United States
Department of
Agriculture

Forest Service

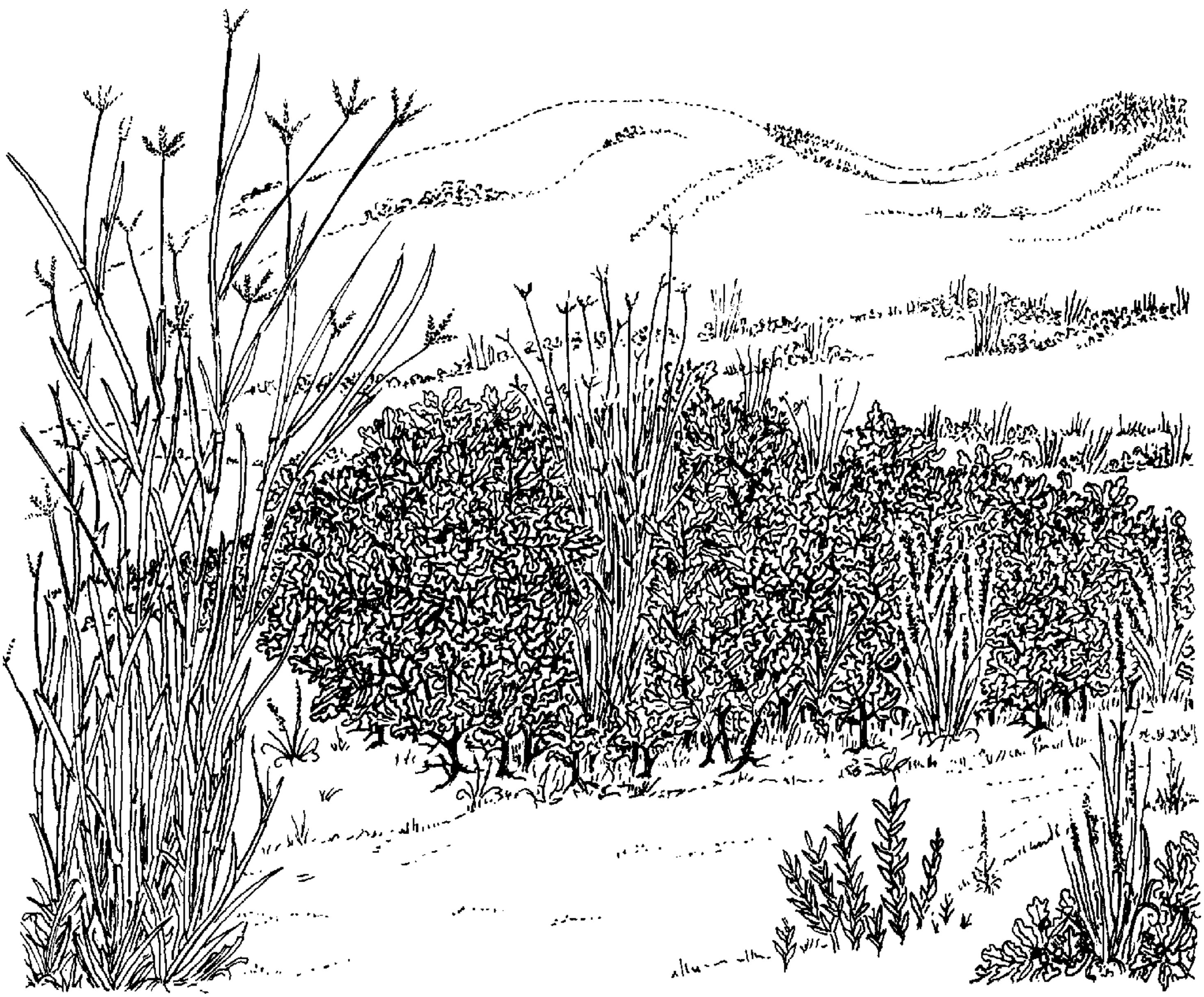
**Rocky Mountain
Research Station**

Fort Collins,
Colorado 80526

**General Technical
Report RMRS–GTR–16**

Ecology and Management of Sand Shinnery Communities: A Literature Review

Roger S. Peterson and Chad S. Boyd



Abstract

Peterson, Roger and Chad S. Boyd. **Ecology and management of sand shinnery communities: a literature review.** Gen. Tech. Rep. RMRS-GTR-16. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 44 p.

Sand shinnery is codominated by oak shrubs and mid and tallgrasses; the grasses are usually taller than the oaks. The shrubs are the small, visible shoots of massive underground stem systems, which are hundreds or thousands of years old. Sand shinnery occupies 5 to 7 M acres in western Oklahoma, western Texas, and southeastern New Mexico. This area is a decrease from the original due to land clearing for agriculture and eradication of oak to improve livestock-grazing. Oak control is controversial because it can open sandy soils to wind erosion and can conflict with wildlife-habitat quality. Of special concern are the lesser prairie-chicken and the sand dune lizard, which are heavily dependent on shinnery vegetation. This review of climate, soils, vegetation, ecosystem dynamics (including responses to drought and fire), wildlife and hunting, livestock grazing, and oak control in the sand shinnery provides managers with a knowledge-base for decision-making and points to areas where research is needed.

Keywords: sand shinnery, *Quercus havardii*, drought, fire, livestock grazing, brush control, wildlife, lesser prairie-chicken, sand dune lizard

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Publisher

Rocky Mountain Research Station

Fort Collins, Colorado

August 1998

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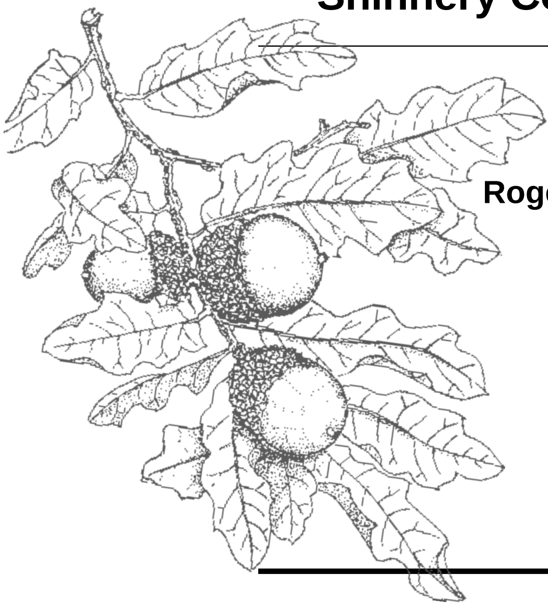

Roger S. Peterson and Chad S. Boyd

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Acknowledgments

Two longtime shinnery researchers helpfully shared their knowledge: E. P. McIlvain, retired supervisor of research, Southern Great Plains Field Station, Agricultural Research Service (Woodward, OK), and R. D. Pettit, retired professor of range management, Texas Tech University (Lubbock). James Zimmerman, research entomologist retired from The Smithsonian Institution provided information on shin-oak gall insects. W. A. Dick-Peddie, professor of biology at New Mexico State University, provided information on historical surveys of shinnery distribution. Calvin Smith, director of the Strecker Museum, Baylor University (Waco, TX) gave information on the New Mexico shinnery and provided figures 6 and 13. The New Mexico Department of Game and Fish provided figures 11 and 14. D. A. Swepston, district leader of the Wildlife Division, Texas Parks and Wildlife Department (Canyon, TX), provided information on mammals and hunting in Texas. Gesina (Niki) Threlkeld kindly created the drawings. The authors are also grateful to T. G. Bidwell (Oklahoma State University) and D. G. Brockway (Rocky Mountain Research Station) for review comments that improved the manuscript, and to Dale Brockway and Deborah Finch (Rocky Mountain Research Station) for facilitating publication of the review.

Introduction

Sand shinnery communities comprise the nation's largest stand of oak and occupy 5 to 7 M acres of the southern Great Plains, extending from northern Texas and western Oklahoma southward into Chihuahuan Desert scrubland. The stand is made up of ancient plants, most of them hundreds or thousands of years old.

This oak forest is only 1 to 4 ft tall. The visible shrubs are mostly the short-lived twigs of massive underground stem systems, which slowly spread under areas up to 2 acres or more. The oaks codominate the community with mid and tallgrasses that are usually taller than themselves.

Sand shinnery is defined by shin-oak (*Quercus havardii* Rydb.), also called Havard oak, midget oak, and sand shinnery oak. Shin and shinnery are Louisiana French from chêne and chênière, which mean oak and oak woodland. Other shinneries cover millions of acres from Louisiana to central Texas and Oklahoma, but they are dominated by oak species that are small trees, rather than codominated by oak-shrubs and grasses as is sand shinnery.

Management of this grass-oak mix is difficult and controversial. This review assembles what is known about sand shinnery communities as part of the search for rational management.

Ecology

Historical Accounts

Historical observation of the sand shinnery comes from nineteenth-century travellers. Josiah Gregg (1844) described a camp on his 1839 journey from Fort Smith, Arkansas, to Santa Fe, New Mexico, as follows:

> ...we encamped in a region covered with sandy hillocks, where there was not a drop of water to be found: in fact, an immense sand-plain was now opening before us,...being entirely barren of vegetation in some places, while others were completely covered with an extraordinarily diminutive growth which has been called *shin-oak*, and a curious plum-bush of equally dwarfish stature. These singular-looking plants (undistinguishable at a distance from the grass of the prairies) were heavily laden with acorns and plums, which, when ripe, are of considerable size, although the trunks of either were seldom thicker than oat-straws, and frequently not a foot high. We also met with the same in many other places on the Prairies.

In 1845, Lt. J. W. Abert (1846) recorded along the Washita that "...the uplands were thickly spread over by diminutive species of oak commonly called shin-oak, not exceeding 2 ft in height. We occasionally saw clumps of oak of greater size." In 1854, R. B. Marcy described a landscape encountered in present-day Beckham County, Oklahoma:

> ...the country we traversed was exceedingly monotonous and uninteresting being a continuous succession of barren sand-hills, producing no other herbage than the artemisia, and a dense growth of dwarf oak bushes, about eighteen inches high, which seem to have attained their full maturity, and bear an abundance of small acorns. The same bush is frequently met with upon the Canadian river, near this longitude, and is always found upon very sandy soil.

To the south, Valery Havard (1885), an army physician, described the sand hills country of the Pecos River area of Texas from visits in the early 1880s. He found only 4 shrubs: mesquite, catclaw acacia, Southwest rabbitbrush, and shin-oak, which he thought to be close to *Quercus undulata* variety *Jamesii*, "spreading into a low thicket, with shallow, strongly tuberculated cups and very large, edible acorns." Of *Quercus undulata*, "several of the smaller forms (Shin Oak) produce edible acorns,...very large in the Sand Hills, which are eaten by Mexicans, raw or baked. They afford excellent mast to hogs in the vicinity of settlements" (Havard 1885). Rydberg (1901) described *Quercus havardii* from one of Havard's collections. Long before the Mexicans, shin-oak acorns were used by the Querecho, Maljamar, and Ochoa phases of the Jornada Mogollon culture, and more recently by the Apaches (Beckett 1976).

Older ranchers remember when the shinnery was dominated by tallgrass. Although oaks were inconspicuous, we deduce from the ages of today's oaks that they were present (Osborn 1942). Probably the invasion and increase reported for shin-oak is the result of the changing appearance of the shinnery due to overgrazing and disappearance of tallgrasses and perhaps to an increase in the height of shin-oak due to fire suppression.

