fluvaquents, Hydraquents), Mollisols (Endoaquolls), Histosols (Haplosaprists)
Common Soil Series	Harris, Veston, Ijam, Allemands, Bancker
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Aquic
Mean Annual Precipitation (in.)	47-57
Mean Annual Frost Free Days	260-280
Mean Temperature (F) (Jan. min/max; July min/max)	42/61; 72/91
Vegetation	Freshwater, brackish, and saltwater marsh vegetation of grasses, sedges, and rushes. Few to no trees. Bulrushes, spikesedges, maidencane, cutgrass, cattails, and arrowheads in freshwater marshes. Marshhay cordgrass, saltgrass, seashore paspalum, Olney bulrush, and saltgrass in brackish areas, with smooth cordgrass, black needlerush, and saltmarsh bulrush in saline marshes.
Land Use and Land Cover	Marshland, wildlife and waterfowl habitat, oil and gas production.

34h Mid-Coast Barrier Islands and Coastal Marshes



The Mid-Coast Barrier Islands and Coastal Marshes portion of the Texas coast stretches from Galveston Bay in the north to Corpus Christi Bay in the south. It is subhumid compared to the humid climate of Ecoregion 34g to the northeast and to the semiarid climate of Ecoregion 34i to the south. Annual precipitation within Ecoregion 34h increases to the northeast, ranging from 34 to 46 inches. The region encompasses primarily the Holocene deposits with saline, brackish, and freshwater marshes, barrier islands with minor washover fans, and tidal flat sands and clays. In the inland section from Matagorda Bay to Corpus Christi Bay, some older Pleistocene barrier island deposits occur. Typical soils on the coastal marshes are Entisols (Fluvaquents), such as the Placedo, Veston, and Ijam series, with minor amounts of Histosols (Haplosaprists), such as the Allemands series. Mollisols (Endoaquolls) occur on tidal flats and coastal marshes such as the Harris, Surfside, and Velasco series. On the sandy barrier islands and dunes, Entisols (Udipsamments, Psammaquents) such as Galveston and Mustang occur.

Smooth cordgrass (*Spartina alterniflora*), marshhay cordgrass (*S. patens*), and coastal saltgrass (*Distichlis spicata*) dominate in more saline zones. Other native vegetation is mainly grassland composed of seacoast bluestem (*Schizachyrium scoparium var. littorale*), sea-oats (*Uniola paniculata*), common reed (*Phragmites australis*), gulfdune paspalum (*Paspalum monstachyum*), and soilbind morning-glory (*Ipomoea pes-caprae*). Some areas have clumps of sweetbay (*Magnolia virginiana*), redbay (*Persea borbonia*), and dwarf southern live oak trees (*Quercus virginiana*). In the Coastal Bend area, the barrier islands support extensive foredunes and back-island dune fields. Scarps can characterize bay margins due to beach erosion. Salt marsh and wind-tidal flats are mostly confined to the back side of the barrier islands with fresh or brackish marshes associated with river-mouth delta areas. Marshhay cordgrass (*Spartina patens*) becomes less important to the south in this region. Black mangrove (*Avicennia germinans*) begins to appear from Port O'Connor south.



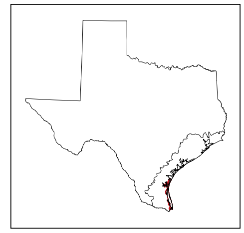
Hurricane Claudette passsed over Ecoregion 34 in July 2003, with moderate damage to human structures. Rainfall associated with hurricanes often increases sediment and nutrient inputs into coastal estuaries, but can lead to both short-term and long-term increases in productivity. *Photo: NOAA*

This area of the coast has all three commercially important species of shrimp (*Penaeus aztecus, P. duorarum,* and *P. setiferus*) as well as important oyster (*Crassostrea virginica*) and blue crab (*Callinectes sapidus*) fisheries. Convergence of longshore currents from the north and south occurs south of the Corpus Christi area near Padre Island National Seashore. Corpus Christi Bay serves as the ecozone or boundary between two distinct estuarine ecosystems. Copano and Mesquite bays to the north are low to moderate-salinity bays and attract whooping cranes and other birdlife. To the south in Ecoregion 34i, hypersaline Laguna Madre forms a unique ecosystem and supports greater expanses of seagrasses.

Level IV Ecoregion	**34h. Mid-Coast Barrier Islands and Coastal Marshes**
Area (sq. mi.)	1335
Physiography	Barrier islands, dunes, beaches, bays, estuaries, tidal marshes, lakes, canals.
Elevation / Local Relief (feet)	0-25 / 2-10
Surficial Geology; Bedrock Geology	Holocene beach sand and shell sand, back-island slope sand and silt, lagoon and tidal flat silt, sand, and clay, marsh silt and clay; Late Pleistocene beach and near-shore marine sand, some delta sand, silt, and clay (Beaumont Formation).
Soil Order (Great Groups)	Entisols (Udipsamments, Psammaquents, Fluvaquents), Mollisols, (Endoaquolls), Alfisols (Natraqualfs)
Common Soil Series	Galveston, Mustang, Tatton, Veston, Placedo, Ijam, Harris, Surfside, Velasco, Matagorda, Livia, Palacios, Narta
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Aquic
Mean Annual Precipitation (in.)	34-46
Mean Annual Frost Free Days	290-320
Mean Temperature (F) (Jan. min/max; July min/max)	47/62; 75/90
Vegetation	Mostly brackish and saltwater marsh vegetation of grasses, sedges, and rushes. Few to no trees. Smooth cordgrass, marshhay cordgrass, gulf cordgrass, and gulf saltgrass; on islands, seacoast bluestem, sea oats, gulfdune paspalum.
Land Use and Land Cover	Marshland, wildlife habitat, recreation, commercial and sport fishing, oil and gas production, some urban and residential.


Intracoastal Waterway near Freeport in Ecoregion 34h. *Photo: NOAA*

34i Laguna Madre Barrier Islands and Coastal Marshes



The Laguna Madre Barrier Islands and Coastal Marshes ecoregion is distinguished by its hypersaline lagoon system, vast seagrass meadows, wide tidal mud flats, large overwintering redhead duck population, numerous protected species, great fishery productivity, and a long, narrow barrier island with a number of washover fans. The lower coastal zone in Texas has a more semi-arid climate and has less precipitation (27 to 30 inches) compared to the coastal ecoregions 34g and 34h to the north. There is extreme variability in annual rainfall, and evapotranspiration is generally two to three times greater than precipitation. Tropical storms and hurricanes can bring large changes to this dynamic ecoregion. It is a unique region where species from the temperate north, tropical south, maritime east, and arid west are found. The northern ecoregion boundary, with 34h, occurs at the northern end of Laguna Madre where it joins Corpus Christi Bay, and where Padre Island and Mustang Island meet, just north of the Padre Island Causeway. The inland boundary is delineated to include most of the salt, brackish, and freshwater marshes, and the low-elevation saline-influenced soils. The inland boundary also generally corresponds to the USDA-NRCS Major Land Resource Boundary for 150B, the Coast Saline Prairies.

Padre Island, over 100 miles long, includes environments such as the sand and shell beaches, fore-island dunes, vegetated flats of grass-stabilized dunes, barren back-island dune fields, and, on the western margin of the island into the lagoon system, wind tidal flats that are subject to flooding by wind tides (Weise and White 1980). Northern Padre Island has almost twice as many flora species as the southern Padre Island (Nelson *et al.*, 2001). Grass vegetation of the island consists mostly of bitter panicum (*Panicum amarum*), sea-oats (*Uniola paniculata*), gulf dune paspalum (*Paspalum monstachyum*), red lovegrass (*Eragrostis secundiflora*), seacoast bluestem (*Schizachyrium scoparium* var. *littorale*), and dropseeds (*Sporobolus* spp.). Interspersed among the grasses are many kinds of herbaceous plants. Common forbs include whitestem wild indigo (*Baptisia bracteata* var. *laevicaulis*), pennywort (*Hydrocotyl* spp.), Gulf croton (*Croton punctatus*), phlox (*Phlox* spp.), morningglory (*Ipomoea* spp.), and sea purslane (*Sesuvium portulacastrum*). The vegetated barrier flats once served as cattle rangeland. Some pond and marsh sites in the region have marshhay cordgrass (*Spartina patens*), gulfdune paspalum (*Paspalum monstachyum*), bulrush (*Scirpus* spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), and pennywort (*Hydrocotyle* spp.). Marshes are generally less extensive on the southern Texas coast compared to the northern portions (ecoregions 34g, 34h). A few stands of black mangrove (*Avicennia germinans*) tidal shrub occur in this region, with its extent limited by occasional winter freezes.

As no rivers drain into the Texas Laguna Madre, the lagoon water can be hypersaline. Combined with the Laguna Madre of Tamaulipas, Mexico, it is the largest hypersaline system in the world (Tunnell and Judd 2002). The shallow depth, clear water, and warm climate of this lagoon are conducive to seagrass production. Nearly 80% of all seagrass beds in Texas are now found in the Laguna Madre (Tunnell and Judd 2002). The food web of the Laguna Madre is predominantly based on this submerged aquatic vegetation (seagrass and algae), rather than free-floating phytoplankton.

Dunes on Padre Island in Ecoregion 34i.
Photo: Phil Slattery, National Park Service

Shoals and islands in the hypersaline Laguna Madre of Ecoregion 34i near Stover Point, Laguna Atascosa National Wildlife Refuge.
Photo: James Aber, Emporia State University

Shoal grass (*Halodule wrightii*) meadows are a critical element supporting the region's fisheries and waterfowl such as the redhead duck (*Aythya americana*). The seagrass meadows have been undergoing changes in recent decades, and are affected by navigational dredging, hydrological modifications, and phytoplankton blooms (Onuf 1995). Manatee grass (*Syringodium filiforme*), less desirable for the redhead ducks, is replacing the shoal grass in many areas. Agricultural contaminants and Arroyo Colorado water quality, channelization and dredging impacts, and barrier island development are issues of concern to the health of the lagoon.

Because of the hypersalinity of the lagoon, oysters (*Crassostrea virginica*) are not commercially harvested to a large extent, although the region does contain the only strain of high-salinity adapted oysters in North America. The blue crab (*Callinectes sapidus*) harvest is also smaller than the other two coastal regions to the north. Pink shrimp (*Penaeus duorarum*) make up an important part of the commercial harvest while white shrimp (*P. setiferus*) are more abundant to the north in Ecoregion 34g. The historically highly productive commercial fisheries have now given way to an important sport fishery for species such as red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), and spotted sea trout (*Cynoscion nebulosus*).

Although barrier islands generally have a more depauperate mammal fauna than mainland coastal areas (Schmidley 2002), Padre Island does support many animals. The island's largest native mammal is the coyote (*Canis latrans*), and other mammals include badger (*Taxidea taxus*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), kangaroo rat (*Dipodomys* spp.), bats, and spotted ground squirrel (*Spermophilus spilosoma*). Deer are often seen, but these usually wade across from the mainland and are not native to the island. On the mainland portion of the region, ocelots (*Leopardus pardalis*) and mountain lions (*Puma concolor*) are known to occur. The National Seashore has documented over 350 species of birds. Many reptiles occur, including five species of sea turtle: the leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*). Along with the public land in the region, large holdings such as King Ranch and Kenedy Ranch offer some wildlife and habitat protection of the mainland portion of the region by limiting access and development.

The seagrass meadows of Ecoregion 34i are important for North America's population of redhead ducks. *Photo: Texas A&M University-Corpus Christi, Center for Coastal Studies*

Mouth of the Rio Grande where it meets the Gulf Mexico. Water flow through the delta is dependent on length of dry periods and agricultural water management upriver and in the Rio Conchos of Mexico. *Photo: TPWD*

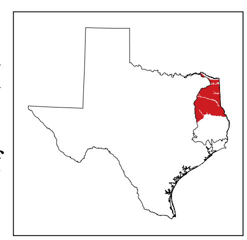
Nearly 60% of the nestings in the United States by the endangered Kemp's ridley sea turtle (*Lepidochelys kempii*) occur on Padre Island in Ecoregion 34i. Nesting numbers increased in 2006. *Photo: NOAA*

Level IV Ecoregion	**34i. Laguna Madre Barrier Islands and Coastal Marshes**
Area (sq. mi.)	668
Physiography	Barrier islands, dunes, beaches, bays, estuaries, tidal marshes, lagoons, lakes, canals.
Elevation / Local Relief (feet)	0-30 / 2-10
Surficial Geology; Bedrock Geology	Holocene alluvium, beach-ridge and barrier-flat sands.
Soil Order (Great Groups)	Aridisols (Aquisalids), Entisols (Psammaquents), Inceptisols (Halaquepts, Haplustepts), Alfisols (Nutraqualfs)
Common Soil Series	Sejita, Latina, Satatton, Tatatton, Mustang, Saucel, Barrada, Arrada, Lalinda, Jarron
Soil Temperature / Soil Moisture Regimes	Hyperthermic / Aquic, some Ustic
Mean Annual Precipitation (in.)	27-30
Mean Annual Frost Free Days	330-360
Mean Temperature (F) (Jan. min/max; July min/max)	50/68; 75/91
Vegetation	Barrier island grasslands of seacoast bluestem, gulfdune paspalum, sea oats, and bitter panicum, and numerous forbs;coastal marshes with marshhay cordgrass, bulrush, cattails, and sedges.
Land Use and Land Cover	Marshland, some bare land and narrow grassland, wildlife habitat, recreation, commercial and sport fishing, oil and gas production, public land (Padre Island National Seashore, Laguna Atascosa National Wildlife Refuge).

35 SOUTH CENTRAL PLAINS

Locally termed the "piney woods", this region of mostly irregular plains represents the western edge of the southern coniferous forest belt. Once blanketed by a mix of pine and hardwood forests, much of the region is now in loblolly and shortleaf pine plantations. Soils are mostly acidic sands and sandy loams. Covering parts of Louisiana, Arkansas, east Texas, and Oklahoma, only about one sixth of the region is in cropland, primarily within the Red River floodplain, while about two thirds of the region is in forests and woodland. Lumber, pulpwood, oil, and gas production are major economic activities.

35a Tertiary Uplands



The rolling Tertiary Uplands, gently to moderately sloping, cover a large area in east Texas, southern Arkansas, and northern Louisiana. The landscape is dissected by numerous small streams, and the region contains a diversity of habitats and species. In east Texas, Tertiary deposits are mostly Eocene sediments, with minor amounts of Paleocene and Cretaceous sediments in the north. Soils are mostly well-drained Ultisols and Alfisols, typically with sandy and loamy surface textures.

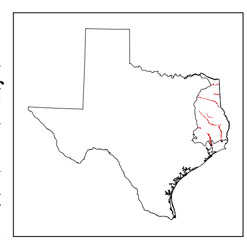
The natural vegetation has been altered by multiple timber harvests and commercial pine plantation activities. The pine-hardwood forests includes tree of loblolly pine (*Pinus taeda*), shortleaf pine (*P. echninata*), southern red oak (*Quercus falcata*), post oak (*Q. stellata*), white oak (*Q. alba*), hickory (*Carya* spp.), and sweetgum (*Liquidamber styraciflua*), and mid and tall grasses such as yellow Indiangrass (*Sorghastrum nutans*), pinehill bluestem (*Schizachyrium scoparium* var. *divergens*), narrowleaf woodoats (*Chasmathium sessiliflorum*), and panicums (*Panicum* spp.). American beautyberry (*Callicarpa americana*), sumac (*Rhus* spp.), greenbriar (*Smilax* spp.), and hawthorn (*Crataegus* spp.) are part of the understory. The sandier areas, mostly found on the Sparta, Queen City, and Carrizo Sand Formations, often have more bluejack oak (*Quercus incana*), post oak (*Q. stellata*), and stunted pines. Pine density is less than in Ecoregions 35e and 35f to the south


Upland oak-pine forest in Ecoregion 35a. *Photo: TPWD*

and in the portions of Ecoregion 35a to the east in Arkansas and Louisiana. Toward the western boundary, this region is slightly drier and has more pasture, oak-pine, and oak-hickory forest compared to the other regions of Ecoregion 35. The western boundary with Ecoregion 33 is transitional and broad in several places. Many areas of the ecoregion are replanted to loblolly pine for timber production, or are in improved pasture. Lumber and pulpwood production, livestock grazing, and poultry production are typical land uses. Oil and gas production activities are also widespread.

Level IV Ecoregion	**35a. Tertiary Uplands**
Area (sq. mi.)	11607
Physiography	Dissected irregular plains with some low, rolling hills; low to moderate gradient streams with sandy and silty substrates.
Elevation / Local Relief (feet)	180-750 / 100-300
Surficial Geology; Bedrock Geology	Quaternary sand and clay decomposition residuum; mostly Eocene and Paleocene sand, silt, and clay of various induration, some lignite; in the far north, some Cretaceous sand, silt, and clay. Salt domes occur.
Soil Order (Great Groups)	Ultisols (Hapludults, Paleudults), Alfisols (Hapludalfs, Paleudalfs)
Common Soil Series	Cuthbert, Tenaha, Briley, Lilbert, Darco, Redsprings, Elrose, Nacogdoches, Trawick, Alto, Bub, Sacul, Sawyer, Eastwood, Scottsville, Bowie, Kirvin, Wolfpen
Soil Temperature / Soil Moisture Regimes	Thermic / Udic
Mean Annual Precipitation (in.)	42-50
Mean Annual Frost Free Days	220-240
Mean Temperature (F) (Jan. min/max; July min/max)	34/55; 71/94
Vegetation	Oak-hickory-pine forest. Post oak, southern red oak, white oak, blackjack oak, black hickory, shortleaf pine, loblolly pine, sweetgum, flowering dogwood, and understory species including American beautyberry, greenbriars, sumac, hawthorns, and some mid and tall grasses.
Land Use and Land Cover	Deciduous forest, mixed forest, pasture, pine plantations, timber production, livestock and poultry production, oil and gas production, some lignite mining.

35b Floodplains and Low Terraces



In Texas, the Floodplains and Low Terraces of Ecoregion 35 comprise the western margin of the southern bottomland hardwood communities that extend along the Gulf and Atlantic coastal plains from Texas to Virginia. As delineated, Ecoregion 35b is mostly the Holocene alluvial floodplains and low terraces where there is a distinct vegetation change into bottomland oaks (*Quercus* spp.) and gum (*Nyssa* spp.) forest. It does not include all of the higher terraces such as the older Deweyville Formation terraces where vegetation tends to be more similar to the uplands, with only some minor swamp and wetland communities. Only the wider areas of floodplains and bottomland hardwoods are delineated at this scale. In Texas, the region includes sections of the Sulphur River, Big Cypress Bayou, Sabine River, Angelina River, Neches River, and Trinity River. Active, meandering alluvial river channels are dynamic systems, with erosion and deposition reworking the topography of levees, ridges, and swales. Overbank flooding, subsurface groundwater, and local precipitation recharge water levels in backswamps, pools, sloughs, oxbows, and depressions of this floodplain region.