Geographical Distribution

Sand shinnery occurs on sandy soils in western Oklahoma, northern and western Texas, and southeastern New Mexico (figure 1). Scattered populations are also in southern Utah and adjacent Arizona (Welsh et al. 1993). Disagreements about acreage of the sand shinnery are striking. Gribble (1981) and McIlvain and Armstrong (1959) think that there are about 15 M acres; McArthur and Ott (1996) estimate 6,400,000 acres. Other estimates are made by Allred (1949), Deering and Pettit (1972), and Scifres (1972). Duck and Fletcher (1944) estimate 750,000 acres in Oklahoma. The Texas brush inventory of 1982 included 2.5 M acres of shinnery in that state, 920,000 of them with an oak canopy less than 11% (USDA SCS 1987). Garrison and McDaniel (1982) estimate 2,640,000 acres in New Mexico. Considering all sources we estimate that historically there were about 1 M acres in Oklahoma, 3.5 M in Texas, and 1.5 M in New Mexico; about one-third of this acreage in each state had a light or scattered oak canopy. If the exceptional figures from Duck and Fletcher, the Texas brush inventory, and Garrison and McDaniel are correct, our estimates may be high in Oklahoma and Texas and low for New Mexico. These acreages comprise about 2% of the area of each of the 3 states. Of these areas, more than 100,000 acres in Oklahoma, almost 1 M in Texas, and an unknown, smaller acreage in New Mexico have been converted to cropland or grassland (Deering and Pettit 1972). Also, 100,000 acres in New Mexico have been treated with herbicide in the past 15 yrs and it is too soon to tell how many of these acres will come back as shinnery. Recent advances in the ability to distinguish shinnery by remote sensing will enable more accurate estimates of its distribution (Everitt et al. 1993, Middleton et al. 1987).

The shinnery has existed for thousands of years (Beckett 1976, Hafsten 1961). It was believed that the shinnery in New Mexico had expanded considerably in historical times (New Mexico Inter-Agency Range Committee 1970, York and Dick-Peddie 1969). However, mid nineteenth-century survey records and present-day boundaries of the shinnery are remarkably similar (Gross and Dick-Peddie 1979, W. A. Dick-Peddie personal communication 1988). The shinnery range has not increased perceptibly in recent years (McIlvain 1954); in fact, it has decreased, due to oak-control efforts and conversion to cultivation. Dhillion et al. (1994) consider the community highly threatened in Texas, as do Bailey and Painter (1994) for shinnery habitat in New Mexico.

Extension of a mid and tallgrass prairie southwestward through shortgrass plains into the northern Chihuahuan Desert has been explained by Weaver and Clements (1938) as survival of a relict of wetter times. Deep sands developed in certain topographic positions during the post-Pleistocene drying of the southern Great Plains (Huffington and Albritton 1941). Weaver and Clements regard the compensatory influence of sand as responsible for the survival of the shinnery, which they call a postclimax community.

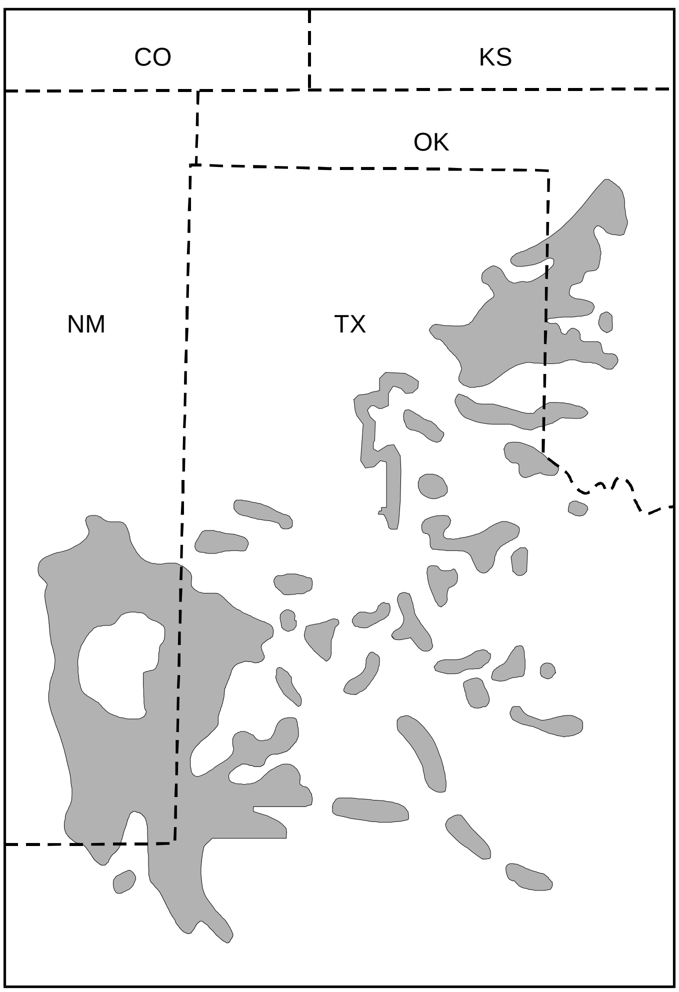


Figure 1. Distribution of sand shinnery in New Mexico, Texas, and Oklahoma. There are also small outlying stands in these states and in Arizona and Utah. The total distribution area of sand shinnery is estimated at 5 to 7 M acres.

Plant Composition

Sand shinnery is always codominated by shrubs and grasses; usually there is also a fairly rich mix of forbs and nondominant grasses. See the appendix for species from 3 areas and scientific names.

Shin-oak occurs as the dominant shrub in shinnery or codominates with sand sagebrush. Broom snakeweed, a half-shrub, is also widespread in the shinnery, as are mesquite and the less common lotebush, netleaf hackberry, and soapberry (chinaberry). In the south, additional shrubs of the shinnery are catclaw acacia, catclaw mimosa, Southwest rabbitbrush, javelina bush, and vine ephedra (Holland 1994, Martin 1990, Sullivan 1980). In the Texas Panhandle and Oklahoma sand plum, Oklahoma plum, prairie baccharis, wolfberry, and skunkbush occur in shinnery, while post oak and eastern red cedar may occur on the eastern fringe (Sullivan 1980, Wiedeman 1960, Boyd 1997 unpublished data). On sands with shallow water sources (for instance, the dunes of Chaves

County, New Mexico) tree poplars and shrub willows occur with shin-oak. On sands near flowing water Goodding's willow and saltcedar may be interspersed with shin-oak. Succulents in sand shinnery include yuccas, pricklypears, and, in the south, barrel cacti (Martin 1990, Smith 1971, Sullivan 1980).

The prominence and composition of grasses in shinnery are affected by grazing (Holland 1994, Sullivan 1980, Wolfe1978). The appearance of ungrazed shinnery may be that of mixed tall and midgrass prairie in which grasses hide the oak shrubs (Brown 1982, Duck and Fletcher 1944), but some mid nineteenth-century descriptions (previously quoted) differ with this description.

Grasses and sedges of the shinnery have been described by many authors (Deering 1972, Dickerson 1985, Jones 1963, Martin 1990, Sullivan 1980, Test 1972). Tallgrasses throughout the shinnery, especially on dunes and other deep sands, include sand bluestem, big bluestem, switchgrass, and giant dropseed. Havard panicum is common in the south; giant sandreed and Indiangrass are common east of New Mexico. Of midgrasses, little bluestem and sand dropseed are common throughout the shinnery and, over considerable areas, are the most prominent grasses. Other widespread midgrasses include spike and mesa dropseeds, fall witchgrass, sand paspalum, plains bristlegrass, side-oats grama, cane bluestem, and red and sand lovegrasses. Short grasses include blue, black, and hairy gramas, sandbur, windmillgrasses, false buffalograss, and three-awns. Schweinitz and one-flower flatsedges dominate the sedge component.

Dominant forbs of the shinnery include annual buckwheat, annual sunflower, and western ragweed (Pettit 1994, Sullivan 1980, Boyd 1997 unpublished data). Other common, widespread forbs are the composites prairie coneflower, camphorweed, false dandelion, gaillardias, gray greenthread, yellow woollywhite, false boneset, palafoxia, greeneyes, cowpen daisy, fleabanes, and woolly paperflower; the legumes woolly dalea, sensitive brier, rushpeas, and prairieclovers; spurge family members queen's-delight, Texas croton, sand reverchonia, and several spurges, and members of other families including erect dayflower, prairie spiderwort, tumble ringwing, snakecotton, James nailwort, snowballs (sandverbena), linear-leaved four-oclock, carpetweeds, portulacas, spectaclepod, flaxes, globemallows, scarlet and woolly gauras, evening primroses, milkweeds, James cryptantha, bindweed heliotrope, woolly plantain, blue sage, and mat bluets (Martin 1990, Sullivan 1980).

Ecological Classification

Sullivan (1980) and Pettit and Sullivan (1981) recognized 3 community types within the shinnery in 6 Texas counties, from Bailey County in the north through Winkler County in the south. Type A is on actively moving sand dunes in Winkler and Andrews counties and comprises 3 mapping units: 1) shin-oak/Havard panicum-giant sandreed, with canopy cover usually less than 5%; 2) shin-oak/Havard panicum-giant dropseed, with canopy cover from 10% to 50%; and 3) shin-oak/giant dropseed-Havard panicum on more stable sand, with plant cover from 50% to 80%. Type B, in all 6 counties, is on sands with slopes up to 30% and with higher percentages of silt, clay, and organic matter in the soil surface layer than in type A. It comprises 2 mapping units: 1) shin-oak/sand dropseed-giant dropseed (figure 2) and 2) shin-oak/giant dropseed. The oak is most vigorous in the latter unit, sometimes almost eliminating associated plants due to the effects of shading and moisture competition. Type C, in all 6 counties, is characterized by honey mesquite. The amount of honey mesquite varied in the 3 mapping units from an average of 6 to 65 mesquite plants per acre; the greater number was on finer-textured soils.

Figure 2. Giant dropseed dominates most of the southernmost sand shinnery communities.

Working in Cochran and Yoakum counties, Texas, Roebuck (1982) distinguished 2 subtypes within Sullivan's type B: 1) oak/grass, with an almost continuous cover of shin-oak to 30 inches tall, with threeawns and sand dropseed and seasonal abundance of false-buffalograss and purple sandgrass; 2) sage/oak, similar to oak/grass but with more sandsage and slightly more grass and forbs.

Martin (1990) classified shinnery vegetation of 4 southeastern New Mexico counties. He recognized 8 distinct communities and 3 outlier communities of limited area. Overall, plant community composition was relatively simple. Shin-oak, yucca, purple three-awn, fall witchgrass, and sand dropseed were in 80% or more of Martin's 149 10-by-20 m plots. An additional 15 species were present in 20% or more of the plots. Major community types included: 1) active duneland, 2) mesquite/shin-oak/hairy grama-purple three-awn, 3) mesquite/shin-oak/purple three-awn-sand dropseed, 4) shin-oak/purple three-awn-fall witchgrass (most common and widespread, in 65 plots), 5) shin-oak/little bluestem-sand bluestem (figure 3), 6) shin-oak/snakeweed/little bluestem-purple three-awn, 7) shin-oak/purple three-awn-sand dropseed, and 8) shin-oak/purple three-awn-sand bluestem.

Figure 3. Little bluestem dominates northern sand shinnery communities, but in this scene most grasses have been removed by livestock grazing.

Figure 4. On dune sands, shin-oak often grows in almost pure stands.

Ahlborn (1980), working in southern Roosevelt and northern Lea counties, New Mexico, delineated 3 subdivisions of the shinnery: 1) shin-oak/sand bluestem-little bluestem, in which bluestems accounted for nearly 40% of all grasses, which he regarded as in good to excellent range condition; 2) shin-oak/midgrass that largely lacked bluestems and had a high abundance of gramas, dropseeds, and three-awns, which he regarded as in poor to fair range condition having lost much of its climax vegetation to heavy grazing by cattle, and 3) sandhills, dominated by shin-oak with few grasses, with range condition fair to good (figure 4).

At least 39 county soil surveys by the Soil Conservation Service (SCS; now the Natural Resources Conservation Service) treat the sand shinnery. They describe the supposed potential natural vegetation of each range site (soil types that support similar plant communities). The SCS descriptions discuss soils and vegetation dynamics, addressed in sections below. However, 9 Oklahoma surveys (for instance Burgess et al. 1963, Ford et al. 1980, Nance et al. 1963) provide the only classification of shinnery for that state. They differentiate 2 range sites, deep sand and deep sand savanna, both dominated by shin-oak and mid and tallgrasses including sand and little bluestem, switchgrass, Indiangrass, and sand lovegrass. The main difference between these 2 sites is the higher clay content of the subsoil on deep sand savanna that increases water-holding capacity and promotes better water relations in dry years.

Shin-oak and Its Hybrids

Quercus havardii, a member of the white oak group, is the defining plant of the shinnery. In its genetically pure form, shin-oak is a low shrub with up to 100 or more short aerial shoots from a massive underground stem system and a deep root system (figure 5; Pettit 1986, USDI BLM 1979). The underground stems are commonly 1 to 4 inches in diameter, some "... are as big in diameter as a man's thigh; these may occur on plants with above-ground portions no more than 2 ft tall and with individual stems not thicker than a pencil" (McIlvain 1954). The underground stems are mostly horizontal (figure 6) and are mostly within 1 or 2 ft from the surface (Bóo and Pettit 1975, Galbraith 1983, Wiedeman 1960). Sears (1982, Sears et al. 1986a) found 73% by weight of the "roots" in the top 30 cm of soil. Where shifting dunes have built up and caused additional layers of stems to be added, the stem system may be 30 ft or more deep (Peterson personal observations).

In the Texas Panhandle, Sears et al. (1986a) found growing-season above-ground biomass in shinnery to be 2,004 kg/ha, with oak comprising 1,821 kg/ha and herbaceous plants 183 kg/ha. They reported below-ground growing-season biomass as 19,841 kg/ha for oak and 1,394 kg/ha for herbaceous plants. Pettit (1986) found the ratio of underground to above-ground tissues in shin-oak to be 10:1 to 16:1, perhaps greater than for any other American shrub. From level ground the vertical root system penetrates 15 to 20 ft below the surface (McIlvain 1954). The above-ground shoots, mostly 1 to 2.5 ft tall (up to twice as tall in Oklahoma), may grow densely; Jones (1982) found 30 m^{-2} in Cochran County, Texas, and Zhang (1996) measured from 32 to 75 m^{-2} in Yoakum County, Texas. Pettit (1986) found 11 to 15 yrs to be a usual lifespan for above-ground shoots though Muller (1951a) found no shoots older than 11 yrs and Wiedeman (1960) found that the smaller shrubs attain ages of only 1 to 5 yrs or 10 to 12 yrs in drier regions.

Figure 5. Shifting sands have exposed a small shin-oak (*Quercus havardii*).

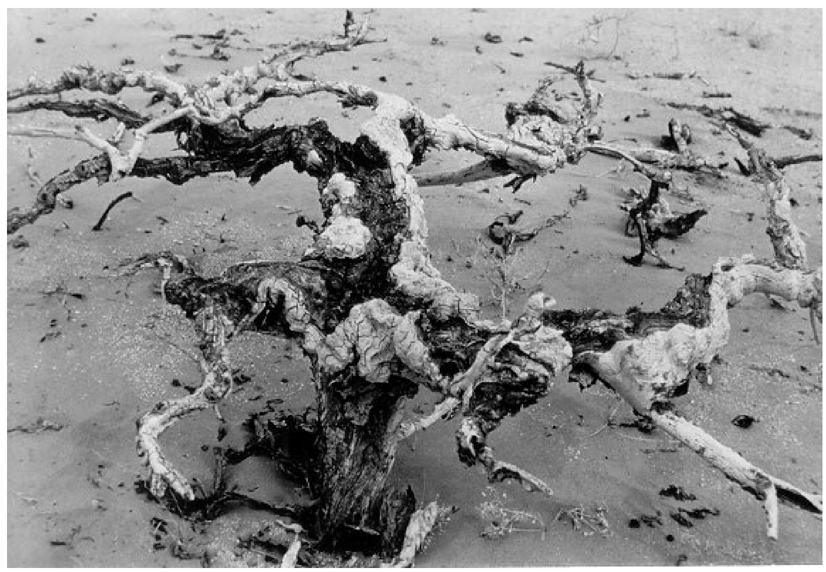


Figure 6. These exposed horizontal shin-oak stems measure to 8 inches in diameter.

The underground stems commonly spread to form plants 10 to 50 ft or more in diameter (Muller 1951a). Using electrophoresis of enzymes to distinguish individuals, Mayes (1994) studied the extent of single plants in a 40,000 m^2 plot in Yoakum County, Texas. He found 56 clones in the plot, but a few large individuals dominated. He estimated the largest clone at 7,000 m^2, equivalent to a square 84 m or 274 ft on a side, about 1.7 acres. "Age has no significance to an individual of this species except that it offers greater opportunity to spread and multiply by fracture. Senescence is limited to individual areal shoots; the entire clone is characterized by continuous rejuvenation" (Muller 1951a). Muller's suggestion of multiplication by fracture for these shrubs remains unconfirmed. The few excavations, for instance by Bóo and Pettit (1975), suggest that the underground system remains intact. Mayes' (1994) data on this point are equivocal; his sampling technique found some evidence for fractured individuals. In species where fracturing occurs so that the original plant (genet) produces many individuals (ramets) vegetatively, single clones are reported to cover up to 81 hectares (205 acres) and to achieve ages over 13,000 yrs (Cook 1985) and maybe 43,000 yrs (Anonymous 1997); maximal extent and age of shin-oak are unknown.

No measurements are available for normal lateral growth rates of the oaks. McIlvain (1954) reports, "Old fields cultivated around 1900 and then abandoned after a few years of cultivation have often returned to solid stands of grass even though dense stands of shinnery oak surround the fields on all sides;" that is, there was no expansion of oaks adjacent to the fields. Exceptionally, from the edge of abandoned fields, oaks spread up to 30 ft in 50 yrs (Sikes and Pettit 1980).

Quercus havardii hybridizes with other oak species, giving rise to distinct growth forms that are important in shinnery ecology (Muller 1952, Wiedeman and Penfound 1960). Small populations of *Q. havardii* var. *tuckeri* in southeastern Utah and adjacent Arizona (Tucker 1961, Welsh et al. 1993) are similar to larger populations of *Q. havardii* in morphology and ecology; *Q. X eastwoodiae* is thought to be its hybrid with *Q. gambelii* (Welsh et al. 1993). On rocky slopes at the breaks of the Texas Plains, *Q. havardii* hybridizes with the scrub oak *Q. mohriana* (Muller 1952). The resulting low shrubs have characteristics intermediate between the parents except that leaves are larger than those of either parent species. The parent species are ecologically separated; *Q. havardii* on deep sands and *Q. mohriana* on exposed limestone (Muller 1952). According to Muller, very dilute hybrids of *Q. havardii* with a few morphological characters of *Q. mohriana* occasionally occur on sand and the reverse on limestone, but the markedly intermediate hybrids are limited to intermediate habitat and the vicinity of both parents (Muller 1951b).

Very different is the hybrid of *Q. havardii* with post oak, *Q. stellata*, whose distribution overlaps *Q. havardii* in western Oklahoma and slightly in the adjacent Texas Panhandle (Muller 1951b, 1952, Correll and Johnston 1970). The hybrids are tall shrubs or small trees up to 20 or more feet high (figure 7); their fruits vary from post oak's small size to the twice-as-large acorns of shin-oak. Post oak, like shin-oak, can grow on sandy soils. Their hybrids are abundant in Oklahoma and the eastern Texas Panhandle, common in northwest Texas, and rare to occasional in New Mexico and the Texas counties near its southeastern corner, far from the post oak parent (Bruner 1931, Muller 1952, Pettit and Kauffman 1978). Great distance from one parental species might indicate that it is the pollen parent, but Muller (1952) thinks it unlikely that pollen was transported 150 mi against prevailing winds. Instead, he speculates that post oak ranged west to New Mexico in wetter times and that the hybrids survive from then. The hybrids share the rhizomatous habit of shin-oak; a "motte" of these taller plants amid the low-growing shin-oak comprises a single plant commonly with 50 to 150 stems (Pettit and Kauffman 1978, Wiedeman and Penfound 1960).

Pettit and Kauffman (1978) studied a motte in the Texas Panhandle of 89 stems of varied ages, the oldest dating from around 1900. They judged that motte to be decadent, with ring growth less than .2 mm/yr and a "heart rot like" condition in stems more than 50 yrs old. They also observed breakup of the horizontal underground system between upright stems; Wiedeman and Penfound (1960) made the same observation in tall mottes. As for shin-oak, no young hybrids have been reported. These taller, hybrid mottes in areas subjected to periodic fire may be due to chance protection and reductions in understory fine fuel as tree height increases. These reductions in fine fuel would decrease the chance of a surface fire spreading through the motte (Wiedeman and Penfound 1960).

Figure 7. A 14-ft shin-oak hybrid stands among 1- to 2-ft shin-oaks.

Soils

Soils of the shinnery are Entisols or Alfisols according to Pettit (1994); Garrison et al. (1977) add Aridsols and "for most of the shinnery ecosystem" Mollisols. Huffington and Albritton (1941), Lotspeich and Coover (1962), and Lotspeich and Everhart (1962) discuss the Pleistocene and post-Pleistocene formation of these soils. The SCS county soil surveys list and describe more than 50 soil types that support shinnery (Pettit 1986). Nearly all are sandy, often fine sands, sometimes with layers of sandy loams or loamy sands. Typical are the Brownfield soils, which occur in all 3 sand shinnery states: the surface horizon of 92% sand, which is yellowish-red to reddish-yellow, is 10 to 40 inches thick and is highly permeable; under it lies a reddish, noncalcareous sandy-clay-loam subsoil that is up to 63 inches deep, up to 40% clay, and only moderately permeable (Dittemore and Hyde 1964, Moldenhauer et al. 1958, Pettit and Deering 1974, Zobeck et al. 1989). Other shinnery soils overlie a hard caliche layer (calcium carbonate accumulation), and effects of lime extend through the subsoil. For instance, the Faskin Series, with a sticky subsoil from 14 to 56 inches deep, has soft masses of calcium carbonate (Lenfesty 1983). Other soils are sandy throughout, lacking clay layers. As the soil clay content increases the oak cover decreases (Pettit 1986). According to Pettit (1978b) soils under shin-oak have distinct, bleached lower A horizons due to the acid content of its leaves.

One report from the Llano Estacado of west Texas (Lotspeich and Everhart 1962) mentions shinnery on a rocky loam not described as sand. These oaks might be the *Quercus havardii-Q. mohriana* hybrids discussed above, which occur in that area. Wiedeman and Penfound (1968) report shinnery on a reddish fine sandy loam and on sandstone in Oklahoma, but regard these as unusual occurrences. Whitford et al. (1986) report shinnery on sandy loams in Eddy County, New Mexico.

Calcium carbonate in shinnery soils increases with depth. Wiedeman and Penfound (1960) concluded that shin-oak does not occur regularly where there is much calcium carbonate in the soil. Small (1975) thought that his study did not support that conclusion, but in fact he did find that the calcium carbonate equivalents of the surface horizons were inversely related to the number of oak stems per unit area. Sullivan (1980) found that when the caliche layer was within a meter of the soil surface, shin-oak was smaller or was replaced by mesquite. Similarly Pettit (1978b) reported that when subsoils are rich in carbonate or clay, sand sagebrush or mimosa dominates.