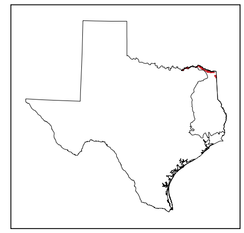
Topographic, hydroperiod, and soil differences create a complex continuum of vegetation, complicated further by current and historical human impacts. In general, water oak (*Quercus nigra*), willow oak (*Q. phellos*), sweetgum (*Liquidambar styraciflua*), blackgum (*Nyssa sylvatica*), elm (*Ulmus* spp.), red maple (*Acer rubrum*), southern red oak (*Q. falcata*), swamp chestnut oak (*Q. michauxii*), and loblolly pine (*Pinus taeda*) are typical, along with holly (*Ilex* spp.), grape (*Vitis* spp.), poison ivy (*Toxicodendron radicans*), crossvine (*Bignonia capreolata*), greenbriar (*Smilax* spp.), and a variety of ferns and mosses. Baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) are found in semipermanently flooded areas, especially in sloughs, channels, and oxbows; Spanish moss (*Tillandsia usneoides*) hangs in these trees, and floating aquatic plants often occur. On wet flats, backswamps, and swamp margins that are seasonally flooded, overcup oak (*Q. lyrata*), water hickory (*Carya aquatica*), water elm (*Planera aquatica*), sweetgum (*Liquidambar styraciflua*), green ash (*Fraxinus pennsylvanica*), and red maple (*Acer rubrum*) occur. River banks may contain black willow (*Salix nigra*), sycamore (*Plantanus americana*), and eastern cottonwood (*Populus deltoides*).

Soils of the floodplains include Inceptisols, Vertisols, Alfisols, and Entisols and are range from somewhat poorly drained to very poorly drained, clayey and loamy. Wetness and flooding present severe limitations for agriculture. A few of the higher terraces may have some pasture, but most of the region has deciduous forest land cover. Silviculture activities range from selective tree removal to clearcutting to, in some areas, replacement with pine monoculture. Reservoirs have inundated large areas of this habitat and have altered downstream hydrology. The bottomland forests provide important wildlife habitat with a high diversity of species. One estimate of East Texas bottomlands fauna listed 119 fish, 36 amphibian, 59 reptile, 279 bird, and 48 mammal species (Wilkinson *et al.*, 1987).

Bald cypress and aquatic plants in the sloughs, bayous, and ponds near Caddo Lake in Ecoregion 35b. *Photo: TPWD*

Level IV Ecoregion	**35b. Floodplains and Low Terraces**
Area (sq. mi.)	1357
Physiography	Nearly level floodplains and associated low terraces; low gradient streams with mostly silty and sandy substrates.
Elevation / Local Relief (feet)	5-330 / 10-40
Surficial Geology; Bedrock Geology	Quaternary (Holocene) alluvial sand, silt, clay, and gravel.
Soil Order (Great Groups)	Inceptisols (Endoaquepts, Eutrudepts,), Vertisols (Hapluderts, Endoaquerts, Dystraquerts), Alfisols (Paleudalfs, Glossaqualfs), Entisols (Udifluvents)
Common Soil Series	Mantachie, Marietta, Tuscosso, Koury, Pophers, Kaufman, Gladewater, Texark, Estes, Ozias, Kaman, Bienville, Latch, Mollville, Iuka
Soil Temperature / Soil Moisture Regimes	Thermic / Aquic, Udic
Mean Annual Precipitation (in.)	42-56
Mean Annual Frost Free Days	220-250
Mean Temperature (F) (Jan. min/max; July min/max)	34/55 north, 40/61 south; 72/93
Vegetation	Southern floodplain forest. Water oak, willow oak, sweetgum, blackgum, elm, red maple, southern red oak, swamp chestnut oak, and loblolly pine; baldcypress and water tupelo in frequently flooded areas; overcup oak, water hickory, swamp privet, sweetgum, green ash, and red maple on seasonally flooded areas; black willow, sycamore, eastern cottonwood, and green ash on river banks.
Land Use and Land Cover	Deciduous forest, forested wetlands, mixed forest, some forest livestock grazing, hunting.

35c Pleistocene Fluvial Terraces

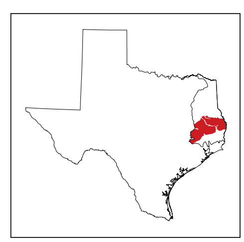


The Pleistocene Fluvial Terraces ecoregion covers significant terrace deposits on major streams in Louisiana and Arkansas, but terraces are less extensive in Texas and Oklahoma, occurring mostly along the Red River. Some terraces are found along the Sulphur River in Texas near the Arkansas state line, and other smaller terraces occur along the Sulphur but are not mapped at this scale. The broad flats and gently sloping stream terraces are lower and less dissected than Ecoregion 35a, but higher than the floodplains of ecoregions 35b and 35g.

The unconsolidated terrace deposits are periodically wet. Soils in the Texas portion are typically Alfisols and range from well to poorly drained. A vertical sequence of terraces often occurs, with age and dissection increasing with elevation. In Texas, current land cover is mostly pine-hardwood forest, with loblolly pine (*Pinus taeda*), shortleaf pine (*P. echinata*), post oak (*Quercus stellata*), Shumard oak (*Q. shumardii*), southern red oak (*Q. falcata*), water oak (*Q. nigra*), willow oak (*Q. phellos*), and sweetgum (*Liquidambar styraciflua*). To the west, pine starts to drop out and post oak (*Quercus stellata*), Shumard oak (*Q. shumardii*), and eastern redcedar (*Juniperus virginiana*) woods are more typical dominants. In Arkansas and Louisiana, loblolly pine (*Pinus taeda*) is more common on the terraces than shortleaf pine (*Pinus echinata*), perhaps influenced by the seasonal wet-dry regime.

Level IV Ecoregion	**35c. Pleistocene Fluvial Terraces**
Area (sq. mi.)	420
Physiography	Broad, flat to undulating terraces, lightly dissected; a few small, low gradient streams; locally some low mounds.
Elevation / Local Relief (feet)	200-550 / 20-50
Surficial Geology; Bedrock Geology	Late to Early Pleistocene alluvial gravel, sand, silt, and clay.
Soil Order (Great Groups)	Alfisols (Glossaqualfs, Paleudalfs, Hapludalfs, Epiaqualfs)
Common Soil Series	Wrightsville, McKamie, Whakana, Vesey, Ivanhoe, Freestone, Derly
Soil Temperature / Soil Moisture Regimes	Thermic / Aquic, Udic
Mean Annual Precipitation (in.)	42-48
Mean Annual Frost Free Days	220-230
Mean Temperature (F) (Jan. min/max; July min/max)	30/52; 72/93
Vegetation	Oak-hickory-pine and oak-hickory forests. Post oak, Shumard oak, southern red oak, water oak, sweetgum, loblolly pine, shortleaf pine.
Land Use and Land Cover	Mixed forest, deciduous forest, pine plantations, pasture, livestock production.

35e Southern Tertiary Uplands



The Southern Tertiary Uplands ecoregion of Texas and Louisiana generally covers the remainder of longleaf pine range north of the Flatwoods (35f). The region of Tertiary geology is more hilly and dissected than the Flatwoods (35f) to the south, and soils (Alfisols and Ultisols) are generally better drained over the more permeable sediments. The Pliocene-age to Eocene-age geology contains a variety of siltstones, sandstones, and calcareous and acidic clays.

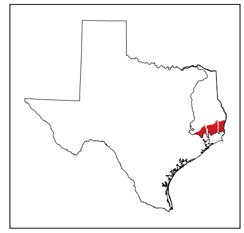
Historical vegetation was dominated by longleaf pine-bluestem woodlands (*Pinus palustris-Schizachyrium* spp. and *Andropogon* spp.), but a variety of forest types were present, including shortleaf pine-hardwood forests (*Pinus echinata-Quercus* spp.), mixed hardwood-loblolly pine (*Pinus taeda*) forests, and hardwood-dominated forests along streams. On more mesic sites, some American beech (*Fagus grandifolia*) or magnolia-beech-loblolly pine forests occurred. Some sandstone outcrops of the Catahoula Formation have distinctive barrens or glades in Texas and Louisiana that contain several rare species (Bezanson 2000). Forested seeps in sand hills support acid bog species including southern sweetbay (*Magnolia virginiana*), hollies or gallbery (*Ilex* spp.), wax-myrtles (*Morella* spp.), insectivorous plants, orchids, and wild azalea (*Rhododendron* spp.); this vegetation becomes more extensive in the Flatwoods (35f). Currently, the ecoregion in Texas and Louisiana has more pine forest than the oak-pine and pasture land cover more typical to the north in Ecoregion 35a. Large parts of the region are public National Forest land.

Many parts of the historic longleaf pine forest on rolling sandy uplands of Ecoregion 35 in Texas were characterized by a species-rich herbaceous understory with bluestem grasses (*Andropogon* and *Schizachyrium* spp.) and a variety of forbs and shrubs.
Photo: R.E. Rosiere, Tarleton State University

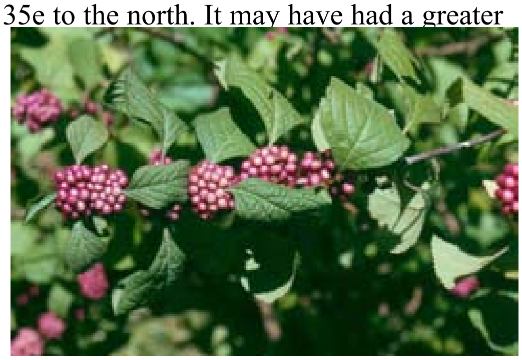
The Louisiana pine snake is one of the rarest snakes in North America and is State-listed as threatened in Texas. Its historical range included longleaf pine woodlands on deep sandy uplands of Ecoregion 35 in west-central Lousiana and eastern Texas. In Texas, it is found mostly in the southern portion of Sabine and Angelina National Forests. The snakes depend on pocket gophers for food and use their burrows for shelter. *Photo: Daniel Saenz*

Level IV Ecoregion	**35e. Southern Tertiary Uplands**
Area (sq. mi.)	7667
Physiography	Dissected irregular plains with some low, rolling hills; low to moderate gradient streams with sandy and silty substrates.
Elevation / Local Relief (feet)	90-550 / 100-300
Surficial Geology; Bedrock Geology	Quaternary clay and sand decomposition residuum; Pliocene, Miocene, Oligocene, and Eocene sand, silt, and clay of various induration.
Soil Order (Great Groups)	Alfisols (Glossudalfs, Hapludalfs, Natraqualfs, Paleudalfs, Glossaqualfs) Ultisols (Paleudults, Hapludults),
Common Soil Series	Keltys, Moswell, Diboll, Kurth, Etoile, Pinetucky, Doucette, Shankler, Woodville, Colita, Oakhurst, Kirvin, Rayburn
Soil Temperature / Soil Moisture Regimes	Thermic / Udic, some Aquic
Mean Annual Precipitation (in.)	44-54
Mean Annual Frost Free Days	230-250
Mean Temperature (F) (Jan. min/max; July min/max)	38/59; 71/94
Vegetation	A diversity of natural communities including upland longleaf pine woodlands (historically dominant), longleaf pine savannas, hardwood slope forests, bogs with pitcher plants and orchids, and sandstone glades with pines and drought tolerant oaks.
Land Use and Land Cover	Mixed forest, evergreen forest, deciduous forest, pine plantations, public land (Sabine, Angelina, Davy Crockett and Sam Houston National Forests), timber production, some pasture and livestock production, recreation, wildlife habitat.

35f Flatwoods



Mostly flat to gently sloping, the Flatwoods ecoregion occurs on Pleistocene sediments in southeast Texas and southwest Louisiana. Soils on the sands in the Pleistocene Lissie Formation are generally more clayey, poorly drained and more acidic than on the Miocene Willis Sands to the north in Ecoregion 35e. Soils are less clayey than in Ecoregion 34a to the south. Some flatwood landscapes are characterized by pimple mounds, small hillocks that are abundant across the flats. The ecoregion boundaries are similar to the USDA NRCS Major Land Resource Area 152B, and somewhat similar to the Big Thicket ecological area defined by McLeod (1971). The northern boundary is generally along the Hockley Scarp or the division between Pleistocene and older Pliocene/Miocene formations to the north. This region is warmer, wetter, flatter, less dissected, and lower in elevation than 35a and 35e to the north. It may have had a greater presettlement fire frequency than the northern regions (Frost 1995). Streams are low gradient and sluggish. Almost all of the Big Thicket National Preserve is within this region. The area has a long history of modification, particularly by the lumber, railroad, and oil and gas industries that contributed to boom and bust cycles of development and occupance (Gunter 1993).



American beautyberry (*Callicarpa americana*) is a deciduous understory shrub found in the Flatwoods (35f) and other parts of Ecoregion 35. The seeds are a favorite of birds and other wildlife.
Photo: R.E. Rosiere, Tarleton State University

Longleaf pine (*Pinus palustris*) flatwoods and savannas were once typical of this ecoregion, but it had a diversity of mixed pine-hardwood forest types with a mosaic of well-drained and poorly drained communities. Longleaf pine was found in a variety of habitats, including dry uplands, mesic uplands, and wet flatwoods (Bridges and Orzell 1989, Harcombe *et al*., 1993). The longleaf pine often occurred over a great diversity of herbaceous species, with the structure and composition varying from the more open forests of the wet savannas to the more closed forests of the dry flatwoods. The upland pine community was mostly longleaf pine along with oaks and other hardwoods that varied in composition due to a gradient of conditions. Poorly drained flat uplands had areas of pine savannas and small prairies with species-rich ground layers. Savanna wetlands on the Montgomery Formation and prairie areas on the Beaumont Formation were most likely larger in the Flatwoods than in ecoregions 35e and 35a to the north. The pine wetland savannas had scattered longleaf pine (*Pinus palustris*) along with with shrubs of sweetbay (*Magnolia virginiana*), wax myrtle (*Morella* spp.), titi (*Cyrilla racemiflora*), and holly (*Ilex* spp.), and a diverse herbaceous layer of grasses, sedges, and, in some places, insectivorous plants and orchids (Harcombe *et al*., 1993, Bezanson 2000). These wetland savannas are one of the rarest habitat types in Texas with only a few small fragments receiving any protected status. Other similar sites have been greatly modified or have become overgrown and less diverse.

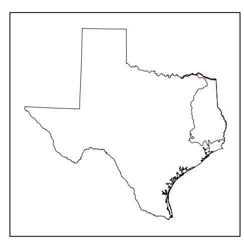
The beech-magnolia association (*Fagus grandifolia - Magnolia grandiflora*), sometimes cited as the climatic climax for this region, was probably not extensive, occurring in narrow areas along some streams and mesic slopes, and it contained a higher percentage of pine than in similar regions to the east (Schafale and Harcombe 1983). In the Flatwoods

Tupelo-red maple forest in a Big Thicket lowland of Ecoregion 35f. *Photo: National Park Service*

(35f), there is less beech (*Fagus grandifolia*) and more swamp chestnut oak (*Quercus michauxii*) and laurel oak (*Q. laurifolia*) compared to Ecoregion 35e (McLeod 1971, Bezanson 2000). Small streams that originate in Ecoregion 35e, however, may carry beech into the Flatwoods (35f). On steeper slopes, along streams and other areas where fire was less frequent, forests contained loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*), white oak (*Quercus alba*), southern red oak (*Q. falcata*), willow oak (*Q. phellos*), blackgum (*Nyssa sylvatica*), and hollies (*Ilex* spp.).

Level IV Ecoregion	**35f. Flatwoods**
Area (sq. mi.)	3345
Physiography	Flat plains, some irregular plains; low gradient streams with sandy and silty substrates; small, undrained depressions and pimple mounds; a few surface mounds from salt domes.
Elevation / Local Relief (feet)	15-250 / 10-100
Surficial Geology; Bedrock Geology	Quaternary (Middle Pleistocene and some Late Pleistocene) sand, silt, clay, and gravel; salt domes
Soil Order (Great Groups)	Ultisols (Paleudults), Alfisols (Paleudalfs, Glossaqualfs, Glossudalfs, Vermaqualfs)
Common Soil Series	Kirbyville, Otanya, Dallardsville, Evadale, Segno, Boy, Waller, Sorter, Splendora, Gist
Soil Temperature / Soil Moisture Regimes	Thermic / Udic, Aquic
Mean Annual Precipitation (in.)	47-58
Mean Annual Frost Free Days	240-260
Mean Temperature (F) (Jan. min/max; July min/max)	40/61; 73/92
Vegetation	Historically, longleaf pine flatwoods and savannas with bluestem grasses and other herbaceous species in understory. Some mixed pine-hardwood forests including trees of longleaf pine, loblolly pine, sweetgum, white oak, southern red oak, willow oak, swamp chestnut oak, blackgum, hickory, southern magnolia, and an understory of holly, yaupon, sweetbay, wax myrtle, sumac, wild grape, and American beautyberry. Acidic drainages with sweetbay, blackgum, red maple, willow oak, and laurel oak
Land Use and Land Cover	Mixed forest, evergeen forest, deciduous forest, forested wetlands, timber production, some pasture and cattle production, oil and gas production, some public land (Big Thicket National Preserve).

35g Red River Bottomlands



The Red River Bottomlands contain the floodplain and low terraces of the Red River within Ecoregion 35. The region occurs in Texas, Oklahoma, Arkansas, and Louisiana, and includes the highly meandering main channel of the Red River, oxbow lakes, meander scars, ridges, and backswamps. The Holocene alluvium associated with Red River deposition is of variable texture and permeability. The lithology contrasts with the Pleistocene terrace deposits of Ecoregion 35c, and the Tertiary sediments of Ecoregion 35a.

Natural vegetation of the bottomland hardwood forests included trees such as water oak (*Quercus nigra*), sweetgum (*Liquidambar styraciflua*), willow oak (*Q. phellos*), southern red oak (*Q. falcata*), eastern red cedar (*Juniperus virginianus*), blackgum (*Nyssa sylvatica*), blackjack oak (*Q. marilandica*), overcup oak (*Q. lyrata*), river birch (*Betula nigra*), red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), and American elm (*Ulmus americana*). There are also some plant distribution differences between the floodplains of Ecoregion 35g and 35b.