The permeability of shinnery soils is generally high and water erosion very low. For instance, in Brownfield fine sand, one of the widespread soil types, the A horizon (40 to 70 cm deep) is 95% sand and overlies a sandy clay loam B horizon. Infiltration rates are rapid, up to 70 cm/hr, and percolation is rapid until the B horizon is reached (Sears et al. 1986a). Small (1975) found maximal densities of shin-oak where the soil surface was sand, especially where the sand layer was relatively thick, permitting water infiltration to greater depths. No oak grew on an adjacent sandy loam site dominated by blue grama and underlain by calcium carbonate layers at shallower depths than the sandy sites. Shin-oak density was most negatively correlated with percentage clay, runoff, and water retention at -1/10 and -1/3 bar.

Especially under dune sands, water may perch above less permeable rock or soil layers, affording a source for riparian-type species, including cottonwoods, willows, and saltcedar (tamarisk), which can then grow with shin-oak. Smith (1985) reports coyotes digging to water 30 inches deep in the Mescalero Sands of Chaves and Eddy counties, New Mexico. In the Mescalero Sands, water wells for domestic or livestock use average only 37 ft deep (Smith 1985) where the depth to groundwater varies from 200 to 400 ft (Geohydrology Associates 1978). It is unknown whether shin-oaks on dunes are larger and more vigorous than those on stable sites because their roots reach the perched water or because of the relative lack of competition from other plants on shifting sands.

Nutrient characteristics of soils supporting shinnery have been examined by several authors. Sears et al. (1986b) reported that total nitrogen concentration of the soils supporting shinnery was relatively low at about .017%. Highest concentrations were in the upper 15 cm of the surface and in the B horizon. This bimodal stratification was attributed to nitrogen leaching through the sandy surface horizon. Secor et al. (1983) compared soils that supported shin-oak and sandsage with soils that supported mesquite and javelina bush. They found nitrogen (especially nitrate), phosphorus, calcium, and magnesium levels higher under mesquite and javelina bush. Surface soils under mesquite and javelina bush contained about twice as much organic matter as those under shin-oak-sandsage. Small (1975) reported that shin-oak grew on sandy sites that averaged only .67% organic matter in the surface horizon; shin-oak grew best on sites with an almost pure sand cover.

Near-surface soil pH in shinnery was measured by Kyrouac (1988) at 6.9. In Small's (1975) shinnery plot, pH increased in the A horizon from 7 to 8.1 and in the C horizon from 7.9 to 8.5; pH was only slightly higher on his adjacent sandy loam plot. Wiedeman and Penfound (1960) found lower pH values in soils of shinnery mottes than under shin-oak shrubs, approximating the pH of forest soil types even though rainfall was less than 25 inches/yr.

Sand shinnery soils are highly susceptible to wind erosion (Pettit 1978a, SCS soil surveys). Moldenhauer et al. (1958) reported that newly broken surfaces of Brownfield soils would lose from 150 to 240 tons/acre/yr under a sustained 38 mi/hr wind. Spring fine sands would lose 650 tons, and Tivoli fine sands, which form dunes in shinnery, would lose 1,600 tons. Zobeck et al. (1989) studied erosion in relation to vegetation cover, soil-particle size, and soil nutrients. An early SCS treatment (Goodding 1938) says of the shinnery: "What this region would be without the oak is hard to conjecture. The bushes are seldom more than 2 ft high but the whole country is completely covered and the sand stays put." Similarly Moldenhauer et al. (1958) regard shinnery vegetation as the most reliable protection for Tivoli fine sands (figure 8). Parks (1937) calls shin-oak "the most valuable of all sand binders."

Figure 8. Shin-oak anchors sands.

Phenology

Plant activity in the shinnery occurs from about February through December; winter annuals can begin growth even earlier in the south, although there can be freezing weather into April. The buds of shin-oak swell in early to late March (Pettit 1986, USDI BLM 1979), leaves open mainly in April and May (Bóo and Pettit 1975, Pettit 1975), and flowering occurs in April and May (Rowell 1967). Early-season grasses are few in the southern shinnery, but those few, such as switchgrass and purple three-awn, begin growth in March or April. In western Oklahoma and adjacent Texas, most grass species begin growth in early May while forb growth begins in early April.

In the northern shinnery, grass and forb growth continues from spring through summer. Most grasses of the southern shinnery begin growth following summer rains, which generally begin in early July. Galbraith (1983) followed perennial grass development in Cochran County for 2 yrs. On June 1 he found greenup, on July 15 vegetative growth, on September 1 flowering, and on October 15 senescence. Most forb growth in the south also follows summer rains, especially that of annual forbs, which may be absent or abundant depending on the timing of rainfall (Pettit 1979). Growth of grasses and forbs in western

Climate

The sand shinnery extends southwestward from a zone of 25 inches average annual precipitation in western Oklahoma 400 mi to a zone of 12 inches precipitation in southeastern New Mexico (Canales 1968, McIlvain 1954). The annual cycle of precipitation also differs between the Oklahoma and New Mexico extremes. To the north, 3 to 4 inches of rain during each spring and summer month are fairly reliable but late summer and fall droughts are common (USDC NOAA 1995). To the south, April through June are generally dry and July through September relatively wet; many grasses do not begin growth until July (USDC NOAA 1996). Snowfall in the shinnery of western Oklahoma averages 12 inches/yr (Burgess et al. 1963) whereas in the southern shinnery snow averages less than 6 inches/yr and none falls in some winters (Chugg et al. 1971, Orton 1964). Table 1 reflects data from 3 disparate climatic regimes of the shinnery.

Because water availability is a limiting factor for plant growth in this community (Pettit 1978a, Sikes and Pettit 1980, Galbraith 1983), climatic differences correlate with profound differences in shinnery vegetation as previously discussed. For additional discussion of shinnery climate see Allred and Mitchell (1955), Campbell (1936), Lotspeich and Everhart (1962), Roebuck (1982), Sullivan (1980), USDOE (1980), USDI BLM (1977), Wiedeman (1960), and SCS soil surveys. Drought is discussed in a separate section. Paleoclimates (under which the shinnery formed) are discussed by Hafsten (1961), Lotspeich and Everhart (1962), Reeves (1965), and USDI BLM (1980).

Table 1. Climatic statistics.

Variable	Roger Mills Co. OK	Yoakum Co. TX	Eddy Co. NM
Average annual precipitation (cm)	65.1	40.4	31.6
Average date of last frost	2 April	13 April	31 March
Average date of first frost	28 Oct.	1 Nov.	7 Nov.
Average Jan. temperature (^oC)	2.7	5.6	6.7
Average July temperature (^oC)	28.2	26.4	27.5

Sources: Burgess et al. 1963, Orton 1964, which uses some data from adjacent Gaines County and Yoakum Co., and Chugg et al. 1971.

Oklahoma and adjacent Texas is not as closely tied to precipitation events due to a more regular cycle of precipitation through the year. Shin-oak acorns mature in July (personal observations). Ninety-five percent of growth of fine roots of shin-oak occurs from July through September, with small amounts detected in fall and winter (Zhang 1996).

Plants remain active in the shinnery well into autumn. Especially in the south, some grasses do not flower until September or October and remain green (depending on moisture and freezing weather) into November or December, although an October frost can end growth (personal observations). Oak leaves normally fall in early November (Bóo and Pettit 1975).

Autoecology of Shin-oak

Pettit (1978a) states that shin-oak does not use more water than the grasses and forbs in the community; however, it begins spring growth about 2 weeks earlier than competing vegetation (Jones and Pettit 1980). Shin-oak rhizomes absorb much water during wet periods, with up to 50% of their weight being water, This is particularly important during dry springs because grasses and forbs cannot mine or store water (Pettit 1986).

Following a drought, shin-oak may not leaf out in the spring, or may lose its leaves. In 1980, shin-oak shed 36% of its leaves in summer but leafout in 1981 was normal (Jones and Pettit 1980, 1984). Having failed to leaf out in spring or having lost its leaves in summer, oak can leaf out later in the growing season after water becomes available. Leaf structure varies over the distribution area of shin-oak, with adaptations to resist dryness, such as thicker leaf epidermis bearing more hairs, in New Mexico and adjacent Texas that are lacking in Oklahoma (Canales 1968).

Bóo and Pettit (1975) studied the annual cycle of nonstructural carbohydrates in the rhizomes and roots of shin-oak. Reserves were gradually depleted through the dormant season, November to April, until a low of 6.5% to 7% was reached in early May. Carbohydrates then began to accumulate when new leaves were 1/3 to 1/2 full-size and reached concentrations of 17% to 25% from early August to early November. Pettit and Hungerford (1973) followed the total available carbohydrate content of shin-oak roots (underground stems) for 14 mos. Concentrations ranged from a low of 6% to 7% in early May, when leaves were 1/2 to 2/3 full-size, to a high of 13% to 15% in January, June, and August.

Plumb (1984) studied variation in shin-oak's crude protein and phosphorus through 2 growing seasons. Protein decreased from about 9% to 5% from June to November while phosphorus trends, although less clear, were generally upward over the same period.

Quercus havardii rarely, if ever, reproduces through the agency of acorns. "...I saw not a single case of germination of acorns" (Wiedeman 1960, Dhillion et al. 1994). Pettit (1977) states that, "It is rare to find a young sand shin-oak plant in the field which had originated from an acorn" except seedlings underground in woodrat nests. Pettit and E. H. McIlvain said that they never found an aboveground seedling in the field (personal communications 1988). Many clonal plants put little energy into seed production and produce seedlings rarely (Cook 1985). Shin-oak's failure to produce seedlings may be from unsuitable moisture conditions rather than from a diversion of reproductive energy. Shin-oak stems are often weighed down to the ground with the large crop of heavy acorns (Palmer 1934).

Under laboratory conditions shin-oak acorns (figure 9) are viable and quickly produce roots that may extend 12 inches before leaves emerge (Pettit 1977, 1986). Sikes and Pettit (1980) measured root growth of seedlings at .05 cm/day in dry soil to .24 cm/day in moist soil. Acorn production may be inhibited by inadequate spring rains or by a freeze after flowering (USDOE 1980). Pettit (1986) estimates that acorn crops occur in 3 out of 10 yrs on average;

Figure 9. A dime shows the size of shin-oak acorns.

in New Mexico the Bureau of Land Management (USDI BLM 1979) estimates that crops occur from 1 yr in 10 to 1 yr in 5. In New Mexico, 1977-1997, we found heavy local crops occurring somewhere every year but in a specific location crops occurred not more than 2 yrs in 5.

Reproduction appears to be almost completely by rhizomes. If destruction of the above ground parts of shrubs through the 18- to 20-yr age group occurs, the buds of the rhizomes sprout and within 1 or 2 mos new growth appears above the ground. The growth during the first year proceeds at a rapid pace until stems one to 2 ft all are produced (Wiedeman 1960, Wiedeman and Penfound 1960). Most new shoots arise from buds covered with no more than 3 inches of sand. If sand is eroded away from the stem, new shoots can develop from more deeply located buds (Pettit 1977).

Zhang (1996) found 2 kinds of ectomycorrhizae on shin-oak roots, 1) a white type was bifurcate and had a smooth gray to white surface; 2) a black type was short, often club-shaped, with radiating black hyphae, formed by the fungus *Cenococcum geophilum,* a highly drought-resistant species. Levels of soil organic matter had the largest direct effect on ectomycorrhizal colonization. The effect of total nitrogen on ectomycorrhizal colonization was significant and negative.

Shin-oak may also have direct allelopathic effects on seedlings of other species. Matizha and Dahl (1991) found that an extract from oak leaves depressed shoot growth of weeping lovegrass by 92%. Pettit and Harbert (1974) found that 5% tannic acid drastically reduced germination of weeping lovegrass and sand dropseed.