Currently in Ecoregion 35g, most of its natural woodland has been cleared for cropland and improved pasture, although some woodland still occurs in very poorly drained and frequently flooded areas. The broad, nearly level bottomlands are often dominated by agriculture, with more cropland than other floodplains of Ecoregion 35. Soybeans, sorghum, wheat, and cotton are principal crops in the Texas portion of the region. The Red River carries high silt loads and is almost continuously turbid compared to other rivers of Ecoregion 35.

Level IV Ecoregion	**35g. Red River Bottomlands**
Area (sq. mi.)	305
Physiography	Broad, level to nearly level floodplains and low terraces, with oxbow lakes, meander scars, backswamps, sloughs, and natural and artificial levees.
Elevation / Local Relief (feet)	270-500 / 10-40
Surficial Geology; Bedrock Geology	Quaternary (Holocene) alluvial clay, silt, and sand.
Soil Order (Great Groups)	Entisols (Udifluvents), Vertisols (Hapluderts), Inceptisols (Eutrudepts), Mollisols (Argiudolls)
Common Soil Series	Severn, Billyhaw, Oklared, Moreland, Redlake, Caspiana
Soil Temperature / Soil Moisture Regimes	Thermic / Udic, some Aquic
Mean Annual Precipitation (in.)	42-48
Mean Annual Frost Free Days	220-230
Mean Temperature (F) (Jan. min/max; July min/max)	30/52; 72/93
Potential Natural Vegetation	Floodplain forest with water oak, willow oak, blackjack oak, overcup oak, southern red oak,sweetgum, blackgum, river birch, red maple, green ash, American elm, cottonwood, hackberry, pecan.
Land Use and Land Cover	Cropland with soybeans, grain sorghum, wheat, and cotton; pastureland, some deciduous forest.

APPLICATIONS AND CONSIDERATIONS IN USE OF THE ECOREGION FRAMEWORK

Ecoregion frameworks have been used in many different applications in a variety of subjects. One review of the literature (Brewer 1999) tallied uses of EPA ecoregions in categories such as agricultural science, biodiversity conservation and preservation, climate and atmospheric studies, ecoregion delineation and theory, entomology, fauna (terrestrial and aquatic), forestry, lake water quality, recreation management, remote sensing, statistical theory, stream water quality, and wetlands. The number of peer-reviewed publications produced per year dealing with ecoregion issues and uses increased greatly in recent years, from less than five in each year of the late 1980's, to about fifteen in the late 1990's, and to more than fifty in 2000 (Loveland and Merchant 2004). As digital data users now have easier access to a variety of spatial frameworks, sometimes these frameworks may be taken from the shelf with little understanding of their nature and used in ways that are beyond the purpose for which they were designed. Some issues associated with use of the ecoregion frameworks are discussed in the following sections.

REGIONAL REFERENCE CONDITION AND STREAM REFERENCE SITES

The interest of the TCEQ in the development of the ecoregion framework was driven in part by applications to water quality assessments. Waterbodies reflect the lands they drain, and similar lands (or regions) tend to produce similar waterbodies. Regional reference conditions are an important aspect to these applications. Our Texas ecoregion project focused primarily on developing the spatial framework, and only indirectly touched on the issue of regional stream reference conditions. As the TCEQ has been dealing with regional reference conditions for many years (Twidwell and Davis 1989, Bayer *et al.*, 1992, Linam *et al.*, 2002) and has been well ahead of many states in these assessments, selection of candidate reference sites was not undertaken in this project. This section, however, offers some background on the reference condition concept, and is intended to help illustrate some of the complexities of the issue.

To develop aquatic biological criteria and evaluate impaired water bodies, it is important to establish reference conditions that are suitable for comparison. A key function of an ecoregion framework is its use in selecting regional reference sites and facilitating the assessment of regionally attainable conditions. Ideally, control sites for estimating attainable conditions should be as minimally disturbed as possible yet representative of the streams for which they are to be controls (Hughes *et al.*, 1986). Although no two streams are alike, we hypothesize that streams within an ecoregion will have generally similar characteristics as compared to all streams within a state, major basin, or larger area. If an ecoregion has a variety of stream types, it is also be important to classify these types and to consider groundwater influences, as these may tend to mask regional differences. Watershed size or area, geology, gradient, etc., are also important elements to consider. Additional classifications or hierarchical levels may be needed to sort out differing stream segments and habitat types.

General guidelines for selecting reference sites have been given in Hughes *et al.*, (1986), Gallant *et al.*, (1989), and Hughes (1995). The process continues to be refined, however, as experience is gained in current and ongoing ecoregion/reference site projects, as well as in EPA's Environmental Monitoring and Assessment Program (EMAP) projects. In EMAP, indicator or index scores for each sampled site need to be evaluated against some measure of reference condition. EMAP's approach is generally to regard reference condition as being defined by a range of indicator or index values (i.e., a distribution), and to select various parameters in that distribution as thresholds for classifying the condition of individual sites.

The term "reference condition" has different definitions and categories, incorporating ideas such as "minimally disturbed condition", "historical condition", "least disturbed condition", and "best attainable condition" (Stoddard *et al.*, 2006). "Minimally disturbed condition" can be considered the condition of streams before significant human disturbance. Some people are tempted to describe this condition as "natural," "pristine" or "undisturbed." It must be recognized, however, that some natural disturbance has always occurred, and should be included in the assessment of the variability present in reference condition (hence, the term "minimally" rather than "un-" disturbed). Once established, minimally disturbed condition is a rather invariant definition of reference condition. It can serve as a benchmark against which all other definitions of reference condition can be compared. Unfortunately, for most regions of the country, the science behind a "minimally disturbed condition" is not well-developed.

"Least disturbed condition" is equivalent to the best available conditions given today's state of the landscape. It is defined ideally by a set of strict criteria to which all reference sites must adhere. Typical criteria might include a minimal amount of agricultural landuse in the watershed, a fully-functional riparian forest, and/or water quality relatively unaffected (or least affected) by human use of the watershed. The specifics of these criteria will vary across the country, as ecological characteristics of the landscape, and human use of the landscape, vary. Because the condition of the environment changes over time, as either degradation or restoration of the landscape proceeds, least disturbed condition is not an invariant measure of reference condition. As the ecological condition of the very best available sites changes through time, so will the measure of least disturbed condition.

"Best attainable condition" can be equivalent to the ecological condition of "least disturbed" sites where the best possible management practices are in use, minimizing the impact of inevitable landuse. It is a somewhat theoretical condition predicted by the convergence of management goals, best available technology, prevailing use of the landscape, and public commitment to achieving environmental goals. The upper and lower limits on "best attainable condition" are related to the previous two definitions of reference condition. Given population and land use increases, it is unlikely that it will ever be as high in quality as was the "minimally disturbed condition". Best attainable condition may also be higher or lower in quality than current "least disturbed condition". As is the case with least disturbed condition, best attainable condition is not invariant, as all of the factors influencing it (e.g., available technology, public commitment) will vary over time.

To illustrate some of these concepts, Figure 3 (p. 97) shows stream quality in three different ecoregions. The historic box, similar to the minimally disturbed condition, refers to quality before extensive human disturbance, the least disturbed and disturbed boxes refer to stream conditions today, and the attainable is the condition or level of quality as it might be with the application of various management strategies (Bryce *et al.*, 1999). The extent and magnitude of the regional disturbance and the difficulty in affecting change increase between ecoregions A and C. Ecoregion A might be characterized by low human population levels and few watershed stressors, with many least-disturbed streams resembling historic conditions. With minimal management efforts, it might be possible for attainable stream quality to approach least-disturbed or historic reference conditions. In ecoregion B, minimally disturbed reference areas are more difficult to find, and more management effort and expense would be required to improve disturbed sites. Economic and political realities would probably dictate that the attainable condition of streams will fall short of least-disturbed conditions. In ecoregion C, disturbance levels are so high that existing reference sites differ little in quality from disturbed sites. Other approaches may be needed to establish reference conditions in such a region. In order to achieve meaningful improvements in stream quality, the goals for attainable quality may have to exceed the current least-disturbed sites (Bryce *et al.*, 1999).

State agencies often use a combination of best professional judgment, criteria-based, and "best biological data" approaches to help define reference condition. Because of practical limitations, reference condition is often heavily based on a set of "least disturbed" stream sites. However, a reference condition approach based on today's best sites creates a moving target, as reference benchmarks will change with time. In addition, a "least disturbed condition" approach may institutionalize acceptance of the level of degradation that has already occurred in the environment. Ultimately, an understanding of the "best attainable condition" can only be realized after good estimates of both "least disturbed" and "minimally disturbed" conditions have been created.

With this background, a typical process of selecting regional candidate reference sites that has been used in some states is outlined below:

1). Level III and level IV ecoregions are defined within which there is apparent homogeneity in a combination

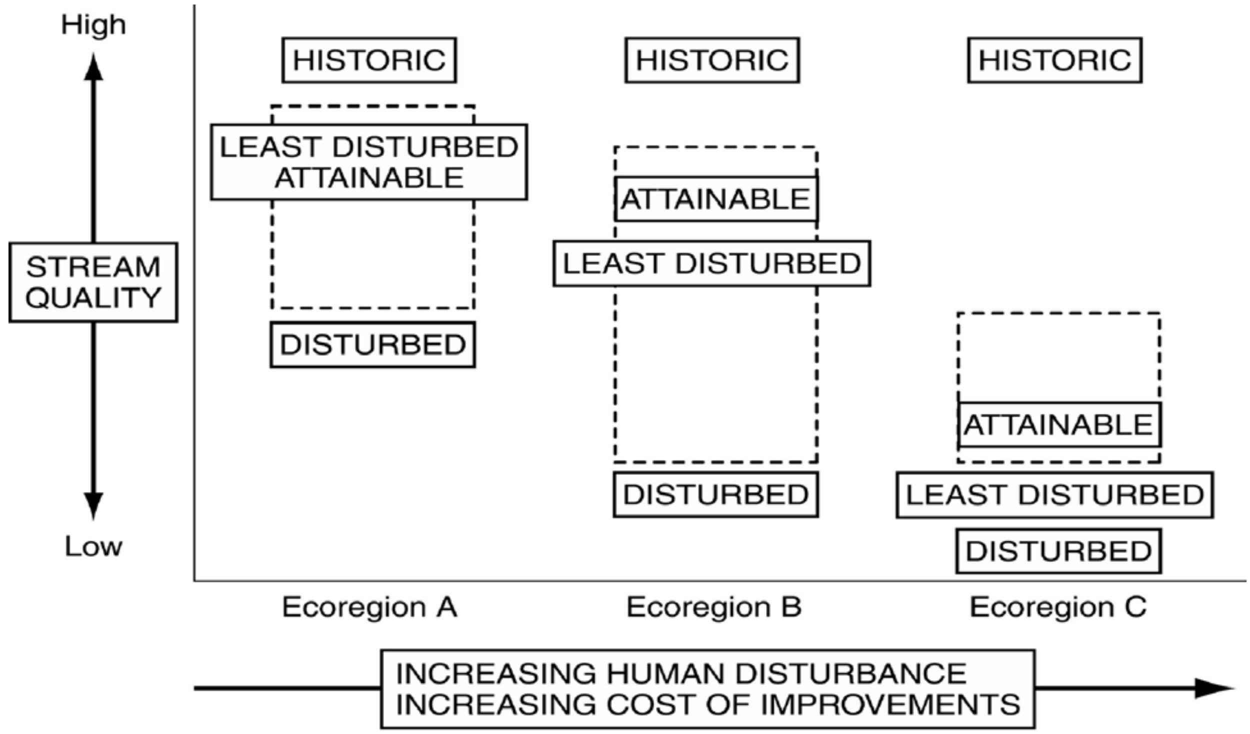


Figure 3. Variations in stream quality as it was historically, as it is presently at disturbed and least-disturbed sites, and as it might be attained in three hypothetical ecoregions of different disturbance levels. The dashed boxes represent the range in attainability with various levels of effort (Bryce *et al*., 1999).

of geographic characteristics that are likely to be associated with resource quality, quantity, and types of stresses and biological responses.

2). Disturbances are generally characterized (such as areal or nonpoint source pollution, and local or point sources of pollution) in each ecoregion and geographic characteristics are analyzed to better understand representative or typical conditions. What comprises disturbance may vary considerably from one region to another. In regions with nutrient-rich soils, poor drainage, but great agricultural potential, all streams may have been channelized at one time or another, and all watersheds may have a high percentage of agricultural land use. Reference streams in such a region comprise those with few if any point sources, lack of recent channelization activity, and riparian zones with a relatively large percentage of woody vegetation. Regions with nutrient-poor soils, lacking agricultural potential, and containing a different set of identifying landscape characteristics such as steep forested mountains and cool, clear, high-gradient streams, are likely to be affected by different types of stressors. Relative lack of silvicultural activities, mining, or heavy recreational usage may be important criteria in selecting least-disturbed, representative reference streams in these regions. It is important to consider not only upstream characteristics, but also downstream disturbances and processes (Pringle 1997).

3). Sets of stream sites are chosen, with watersheds that appear relatively undisturbed and are completely within the ecoregion. The area of the surface watersheds are measured or approximated. A list of candidate reference sites can be compiled from suggestions made by personnel from various state and federal agencies within a state, as well as from examination of maps to find streams that appear to be relatively undisturbed yet representative of the ecoregion. The actual number of sites/watersheds selected is a function of the apparent homogeneity or heterogeneity of the region, the size of the region, hydrologic characteristics, and simply how many stream sites/watersheds are available for selection. The point of diminishing returns, regarding the number of streams necessary to address regional attainable quality and within-region variability, may be reached with only a few sites in ecoregions that are relatively homogeneous and/or small. Complex regions, on the other hand, are likely to require a large number of sites. Another consideration is access, that is, do roads or trails allow the biologists to get near the stream section for sampling? Although sampling locations should be as far from bridges as possible, access across private property or other cultural and natural hazards can reduce the number of candidate sites for consideration as final reference sites to be sampled.

Disturbance and typicalness are interpreted from information shown on 1:250,000-scale, 1:100,000-scale, or larger scale USGS topographic maps, land use and land cover maps, county soil surveys, aerial imagery, and local expert judgement. The existence of populated areas, industry, agricultural land use, forestry, mining, fish hatcheries, transportation routes, etc., are interpreted from mapped information and other sources. Lists of the candidate sites can be developed that include the ecoregion, site number, stream name and location, watershed area, major basin, county, map names, and additional comments. The spatial distribution of these candidate sites can be mapped to show areas that might be over- or under-represented.

4). The list of sites is reviewed by state personnel, compared with existing data, and sites and watersheds are inspected during ground reconnaissance. These field inspections also evaluate the usefulness of the ecoregions, the characteristics that comprise reference sites in each ecoregion, the range of characteristics and types of disturbances in each region, and the way in which site characteristics and stream types vary between regions. In this process, sites found to be unsuitable are dropped (because of disturbances not apparent on the maps or due to anomalous situations) and other sites can be added.

5) Some aerial reconnaissance is often conducted in these types of projects to identify disturbances not observable from the ground, to get a better sense for the spatial patterns of disturbances and geographic characteristics in each region, and to photograph typical characteristics, site locations, or disturbances for use in briefings and reports.

It should be remembered that all reference sites have some level of disturbance. There are no pristine, unimpacted watersheds in Texas, or, considering atmospheric deposition of contaminants, anywhere else in the U.S. Least-impacted sites are searched for, but levels of impact are relative on a regional basis. The characteristics of appropriate reference sites will be different in different ecoregions and for different waterbody and habitat types. It is desirable, therefore, to have a large number of candidate reference sites for each region to help define the different types of streams, to illustrate the natural variability within similar stream types, and to clarify the factors that characterize the best sites from factors present in the lower quality sites.

A set of current reference stream sites should be just one part in determining reference stream condition. Other aids such as historical data, laboratory data, quantitative models, and best professional judgement can also be helpful (Hughes 1995, Stoddard *et al*., 2006). If combined with probability samples, such as an EMAP-style of survey, the selection of least-disturbed reference sites can be evaluated against the condition of the entire population of streams in the region, inferred from the probability sites.

REGIONAL WATER QUALITY STANDARDS AND GOALS

As mentioned briefly in the Introduction of this document, ecoregions have had many applications relative to water quality. After ecoregions are delineated, and sets of reference sites are established within that spatial framework, regional criteria for chemical, biological, and physical variables can be assessed and developed. The process of developing water quality criteria and standards is enhanced by estimates of regional expectations that depend on the use of reference sites and proper spatial frameworks.

Many U.S. states, including some southern examples noted here, have applied such a regional approach.

Mississippi's biological monitoring includes ecoregion-based assessment criteria for Section 303(d) listing purposes. Kentucky has used ecoregional reference data to establish criteria for outstanding state resource waters. Arkansas has used reference watersheds within ecoregions to set seasonal dissolved oxygen criteria and standards that reflect regional potentials. In Florida, the ecoregional approach and reference site data have been used in a variety of programs of the Florida Department of Environmental Protection, including ambient monitoring, TMDL monitoring, facilities permitting programs, waste management programs, springs sampling program, basin assessment program, and water quality standards program. Florida has used Level IV ecoregions as the spatial basis for developing and implementing the Stream Condition Index, a macroinvertebrate monitoring and assessment tool, and the Lake Vegetation Index, a lake macrophyte tool (Ellen McCarron, FL DEP, personal communication).

In Tennessee, the Division of Water Pollution Control has developed ecoregion-based numeric interpretations of their narrative biocriteria and nutrient criteria for streams. That agency has also been evaluating habitat at stream sites using a standardized numeric assessment approach for about the past ten years. They can assess the status of each site relative to it's regional potential, in part by using reference sites that are least-impacted but representative of streams in each of 25 Level IV ecological regions across the state. Habitat goals in each region are based on comparison to median reference values. A habitat score comparable to 75% or greater of the reference condition would be considered the quality of habitat most likely to maintain biological integrity. The use of regional habitat guidance for interpretation of narrative criterion in conjunction with numeric biocriteria helps standardize Tennessee's stream assessments and can help account for regional differences in aquatic communities (Arnwine and Denton 2001).

Multimetric indices, such as the Index of Biotic Integrity (IBI), are increasingly used to evaluate the ecological condition of aquatic ecosystems. Many states use IBIs based on fish or macroinvertebrate assemblages to evaluate whether water bodies meet their designated aquatic life uses under their water quality standards. Despite the diversity of streams in Texas, a statewide IBI was often applied across the state, along with water quality, benthic macroinvertebrate, and habitat data, to set aquatic life uses in streams. Linam *et al*., (2002) demonstrated that the statewide IBI for Texas did not consider the important regional differences and it produced lower scores and aquatic life uses. Using a single index over such a large land area ignored the diversity of landforms, soils, vegetation, climatic conditions, and zoogeographic factors. They examined least-disturbed reference streams within ecoregions to better consider these natural differences and the regional variation in the integrity of fish assemblages.

Recently, Whittier et al., (2007) analyzed fish and amphibian species data in conjunction with chemical, physical, and landscape indicators of human disturbance across 12 western states of the U.S. to develop site disturbance scores and species and assemblage tolerance values. With data collected at 1,001 stream and river sites sampled from the US EPA's Environmental Monitoring and Assessment Program, they used principal components analyses to create synthetic disturbance variables for water nutrients, site-scale physical habitat, catchment-scale land use, and overall human disturbance. They used tolerance values and relative abundances of species at each site to calculate an assemblage tolerance index score for each site. There were distinct regional differences in the disturbance scores and in the assemblage tolerance index scores between ecoregions lumped as "mountains", "xeric", and "plains". Regional differences in these scores were also distinct between many of the 10 ecoregions (aggregated from Level III) that were used in the West-wide study (Thomas Whittier, personal communication). Such work can help to regionalize IBIs and bioassessment.

The manner in which water quality monitoring results are displayed and presented can greatly affect how patterns, problems, and associations are perceived. Presentation of results by ecoregions, rather than by political units or basins, can highlight important patterns in data and help influence environmental management (Stoddard 2004, Griffith *et al*., 1999). The use of political, watershed, ecoregion, or other hybrid unit frameworks for extrapolating and reporting data requires careful consideration. Omernik (2003) clarified the difference between watersheds and hydrological units in Texas, and demonstrated some of the implications of the misuse of hydrologic units for water quality assessments. Hydrologic unit maps are not maps of watersheds, as is commonly believed. Typically, about one-half or more of hydrologic units are not true watersheds (Figure 4). Omernik (2003) illustrated how four contiguous 8-digit hydrologic units located in the central portion of Ecoregions 32 and 33 can have drastically different water quality characteristics and different drainage areas.

A more effective way of showing regional patterns in environmental resources is by using data from true watersheds representative of the different ecological regions. The quality of water at any point on a stream does usually reflect the aggregate of characteristics upgradient from that point, ie., its watershed. It is important to recognize, however, that basins, watersheds, and hydrologic units, which tend to cross ecoregions, seldom depict areas of similar combinations of characteristics that are associated with water quality (Omernik and Bailey, 1997; Bryce *et al.,* 1999; Griffith *et al.,* 1999). The areas with similar patterns of physiography, geology, soils, climate, vegetation, land use, etc., that influence water quality are the ecological regions. Only data representative of the region from which the data were collected should be used to develop maps illustrating patterns in stream quality. Watershed and ecoregion frameworks are complementary. Watersheds are areas for determining the land/water associations, and ecoregions provide the framework for extrapolating and reporting this information.

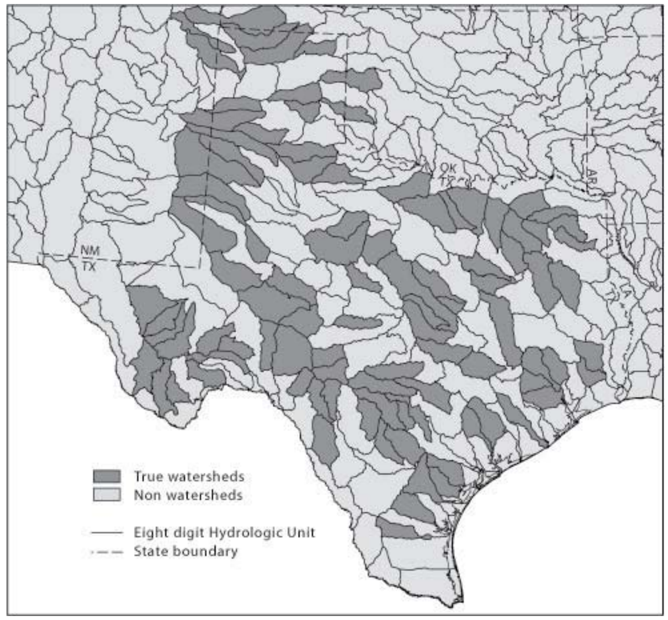


Figure 4. Eight-Digit Hydrologic Units in Texas

A Discussion About Boundaries

Ecoregion boundaries are often portrayed by a single line, but in reality they are transition zones of varying widths. In some areas, the change is distinct and abrupt, in other areas, the boundary is fuzzy and more difficult to determine. Fuzzy boundaries are areas of uncertainty or where there may be a heterogeneous mosaic of characteristics from each of the adjacent areas.

One problem that arises in delineating a hierarchy of ecoregions is that the boundaries are not precise and the regions at the different levels of detail do not necessarily nest perfectly. In such mapping, we represent the boundaries as lines, and force a nested hierarchy of regions. Some boundaries are shown as being smooth and general, while others are finely crenulated, but almost always, the boundaries are represented as lines. In fact, ecoregion boundaries are *areas*, rather than lines, where the predominant characteristics of one region meet the predominant characteristics of another (Omernik 2004). On a map of Level I ecological regions of North America (Commission for Environmental Cooperation 1997), the boundary between the Great Plains and the Eastern Temperate Forests is represented by a crenulated line, reflecting boundaries of smaller and more detailed ecological regions at lower hierarchical levels (Figure 5, p. 101). The Great Plains ecological region, generally a drier, grass-covered region of rolling plains, is distinguished from the Eastern Temperate Forests ecological region, a mostly forested, mosaic of plains, hills, and low mountains. The broad area where the characteristics of each of these ecological regions meet covers entire states (Lewis 1966, Rossum and Lavin 2000) (Figure 6, p. 101). Entire Level III ecoregions, including the Cross Timbers (29), the Central Irregular Plains (40) of eastern Kansas and western and northern Missouri, and the Central Corn Belt Plains (54) of northern and central Illinois occupy the fuzzy boundary between the Level I ecoregions.

Another issue is defining boundaries between regions based on the mosaic of characteristics or delineating them based on only one factor. There is a strong tendency for people mapping ecological regions to base each boundary on a single determining characteristic, and an even stronger tendency to choose that characteristic

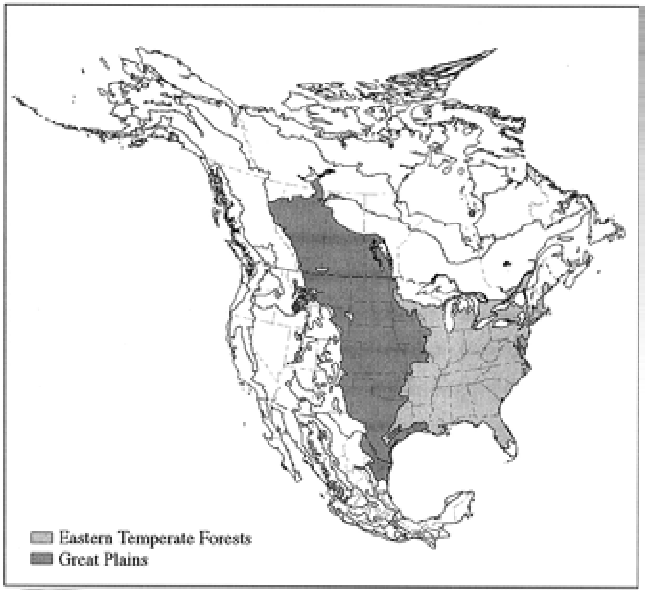


Figure 5. North American Great Plains and Eastern Temperate Forests Level 1 Ecoregions (Omernik 2004).

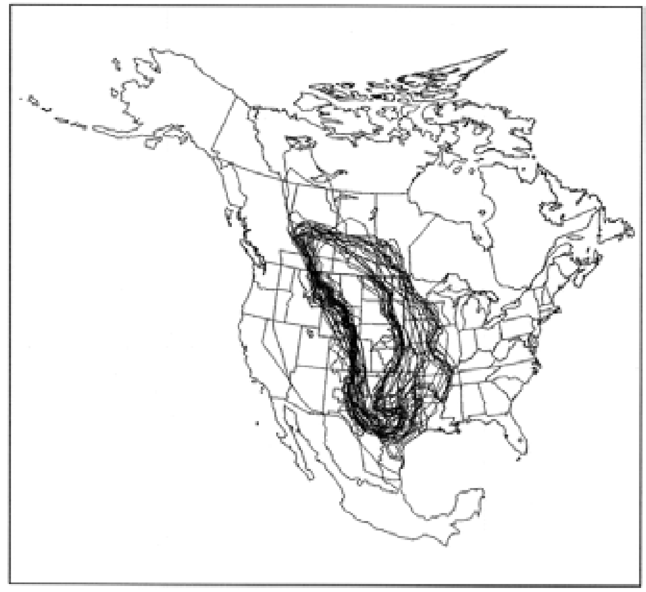


Figure 6. Fifty Versions of the Great Plains (Rossum and Lavin 2000).

based on one's area of specialization or background. Each distinguishing characteristic (including geology, physiography, climate, and soils) is important in determining the mosaic of terrestrial and aquatic plants and animals in each ecoregion. The problem is that if the boundary is based mainly on geology it will be different than if it is based primarily on vegetation, different yet again if it is based on soils, and different from all of these if it is based mainly on physiography. When a boundary is based on one characteristic, it is usually done, whether consciously or subconsciously, with a desire to have the region serve a particular purpose. As a result, many mapped geographic frameworks labeled ecoregions were in fact compiled to address specific purposes (Omernik 2004).

It is important to observe that as sharp as the differences appear along some boundaries of ecoregions, such as that between the High Plains (25) and the Southwestern Tablelands (26), the ecological boundaries are not precise and do not always follow specific characteristics. Similar to many ecoregion boundaries, this one comprises a transition area that varies in width from one place to another. Although there is a common tendency to draw the ecoregion boundary between the two regions along one characteristic, in this case, the sharpest topographic break or apparent edge of the cliff, many ecological characteristics cross that boundary. Even along seemingly sharp boundaries such as these, there are transitions. Birds of prey, for example, may be more likely to nest in the more rugged portions of the Southwestern Tablelands (26) but depend on rodents found on the plains within the High Plains (25). The break in vegetation from cropland in the High Plains to juniper, grasses and shrubs of the Southwestern Tablelands does not occur at the edge of the cliff (where it is sharp) but often a short distance beyond on the more level land above the cliff reflecting the gradation in soil type and depth and the effect of the aquifer along the border. As is the case in mapping any ecoregion boundary, it is important to consider all aspects of ecosystems, biotic, abiotic, terrestrial and aquatic.

CONCLUSIONS AND RECOMMENDATIONS

This general ecoregion framework developed for Texas is intended to be a useful framework for environmental resource assessment and management. It is a formalization of some commonly recognized regions in Texas and has similarities to other frameworks of the area. The interest in such a multi-purpose regional framework should be in its potential usefulness, rather than the absolute truth of boundary line placement on the ground, or the correspondence of any one ecological component. Modifications of the framework might be warranted, however, as more information and understanding is gained. Our intent was to make the ecoregion framework compatible and consistent with the US EPA ecoregion framework in surrounding states. This consistency allows biologists, ecologists, and resource managers to share and compare environmental data across political boundaries. We encourage TCEQ and other Texas agencies and organizations to consider the analysis of compatible data from these neighboring states, as well as from Mexico, that share ecological regions to help clarify regional conditions and characteristics.

The hypothesis that a regional framework and sets of regional reference sites can give managers and scientists a better understanding of the spatial variations in the chemical, physical, and biological components of water bodies in Texas is intuitive, but must continue to be tested and developed. We believe that these tools can help build a foundation for assessing attainable conditions. Assessments of stream chemistry and biota from sampled reference sites in Texas and from adjacent states generally do indicate some distinct regional differences, either at level III, level IV, or some combination of regions. Significant time and effort will be required for the collection and creative analysis of data to develop biological criteria and regional water quality standards, and to more fully understand attainable water conditions. The process of selecting regional reference sites requires considerable time, conscientious map analysis, and thorough field reconnaissance. Enough reference sites must be selected to account for the natural variability within the ecoregions. If the selected reference sites show a high range of variability, additional stratification may be necessary. Developing or modifying multimetric indices for fish, macroinvertebrate, and habitat evaluations at reference sites also requires significant time and experimentation. Part of the challenge will be to analyze and integrate environmental data in meaningful ways, with the desirable longer-term goal of developing potential indexes of ecological integrity to assess more holistically the health of Texas ecosystems.

A goal of most state water quality agencies is to reclaim polluted waters, to prevent future pollution, and to plan for the future use of the waters of the state. The ecoregion framework is one tool to help implement that goal and develop water quality criteria that will protect designated uses of water bodies. It is a tool that allows for the recognition of natural differences in different areas of the state, and, together with the reference sites, clarifies the regional definition of water quality. Avenues for maintaining or even improving the quality of identified reference streams should be explored, since these are some of the best quality streams remaining.

Water cannot be viewed in isolation from its watershed and that is why holistic perspectives are important. Although watersheds are useful study units for understanding the quantity and quality of water at any given point on a stream, it must be recognized that the spatial distribution of factors that affect water quantity and quality (such as vegetation, land cover, soils, geology, etc.), does not coincide with topographic watershed boundaries (Omernik and Griffith 1991; Omernik and Bailey 1997; Griffith *et al.*, 1999, Omernik 2003). Because there are an infinite number of points on a stream from which watersheds can be defined, watershed management or ecosystem management requires a spatial framework that considers the regional tolerances and capacities of landscapes. That is why the ecoregion framework can complement a watershed management approach. When ecoregions and watersheds are used together correctly, they provide a powerful mechanism for developing resource management strategies.

While the ecoregion framework may be useful for developing regionalized chemical and biological criteria for streams, other uses of such a framework in different parts of the country have included: lake classification and development of eutrophication criteria; development of nonpoint-source pollution management goals; reporting on the status or attainment of water quality; assisting programs addressing wetland classification and management; analyzing types and distributions of protected areas or ecological reserves; and developing regional indicators of forest disturbance and biodiversity. Scott *et al.*, (1993) suggested that identifying management areas for biological diversity requires an analysis of the distribution of biodiversity from the perspective of ecoregions rather than political units.

Improving the quality of aquatic and terrestrial ecosystems in Texas will require the cooperation and coordination of federal, state, and local interests. It is our hope that a consistent hierarchical ecoregion framework will help improve communication and assessment within and among different agencies. Although pollution of water bodies, fragmentation or loss of habitat, and alteration of landscapes have many causes, regional assessment tools can be valuable to both resource managers and researchers for stratifying natural variability and addressing the nature of these issues.

REFERENCES

Aide, M., and O.W. van Auken. 1985. Chihuahuan desert vegetation of limestone and basalt slopes in west Texas. Southwestern Naturalist 30:533-542.

Allred, B.W., and H.C. Mitchell. 1955. Major plant types of Arkansas, Louisiana, Oklahoma and Texas and their relation to climate and soils. Texas Journal of Science 7:7-19.

Amos, B.B., and C. M. Rowell. 1988. Floristic geography of woody and endemic plants. In: Amos, B.B. and F.R. Gehlbach (eds.). Edwards Plateau vegetation: Plant ecological studies in central Texas. Baylor University Press, Waco, Texas. pp. 25-42.

Anderson, J.R. 1970. Major land uses. In: The national atlas of the United States of America. Washington, D.C., U.S. Geological Survey, p. 158-159, scale 1:7,500,000.

Archer, S. 1995. Tree-grass dynamics in a Prosopis-thornscrub savanna parkland: reconstructing the past and predicting the future. Ecoscience 2:83-99.

Arnwine, D.H., and G.M. Denton. 2001. Habitat quality of least-impacted streams in Tennessee. Tennessee Deapartment of Environment and Conservation, Nashville, Tennessee. 60p.

Ashworth, J.B., and J. Hopkins. 1995. Aquifers of Texas, Report #345, Texas Water Development Board, Austin, Texas.

Bailey, R.G. 1976. Ecoregions of the United States. (Map). U.S. Department of Agriculture, Forest Service. Ogden, Utah.

Bailey, R.G. 1983. Delineation of ecosystem regions. Environmental Management 7(4):365-373.

Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd edition. Miscellaneous Publication No. 1391. U.S. Department of Agriculture, Forest Service, Washington, D.C. 108p. + map.

Bailey, R.G., S.C. Zoltai, and E.B. Wiken. 1985. Ecological regionalization in Canada and the United States. Geoforum 16(3):265-275.

Bailey, R.G., P.E. Avers, T. King, , and W.H. McNab, eds. 1994. Ecoregions and subregions of the United States (map) (supplementary table of map unit descriptions compiled and edited by W.H. McNab, and R.G. Bailey). U.S. Department of Agriculture, Forest Service, Washington, D.C., scale 1:7,500,000.

Barbour, M.T., J. Gerritsen, G.E. Griffith, R. Frydenborg, E. McCarron, J.S. White, and M.L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of the North American Benthological Society 15(2):185-211.

Barnes, C.P. and F.J. Marschner. 1933. Natural land-use areas of the United States. U.S. Department of Agriculture. Scale: 1:4,000,000.

Barnes, V.E., compiler. 1992. Geologic map of Texas. University of Texas, Bureau of Economic Geology, Austin, Texas. 4 sheets, scale 1:500,000.

Bayer, C.W., J.R. Davis, S.R. Twidwell, R. Kleinsasser, G. Linam, K. Mayes, and E. Hornig. 1992. Texas aquatic ecoregion project: an assessment of least disturbed streams (draft). Texas Water Commission, Austin, Texas.

Bayer, K.C. 1983. Generalized structural lithologic and physiographic provinces in the fold and thrust belts of the United States. U.S. Geological Survey. Scale 1:2,500,000.

Belisle, H.J., and R. Josselet. 1999. An analysis of Texas waterways: Llano River. Texas Parks and Wildlife Department, Austin, Texas.

Bezanson, D. 2000. Natural vegetation types of Texas and their representation in conservation areas. University of Texas, Master’s thesis, Austin, Texas. 215p.