Several insects attack shin-oak but reportedly do not cause mortality. A buckmoth larva, *Hemileuca slosseri*, completely defoliates areas of a few acres (Peigler 1989, Pettit 1986, Pettit and Sullivan 1981, Stone and Smith 1990, Turrentine 1971, Wangberg 1983). The lined bird grasshopper (*Schistocerca alutacea* ssp.*lineata*) partially defoliates oaks over large areas (Dodson 1987, Peterson unpublished data). Cynipid gall-wasps are everywhere abundant on shin-oak stems and leaves (figure 10; Pettit 1977); Tucker (1970) lists *Atrusca bella*, *Callirhytis frequens*, *C. juvenca*, *Disholcaspis rubens*, *D. spissa*, and *Neuroteras howertoni* and Zimmerman (personal comm. 1997) adds *Xystoteras* sp. and *Xanthoteras eburneum*, the latter studied by Dodson (1987). Large roots are infested by long-horned beetle larvae (Cerambycidae) that leave only a small part of a root intact, yet do not limit rhizome and shoot growth (Pettit 1977). Most acorns become infested by weevils (*Curculio* sp.), often 2 or more larvae per fruit, but these do not always destroy acorn viability (Pettit 1973, 1977, Wiedeman 1960). Acorns decompose rapidly after falling (Mayes 1994) and few survive after January 1 (Hanson 1957).

A number of birds and mammals affect shin-oak by consumption of leaves, roots, acorns, buds, and catkins. These species are reviewed under the section Wildlife Species.

Figure 10. Galls of cyniped wasps are abundant on shin-oak and provide an important food source for prairie-chickens.

Vegetation Dynamics and Water Relations

Sand shinnery is an unusually stable community; individuals of its principal species, shin-oak, grow slowly and live for hundreds of years, and the species has produced a continuous pollen profile for at least 3000 yrs (Gross and Dick Peddie 1979, Hafsten 1961). Drought, fire, livestock grazing, and brush treatment do modify or transform the community. Each of these disturbance factors is discussed below.

Although shin-oak may constitute 80% to 90% of plant mass or ground cover in shinnery (Biondini et al. 1986, Dhillion et al. 1994, Pettit 1994, Plumb 1984), in SCS surveys shin-oak is usually said to make up 5% to 25% of the plant composition or biomass of the pre-settlement plant community (Conner et al. 1974, Hodson et al. 1980). Correspondence with SCS offices in the 3 shinnery states failed to identify data that support these low percentages. All of the soil surveys describe shin-oak as an “increaser” under livestock grazing. Tallgrasses and most midgrasses decrease under grazing. When these studies were prepared (1963 to1983) "increaser" was a species that increased in percentage composition of the community, although it could be decreasing in absolute amount. So defined, shin-oak is an increaser under grazing pressure.

However, some of the studies (e.g. Lenfesty 1983) also claim that shin-oak increases in absolute amount under grazing pressure, which is the current definition of "increaser" (Society for Range Management 1995). The SCS in 3 shinnery states has been unable to support this claim with data. Although it seems possible that shin-oak would increase when without grass competition (Muller 1951a), this assumes that shin-oak is limited by competition with grasses, which is not supported by data. It is clear that under some circumstances, perhaps all circumstances, the abundance of shin-oak under grazing pressure either remains constant (Dickerson 1985, Holland 1994) or decreases along with grasses. Davis et al. (1979) found that, unlike instances where shrubs have invaded herbaceous communities, oak and grass densities are positively correlated; the more oak, the more grass (table 2).

The SCS and others claim that shin-oak invades overgrazed rangeland (Herbel 1979, Herndon 1981, Lenfesty 1983, York and Dick-Peddie 1969). BLM stated that shin-oak increases in absolute amount under grazing pressure and that former grassland was invaded and taken over by shin-oak (USDI BLM 1979). The idea that shin-oak was not part of the historic plant community has influenced BLM's decision to treat 100,000 acres in New Mexico with herbicides (USDI BLM 1979, BLM Roswell District Manager letter to the Sierra Club September 24, 1991). However, stable existence of shinnery for hundreds of years (Beckett 1976, Gross and Dick-Peddie 1979) and lack of spread of shin-oak by seeds negate claims that shinnery have increased in historical time.

Several SCS writers believe that mottes are the historic form of shin-oak, and that the low-growing shrubs surrounding them have spread from the mottes as the grass cover disappears under heavy grazing (e.g. Newman 1964). Apparently this was also the view of Osborn (1942). This hypothesis seems unreasonable because the taller oak mottes are single clones (Pettit and Kauffman 1978) and are hybrids distinguishable by botanical characteristics from the lower-growing shin-oak surrounding them (Muller 1952, Pettit 1986).

Table 2. Percentage of ground covered by plant type.

Plant type	Most grass	Medium	Least grass
Oak	6	3	4
Grass	11	7	4

Water is a limiting factor for plant growth across the range of shinnery (Galbraith 1983, Pettit 1978a, Sikes and Pettit 1980). Shin-oak absorbs water efficiently when available (Pettit 1986), "even while the plant is still in winter dormancy" (Sullivan 1980). "Grasses in a vigorous state extract more deep soil water than sand-shinnery oak" (Jones and Pettit 1980), but when water is in short supply, shin-oak biomass may decline less than that of competing herbaceous vegetation. When water is available tallgrasses may overtop the oak and perhaps by shading the oak they achieve a balance. In southern shinnery, tallgrasses may grow twice as high as the oak. Muller (1951a) observed that, "The clones of *Quercus Havardi* are not so luxuriant and dense where they are subject to heavy competition by grasses." Similarly Frary (1957) opined that "shinoak seems to alter its growth form when under heavy competition from other vegetation. The vigor of the plant seems to be lower and fruiting is practically nonexistent even when other plants are producing acorns." Moldenhauer et al. (1958) believed that in the original vegetation, "The grasses were dominant and kept the Shinnery and Yucca from spreading."

Dhillion et al. (1994) studied the influence of animal disturbances (rodent and lagomorph burrows and ant hills) on the structure of shinnery communities. They found that density of herbaceous seedlings was not influenced by oak cover. However, the density of herbaceous seedlings was positively correlated with increasing bare ground and with the number of animal disturbance types. The number of seedlings was correlated, though not significantly, with the absolute number of animal disturbances. Undisturbed areas were covered in a mat of oak-leaf litter and offered little opportunity for plant establishment. In fact, over 70% of the herbaceous seedling density was associated with animal-disturbed sites. Shin-oak ground cover was not correlated with the number of disturbances.

Holland (1994) working in the same area as Dhillion et al. found that the density of herbs was much lower where there was a dense oak cover. Holland explained this by noting that Dhillion et al. were concerned with herbaceous seedlings whereas she dealt with mature herbaceous plants. Holland hypothesized that oak canopy cover does not impede colonization by herbaceous seedlings but has a negative effect on seedling recruitment and density of adult herbaceous plants.

Pettit and Holder (1973), Pettit and Small (1974), and Test (1972) manipulated vegetation composition in shinnery communities and examined soil-water use to a depth of 150 cm by different classes of vegetation. Treatments included: 1) remove shin-oak and leave herbaceous vegetation, 2) remove herbaceous vegetation and leave oak, 3) remove all vegetation, and 4) control (leave all vegetation). From September 1972 through August 1973 results of the 4 treatments were similar at depths from 15 cm to 45 cm, but from 90 cm to 150 cm the remove-all-vegetation treatment stored 24.3 cm of water and the other 3 treatments about 17.5 cm of water (Pettit and Holder 1973). Because the authors did not quantify evaporative water losses from bare ground, it is difficult to assess water use among herbs and oaks from these data.

Jones (1982) presents 28-mo records of precipitation and water in the soil horizons A and B of shinnery in Cochran County, Texas. He concluded from the position of oak roots and soil-water responses that shin-oak concentrates its water absorption near the soil surface and at the interface between A and B horizons. Test (1972) and Galbraith (1983) found a concentration of fine oak roots just above that interface, possibly in response to water perched above the less permeable B horizon. Small (1975) and Zhang (1996) also report the annual course of percentage soil moisture for shinnery areas in Texas. Biondini and Pettit (1980) modified a soil water-flow model to predict changes in soil water content through a growing season at the 30 cm depth in shinnery from precipitation data. Data from this study indicate that peak water concentration occurs in August and a low-point concentration in May.

Shin-oak is an effective water-gatherer. In response to precipitation, shin-oak produces from 41 to 113 $g/m^2/yr$ of fine roots (Zhang 1996). Bóo (1974) measured xylem water potentials as approximately -25 bars with a pressure bomb. Galbraith (1983) found shin-oak to be a highly efficient water-user due in part to the oak's maintaining more negative leaf water potentials than associated plants. Oak's negative leaf water potential was between -25 to -32 bars at midday compared with -12 to -18 bars for grasses and -12 to -25 bars for forbs. Galbraith found that oak absorbed large quantities of water in the top 137 cm of soil when water was available at low potentials, and to 198 cm depth when water supplies became limiting. Other authors emphasize the shallowness of shin-oak's underground system and suggest that grasses are more efficient at harvesting water at greater depths than shin-oak (Jones and Pettit 1981, Jones 1982). Galbraith (1983) emphasizes the greater effectiveness of the oak's absorption down to 2 m depth compared with associated plants.

Given the limited water supply, shinnery is a productive ecosystem. SCS surveys estimate that in untreated shinnery up to 3,000 lbs of air-dry forage are produced per acre per year in New Mexico (Lenfesty 1983), up to 3,500 in Texas (Crump and Williams 1975, Richardson et al. 1975), and up to 4,500 in Oklahoma (Nance et al. 1963). Production is much lower on shifting sands and other poor soils or where vegetation is in poor condition or during low-rainfall years. In depauperate stands, up to 90% of production can be oak (Pettit 1994).

Garrison et al. (1977) recognized 4 productivity classes in the shinnery. Class 1 produces an average of 2,000 lbs of herbage per acre per year on Mollisols (Calciustolls plus Haplustolls). Class 2 produces 1,500 lbs of herbage per acre per year on Alfisols (Haplustolls). Class 3 produces 1000 lbs of herbage per acre per year on Aridisols (Haplargids). Class 4 produces 500 lbs of herbage per acre per year on Entisols (Ustipsamments) of stabilized sand dunes.

Sullivan and Pettit (1977) found the most productive shinnery in west Texas on younger sands, which are deeper and lighter in color than older sands. These most productive stands were also the most easily disturbed and were often interspersed with blow-out areas. Dark red or brown soils, characterized by a clay layer close to ground level, support a stable but marginal shin-oak community. Sullivan and Pettit (1977) found that in heavier soils shin-oak and tallgrasses are replaced by mesquite and shortgrasses and midgrasses including sand dropseed.

Organic Matter and Decomposition

The organic-matter content of shinnery soils is low even in the A horizon. Secor et al. (1983) found a mean value of .36% under shin-oak in Eddy County, New Mexico, less than half of what they measured under adjacent vegetation dominated by mesquite and javelina bush. In Roosevelt County, New Mexico, Keesee (1992) measured organic-matter contents of .40% to .48% in the top 3.75 cm of soil and .35% to .40% from 3.75 to 7.5 cm. In Yoakum County, Texas, Small (1975) found a range of .20% to 1.39% (average .67%) in shinnery, which was not significantly less than in adjacent blue grama-buffalo grass (average .73%). Sears (1982) and Sears et al. (1986a) measured soil organic matter in west Texas shinnery at 3,200 kg/ha.

Elkins and Whitford (1982) and Elkins et al. (1982) measured annual weight losses of shin-oak leaves in Eddy County, New Mexico, of 20% for unburied and 35% for buried leaves. Working in Yoakum County, Texas, Zhang (1996) reported that over a 3-mo period, fine shin-oak roots lost 12 to 16% of their weight. Decomposition then slowed, due to the exhaustion of soluble carbon, and after 15 mos, weight loss totaled 22% of initial weight.