Biggs, B.J.F., M.J. Duncan, I.G. Jowett, J.M. Quinn, C.W. Hickey, R.J. Davies-Colley, and M.E. Close. 1990. Ecological characterisation, classification and modelling of New Zealand rivers: an introduction and synthesis. New Zealand Journal of Marine and Freshwater Research 24: 277-304.

Blair, W.F. 1950. The biotic provinces of Texas. Texas Journal of Science 2:93-117.

Bolen, E.G. 2004. Playas. The Handbook of Texas Online. http://www.tsha.utexas.edu/handbook/online/articles/view/PP/rop7.html. Accessed 9/27/04.

Bonner, T.A., G.R. Wilde, and R. Jimenez, Jr. 1997. Historical changes in fish assemblages of the Canadian River, Texas. Abstract of paper presented at the 1997 Southern Division American Fisheries Society meeting, San Antonio, Texas.

Bonner, T.H., C. Thomas, C. S. Williams, and J.P. Karges. 2004. Temporal assessment of a West Texas stream fish assemblage. The Southwestern Naturalist. 50(1):74–78.

Bowles, D.E. and T.L. Arsuffi. 1993. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, U.S.A. - a consideration of their importance, threats to their existence, and efforts for their conservation. Aquatic Conservation, Marine and Freshwater Ecosytems 3:317-329.

Braun, E.L. 1950. Deciduous forests of eastern North America. Hafner Publishing Company, New York. 596p.

Brewer, I. 1999. The conceptual development and use of ecoregion classifications. Master's Thesis, Oregon State University, Corvallis, Oregon. 216 p.

Bridges, E.L. and S.L. Orzell. 1989. Longleaf pine communities of the west Gulf Coastal Plain. Natural Areas Journal 9:246-263.

Brooks, A.R., E.S. Nixon, and J.A. Neal. 1993. Woody vegetation of wet creek bottom communities in eastern Texas. Castanea 58:185-196.

Brown, D.E., editor. 1994. Biotic communities - southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah. 342p.

Brown, J. R. and S. Archer. 1987. Woody plant invasion of grasslands: establishment of honey mesquite (Prosopis glandulosa var. glandulosa) on sites differing in herbaceous biomass and grazing history. Oecologia 80:19-26.

Bryce, S.A., J.M. Omernik, and D.P. Larsen. 1999. Ecoregions: a geographic framework to guide risk characterization and ecosystem management. Environmental Practice 1(3):141-155.

Bryce, S.A., D.P. Larsen, R.M. Hughes, and P.R. Kaufmann. 1999. Assessing relative risks to aquatic ecosystems: a mid-Appalachian case study. Journal of the American Water Resources Association 35(1):23-36.

Bryce, S.A., A.J. Woods, J.D. Morefield, J.M. Omernik, T.R. McKay, G.K. Brackley, R.K. Hall, D.K. Higgins, D.C. McMorran, K.E. Vargas, E.B. Petersen, D.C. Zamudio, and J.A. Comstock. 2003. Ecoregions of Nevada. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,350,000.

Buckler, D., D. Papoulias, G. Ozuna, D. Woodward, M. Flora, and L. Ditto. 2002. Water resources issues in the lower Rio Grande valley – below Falcon Reservoir to the Gulf of Mexico subarea. U.S. Department of the Interior, U.S.-Mexico Border Field Coordinating Committee, Fact Sheet, 8p.

Bureau of Economic Geology. 1996. Physiographic map of Texas. Bureau of Economic Geology, University of Texas, Austin, TX.

Burleson, M.F. 1993. The vanished tallgrass prairie: what we have lost, what we have gained. In: Sharpless, M.R. and J.C. Yelderman (eds.). The Texas Blackland Prairie, land, history, and culture. Baylor University, Program for Regional Studies, Waco, Texas. pp. 281-297.

Byrns, S. 2003. Meat goats stampeding into Texas pastures. AgNews, Texas A&M University System Agriculture Program, Texas A&M University, College Station, Texas.

Campbell, L. 1995. Endangered and threatened animals of Texas; their life history and management. Texas Parks and Wildlife Press, Austin, Texas. 130p.

Center for Plant Conservation, National Collection Plant Profile, http://ridgwaydb.mobot.org/cpcweb/ (Accessed 8/23/04).

Chapman, D.C., D.M. Papoulias, and C.P. Onuf. 1998. Environmental change in South Texas. In: Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran (eds.). Status and trends of the nation's biological resources. U.S. Department of the Interior. U.S. Geological Survey, Reston, Virginia. pp. 268-272.

Christensen, N.L. 1988. Vegetation of the Southeastern Coastal Plain. In: Barbour, M.G. and W.D. Billings (eds.). North American Terrestrial Vegetation. Cambridge University Press, Cambridge. pp. 317-363.

Commission for Environmental Cooperation. 1997. Ecological regions of North America: Towards a common perspective. Commission for Environmental Cooperation. Montreal, Quebec, Canada. 71p.

Cottle, H.J. 1931. Studies in the vegetation of southwestern Texas. Ecology 12(1):105-155.

Daigle, J.J., G.E. Griffith, J.M. Omernik, P.L. Faulkner, R.P. McCulloh, L.R. Handley, L.M. Smith, and S.S. Chapman. 2006. Ecoregions of Louisiana. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, VA. Scale 1:1,000,000.

Daly, C., G. Taylor, and W. Gibson. 1997. The PRISM approach to mapping precipitation and temperature. Proceedings, 10th Conference on Applied Climatology, American Meteorology Society, pp. 10-12.

Dane, C.H. and G.O. Bachman. 1965. Geologic map of New Mexico. U.S. Geological Survey, Reston, Virginia, scale 1:500,000.

Davis, W.B. 1974. The mammals of Texas. Texas Parks and Wildlife Department, Bulletin 41, Austin, Texas. 294p.

Davis, W.S., B.D. Snyder, J.B. Stribling, and C. Stoughton. 1996. Summary of state biological assessment programs for streams and wadeable rivers. EPA230-R-96-007. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Washington, D.C.

Diamond, D.D. 1998. An old-growth definition for southwestern subtropical upland forests. General Technical Report SRS-21. U.S. Department of Agriculture, Forest Service, Southern Research Station. Asheville, North Carolina. 7p.

Diamond, D.D. and T.E. Fulbright. 1990. Contemporary plant communities of the upland grasslands of the Coastal Sand Plain, Texas. Southwestern Naturalist 35:385-392.

Diamond, D.D. and F.E. Smeins. 1985. Composition, classification and species response patterns of remnant tallgrass prairies in Texas. American Midland Naturalist 113:294-308.

Diamond, D.D. and F.E. Smeins. 1993. The native plant communities of the Blackland Prairie. In: Sharpless, M.R. and J.C. Yelderman (eds.). The Texas Blackland Prairie, land, history, and culture. Baylor University, Program for Regional Studies, Waco, Texas. pp. 66-81.

Diamond, D.D., D.H. Riskind, and S.L. Orzell. 1987. A framework for plant community classification and conservation in Texas. Texas Journal of Science 39:203-221.

Diamond, D.D., G.A. Rowell, and D.P. Keddy-Hector. 1995. Conservation of Ashe juniper (Juniperus ashei Buchholz) woodlands of the central Texas Hill Country. Natural Areas Journal 15:189-197.

Diggs, G.M., B.L. Lipscomb and R.J. O'Kennon. 1999. Shinners' and Mahler's illustrated flora of North Central Texas. Botanical Research Institute of Texas, Fort Worth, Texas. 1626p.

Diggs, G.M., Jr., and P.C. Schulze. 2003. Soil-dependent fire frequency - a new hypothesis for the distribution of prairies and oak woodlands/savannas in north central and east Texas. Sida 20(3):1139-1153.

Doughty, R.W. 1983. Wildlife and man in Texas; environmental change and conservation. Texas A&M University Press, College Station, Texas. 246p.

Doughty, R.W. 1987. At home in Texas; early views of the land. Texas A&M University Press, College Station, Texas. 164p.

Doughty, R.W. 2004. Prairie dog. The Handbook of Texas Online. http://www.tsha.utexas.edu/handbook/online/articles/view/PP/tcp1.html. Accessed 10/24/04.

Dyksterhuis, E.H. 1946. The vegetation of the Fort Worth Plains prairie. Ecological Monographs 16(1):1-29.

Dyksterhuis, E.H. 1948. The vegetation of the Western Cross Timbers. Ecological Monographs 18(3):326-376.

Echelle, A.A., G.R. Luttrell, R.D. Larson, A.V. Zale, W.L. Fisher, and D.M. Leslie, Jr. 1995. Decline of native prairie fishes. Our living resources: A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C. http://biology.usgs.gov/s+t/index.htm.

Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research; and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull, Ontario. Report and national map at 1:7,500,000 scale. 125p.

Edwards, R.J. and S. Contreras-Balderas. 1991. Historical changes in the ichthyofauna of the Lower Rio Grande (Rio Bravo del Norte), Texas and Mexico. Southwestern Naturalist 36:201212.

El-Hage, A. and D.W. Moulton. 2001. Ecologically Significant River & Stream Segments of Region J (Plateau), Regional Water Planning Area, A report offered to The Region J (Plateau) Regional Water Planning Area, May 2001 (http://www.tpwd.state.tx.us/texaswater/sb1/rivers/unique/regions_text/report_j/coverpage_j.phtml).

Elliott, W.R. Overview of Texas Caves & Karst. Texas Speleological Survey, http://www.utexas.edu/depts/tnhc/.www/tss/tsscavesandkarst.htm. Accessed 9/24/04.

Environment Canada. 1989. Canada committee on ecological land classification: achievements (1976-1989) and long term plan. Environment Canada, Ottawa, Ontario. 6p.

Fantina, D.E. 2001. The Mississippi kite. The Texas Breeding Bird Atlas. Texas A&M University System, College Station and Corpus Christi, Texas. http://tbba.cbi.tamucc.edu. Accessed 10/21/04.

Feldhamer, G.A. and W.E. Armstrong. 1993. Interspecific competition between four exotic species and native artiodactyls in the United States. Transactions, North American Wildlife and Natural Resources Conference 58:468-478.

Feminella, J.W. 2000. Correspondence between stream macroinvertebrate assemblages and 4 ecoregions of the southeastern USA. Journal of the North American Benthological Society 19:442-461.

Fenneman, N.M. 1914. Physiographic boundaries within the United States. Annals of the Association of American Geographers 4:84-134.

Fenneman, N.M. 1931. Physiography of western United States. McGraw-Hill, New York. 534p.

Fenneman, N.M. 1938. Physiography of eastern United States. McGraw-Hill, New York. 714p.

Fleming, K.M., J.R. Singhurst, and W.C. Holmes. 2002. Vascular flora of Big Lake Bottom Wildlife Management Area, Anderson County, Texas. Sida 20(1):355-371.

Flores, D.L. 1990. Caprock canyonlands: journeys into the heart of the southern plains. University of Texas Press, Austin, Texas. 200p.

Fonteyn, P.J., M.W. Stone, M.A. Yancy, J.T. Baccus, and N.M. Nadkarni. 1988. Determination of community structure by fire. In: Amos, B.B. and F.R. Gehlbach (eds.). Edwards Plateau vegetation: Plant ecological studies in central Texas. Baylor University Press, Waco, Texas. pp. 79-90.

Fowler, N. 1988. Grasslands, nurse trees, and coexistence. In: Amos, B.B. and F.R. Gehlbach (eds.). Edwards Plateau vegetation: Plant ecological studies in central Texas. Baylor University Press, Waco, Texas.

Francaviglia, R.V. 2000. The cast iron forest: a natural and cultural history of the North American Cross Timbers. University of Texas Press, Austin, Texas. 296p.

Frost, C.C. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. In: S.M. Hermann (ed.). The Longleaf Pine Ecosystem: Ecology, Restoration and Management, Proceedings of the 18th Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, Florida. pp. 17-43.

Frost, C.C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. In: S.I. Cerulean and R.T. Engstrom, (eds.). Fire in Wetlands: A Management Perspective. Proceedings of the 19th Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, Florida. pp. 39-60.

Frye, R.G., K.L. Brown, and C.A. McMahon. 1984. The vegetation types of Texas (map). Texas Parks and Wildlife Department.

Fullerton, D.S., C.A. Bush, and J.N. Pennell. 2003. Map of Surficial Deposits and Materials in the Eastern and Central United States (East of 102° West Longitude). U.S. Department of the Interior, U.S. Geological Survey Geologic Investigations Series I–2789. Scale 1:2,500,000.

Gallant, A.L., E.F. Binnian, J.M. Omernik, and M.B. Shasby. 1995. Ecoregions of Alaska. U.S. Geological Survey Professional Paper 1567. 73p.

Gallant, A.L., T.R. Whittier, D.P. Larsen, J.M. Omernik, and R.M. Hughes. 1989. Regionalization as a tool for managing environmental resources. EPA/600/3-89/060. U.S. Environmental Protection Agency, Corvallis, Oregon. 152p.

Garner, E.L. 2002. Mineral resources and mining. The Handbook of Texas Online. <http://www.tsha.utexas.edu/handbook/online/articles/view/MM/gpm1.html> [Accessed Fri Jun 4 2004]

Gehlbach, F.R. 1979. Biomes of the Guadalupe Escarpment: Vegetation, lizards, and human impact. In: Biological investigations in the Guadalupe Mountains National Park, Texas, Symposium Proceedings. H.H. Genoways and R.J. Baker (eds.). National Park Service Proceedings and Transactions Series No. 4. pp. 427-439.

Gehlbach, F.R. 1993. Mountain islands and desert seas: a natural history of the U.S.-Mexican borderlands. Texas A&M University Press, College Station, Texas. 298p.

Godfrey, C.L., G.S. McKee, and H. Oakes. 1973. General soil map of Texas. Texas Agricultural Experiment Station, Texas A&M University in cooperation with Soil Conservation Service, U.S. Department of Agriculture, College Station, Texas, scale 1:1,500,000.

Gould, F.W. 1975. Texas plants: a checklist and ecological summary. Miscellaneous publication 585, revised. Texas Agricultural Experiment Station, College Station, Texas. 121p.

Gould, F.W., G.O. Hoffman, and C.A. Rechenthin. 1960. Vegetational areas of Texas. Leaflet 492. Texas Agricultural Experiment Station, College Station, Texas.

Governments of Mexico and the United States of America. 1997. Second Phase of the Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/Rio Bravo and its Tributaries Along the Boundary Portion Between the United States and Mexico, Vol. II. Final Report.

Grafe, V., L. Allain, M. Vidrine, C. Allen, and S. Johnson. 1999. Paradise Lost? The coastal prairie of Louisiania and Texas. U.S. Fish and Wildlife Service and U.S. Geological Survey Pamphlet, 39p.

Graham, G.L. 1992. Texas wildlife viewing guide. Falcon Press Publishing Company, Helena and Billings, Montana, 160p.

Graves, J. 2002. Texas Rivers. Texas Parks and Wildlife Press, Austin, Texas. 144p.

Griffith, G.E., J.M. Omernik, S.M. Pierson, and C.W. Kiilsgaard. 1994a. Massachusetts ecological regions project. Prepared by the U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon, for the Commonwealth of Massachusetts, Department of Environmental Protection. Publication No. 17587-74-70-6/94-DEP. (also available as EPA/600/A-94/111).

Griffith, G.E., J.M. Omernik, C.M. Rohm, and S.M. Pierson. 1994b. Florida regionalization project. EPA/600/Q-95-002. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon. 83p.

Griffith, G.E., J.M. Omernik, T.F. Wilton, and S.M. Pierson. 1994c. Ecoregions and subregions of Iowa: a framework for water quality assessment and management. Journal of the Iowa Academy of Science 101(1):5-13.

Griffith, G.E., J.M. Omernik, and S.H. Azevedo. 1997. Ecoregions of Tennessee. EPA/600/R-97/022. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. 51p.

Griffith, G.E., J.M. Omernik, and S.H. Azevedo. 1998. Ecoregions of Tennessee. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:940,000.

Griffith, G.E., J.M. Omernik, and A.J. Woods. 1999. Ecoregions, watersheds, basins, and HUCs: How state and federal agencies frame water quality. Journal of Soil and Water Conservation 54(4):666-677.

Griffith, G.E., J.M. Omernik, J.A. Comstock, S. Lawrence, G. Martin, A. Goddard, V.J. Hulcher, and T. Foster. 2001. Ecoregions of Alabama and Georgia. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,700,000.

Griffith, G.E., J.M. Omernik, J.A. Comstock, M.P. Shafale, W.H. McNab, D.R. Lenat, T.F. MacPherson, J.B. Glover, and V.B. Shelburne. 2002. Ecoregions of North and South Carolina. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,500,000.

Griffith, G.E., S.A. Bryce, J.M. Omernik, J.A. Comstock, A.C. Rogers, B. Harrison, S.L. Hatch, and D. Bezanson. 2004. Ecoregions of Texas. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:2,500,000.

Griffith, G.E., J.M. Omernik, M.M. McGraw, G.Z. Jacobi, C.M. Canavan, T.S. Schrader, D. Mercer, R. Hill, and B.C. Moran. 2006. Ecoregions of New Mexico (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,400,000.

Gunter, P.A.Y. 1993. The Big Thicket: an ecological reevaluation. University of North Texas Press, Denton, Texas. 229p.

Hackney, C.T., S.M. Adams, and W.H. Martin, (eds.). 1992. Biodiversity of the southeastern United States-aquatic communities. John Wiley and Sons, Inc., New York, 779p.

Hallmark, T.C. 1993. The nature and origin of the Blackland soils. In: M.R. Sharpless and J.C. Yelderman, (eds.). The Texas Blackland Prairie, land, history, and culture. Baylor University, Program for Regional Studies, Waco, Texas. pp. 41-47.

Halstead, L. 2001. Conservation plan for the Big Thicket-Sandylands Conservation Area. The Nature Conservancy of Texas. 61p.

Hammond, E.H. 1970. Classes of land-surface form. Map scale 1:7,500,000. In: The national atlas of the United States of America. U.S. Geological Survey, Washington, D.C. pp. 62-63.

Hanselka, C.W. and S. Archer. 1998. Rangeland ecosystems of South Texas: the keys to sustainability, In: Proceedings, Mexico-US workshop on “Management of Grazing Land in Northern Mexico and South Texas” W. Hamilton, M. Lee, and A. Molina, (eds.). Texas A&M Agricultural Experiment Station. pp. 1-11.

Harcombe, P.A. and J.E. Neaville. 1977. Vegetation types of Chambers County, Texas. Texas Journal of Science 29:209-234.