Sears et al. (1986a) found that below-ground biomass totaled 27,000 kg/ha, of which 22,500 kg/ha were roots, 94% of them oak roots including underground stems. Comparing an untreated plot with plots in which oak had been killed with herbicides 3 and 6 yrs previously, they found that large (> 2 mm) oak-root biomass decreased 8% in 3 yrs and 41% in 6 yrs. Small oak-root biomass was 19% lower in the 3-yr plot and 29% in the 6-yr plot. Sears et al. regarded these as slow rates of decomposition. These authors measured carbon-nitrogen ratios for large oak roots from 86:1 to 92:1 and stated that ratios greater than

20 favor immobilization of nitrogen and slow decomposition rates.

Nutrient Cycling

The soils of shinnery communities are critically low in nitrogen and phosphorus (Pettit 1983b). In Eddy County, New Mexico, Secor et al. (1983) measured .5 ppm of NO_3 + NH_4 nitrogen in shinnery soils, compared with 5.2 ppm under mesquite, and .1 ppm of phosphorus, compared with .2 under mesquite. In Garza County, Texas, Matizha and Dahl (1991) measured 3.4 ppm of available nitrogen, 3.1 ppm available phosphorus, and 93.8 ppm of available potassium. In the same Brownfield fine sand in Yoakum County, Texas, Sears et al. (1986b) measured a soil nitrogen concentration of .017% and Dittemore and Hyde (1964) measured a range of .011% to .019% nearby.

Forage production can be increased with fertilizers. Pettit and Deering (1974) working in Yoakum County found that 60 kg/ha of nitrogen in the form of ammonium sulfate or as ammonium-phosphate-sulfate increased total vegetative production by 51% to 54% including increased grass yields of 84% to 100%. Sulfur as well as nitrogen was important; in this study they did not find evidence that phosphorus was beneficial. Deering (1972) reported that nitrogen applied at 30 lb/ac to a Yoakum County shinnery community had no effect on shin-oak stem density or grass canopy cover but did increase forb cover canopy at the end of the growing season. Holland (1994) found a strong association between oak height and soil potassium, which lead her to suggest that oak growth is limited by potassium.

In Cochran County, Texas, Biondini et al. (1986) measured the crude protein content of little bluestem and purple three-awn at 6.3%, red lovegrass at 7.1%, and sand dropseed at 8.6%. The first 3 species had phosphorus contents of .08% and sand dropseed contents of .11%. Pettit (1983b) reported the crude protein content of both shin-oak leaves and forbs at 9% to 11% in June, but the forbs contained only 6% by late summer. Phosphorus levels in all forages ranged from .04% to .12%. Pettit concluded that phosphorus must be provided as a supplement for livestock year-round. Villena-Rodriguez (1987) found crude protein values for shin-oak leaves and current-years twig growth to range from 8.5% in late June to 6.9% in late August.

Zhang (1996) considered the shinnery ecosystem to be nitrogen-limited. He stated that soil nitrogen dynamics and microbial biomass are tightly coupled and provide for efficient nitrogen retention. Microbial biomass increased from late summer through late fall, decreased during the winter, and continued at a minimal, steady level from May through August in the 2 yrs sampled. Nitrogen mineralization rates changed seasonally, with higher rates from February through September; the year-long monthly average was .75 mg N/g soil, of which 85% was nitrate nitrogen. Nitrification rates were also highest during late summer and declined through the fall as leaves became senescent; monthly nitrification averaged .60 mg N/g soil. Thus, N mineralization and nitrification rates were inverse to microbial biomass and highest during the growing season. Zhang suggested that microbial biomass responds to carbon inputs as plants shed leaves and fine roots during late fall and winter. Soil organic matter, total nitrogen, and above-ground stem density had large, significant, positive, direct effects on microbial biomass..., soil nitrogen mineralization and nitrification rates. Low nitrogen availability is related to increased colonization of oak roots by ectomycorrhizal fungi, which help the oak obtain nitrogen. The addition of 50 g ammonium nitrate/m^2 depressed mycorrhizal fungi but sharply increased microbial biomass and nitrogen mineralization for up to 4 mos.

Kyrouac (1988) examined vesicular-arbuscular mycorrhizae (VAM) of little bluestem and purple three-awn grasses in shinnery, formed by *Scutellospora, Glomus,* and *Acaulospora* species. From 8% to 25% of grass plants were infected. VAM root lengths in little bluestem increased from 200 to 540 cm from April to August, then fell off to 400 cm by October. In purple three-awn, VAM root length declined from 270 cm in April to 100 cm in August, then rose to 190 cm in October. It is difficult to see how these differing responses could relate to nutrient availability in the same soil. McGinley et al. (1994) found that the importance of mycorrhizae to little bluestem varied in shinnery depending on differences in nutrient availability, which are caused by animal (mainly ant) disturbances.

McIlvain and Armstrong (1965) pointed out the importance of deep-rooted oaks in recirculation of deeply leached soil nutrients. Important to nutrient cycling are the thousand species of insects collected in one shinnery area; the biomass of termites alone equalled that of cattle grazing the surface (USDOE 1980). Whitford et al. (1986) calculated that ants bring 84 $g/m^2/yr$ of soil to the surface in Eddy County shinnery.

In the shinnery ecosystem of Cochran and Yoakum counties, Texas, Sears et al. (1986a, 1986b) determined that where oak comprised 92% of the living above-ground biomass, above-ground nitrogen (kg/ha) was distributed as follows: live oak stems 4.4, dead oak stems 1.6, live oak leaves 5.4, herbaceous shoots 2, and above-ground litter 31, for a total of 44.2 kg/ha. Nitrogen (kg/ha) associated with below-ground biomass averaged: large oak roots 75.8, small oak roots 41.5, herbaceous roots 8.3, and litter 36.5, for a total of 167.1 kg/ha. Soil nitrogen averaged 405 kg/ha. About 5% of soil nitrogen was available for plant use (Sears et al. 1983). Soil nitrogen was significantly higher in July (507 kg/ha) than in April or December (337 and 370 kg/ha). Sears et al. also sampled plots where oak had been killed with herbicide 3 and 6 yrs previously. Above-ground nitrogen did not differ between control and herbicide-treated plots; however, below-ground biomass-associated nitrogen decreased in the 6-yr plots. Total soil nitrogen was similar across treatments for the July and December sampling periods, and was higher for the 6-yr plots in April.

Working in the shinnery of Yoakum County, McGinley et al. (1994) found the soils associated with nests of a harvester ant, *Pogonomyrmex barbatus*, to be much richer in NO_3 + NH_4 nitrogen than soils associated with nests of *Pheidole dentata* or *Crematogaster punctulata* or soils not associated with ant nests. At the same site Dhillion et al. (1994) found disturbed soil associated with rabbit burrows to be richer in organic matter, total nitrogen, ammonium, nitrate, iron, and magnesium than off-mound soils.

Drought

Season-long, multiple-year, or droughts for periods as long as a decade are common in shinnery. In this century, the droughts of 1906-1911, 1921-1926, 1933-1936, 1946-1948, and especially 1951-1956 have been the most serious in the shinnery area; 1994 to mid-1996 was the most recent drought. In the northern shinnery region, in any 10-yr period expectation is for 1 or 2 yrs with less than 75% of the average annual precipitation. In the southern shinnery region, in any 10-yr period expectation is for 2 or 3 yrs with less than 75% of the average annual precipitation (Campbell 1936).

The effects of drought are more severe on grasses than on shrubs in the shinnery, since shrubs can store water and carbohydrates (USDI BLM 1977). Even a mild drought is apt to decrease grass production from 1200 to 1400 lbs/ac/yr down to 400 to 600 lbs/ac/yr. This happened in Garza County, Texas, shinnery in 1983 and 1984, when precipitation totaled 8 and 6.9 inches rather than the historical average of 13.9 inches (Mosley et al. 1985b).

Drought will have stronger negative effects on grass production than on oak, given the oak's extensive root system, its ability to store water, and its strongly negative leaf water potentials (Galbraith 1983). Observations in New Mexico (Peterson unpublished data) at the end of the 1994 to 1996 drought support this speculation. Peterson found that oak began sprouting vigorously after rains in June 1996, but many grasses had died (or nearly so) and were slowly replaced, mostly by annual herbs. However, there are no quantitative studies that show a relative increase of oak under drought.

Forage removal by grasshoppers is considerable during drought (Coupland 1958). The 1994 to 1996 drought was accompanied and followed by a grasshopper outbreak in the sand shinnery of west Texas and New Mexico. At 17 points sampled in 1996 the predominant grasshopper was *Schistocerca alutacea* subspecies *lineata*, which was eating oak predominantly or exclusively. Grasses were not noticeably damaged by grasshoppers (Peterson unpublished data).

Fire

In the twentieth century, wildfire has become less common in the western United States due to human control of fire and to the loss of fine fuel due to livestock grazing (Box 1967). Shin-oak and associated vegetation have evolved under the influence of fire. However, the pre-European settlement fire regime for shin-oak is unknown. Shoop and McIlvain (1964) speculated that shinnery in western Oklahoma was historically burned on an annual basis by Indians. In this same region, historical references to shin-oak (Marcy 1854) indicated that it was a low-growing shrub, generally less than 18 inches high. Possibly these plants were under a reliable and strong pyritic influence because shin-oak plants in this region today may approach or exceed 40 inches in height.

Knowledge about the response of shinnery to fire is lacking, relative to that for other vegetation types of the Great Plains. However, vegetation trends following single-event, planned spring burns in Woodward County, Oklahoma, have been described by McIlvain and Armstrong (1966), McIlvain and Shoop (1965), and Shoop and McIlvain (1964). These authors reported a variable plant response to fire, relative to the timing of the burn and amount of precipitation. In 1964, a dry year, burning on April 8 increased total grass and forb production and shin-oak density, but total grass production remained relatively unchanged. In the same year, burning on May 8 increased shin-oak density and decreased forb and grass production. In 1965, a wet year, grass and forb production showed dramatic increases in response to burning. Grass production increased 29% after a burn on April 19 and 66% after a burn on May 11, while forb production increased 140% after the April 19 burn and decreased 19% after the May burn. No shin-oak response data were reported for this year. Spring burning in years of adequate rainfall will increase production of sand bluestem and switchgrass, decrease production of little bluestem, and induce prolific resprouting of top-killed shin-oak (McIlvain and Armstrong 1966). Shin-oak stems are highly susceptible to fire, with post-burn top-kill often approaching or equaling 100% (Boyd and Bidwell unpublished data1997).

Slosser et al. (1985) reported that a March 11 burn of shinnery in Kent County, Texas, had little effect on vegetative composition but decreased leaf litter for 3 yrs following treatment. These authors noted that although top-kill of shin-oak was near 100%, frequency of oak occurrence had equalized between burned and unburned treatments within 8 mos due to vigorous oak resprouting. Frary

(1955) reported shifts in cover of plant species 1 yr following a controlled burn on March 10 in Roosevelt County, New Mexico. Total plant density was reduced from 37% to 26%, annual forbs increased from 43% to 51% of total cover, grasses decreased from 49% to 44% (including no change in little bluestem at 10%), and shin-oak decreased from 8% to 5%.

Zobeck et al. (1989) studied the effects of fire on wind erosion and soil nutrients. They measured 330 times more sediment from burned plots relative to controls. However, measurement of sediment used a qualitative measure, making it difficult to assess the biological significance of increased wind-borne sediments. Pettit (1984) observed little recovery of grasses from a September wildfire, leaving insufficient cover for soil protection during winter.

Wildlife Species

Mammoth, bison, and elk remains are found in the shinnery, accompanied by Indian sites dating from 11,500 yrs ago to historic times (Beckett 1976, Smith 1971, Smith 1985). The shinnery remains rich in wildlife.

Mule deer

Mule deer (*Odocoileus hemionus*) are common in shinnery in Texas and New Mexico (Bryant and Morrison 1985) and occasionally cross from Texas into southwestern Oklahoma (Caire et al. 1989). Oak, including acorns, buds, and leaves, is the principal food for mule deer that inhabit shinnery (Ligon 1927). Studies in Palo Duro Canyon in the Texas Panhandle have shown oak to comprise 37% of mule deer diets even where shinnery was only 1 of several vegetation types comprising the habitat (Krysl et al. 1980); in autumn the figure was 78% (Gray et al. 1978). However, although these studies claimed to deal with *Quercus havardii*, *Q. mohriana* seems more likely for Palo Duro Canyon. “Generally, Texas and Eastern New Mexico mule deer are on a ‘poor to fair’ nutritional plane” (Bryant and Morrison 1985), but deer in the shinnery appear heavy-bodied with broad antlers, probably due to the nutritional value of acorns (USDI BLM 1979). “The deer appear to be heavily dependent upon shinnery oak yearlong” (USDI BLM 1980). The tall mottes of hybrid oak provide important cover for deer (Turrentine 1971). Shin-oak is a species of prime importance and should be protected as mule deer habitat. Small patches (less than 5 acres) of shinnery should be burned in February or March to encourage sprouting of nutritious new oak growth (Bryant and Morrison 1985).

White-tailed deer

Shinnery is a principal home for white-tailed deer (*Odocoileus virginianus*) in the southern Great Plains. For instance, in Harmon County, Oklahoma, white-tails were reported only in a riparian area and shinnery (Martin and Preston 1970). In New Mexico, white-tails on the plains may be limited to shinnery habitat (Ligon 1927, Raught 1967). Bailey (1905) thought that the sandhills deer might be a separate subspecies, an idea entertained by Ligon (1927), pursued by Calvin Smith (Huey 1970, Smith 1985), and accepted by Raught (1967), but Findley et al. (1975) assign them to subspecies *texanus*. Ligon (1927) described acorns as superior food for the sandhills white-tails, and Raught (1967) also referred to the importance of acorns. Bryant and Demarais (1992) emphasized the importance of forbs and acorns in white-tail diets and the importance of a wide diversity of plant species. They recommended the use of prescribed fire to top-kill shrubs and obtain nutritious new sprouts. Darr and Klebenow (1975) reported that shin-oak constituted 11% of white-tails’ autumn diet on a ranch that included only 1.6% shinnery. Oak mottes provided important cover; of 6 vegetative types on the ranch, only the riparian type supported higher deer densities than shinnery, although others provided better cover than the 18-inch tall shin-oak.

Pronghorn antelope

Now uncommon in Oklahoma and adjacent Texas, pronghorns (*Antilocapra americana*) are common in the southwestern Texas Panhandle and southward in shinnery (Pettit 1978a, USDI BLM 1980; D. A. Swepston personal communiction 1997), including areas far from open grassland. Pronghorns are not limited to shinnery. They are opportunistic feeders, with a diet of up to 71% shrubs (Yoakum 1980), which they may rely on for winter survival (Harmel 1979, Howard et al. 1990). In shinnery of Cochran and Yoakum counties, however, Roebuck (1982) and Roebuck and Simpson (1982) found pronghorns eating an average of 68% forbs, 22% shrubs (including 13% shin-oak), and 4% grass. Roebuck compared the amount eaten to the relative availability of the various forages and derived selection indices. A selection index of 1 indicates a plant eaten in the same proportion as its availability. On that scale trailing ratany had an index of over 2,000, from a trace to .2% of available forage but 21% to 34% of diet. The index for spectaclepod rose to 940 in autumn and that for mesquite to 510 in winter. The index for sandsage was 2.3 in winter and 3.7 in spring and shin-oak indices, the most abundant plant in the community, ranged from .1 in winter to .7 in summer and fall.

Peccary (Javelina)

Collared peccaries (*Dicotyles tajacu*) occur in the southernmost shinnery in Eddy and Lea counties, New Mexico, and there are a few peccaries in the adjacent Texas counties (Andrews, Loving, and Winkler). In 1927, Ligon reported that only a few individuals remained in shinnery country, and Donaldson (1967) reported none, but they have been sighted often in the 1990s. Although Donaldson lists peccary foods in southwestern New Mexico, of which acorns, mesquite beans, prickly pear and cholla, hog potato (rushpea), and filaree would also be available in the shinnery area, there are no studies of peccaries specifically in shinnery. In Arizona studies, Knipe (1956) describes acorns as their most sought-after food, leading to local migrations in search of good crops.

Barbary sheep

In 1957 and 1958, 44 Barbary sheep (*Ammotragus lervia*) were introduced into Palo Duro Canyon near Amarillo. The population prospered and by 1980 was competing for food resources with native mule deer. Of the several habitat types available, the sheep favored shinnery, and 31% of their diets was shin-oak. Other shrubs, mostly not in shinnery, constituted 19%, forbs 26%, and grasses 24% of their diet (Krysl et al. 1980).

Lagomorphs

Black-tailed jackrabbits (*Lepus californicus*) and desert cottontails (*Sylvilagus auduboni*) occur throughout the shinnery. Eastern cottontails (*S. floridanus*) are in shinnery in Oklahoma (Martin and Preston 1970), but because of its use of heavily wooded cover, the Eastern cottontail is less common than its congener in shinnery. A subspecies, *S. floridanus llanensis*, was described from the shinnery country of west Texas (Blair 1938).

Little is known about the ecology of hares and rabbits in this vegetation. Davis et al. (1975a) and Griffing and Davis (1976b) observed the feeding of jackrabbits on yucca leaves, mesquite leaves and pods, snakeweed, and forbs near the southern limit of the shinnery. Jackrabbits preferred more open grass-shrub stands compared with cottontails, which depend upon low-hanging vegetation for escape cover and concealment (Davis et al. 1975a). The ecology of rabbit mounds in relation to soil nutrients, mycorrhizal spores, and other fungi and bacteria, and as a disturbance factor permitting establishment of seedlings is discussed by Dhillion et al. (1994).

Rodents

About 16 rodent species commonly make their homes in shinnery; none is limited to the community. Occurrences are given in table 3 for 3 widely separate sampling points (Martin and Preston 1970, USDOE 1980, Caire et al. 1989, Willig et al. 1993).

The greater number of species at the Department of Energy's (DOE) Eddy County site, driest and least productive of the sites recorded in table 3, reflects the inten-

Table 3. Rodents of sand shinnery communities.

	Harmon Co. OK	Yoakum Co. TX	Eddy Co. NM
Dipodomys ordii, Ord's kangaroo rat	+	+	+
Erethizon dorsatum, porcupine	+	-	+
Geomys bursarius, plains pocket gopher	+	-	+
Mus musculus, house mouse	-	+	+
Neotoma micropus, southern plains woodrat	+	+	+
Onychomys leucogaster, northern grasshopper mouse	+	+	+
Perognathus flavescens, plains pocket mouse	+	+	+
Perognathus flavus, silky pocket mouse	-	-	+
Perognathus hispidus, hispid pocket mouse	+	-	+
Peromyscus leucopus, white-footed mouse	+	-	+
Peromyscus maniculatus, deer mouse	+	+	+
Reithrodontomys megalotis, western harvest mouse	-	-	+
Sigmodon hispidus, hispid cotton rat	+	-	+
Spermophilus mexicanus, Mexican ground squirrel	-	-	+
Spermophilus spilosoma, spotted ground squirrel	+	-	+

sity of DOE's several-year trapping effort. The desert pocket mouse, *Perognathus penicillatus*, and Merriam's kangaroo rat, *Dipodomys merriami*, were also trapped on dunes at the site; shin-oak was present but their habitat was not recorded as shinnery. The nonnative house mouse was not trapped regularly nor year-round at either site where it was recorded. Colbert (1986) regarded this species as unexpected because it is usually associated with more mesic areas. Although not listed by Willig et al., pocket gophers do occur in west Texas shinnery. In the northern counties, *Geomys bursarius* occurs and from Yoakum and Terry counties southward, *G. knoxjonesii*, which has been split from *G. bursarius*, occurs (Davis and Schmidly 1994).

Although not commonly found in shinnery, prairie dogs (*Cynomys ludovicianus*) in Oklahoma converted more than 100 acres of shinnery to forb-rich, depauperate grassland (Osborn 1942). Osborn stated that human intervention, especially overgrazing by livestock in the tallgrasses in shinnery, which was previously unsuitable habitat for prairie dogs, and destruction of prairie dog predators contributed to this conversion. Prairie dogs are not found in shinnery when its tallgrasses are abundant (Allan and Osborn 1954).

Best et al. (1993) studied food habits of the 4 rodents most common in shinnery at the DOE site. Ord's kangaroo rats primarily ate seeds and fruits of purple sandgrass, mesquite, and euphorbia, plus arthropods. Northern grasshopper mice predominantly ate arthropods. Southern plains woodrats consumed plant fibers, new forb growth, and mesquite, mostly green forage. Spotted ground squirrels ate mostly arthropods, new forb growth, and grasses. All 4, especially the woodrat, ate shin-oak. The ground squirrel hibernates, and the others are active throughout the year.

In general, but not necessarily in shinnery, rodents disperse seeds, shred vegetation and contribute it to humus, mix and aerate soils, and are major food sources for predators (Jones and Manning 1996). Rodents, especially pocket gophers, as disturbance factors and in relation to plant succession in shinnery are discussed by Dhillion et al. (1994). Several important midgrass and tallgrass species of the shinnery are highly preferred by plains pocket gophers. In Texas, but not in shinnery, biomass increased 22% when plains pocket gophers were excluded (Fagerstone and Ramey 1996).

Insectivores

Desert shrews (*Notiosorex crawfordi*) may occur throughout the shinnery, though records are few. Eastern moles (*Scalopus aquaticus*) occur in shinnery in Oklahoma (Caire et al. 1989).

Lesser prairie-chicken

Lesser prairie-chickens (*Tympanuchus pallidicinctus*) are closely associated with shinnery vegetation through most of their range. (North of the shinnery they occur in sandsage-dominated communities.) From extreme abundance in the nineteenth century, when they were used to supply meat in place of domestic poultry, populations declined to a few thousand in their 5-state area in this century. Crawford (1980) estimated a 97% decline in lesser prairie-chickens, while Taylor and Guthery (1980a) estimated a 92% decrease in occupied range. Hunting was prohibited in Oklahoma from 1915, in New Mexico from 1934, and in Texas from 1937 (Duck and Fletcher 1944, Lee 1950, Litton et al. 1994).

Populations increased and limited hunts were allowed in some years in Oklahoma and New Mexico, but not during the drought of the 1950s. Edminster (1954) thought that hunting is warranted when populations reach 20/mi^2, which at the time occurred in only about half the years. Since 1958 in New Mexico, 1959 in Oklahoma, and 1967 in Texas limited hunts have been allowed almost every year. Crawford (1980) estimated that the kill averaged 12% of the fall population. In the face of a new population decline throughout the species' range, New Mexico cancelled its 1996 to 1998 hunts, Oklahoma cancelled its 1998 hunt, and the U. S. Fish and Wildlife Service is considering a 1995 petition to list the species as threatened. Concern for the lesser prairie-chicken strongly affects management of the shinnery on public lands and some private ranches.

Taylor and Guthery (1980b) reported that lesser prairie-chickens in Yoakum County, Texas, preferred sunflower, shin-oak/bluestem, and shin-oak/sand sagebrush vegetation, in that order, while shin-oak/mesquite and shin-oak without other shrubs were used less than in proportion to their abundance. At least in spring, prairie-chickens in shinnery avoid areas of dense oak cover and favor areas in which grasses are more abundant (figure 11; Cannon and Knopf 1981, Davis et al. 1979).