Harcombe, P.A., J.S. Glitzenstein, R.G. Knox, S.L. Orzell, and E.L. Bridges. 1993. Vegetation of the longleaf pine region of the West Gulf Coastal Plain. In: 18th Tall Timbers Fire Ecology Conference, the longleaf pine ecosystem: ecology, restoration and management, Tallahassee, Florida, 1991. S.M. Hermann (ed.). Proceedings, Tall Timbers Research Station. pp. 83-104.

Hatch, S.L., K.N. Gandhi, and L.E. Brown. 1990. Checklist of the vascular plants of Texas. Texas Agricultural Experiment Station, College Station, Texas. 158p.

Hayward, O.T. and J.C. Yelderman. 1991. A field guide to the Blackland Prairie of Texas, from frontier to heartland in one long century. Program for Regional Studies, Baylor University, Waco, TX.

Heino, J, T. Muotka, R. Paavola, H. Hamalainen, and E. Koskenniemi. 2002. Correspondence between regional delineations and spatial patterns in macroinvertebrate assemblages of boreal headwater streams. Journal of the North American Benthological Society 21(3):397-413.

Heiskary, S.A. and B.C. Wilson. 1989. The regional nature of lake quality across Minnesota: an analysis for improving resource management. Journal of the Minnesota Academy of Science 55(1):71-77.

Heiskary, S.A., B.C. Wilson, and D.P. Larsen. 1987. Analysis of regional patterns in lake water quality: using ecoregions for lake management in Minnesota. Lake and Reservoir Management 3:337-344.

Hoagland, B.W., I.H. Butler, F.L. Johnson, and S. Glenn. 1999. The Cross Timbers. In: Anderson, R.C., J.S. Fralish, and J.M. Baskin (eds.). Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, U.K., pp. 231-246.

Hocutt, C.H., and E.O. Wiley (eds.). 1986. The zoogeography of North American freshwater fishes. John Wiley and Sons, New York, New York. 866 pp.

Hodge, L.D. 2000. Official guide to Texas Wildlife Management Areas. Texas Parks and Wildlife Press, Austin, Texas, 258p.

Hornig, C.E., C.W. Bayer, S.R. Twidwell, J.R. Davis, R.J. Kleinsasser, G.W. Linam, and K.B. Mayes. 1995. Development of regionally based biological criteria in Texas. In: Davis, W. and T. Simon (eds). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, Florida. pp. 145-152.

Hubbs, C., R.J. Edwards, and G.P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science 43: 1-56.

Hughes, D.T., and A. Hughes-Jones. 1986. Buried city Indian ruins. Http://www.perryton.com/city.htm [Accessed 2/25/05].

Hughes, R.M. 1989. Ecoregional biological criteria. In: Proceedings of an EPA Conference, Water Quality Standards for the 21st Century, Dallas, Texas, March, 1989. pp. 147-151.

Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. In: Davis, W.S. and T.P. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL. pp. 31-47

Hughes, R.M., S.A. Heiskary, W.J. Matthews, and C.O. Yoder. 1994. Use of ecoregions in biological monitoring. In: Loeb, S.L. and A. Spacie (eds.). Biological Monitoring of Aquatic Systems. Lewis Publishers, Boca Raton, Florida. pp. 125-151.

Hughes, R.M., D.P. Larsen, and J.M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental Management 10(5): 629-635.

Hughes, R.M., E. Rexstad, and C.E. Bond. 1987. The relationship of aquatic ecoregions, river basins, and physiographic provinces to the ichthyogeographic regions of Oregon. Copeia 2:423-432.

Hughes, R.M., T.R. Whittier, C.M. Rohm, and D.P. Larsen. 1990. A regional framework for establishing recovery criteria. Environmental Management 14(5):673-683.

Hunt, C.B. 1967. Physiography of the United States. W.H. Freeman and Company. San Francisco.

Hunt, C.B. 1974. Natural regions of the United States and Canada. W.H. Freeman and Company, San Francisco. 725p.

Hunt, C.B. 1979. Surficial geology. Map scale 1:7,500,000. U.S. Geological Survey, Reston, Virginia.

Huser, V. 2000. Rivers of Texas. Texas A&M Press. College Station, Texas. 264p.

Jahrsdoerfer, S.E., and D.M. Leslie, Jr. 1988. Tamaulipan brushland of the Lower Rio Grande Valley of south Texas: description, human impacts, and management options. U.S. Fish and Wildlife Service, Biological Report 88-36, Washington, D.C., 63p.

Johnston, M.C. 1963. Past and present grasslands of South Texas and northeastern Mexico. Ecology 44:456-465.

Johnston, M.C. 1979. The Guadalupe Mountains - A chink in the mosaic of the Chihuahuan Desert? In: H.H. Genoways and R.J. Baker (eds.). Biological investigations in the Guadalupe Mountains National Park, Texas, Symposium Proceedings, National Park Service Proceedings and Transactions Series No. 4. pp. 45-49.

Jones, J.O., and T.F. Hentz. 1988. Permian strata of north-central Texas. pp. 309-316. In: Hayward et al., (eds.), Centennial Field Guide Volume 4, South-Central Section of the Geological Society of America, Geological Society of America, Boulder, Colorado. 468p.

Jordan, T. 1978. Perceptual regions in Texas. Geographical Review 68:293-307.

Jordan, T., J.L. Bean, Jr., and W.M. Holmes. 1984. Texas - a geography. Westview Press, Boulder, Colorado. 288p.

Jordan, T.G. 1977. Early northeast Texas and evolution of western ranching. Annals of the Association of American Geographers 67(1):66-87.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspectives on water quality goals. Environmental Management 5:55-68.

Keys, J., Jr., C. Carpenter, S. Hooks, F. Koenig, W.H.. McNab, W.E. Russell, and M-L. Smith. 1995. Ecological units of the eastern United States - first approximation. Technical Publication R8-TP 21. U.S. Department of Agriculture, Forest Service. Atlanta, Georgia. Scale 1:3,500,000.

Kier, R.S., L.E. Garner, and , L.F. Brown Jr. 1977. Land resources of Texas; a map of Texas lands classified according to natural suitability and use considerations. University of Texas, Bureau of Economic Geology, Austin, Texas. Scale 1:500,000.

King, P.B. and H.M. Biekman. 1974. Geologic map of the United States. Map scale 1:2,500,000. U.S. Geological Survey, Reston, Virginia.

Klijn, F. 1994. Spatially nested ecosystems: guidelines for classification from a hierarchical perspective. In: Klijn, F. (ed.). Ecosystem Classification for Environmental Management. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 85-116.

Knopf, F.L. 1995. Declining grassland birds. Our living resources: A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C. http://biology.usgs.gov/s+t/index.htm.

Koss, W.J., J.R. Owenby, P.M. Steurer, and D.S. Ezell. 1988. Freeze/frost data. Climatography of the U.S. No. 20, Supplement No. 1, National Climatic Data Center, Asheville, North Carolina. 186p.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. Special Publication No. 36, American Geographical Society, New York. 116p. Map Scale 1:3,168,000.

Kuchler, A.W. 1970. Potential natural vegetation. Scale 1:7,500,000. In: The National Atlas of the United States of America. U.S. Geological Survey. Washington, D.C. pp. 89-91.

Larkin, T.J. and G.W. Bomar. 1983. Climatic atlas of Texas. Texas Department of Water Resources, Austin, Texas. 151p.

Larsen, D.P., D.R. Dudley, and R.M. Hughes. 1988. A regional approach for assessing attainable surface water quality: an Ohio case study. Journal of Soil and Water Conservation 43(2):171-176.

Launchbaugh, J.R. 1955. Vegetational changes in the San Antonio Prairie associated with grazing, retirement from grazing, and abandonment from cultivation. Ecological Monographs 25(1):39-57.

Leatherwood, A. 2004. Llano Estacado. The Handbook of Texas Online. http://www.tsha.utexas.edu/handbook/online/articles/view/LL/ryl2.html. Accessed 9/26/04.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina. 854p.

Lehmann, V.W. 1965. Fire in the range of Attwater's prairie chicken. Proceedings of the 4th Tall Timbers Fire Ecology Conference, pp. 127-143.

Lehmann, V.W. 1968. The Attwater's prairie chicken, current status and restoration opportunities. Transactions North American Wildlife Conference 33:398-407.

Lewis, G.M. 1966. Regional ideas and reality in the Cis-Rocky Mountain West. Transactions of the Institute of British Geographers 38:135-150.

Linam, G.W., L.J. Kleinsasser, and K.B. Mayes. 2002. Regionalization of the index of biotic integrity for Texas streams. River Studies Report No. 17, Texas Parks and Wildlife Department, Austin, Texas, 26p. + appendices.

Lind, O.T. 1979. Limnology of McKittrick Creek, Guadalupe Mountains National Park. in Genoways, H.H. and R.J. Baker (eds.). Biological investigations in the Guadalupe Mountains National Park, Texas, Symposium Proceedings, National Park Service Proceedings and Transactions Series No. 4. pp. 123-139.

Loveland, T.R., and J.M. Mercant. 2004. Ecoregions and ecoregionalization: geographical and ecological perspectives. Environmental Management 34(Supplement 1):s1-s13.

Loveland, T.R., J.W. Merchant, D.O. Ohlen, J.F. Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering and Remote Sensing 57(11):1453-1463.

Loveland, T.R., J.W. Merchant, J.F. Brown, D.O. Ohlen, B.C. Reed, P. Olsen, and J. Hutchinson. 1995. Seasonal land-cover regions of the United States. Annals of the Association of American Geographers 85(2):339-355.

Lower Colorado Water Authority. 2005. Water Quality Data. http://crwn.lcra.org/TravisBasin.asp [Accessed 3/1/05].

Lyndon B. Johnson School of Public Affairs. 1978. Preserving Texas' natural heritage. Natural Heritage Policy Research Project Report no. 31. Lyndon B. Johnson School of Public Affairs, University of Texas, Austin, Texas. 34p. + maps.

MacRoberts, B.R., M.H. MacRoberts, and J.C. Cathey. 2002. Floristics of xeric sandylands in the Post Oak Savanna region of East Texas. Sida 20(1):373-386.

Marks, P.L. and P.A. Harcombe. 1981. Forest vegetation of the Big Thicket, southeast Texas. Ecological Monographs 51:287-305.

Martin, W.H., S.G. Boyce, and A.C. Echternacht (eds.). 1993a. Biodiversity of the southeastern United States: lowland terrestrial communities. John Wiley and Sons, New York, 502p.

Martin, W.H., S.G. Boyce, and A.C. Echternacht (eds.). 1993b. Biodiversity of the southeastern United States: upland terrestrial communities. John Wiley and Sons, New York, 373p.

Matos, J.A. and D.C. Rudolph. 1985. The vegetation of the Roy E. Larsen Sandylands Sanctuary in the Big Thicket of Texas. Castanea 50:228-249.

Maxwell, T.C. 1979. Avifauna of the Concho Valley of west-central Texas with special reference to historical change. PhD Dissertation, Texas A & M University, College Station, Texas.

McLeod, C.A. 1971. The Big Thicket Forest of east Texas. Texas Journal of Science 23:221-233.

McLendon, T. 1991. Preliminary description of the vegetation of south Texas exclusive of coastal saline zones. Texas Journal of Science 43:13-32.

McMahan, C.A., R.G. Frye, and K.L. Brown. 1984. The vegetation types of Texas including cropland; an illustrated synopsis to accompany the map. Texas Parks and Wildlife Department, Wildlife Division, Austin, Texas. 40p.

McMahon, G., S.M. Gregonis, S.W. Waltman, J.M. Omernik, T.D. Thorson, J.A. Freeouf, A.H. Rorick, and J.E. Keys. 2001. Developing a spatial framework of common ecological regions for the conterminous United States. Environmental Management 28(3):293-316.

McNab, W.H. and P.E. Avers (compilers). 1994. Ecological subregions of the United States: section descriptions. Administrative Publication WO-WSA-5. U.S. Department of Agriculture, Forest Service. Washington, D.C. 267p.

Monk, C.D., D.W. Imm, and R.L. Potter. 1990. Oak forests of eastern North America. Castanea 55(2):77-96.

Moog, O., A. Schmidt-Kloiber, T. Ofenbock, and J. Gerritsen. 2004. Does the ecoregion approach support the typological demands of EU 'Water Framework Directive'? Hydrobiologia 516:21-33.

Moore, D.W., G.M. Richmond, and A.C. Christiansen (eds.). 1993. Quaternary geologic map of the Austin 4º x 6º quadrangle, United States. U.S. Geological Survey, Map I-1420 (NH-14), scale 1:1,000,000.

Moulton, D.W., T.E. Dahl, and D.M. Dall. 1997. Texas coastal wetlands: status and trends, mid-1950s to early 1990s. U.S. Department of the Interior, Fish and Wildlife Service, Albuquerque, New Mexico. 32p.

NatureServe. 2002. International classification of ecological communities: terrestrial vegetation of the United States, Tamaulipan Thornscrub Ecoregion. NatureServe, Arlington, Virginia, and The Nature Conservancy of Texas, San Antonio, Texas.

Nelson, A., J. Goetze, and A. Lucksinger. 2001. A comparison of the flora of Northern Padre Island to that of Matagorda Island, Mustang Island and Southern Padre Island, Texas. Occasional Papers No. 209, Museum of Texas Tech University, Lubbock, Texas, 23p.

New Mexico Bureau of Geology and Mineral Resources. 2003. Geologic Map of New Mexico. Map scale 1:500,000. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico.

Nix, S.J. 2002. Buffalo Gap, Texas. Handbook of Texas online. http://www.tsha.utexas.edu/handbook/online/articles/view/BB/hlb60.html [Accessed 2/25/2005].

Nixon, E.S., J. Matos, and R.S. Hansen. 1987. The response of woody vegetation to a topographic gradient in eastern Texas. Texas Journal of Science 39:367-375.

Northington, D.K., and T.L. Burgess. 1979. Summary of the vegetative zones of the Guadalupe Mountains National Park, Texas. In: Genoways, H.H. and R.J. Baker (eds.), Biological investigations in the Guadalupe Mountains National Park, Texas, Symposium Proceedings, National Park Service Proceedings and Transactions Series No. 4. pp. 51-57.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1):118-125.

Omernik, J.M. 1995. Ecoregions: A framework for environmental management. In: Davis, W. and T. Simon (eds). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, Florida. pp. 49-62.

Omernik, J.M. 2003. The misuse of hydrologic unit maps for extrapolation, reporting, and ecosystem management. Journal of the American Water Resources Association 39(3):563-573.

Omernik, J.M. 2004. Perspectives on the nature and definition of ecological regions. Environmental Management 34(Supplement 1):s27-s38.

Omernik, J.M. and R.G. Bailey. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association 33(5):935-949.

Omernik, J.M. and A.L. Gallant. 1987. Ecoregions of the South Central States. Map (scale 1:2,500,000. EPA/600/D-87/315. U.S. EPA, Environmental Research Laboratory, Corvallis, Oregon.

Omernik, J.M. and A.L. Gallant. 1990. Defining regions for evaluating environmental resources. In: Global Natural Resource Monitoring and Assessments. Proceedings of the International Conference and Workshop, Venice, Italy. pp. 936-947.

Omernik, J.M. and G.E. Griffith. 1991. Ecological regions versus hydrological units: frameworks for managing water quality. Journal of Soil and Water Conservation 46(5):334-340.

Omernik, J.M., S.S. Chapman, R.A. Lillie, and R.T. Dumke. 2000. Ecoregions of Wisconsin. Transactions of the Wisconsin Academy of Science, Arts and Letters 88(2000):77-103.

Onuf, C.P. 1995. Seagrass meadows of the Laguna Madre of Texas. In: LaRoe, E.T., G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac, (eds.). Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. National Biological Service, Washington, DC. pp. 275-277.

Orton, R.B. 1974. The climate of Texas. In: Climates of the States, v. 2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Water Information Center, Inc. Port Washington, N.Y. pp. 877-920.

Parent, L., and J.N. Patoski. 2001. Texas mountains. University of Texas Press, Austin, Texas. 155p.

Peterson, R., and C.S. Boyd. 1998. Ecology and management of sand shinnery communities: a literature review. General Technical Report RMRS-GTR-16, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, 44p.

Phelan, R. 1976. Texas wild: The land, plants, and animals of the Lone Star state. E.P. Dutton and Company, New York, New York. 255p.

Phelan, R., and J. Bones. 1976. Texas wild: the land, plants, and animals of the Lone Star State. E.P. Dutton and Company, New York. 256p.

Plumb, G.A. 1992. Vegetation classifications of Big Bend National Park, Texas. Texas Journal of Science 44:375-387.

Pringle, C. 1997. Exploring how disturbance is transmitted upstream: going against the flow. Journal of the North American Benthological Society 16(2):425-438.

Raisz, E. 1957. Landforms of the United States. Sixth revised edition. Scale about 1:4,500,000.

Red River Authority. 2003. The clean rivers program basin highlights report: Canadian River Basin. Red River Authority, Wichita Falls, Texas.

Red River Authority of Texas. 2004. http://www.eos.ncsu.edu/bae/courses/bae472/perspectives/1996/arblanke.html

Renfro, H.B. 1973. Geological highway map of Texas. American Association of Petroleum Geologists Map 7, scale approximately 1:1,900,000, 1 sheet.

Richmond, G.M. and A.C. Christiansen (eds.). 1994. Quaternary geologic map of the Dallas 4^{o} x 6^{o} quadrangle, United States. U.S. Geological Survey. Map I-1420 (NI-14). Scale 1:1,000,000.

Richmond, G.M., D.S. Fullerton, and D.L. Weide (eds.). 1990. Quaternary geologic map of the Vicksburg 4^{o} x 6^{o} quadrangle, United States. U.S. Geological Survey. Map I-1420 (NI-15). Scale 1:1,000,000.

Richmond, G.M., D.L. Weide, and D.W. Moore (eds.). 1990. Quaternary geologic map of the White Lake 4º x 6º quadrangle, United States. U.S. Geological Survey. Map I-1420 (NH-15). Scale 1:1,000,000.

Ricketts, T.H., E. Dinerstein, D.M. Olson, C.J. Loucks, W. Eichbaum, D. DellaSala, K. Kavanagh, P. Hedao, P.T. Hurley, K.M. Carney, R. Abell, and S. Walters. 1999. Terrestrial ecoregions of North America: A conservation assessment. World Wildlife Fund, Island Press, Washington, D.C. 485p.

Riparian Habitat Joint Venture. 2004. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. Version 2.0. California Partners in Flight. http://www.prbo.org/calpif/pdfs/riparian.v-2.pdf

Riskind, D.H., and D.D. Diamond. 1988. An introduction to environments and vegetation. In: Amos, B.B. and F.R. Gehlbach, eds. Edwards Plateau Vegetation: Plant Ecological Studies in Central Texas. Baylor University Press, Waco, Texas.

Rohm, C.M., J.W. Giese, and C.C. Bennett. 1987. Evaluation of an aquatic ecoregion classification of streams in Arkansas. Journal of Freshwater Ecology 4(1):127-140.

Rossum, S., and S. Lavin. 2000. Where are the Great Plains? A cartographic analysis. Professional Geographer 52: 543-552.

Russell, R.J. 1945. Climates of Texas. Annals of the Association of American Geographers 35:37-52.

Ryder, P.D. 1996. Ground Water Atlas of the United States: Oklahoma, Texas. HA 730-E. http://capp.water.usgs.gov/gwa/ch_e/index.html. Accessed 10/17/04.

Sanger, M., and C. Reed (eds.). 2000. Texas environmental almanac: Second edition. Texas Center for Policy Studies, University of Texas Press, Austin, Texas. 387p.

Schafale, M.P. and P.A. Harcombe. 1983. Presettlement vegetation of Hardin County, Texas. American Midland Naturalist 109:355-366.

Schmidly, D.J. 2002. Texas natural history: a century of change. Texas Tech University Press, Lubbock, Texas. 534p.

Scott, J.M., and 11 coauthors. 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 123:1-41.

Sharitz, R.R. and W.J. Mitsch. 1993. Southern floodplain forests. In: Martin, W.H., S.G. Boyce, and A.C. Echternacht (eds.). Biodiversity of the southeastern United States-lowland terrestrial communities. John Wiley and Sons, Inc. New York. pp. 311-372.

Shew, D.M., R.H. Baumann, T.H. Fritts, and L.S. Dunn. 1981. Texas barrier islands region ecological characterizations: environmental synthesis papers. FWS/OBS-81/32, U.S. Fish and Wildlife Service, Biological Services Program. Washington, D.C. 413p.

Smeins, F.E., and D.D. Diamond. 1983. Remnant grasslands of the Fayette Prairie. American Midland Naturalist 110:1-13.

Smeins, F.E., D.D. Diamond, and C.W. Hanselka. 1992. Coastal prairie. Chapter 13. In: Coupland, R.T. (ed.). Natural grasslands, introduction and Western Hemisphere, ecosystems of the world, volume 8A. Elsevier, New York. pp. 269-290.

Smith, H.N. and C.A. Rechenthin. 1964. Grassland restoration: The Texas brush problem. U.S. Department of Agriculture, Soil Conservation Service, Temple, Texas.

Smith, L.M. 2003. Playas of the Great Plains. University of Texas Press, Austin, Texas. 257p.

Snead, J.I. and R.P. McCulloh, (compilers). 1984. Geologic map of Louisiana. Louisiana Geological Survey. Baton Rouge, Louisiana. Scale 1:500,000.

Sneegas, G.W. 1997. Beneath the Waters of Balmorhea State Park, North American Native Fishes Association, http://www.nativefish.org/Articles/Sneegas.htm. Accessed 9/24/04.

Spearing, D. 1991. Roadside geology of Texas. Mountain Press Publishing Company. Missoula, Montana. 418p.

Springer, C. 2000. A road trip for recovery. U.S. Fish and Wildlife Service, Endangered Species Bulletin 25(3):27.

Stahle, D.W., M.D. Therrell, and K. L. Clements. 2003. Ancient cross timbers. Ancient Cross Timbers Consortium, University of Arkansas, Fayetteville, Arkansas.

Stoddard, J.L. 2004. Use of ecological regions in aquatic assessments of ecological condition. Environmental Management 34(Supplement 1):s61-s70.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267-1276.

Telfair, R.C., II (ed.). 1999. Texas wildlife resources and land uses. University of Texas Press, Austin, Texas, 404p.

Texas A&M Bioformatics Working Group. 1996. Checklist of the vascular plants of Texas: Ecological Summary, Vegetation Area 7, Edwards Plateau. http://botany.cs.tamu.edu/FLORA/tracy/taesreg7.htm. Accessed 9/25/04.

Texas Parks and Wildlife. 2004. 2003-2004 trout stocking schedule. http://www.tpwd.state.tx.us/fish/infish/txrivers/brazos/brazos_pk_hw4.htm

Texas Parks and Wildlife. 2006. South Texas wildlife management – historical perspective. http://www.tpwd.state.tx.us/landwater/land/habitats/southtx_plain/. Accessed 10/03/06.

Texas State Historical Association. 2002. Handbook of Texas Online. Guadalupe Mountains National Park http://www.tsha.utexas.edu/handbook/online/articles/view/GG/gkg2.html. Accessed 10/07/04.

Thackway, R. and I.D. Cresswell (eds.). 1995. An interim biogeographic regionalization for Australia: a framework for establishing the national system of reserves. Version 4.0. Australian Nature Conservancy Agency, Canberra, Australia. 88p.

Tharp, B. C. 1939. The vegetation of Texas. Texas Academy of Science, The Anson Jones Press, Houston, Texas, 74p.

The Nature Conservancy. 2003. The West Gulf Coastal Plain Ecoregional Conservation Plan. The Nature Conservancy, San Antonio, Texas. 142p.

The Nature Conservancy. 2004. Independence Creek Preserve. http://nature.org/wherewework/northamerica/states/texas/preserves/art9517.html. Accessed 3/10/05.

The Nature Conservancy Ecoregional Working Group. 1997. Designing a geography of hope: guidelines for ecoregional-based conservation in The Nature Conservancy. The Nature Conservancy, Arlington, Virginia. 84p.

Thelin, G.P., and R.J. Pike. 1991. Landforms of the conterminous United States – a digital shaded-relief portrayal. U.S. Geological Survey Miscellaneous Investigations, Map I-2206, 16p., map scale 1:3,500,000.

Thompson, C.M. 1993. More from less: Greater demand from fewer acres of productive soils. In: Sharpless, M.R. and J.C. Yelderman (eds.). The Texas Blackland Prairie, land, history, and culture. Baylor University, Program for Regional Studies. Waco, Texas. pp. 252-261.

Traylor, R.J. 2004. Impact of sandstone strip-mining on the Brazos River geomorphology between Lake Possum Kingdom and Lake Grandbury, Palo Pinto and Parker Counties, Texas. Geological Society of America Abstracts with Programs, Vol. 36, No. 1, p. 23, Geological Society of America South-Central Meeting, March 2004, Texas A&M University, College Station, Texas

Tunnell, J.W., Jr., and Judd, F.W. (eds.). 2002. The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, Texas. 346p.

Twidwell, S. and J.R. Davis. 1989. An assessment of six least disturbed unclassified Texas streams. Report no. LP89-04. Texas Natural Resources Conservation Commission. Austin, Texas.

U.S. Department of Agriculture, Forest Service. 1969. A Forest Atlas of the South. Southern Forest Experiment Station, New Orleans, Louisiana, and Southeastern Forest Experiment Station, Asheville, North Carolina. 27p.

U.S. Department of Agriculture, Forest Service. 1997. Forest type groups of the United States, scale 1:7,500,000. In: Powell, D.S., J.L. Faulkner, D.R. Darr, Z. Zhu, and D.W. MacCleery. Forest resources of the United States. General Technical Report RM-234. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado, 132p.

U.S. Department of Agriculture, National Agricultural Statistics Service. 1999. Census of agriculture, 1997. Volume 2, subject series, part 1, agricultural atlas of the United States. U.S. Government Printing Office, Washington, D.C., 163p.

U.S. Department of Agriculture, Natural Resource Conservation Service. 1994. State Soil Geographic (STATSGO) data base for Texas. Fort Worth, Texas.

U.S. Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service). Various county soil surveys of Texas.

U.S. Department of Agriculture, Soil Conservation Service. 1981. Land Resource Regions and Major Land Resource Areas of the United States. Agriculture Handbook 296. U.S. Government Printing Office, Washington, D.C. 156p + map.

U.S. Department of Commerce. 1990. Census of Agriculture, 1987. Volume 2, Subject Series. Part 1, Agricultural Atlas of the United States. Bureau of the Census. U.S. Government Printing Office, Washington, D.C. 199p.

U.S. Department of Commerce. 1995. Census of Agriculture, 1992. Volume 2, Subject Series. Part 1, Agricultural Atlas of the United States. Bureau of the Census. U.S. Government Printing Office, Washington, D.C. 204p.

U.S. Environmental Protection Agency. 1990. Biological criteria: national program guidance for surface waters. EPA-440/5-90-004, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

U.S. Environmental Protection Agency. 2006. Level III ecoregions of the continental United States (revision of Omernik 1987). U.S. Environmental Protection Agency, National Health and Ecological Effects Research Laboratory, Corvallis, OR. Map M-1.

U.S. Environmental Protection Agency, Science Advisory Board. 1991. Evaluation of the ecoregion concept. Report of The Ecoregions Subcommittee of The Ecological Processes and Effects Committee. EPA-SAB-EPEC-91-003. U.S. Environmental Protection Agency, Washington, D.C. 25p.

U.S. Fish and Wildlife Service. 1992. Attwater's Prairie Chicken Recovery Plan. Albuquerque, New Mexico. 48p.

U.S. Forest Service. 1970. Major forest types. In: The national atlas of the United States of America. U.S. Geological Survey, Reston, Virginia. pp. 154-155.

U.S. Geological Survey. 1986. Land use and land cover data from 1:250,000- and 1:100,000-scale maps. U.S. Geological Survey Data Users Guide Number 4. U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey. 2002. Ground Water Atlas of the United States. http://capp.water.usgs.gov/gwa/index.html. Accessed 9/11/04.

Van Auken, O.W. 1988. Woody vegetation of the southeastern escarpment and plateau. In: Amos, B.B. and F.R. Gehlbach (eds.). Edwards Plateau vegetation: Plant ecological studies in central Texas. Baylor University Press, Waco, Texas. pp. 43-55.

Van Auken, O.W. 1993. Size distribution patterns and potential population change of some dominant woody species in the Edwards Plateau of Texas. Texas Journal of Science 45:199-210.

Van Auken, O.W., A.L. Ford, A. Stein, and A.G. Stein. 1980. Woody vegetation of upland plant communities of the southern Edwards Plateau. Texas Journal of Science 32:24-35.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel. 2001. Completion of the 1990's National Land Cover Data set of the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing 67(6):650-662.

Waggoner, G.S. 1975. Southeastern evergreen and oak-pine region; inventory of natural areas and sites recommended as potential natural landmarks. U.S. National Park Service, Washington, D.C. 206p.

Walters, T.W., and R. Wyatt. 1982. The vascular flora of granite outcrops in the central mineral region of Texas. Bulletin of the Torrey Botanical Club 109(3):344-364.

Ward, J.R. and E.S. Nixon. 1992. Woody vegetation of the dry, sandy uplands of east Texas. Texas Journal of Science 44:283-294.

Ware, S., C. Frost, and P.D. Doerr. 1993. Southern mixed hardwood forest: the former longleaf pine forest. In: Martin, W.H., S.G. Boyce, and A.C. Echternacht (eds.). Biodiversity of the southeastern United States: lowland terrestrial communities. John Wiley and Sons, Inc., New York. pp. 447-493.

Warry, N.D. and M. Hanau. 1993. The use of terrestrial ecoregions as a regional-scale screen for selecting representative reference sites for water quality monitoring. Environmental Management 17(2):267-276.

Webb, W.L. 1950. Biogeographical regions of Texas and Oklahoma. Ecology 31:426-433.

Weise, B.R., and W.A. White. 1980. Padre Island National Seashore: A guide to the geology, natural environments, and history of a Texas barrier island. Guidebook 17, Bureau of Economic Geology, University of Texas, Austin, Texas. 94p.

Whisenant, S.G. 1981. The vascular flora of McCulloch County, Texas. Texas Journal of Science 33:197-220.

White, D.H., C.A. Mitchell, H.D. Kennedy, A.J. Krynitsky, and M.A. Ribick. 1983. Elevated DDE and toxaphene residues in fishes and birds reflect local contamination in the Lower Rio Grande valley, Texas. Southwestern Naturalist 28(3):325333.

Whittier, T.R., R.M. Hughes, and D.P. Larsen. 1988. Correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. Canadian Journal of Fisheries and Aquatic Sciences 45:1264-1278.

Whittier, T.R., R.M. Hughes, G.A. Lomnicky, and D.V. Peck. 2007. Fish and amphibian tolerance values and an assemblage tolerance index for streams and rivers in the western USA. Transactions of the American Fisheries Society 136:254-271.

Wiken, E. 1986. Terrestrial ecozones of Canada. Environment Canada. Ecological Land Classification Series No. 19. Ottawa, Ontario. 26p.

Wilkinson, D.L., K. Schneller-McDonald, and G.T. Auble. 1987. Synopsis of wetland functions and values: bottomland hardwoods with special emphasis on eastern Texas and Oklahoma. Biological Report 87-12. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., 132p.

Wilson, R.E. 1989. The vegetation of a pine-oak forest in Franklin County, Texas, and its comparison with a similar forest in Lamar County, Texas. Texas Journal of Science 41:167-176.

Wilson, R.E. 1990. The eastward recession of the Piney Woods of northeastern Texas, 1815 to 1989. Texas Journal of Science 42:179-189.

Woods, A.J., J.M. Omernik, D.D. Brown, and C.W. Kiilsgaard. 1996. Level III and IV ecoregions of Pennsylvania and the Blue Ridge Mountains, the Ridge and Valley, and Central Appalachians of Virginia, West Virginia, and Maryland. EPA/600/R-96/077. USEPA National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. 50p.

Woods, A.J., J.M. Omernik, C.S. Brockman, T.D. Gerber, W.D. Hosteter, and S.H. Azevedo. 1998. Ecoregions of Indiana and Ohio (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:500,000.

Woods, A.J., T.L. Foti, Chapman, S.S., J.M. Omernik, J. Wise, E.O. Murray, W.L. Prior, J. Pagan, J.A. Comstock, and M. Radford. 2004. Ecoregions of Arkansas. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,000,000.

Woods, A.J., J.M. Omernik, D.R. Butler, J.G. Ford, J.E. Henley, B.W. Hoagland, D.S. Arndt, and B.C. Moran. 2005. Ecoregions of Oklahoma. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. Scale 1:1,250,000.

Wright, G.M., J.S. Dixon, and B.H. Thompson. 1932. Pp. 87-91. In: Fauna of the National Parks of the United States, Wildlife Survey, Fauna Series No. 1, Government Printing Office, Washington, D.C.

Wu, X.B., N.J. Silvy, F.E. Smeins, M.J. Peterson, R.M. Sullivan, and S.J. DeMaso. 2001. Wildlife Research Highlights, http://www.tpwd.state.tx.us/hunt/researchhighlights/2001/landscape_change_lesser.html. Accessed 4/04.

Wuerthner, G. 1989. Texas' Big Bend country. American Geographic Publishing, Helena, Montana. 104p.

Yoder, C.O. and E.T. Rankin. 1995. Biological criteria program development and implementation in Ohio. In: Davis W. and T. Simon (eds). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, Florida. pp.109-144.

APPENDIX

List of Common and Scientific Names

Herbaceous Plants (Forbs, Grasses, and Sedges)

Anemone, Tuber	*Anemone edwardsiana*
Aster	*Aster* spp.
Bedstraw, Cliff	*Gallium correllii*
Black-eyed Susan	*Rudbeckia hirta*
Bladderworts	*Utricularia* spp.
Blanket, Indian	*Gaillardia aestivalus*
Bluebonnet, Texas	*Lupinus texensis*
Bluestem, Big	*Andropogon gerardii*
Bluestem, Cane	*Bothriochloa barbinodis*
Bluestem, Little	*Schizachyrium scoparium*
Bluestem, Pinehill	*Schizachyrium scoparium* var. *divergens*
Bluestem, Sand	*Andropogon gerardii* var. *paucipilus*
Bluestem, Seacoast	*Schizoparium scoparium* var. *littorale*
Bluestem, Silver	*Bothriochloa laguroides ssp. torreyana*
Bluestems	*Andropogon* spp.*, Bothriochloa* spp.*, and Schizachyrium* spp.
Bluet, Prairie	*Hedyotis nigricans*
Bristlegrass	*Setaria* spp.
Bristlegrass, Plains	*Setaria macrostachya*
Broomweed	*Amphiachyris and Gutierrezia* spp.
Buffalograss	*Buchloe dactyloides*
Bulrush	*Scirpus* spp.
Burrograss	*Scleropogon brevifolius*
Cane, Giant	*Arundinaria gigantea*
Cattail	*Typha* spp.
Clematis	*Clematis* spp.
Clover, Prairie	*Dalea* spp.
Columbine, Chapline	*Aquilegia chrysantha* var. *chaplinei*
Coneflower, Pale Purple	*Echinacea pallida*
Cordgrass	*Spartina* spp.
Cordgrass, Gulf	*Spartina spartinae*
Cordgrass, Marshhay	*Spartina patens*
Cordgrass, Smooth	*Spartina alterniflora* var. *glabra*
Coreopsis	*Coreopsis basalis*
Cottontop, Arizona	*Digitaria california*
Cupgrass, Texas	*Eriochloa sericea*
Curlymesquite, Common	*Hilaria belangeri*
Daisy, Engelmann	*Engelmannia pinnatifida*
Dalea	*Dalea* spp.
Deathcamas, Mountain	*Zigadenus elegans*
Dropseed, Sand	*Sporobolus cryptandrus*
Dropseed, Silveanus	*Sporobolus silveanus*
Dropseed, Tall	*Sporobolus asper* var. *asper*
False Rhodesgrass	*Trichloris crinita*
False Rhodesgrass, Multiflowered	*Trichloris pluriflora*
Fern, Cliffbrake	*Pellaeae spp*
Fern, Maidenhair	*Adiantium capillus-veneris*
Fern, Southern Shield	*Thelypteris kunthii*
Flax, Stiffstem	*Linum rigidum*
Galleta	*Hilaria jamesii*
Gamagrass, Eastern	*Tripsacum didactylus*
Gayfeather	*Liatris lancifolia*
Globe-mallow, Scarlet	*Sphaeralcea coccinea* var. *coccinea*
Goldaster, Gray	*Heterotheca canescens*
Grama	*Bouteloua* spp.
Grama, Black	*Bouteloua eriopoda*
Grama, Blue	*Bouteloua gracilis*
Grama, Gyp	*Bouteloua breviseta*
Grama, Hairy	*Bouteloua hirsuta*
Grama, Red	*Bouteloua trifida*
Grama, Sideoats	*Bouteloua curtipendula*
Grama, Texas	*Bouteloua rigidiseta* var. *rigidiseta*
Grama, Warnock	*Bouteloua warnockii*
Indiangrass, Yellow	*Sorghastrum nutans*
Lovegrass	*Eragrostis* spp.
Lovegrass, Mourning	*Eragrostis lugens*
Lovegrass, Red	*Eragrostis secundiflora*
Lovegrass, Sand	*Eragrostis trichodes*
Lovegrass, Weeping	*Eragrostis curvula*
Mentzelia, Gyp	*Mentzelia humilis*
Morning-glory, Soilbind	*Ipomoea pes-caprae*
Muhly	*Muhlenbergia* spp.
Muhly, Bush	*Muhlenbergia porteri*
Muhly, Curlyleaf	*Muhlenbergia setifolia*
Muhly, Gulf	*Muhlenbergia capillaris*
Muhly, Seep	*Muhlenbergia reverchonii*
Needlegrass	*Stipa* spp.
Paspalum, Brownseed	*Paspalum plicatulum*
Paspalum, Fringeleaf	*Paspalum citialifolium*
Paspalum, Gulfdune	*Paspalum monstachyum*
Panicum	*Panicum* spp.
Panicum, Bitter	*Panicum amarum*
Pappusgrass, Pink	*Pappophorum bicolor*
Pickleweed	*Allenrolfea occidentalis*
Pricklypoppy, Mexican	*Argemone mexicana*
Purpletop	*Tridens flavus*
Quillworts	*Isoetes* spp.
Reed, Common	*Phragmites australis*
Rhodegrass, Multiflowered False	*Chloris crinita*
Ricegrass, Pinyon	*Piptochaetium fimbriatum*
Rosemary-mint, Hoary	*Poliomintha incana*
Rush	*Juncus* spp.
Sacaton	*Sporobolus wrightii*
Sacaton, Alkali	*Sporobolus airoides*
Sagewort, Fringed	*Artemisia frigida*
Saltgrass, Coastal	*Distichalis spicata* var. *spicata*
Sandbur	*Cenchrus* spp.
Sandreed, Big	*Calamovilfa gigantea*
Sawgrass	*Cladium mariscus*
Sea-oats	*Uniola paniculata*
Sedge	*Carex* spp.
Sedge, Meade's	*Carex meadii*
Seepweed	*Suaeda* spp.
Snakeweed, Broom	*Gutierrezia sarothrae* var. *squarrosa*
Spikemoss	*Selaginella apoda*
Sprangletop, Green	*Leptochloa dubia*
Squirreltail, Bottlebrush	*Elymus elymoides*
Stonecrop, Nuttall's	*Sedum nuttallianum*
Sunflower	*Helianthus* spp.

Sunflower, Bush	*Simsia calva*
Switchgrass	*Panicum virgatum*
Threeawn	*Aristida* spp.
Threeawn, Purple	*Aristida purpurea* var. *purpurea*
Threeawn, Wright's	*Aristida purpurea* var. *wrightii*
Tobosa	*Pleuraphis mutica*
Wheatgrass, Western	*Elytrigia smithii*
Wintergrass, Texas	*Stipa leucotricha*
Tridens, Hairy	*Erioneuron pilosum*
Tridens, Long-spike	*Tridens strictus*
Tridens, Lovegrass	*Tridens eragrostoides*
Tridens, Slim	*Tridens muticus* var. *muticus*
Tridens, White	*Tridens albescens*
Verbena, Sand	*Abronia* spp.
Vine-mesquite	*Panicum obtusum*
Winecups	*Callirhoe digitata*
Woodoats, Narrowleaf	*Chasmathium sessiliflorum*

Woody Plants

Shrubs

Acacia	*Acacia* spp.
Acacia, Catclaw	*Acacia greggii*
Agarita	*Mahonia trifoliolata*
Amargosa (Allthorn)	*Castela texana*
Anacahuita (Wild Olive)	*Cordia boissieri*
Azalea	*Rhododendron* spp.
Beargrass	*Nolia arenicola*
Beautyberry, American	*Callicarpa americana*
Blackbrush	*Acacia rigidula*
Bumelia	*Bumelia lanuginosa*
Cactus, Strawberry Hedgehog	*Echinocereus stramineus*
Ceniza	*Leucophyllum* spp.
Ceniza (Texas silverleaf)	*Leucophyllum frutescens*
Cholla	*Opuntia* spp.
Cholla, Tree	*Opuntia imbricata*
Ceanothus, Desert	*Ceanothus greggii*
Ceanothus, Fendler	*Ceanothus fendleri*
Coyotillo	*Karwinskia humboldtiana*
Creeper, Virginia	*Parthenochissus quinquefolia*
Creosotebush	*Larrea tridentata*
Elbowbush	*Forestiera pubescens*
Ephedra	*Ephedra* spp.
Ephedra, Torrey	*Ephedra torreyana*
Granjeno	*Celtis pallida*
Grape	*Vitis* spp.
Greenbriar	*Smilax* spp.
Greenbriar, Thorny	*Smilax bona-nox*
Guajillo	*Acacia berlandieri*
Guayacan	*Guaicum angustifolium*
Hawthorn	*Crataegus* spp.
Lechuguilla	*Agave lechuguilla*
Lotebush	*Zizyphus obtusifolia*
Mimosa, Black	*Mimosa pigra*
Mimosa, Catclaw	*Mimosa aculeaticarpa*
Mockorange	*Philadelphus* spp.
Mockorange, Canyon	*Philadelphus ernestii*
Mahogany, True Mountain	*Cercocarpus montanus*
Ninebark, Mountain	*Physocarpus monogynus*
Ocotillo	*Fouquieria splendens*
Olive, Russian	*Elaeagnus angustifolia*
Palmetto, Texas	*Sabal mexicana*
Pricklyash, Lime (Colima)	*Zanthoxylum fagara*
Pricklypear	*Opuntia* spp.
Pricklypear, Texas	*Opuntia lindheimeri*
Privet, Chinese	*Ligustrum sinense*
Sagebrush, Sand	*Artemisia filifolia*
Saltbush, Fourwing	*Atriplex canescens*
Saltcedar	*Tamarix* spp.
Sassafras	*Sassafras albidum*
Silktassel	*Garrya wrightii*
Snowbell, Texas	*Styrax texana*
Soapberry, Western	*Sapindus saponaria*
Sotol	*Dasylirion* spp.
Sumac	*Rhus* spp.
Sumac, Skunkbush	*Rhus aromatica* var. *flabelliformis*
Tarbush	*Flourensia cernua*
Tasajillo	*Opuntia leptocaulis*
Wax-myrtle	*Morella* spp.
Willow, Sandbar	*Salix exigua*
Wolfberry	*Lycium berlandieri*
Yaupon	*Ilex vomitoria*
Yucca	*Yucca* spp.
Yucca, Narrowleaf	*Yucca glauca* var. *glauca*
Yucca, Pale	*Yucca pallida*
Yucca, Soaptree	*Yucca elata*

Trees

Ash	*Fraxinus* spp.
Ash, Carolina	*Fraxinus caroliniana*
Ash, Green	*Fraxinus pennsylvanica*
Ash, Mexican	*Fraxinus berlandieriana*
Ash, Texas	*Fraxinus texensis*
Ash, Velvet	*Fraxinus velutina*
Aspen, Quaking	*Populus tremuloides*
Baldcypress	*Taxodium distichum*
Basswood, Carolina	*Tilia caroliniana*
Beech, American	*Fagus grandifolia*
Birch, River	*Betula nigra*
Blackgum	*Nyssa sylvatica*
Boxelder	*Acer negundo*
Brasil (Bluewood)	*Condalia hookeri*
Buckeye, Ohio	*Aesculus glabra*
Cherry, Escarpment Black	*Prunus serotina* var. *exima*
Cottonwood	*Populus* spp.
Cottonwood, Eastern	*Populus deltoides*
Cottonwood, Rio Grande	*Populus deltoides ssp. wislizenii*
Cypress, Arizona	*Cupressus arizonica*
Douglas-fir	*Pseudotsuga menziesii* var. *glauca*
Ebony, Texas	*Pithecellobium flexicaule*
Elm	*Ulmus* spp.
Elm, American	*Ulmus americana*
Elm, Cedar	*Ulmus crassifolia*
Elm, Slippery	*Ulmus rubra*
Hackberry	*Celtis* spp.
Hackberry, Sugar	*Celtis laevigata*
Hickory	*Carya* spp.

Hickory, Black	*Carya texana*
Hickory, Water	*Carya aquatica*
Holly	*Ilex* spp.
Huisache	*Acacia minuata*
Juniper	*Juniperus* spp.
Juniper, Alligator	*Juniperus deppeana*
Juniper, Ashe	*Juniperus ashei*
Juniper, One-seeded	*Juniperus monosperma*
Juniper, Redberry	*Juniperus pinchotii*
Kidneywood	*Eysenhardtia texana*
Madrone, Texas	*Arbutus xalapensis*
Mangrove, Black	*Avicennia germinans*
Maple, Bigtooth	*Acer grandidentatum*
Maple, Red	*Acer rubrum*
Mesquite	*Prosopis* spp.
Mesquite, Honey	*Prosopis glandulosa*
Mountain Laurel, Texas	*Sophora secundiflora*
Mountain Mahogony	*Cercocarpus montanus*
Oak	*Quercus* spp.
Oak, Blackjack	*Quercus marilandica*
Oak, Bur	*Quercus macrocarpa*
Oak, Chinkapin	*Quercus muehlenbergii*
Oak, Gray	*Quercus grisea*
Oak, Havard	*Quercus havardii*
Oak, Lacey	*Quercus laceyi*
Oak, Laurel	*Quercus laurifolia*
Oak, Mohr (Shinnery)	*Quercus mohriana*
Oak, Overcup	*Quercus lyrata*
Oak, Plateau Live	*Quercus fusiformis*
Oak, Post	*Quercus stellata*
Oak, Shumard	*Quercus shumardii*
Oak, Southern Live	*Quercus virginiana*
Oak, Southern Red	*Quercus falcata*
Oak, Swamp Chestnut	*Quercus michauxii*
Oak, Texas (Buckley)	*Quercus buckleyi*
Oak, Vasey	*Quercus vaseyana*
Oak, Water	*Quercus nigra*
Oak, Wavyleaf	*Quercus pauciloba*
Oak, White	*Quercus alba*
Oak, Whiteleaf	*Quercus hypoleucoides*
Oak, White Shin	*Quercus sinuata*
Oak, Willow	*Quercus phellos*
Paloverde, Texas	*Parkinsonia texana*
Pecan	*Carya illinoensis*
Persimmon	*Diospyros* spp.
Persimmon, Texas	*Diospyros texana*
Pine	*Pinus* spp.
Pine, Arizona	*Pinus ponderosa* var. *arizonica*
Pine, Mexican Pinyon	*Pinus cembroides*
Pine, Papershell Pinyon	*Pinus remota*
Pine, Pinyon	*Pinus edulis*
Pine, Ponderosa	*Pinus ponderosa*
Pine, Loblolly	*Pinus taeda*
Pine, Longleaf	*Pinus palustris*
Pine, Shortleaf	*Pinus echinata*
Pine, Southwestern White	*Pinus strobiformis*
Plum	*Prunus* spp.
Plum, Chickasaw	*Prunus angustifolia*
Poplar, Black	*Populus nigra*
Redbay	*Persea borbonia*
Red Cedar, Eastern	*Juniperus virginianus*
Saltcedar	*Tamarix ramosissima*
Saltcedar, French	*Tamarix gallica*
Sweetbay, Southern	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Sycamore, American	*Plantanus americanus*
Tallow Tree, Chinese	*Sapium sebiferum*
Tupelo	*Nyssa* spp.
Tupelo, Water	*Nyssa aquatica*
Walnut, Little (Texas)	*Juglans microcarpa*
Willow	*Salix* spp.
Willow, Black	*Salix nigra*
Willow, Desert	*Chilopsis linearis*
Willow, Sandbar	*Salix exigua*

Animals

Aquatic and Marine Animals

Alligator, American	*Alligator mississippiensis*
Bass, Guadalupe	*Micropterus treculi*
Bass, Largemouth	*Micropterus salmoides*
Blindcat, Widemouth	*Satan eurystomus*
Catfish, Channel	*Ictalurus punctatus*
Catfish, Headwater	*Ictalurus lupus*
Crab, Blue	*Callinectes sapidus*
Darter, Rio Grande	*Etheostoma grahami*
Drum, Black	*Pogonias cromis*
Drum, Red	*Sciaenops ocellatus*
Flounder, Southern	*Paralichthys lethostigma*
Gambusia, Pecos	*Gambusia nobilis*
Minnow, Devils River	*Dionda diaboli*
Minnow, Plains	*Hybognathus placitus*
Oyster, Eastern	*Crassostrea virginica*
Perch, Rio Grande	*Cichlasoma cyanoguttatum*
Pintail, Northern	*Anas acuta*
Pupfish, Comanche Springs	*Cyprinodon elegans*
Seatrout, Spotted	*Cynoscion nebulosus*
Sea Turtle, Hawksbill	*Eretmochelys imbricata*
Shiner, Arkansas River	*Notropis girardi*
Shiner, Proserpine	*Cyprinella proserpina*
Shrimp, Brown	*Penaeus aztecus*
Shrimp, Pink	*Penaeus duorarum*
Shrimp, White	*Penaeus setiferus*
Sunfish	*Lepomis* spp.
Teal, Green-winged	*Anas crecca*
Trout, Rainbow	*Salmo gairdneri*
Turtle, Soft-shelled	*Apalone* spp.
Widgeon	*Anas americana*

Terrestrial Animals

Antelope, Blackbuck	*Antelope cervicapra*
Aoudad (Barbary Sheep)	*Ammotragus lervia*
Armadillo	*Dasypus novemcinctus*
Badger	*Taxidea taxus*
Bat, Mexican Free-tailed	*Tadarida brasiliensis*

Bear, Black	*Ursus americanus*
Bison, American	*Bison bison*
Black-hawk, Common	*Buteogallus anthracinus*
Boar, Wild	*Sus scrofa*
Bobcat	*Lynx rufus*
Bobwhite, Northern	*Colinus virginianus*
Chipmunk, Gray-footed	*Tamias canipes*
Civet	*Bassariscus astutus*
Cougar	*Puma concolor*
Cowbird, Brown-headed	*Molothrus ater*
Coyote	*Canis latrans*
Crane, Sandhill	*Grus canadensis*
Crane, Whooping	*Grus americana*
Deer, Axis	*Cervus axis*
Deer, Fallow	*Cervus dama*
Deer, Mule	*Odocoileus hemionus*
Deer, Sika	*Cervus nippon*
Deer, White-tailed	*Odocoileus virginianus*
Dove, Mourning	*Zenaida macroura*
Dove, White-winged	*Zenaida asiatica*
Duck, Redhead	*Aythya americana*
Elk	*Cervus elaphus*
Eagle, Golden	*Aquila chrysaetos*
Ferret, Black-footed	*Mustela nigripes*
Flycatcher, Scissor-tailed	*Tyrannus forficatus*
Fox, Swift	*Vulpes velox velox*
Fox, Kit	*Vulpes velox macrotis*
Fox, Swift	*Vulpes velox*
Gopher, Llano Pocket	*Geomys texensis*
Hawk, Ferruginous	*Buteo regalis*
Hawk, Swainson's	*Buteo swainsoni*
Jackrabbit, Black-tailed	*Lepus californicus*
Jay, Mexican	*Aphelocoma ultramarina*
Kite, Mississippi	*Ictinia mississippiensis*
Lion, Mountain	*Puma concolor*
Lizard, Checkered Whiptail	*Cnemidophorus tesselatus*
Lizard, Greater Earless	*Cophosaurus texanus scitulus*
Lizard, Little-striped Whiptail	*Cnemidophorus inornatus*
Lizard, Round-tailed Horned	*Phrynosoma modestum*
Lizard, Side-blotched	*Uta stansburiana*
Lizard, Texas Horned	*Phrynosoma cornutum*
Mink, Large Brown	*Lutreola lutreocephala*
Muskrat	*Ondatra zibethicus*
Ocelot	*Leopardus pardalis*
Owl, Burrowing	*Athene cunicularia*
Peccary, Collared (Javelina)	*Pecari tajacu*
Plover, Mountain	*Charadrius montanus*
Porcupine	*Erithizon dorsatum*
Prairie-Chicken, Lesser	*Tympanuchus pallidicinctus*
Prairie Dog, Black-tailed	*Cynomys ludovicianus*
Pronghorn	*Antilocapra americana americana and Antilocapra americana mexicana*
Quail, Montezuma	*Cyrtonyx montezumae*
Racoon, Common	*Procyon lotor*
Rat, Kangaroo	*Dipodomys* spp.
Rattlesnake	*Crotalus* spp.
Redstart, Painted	*Myioborus pictus*
Roadrunner, Greater	*Geococcyx californianus*
Salamander, Blanco Blind	*Typhlomolge robusta*
Salamander, Comal Blind	*Eurycea tridentifera*
Sheep, Desert Bighorn	*Ovis canadensis mexicana and Ovis canadensis nelsoni*
Snake, Texas Indigo	*Drymarchon corais erebennus*
Sparrow, Black-throated	*Amphispiza bilineata*
Squirrel	*Sciurus* spp.
Squirrel, Eastern Fox	*Sciurus niger*
Squirrel, Eastern Gray	*Sciurus carolinensis*
Tarantula	*Aphonopelma* spp.
Toad, Houston	*Bufo houstonensis*
Turkey, Eastern Wild	*Meleagris gallopavo silvestris*
Turkey, Rio Grande Wild	*Meleagris gallopavo intermedia*
Turkey, Wild	*Meleagris gallopavo*
Vireo, Black-capped	*Vireo atricapillus*
Warbler, Colima	*Vermivora crissalis*
Warbler, Golden-cheeked	*Dendroica chrysoparia*
Wolf, Gray	*Canis lupus*
Wolf, Plains Gray	*Canis lupus monstrabilis*
Wolf, Red	*Canis rufus*
Woodpecker, Red-cockaded	*Picoides borealis*