Lesser prairie-chickens in shinnery eat mostly plant material except in summer, when insects, mainly grasshoppers, predominate. Table 4 records foods by season from Chaves County, New Mexico, in 1976 to 1978 (Davis et al. 1980, Riley et al. 1993a). Davis et al. (1981) reported dietary composition of lesser prairie-chickens in Roosevelt County, New Mexico, in 1979 and 1980 with similar results; major differences were a shortage of acorns (1%, 0%, 14%, and 25% by season) and greater consumption of insects (1%, 88%, 69%, and 0% by season). In Cochran County, Texas, Crawford and Bolen (1976a) found autumn diets of prairie-chickens, with access to cultivated fields, to be 62% grain sorghum, 7% acorns, 8% oak galls, 13% other plants, 6% grasshoppers, and 4% other insects. Davis et al. (1981) sampled crops of hunter-killed birds from Cochran County and obtained similar results. Doerr and Guthery (1983a) studied frequency of foods in prairie-chicken droppings in Cochran County. Their figures were close to those in table 4 except that in spring catkins were

Figure 11. A male prairie-chicken struts in springtime with an upright horn of feathers.

19% of diet while insects were 27%, acorns were lacking from in summer and fall diets, while percentages of insects were 60% in summer and 65% in fall. respectively. An absence of acorns in the diet probably relates less to preference and more to the variability of shin-oak acorn production.

Shin-oak catkins, and perhaps buds, may be an important food source during midspring, given that they are high in crude protein content (catkins = 22.3%, buds = 19.1% crude protein) and are available when other food sources may be in limited supply (Vermeire and Boyd unpublished manuscript 1997). Consumption of these food items is of interest given their high phenolic content (catkins = 17.5% and buds = 16.6% gallic acid units) (Vermeire and Boyd unpublished manuscript 1997). High levels of phenolic intake in domestic bird species leads to decreased weight gain and to egg shell thinning (Sell et al. 1983), although other free-ranging gallinaceous birds have been reported to consume forages high in phenols (Moss 1972).

Diets of chicks and juveniles are comprised of 85% to 99% insects (Davis et al. 1981, Taylor and Guthery 1980a). In New Mexico, brood foraging sites are less grassy, more shrubby, and the vegetation is shorter than in nesting sites (Riley and Davis 1993). In west Texas and eastern New Mexico, brooding territory was more dune-like than general habitat and had the greatest coverage and height of shin-oak (Ahlborn 1980, Sell 1979). In Oklahoma, Copelin (1963) found broods mostly in oak mottes. Jones (1963) noted that communities rich in forbs produced more insects than other habitat types.

The supply of safe nest sites limits prairie-chicken populations (Davis et al. 1981, Doerr and Guthery 1983b, Haukos and Smith 1989b, Sell 1979). Most nesting attempts are unsuccessful in Chaves County due to coyotes, striped skunks, and snakes (Riley et al. 1992) and in Oklahoma due to bullsnakes, Cooper's hawks, sharp-shinned hawks, crows, and ravens (Duck and Fletcher 1944). In 3 studies, nest failures were 5 of 8, 26 of 36, and 11 of 13 (Haukos and Smith 1989a, Riley et al. 1992, Sell 1979). Successful nests are mostly in dense grass, surrounded by tallgrass (Riley et al. 1992). Overhead cover, which can be oak, should be at least 50% for successful nests (Haukos and Smith 1989b).

Management of lesser prairie-chicken habitat involves maintenance of a mosaic of vegetative conditions. Nesting cover may be improved with light stocking rates, periodic deferment, or exclosure of grazing livestock (Ahlborn 1980, Davis et al. 1979, 1981, Donaldson 1969, Frary 1957, Haukos and Smith 1989b, Jackson and DeArment 1963, Ligon 1927, Litton et al. 1994, N. M. Dept. Game & Fish 1984, Taylor and Guthery 1980a). Although prairie fires were the nesting hen's worst enemy (Bent 1932), prescribed fire may be used to improve courting areas (Cannon 1979), increase forbs (McIlvain and Shoop 1965), and improve the quality of nesting habitat in years subsequent to burning (Cannon 1979). Additionally, prairie-chickens require shady resting cover, escape cover, and roosting sites as discussed by Copelin (1963), Crawford and Bolen (1976b), Davis et al. (1981), Donaldson (1969), Jones (1963), Riley et al. (1993b), Sell (1979), Snyder (1967), Taylor and Guthery (1980a, 1980b), and Turrentine and Klebenow (1972).

Table 4. Adult prairie-chicken foods.

	Percent by volume			
Food	Spring	Summer	Autumn	Winter
Acorns	15	21	39	69
Other seeds	0	0	4	0
Oak insect galls	0	1	10	0
Oak catkins, leaves	34	0	2	0
Other plants	45	22	27	26
Grasshoppers	0	39	15	0
Other insects	6	16	3	5

Quail

Scaled quail (*Callipepla squamata*) inhabit the southern and central parts of the shinnery; they become less common northward but do reach western Oklahoma. Bobwhite quail (*Colinus virginianus*) inhabit the northern and central parts of the shinnery, becoming less common southwestward, although they are spreading and increasing in that direction. Neither species is limited to shinnery but both use the type extensively. Both species nest on the ground, usually under shrubs (yucca, mesquite, shin-oak) surrounded by relatively dense cover mostly of mid and tallgrasses, or in the case of bobwhite, nests may be located within perennial grass clumps (Bidwell et al. 1991). Both species use shin-oak and other shrubs as loafing, hiding, and roosting cover (Davis et al. 1974, Guthery 1982, Sawyer 1973, Tharp 1971, Turrentine 1971, Turrentine and Klebenow 1971, Webb and Guthery 1982, Wood and Schnell 1984).

Scaled quail eat mainly seeds, mostly of woody plants and forbs but also of grasses. In winter, mesquite seeds may supply as much as 37% of their food and snakeweed seeds up to 35%; shin-oak acorns are a minor item. Green vegetation can supply up to 20% of scaled quail diet, and, in summer, insects supply up to 48%. Insects are the primary food for quail chicks (Best and Smartt 1985, Campbell et al. 1973, Davis et al. 1975b, Dixon and Knight 1993).

Bobwhite foods are similar to those of scaled quail in shinnery (Guthery 1982, Jackson 1969), but bobwhites may be more effective at cracking and eating shin-oak acorns (Bird and Bird 1931, Guthery 1980, Jackson et al. 1962). Food supplies may become critical from the first frost until spring (Turrentine 1971); competition with kangaroo rats can be acute (Inglis 1960). Early winter foods of bobwhites in shinnery in Oklahoma, by percentage volume, were cultivated grains 29, grass seeds 16, ragweed seeds 22, other forb seeds 12, acorns 11, other woody-plant seeds 9, green herbage 1, and animal matter 1 (Hanson 1957). Bird and Bird (1931) reported that seeds of sunflower and ground cherry may also be important winter food items in the shinnery region of Oklahoma. Brood habitat is characterized by high insect (Hurst 1972) and forb availability with sufficient bare ground to allow movement of chicks through understory vegetation (Bidwell et al. 1991). Insect and forb availability may be increased by burning or spring disking (Bidwell et al. 1991, Hurst 1972, Turrentine 1972).

Turkey

Rio Grande turkeys (*Melagris gallopavo* subsp. *intermedia*) occur in shinnery in southwestern Oklahoma and the adjacent Texas Panhandle. Logan (1973) described seasonal behavior of Rio Grande turkeys in southern Roger Mills and northern Beckham counties, Oklahoma. Use of shrub habitat, which included a mix of shin-oak, sand plum, skunkbrush, and sandsage, was primarily associated with loafing activities during the midday period and with nesting (figure 12). Twenty percent of located nests were within shrub habitat, however, most birds selected nests sites within alfalfa fields (56% of located nests).

Figure 12. A turkey nest is under sandsage and shin-oak in western Oklahoma.

Mourning doves

Mourning doves (*Zenaidura macroura*) occur throughout the shinnery during the warm seasons and sporadically in winter, or regularly in the south. They are not restricted to the community, but Downing (1957) noted that ground-nesting mourning doves had higher nesting success in shinnery than in other vegetation types studied in northwestern Oklahoma. They nest from May through early September. In the southern shinnery, their summer foods (by percentage of volume) were croton seeds 81, leaf-flower seeds 16, other forb seeds 3; in winter leaf-flower seeds 48, spurge seeds 23, other forb seeds 10, grass seeds 18 (Griffing and Davis 1974). Broader studies in Texas and northwestern Oklahoma, applying partly to shinnery, found croton, sunflower, amaranth, and sand paspalum seeds predominant in mourning dove diets, plus sorghum and wheat when available (Carpenter 1971, Dillon 1961). In the southern shinnery, mourning dove and scaled quail diets conflicted only with regard to croton seeds (Griffing and Davis 1976a).

Perching birds

About 20 species of songbird nest in shinnery and perhaps 80 more visit it regularly, but none is restricted to the community. In the southernmost shinnery, where 31 species were observed, the most common passerines were white-necked raven, loggerhead shrike, pyrrhuloxia, black-throated sparrow, and lark bunting, all but the last nesting in shinnery (Davis et al. 1974). In Yoakum and Bailey counties, Texas, 50 passerine species were censused in shinnery, 17 of them nesting, 21 wintering, and 23 migrant (Fischer and Bolen 1980). In Oklahoma, county-wide records for Beckham, Ellis, and Roger Mills counties indicated the occurrence of 142 species of passerine birds. Of these 94 species are associated with brush habitat—shin-oak, fence rows, and windbreaks (ODWC 1985).

Predators (mammals and birds)

Several predators have been previously mentioned: insect-eating rodents, insectivores, gallinaceous birds, and perching birds. In addition, the cave myotis, pallid bat, and Brazilian free-tailed bat, and probably several others, are associated with water (primarily stock tanks) in shinnery (USDOE 1980). Mainly the meat-eating predators are the Carnivora and raptors discussed here.

Gray wolves and cougars were formerly top carnivores of the plains; omnivorous black bears and grizzlies also ranged into shinnery country. Currently the principal native carnivores of the shinnery are coyote, bobcat, badger (figure 13), striped skunk, and swift fox. Cougars are occasional in the New Mexico shinnery and are rare farther east and north. Carnivorous gray fox and red fox and omnivorous ringtail and raccoon are uncommon to rare in the shinnery. None of these species is restricted to shinnery (Caire et al. 1989, Davis and Schmidly 1994, Findley et al. 1975, Kilgore 1969, Martin and Preston 1970, USDOE 1980).

Northern harriers, Swainson's hawks, red-tailed hawks, kestrels, burrowing owls, and short-eared owls are fairly regular inhabitants of (or foragers in) all of the shinnery. Mississippi kites are common in the northern and eastern parts of the shinnery, Harris' hawks are common in the south. Less common are sharp-shinned hawks, rough-legged hawks, ferruginous hawks, golden eagles, prairie falcons, barn owls, and great-horned owls. Though not raptors, roadrunners and loggerhead shrikes are also predatory birds in shinnery. Although none of these species is limited to shinnery, Harris' and Swainson's hawks are nearly so-limited in eastern New Mexico (Bailey 1928, Bednarz 1988, USDOE 1980, Wood and Schnell 1984).

Figure 13. A badger amid shin-oaks.

On a shinnery ranch in Oklahoma, the ranchers "figure each coyote worth $25/yr increased beef production and we are of the opinion that the bobcat is even more valuable" for their control of forage-consuming rodents and lagomorphs (Bunch 1961). Rodents, lagomorphs, and grasshoppers are the main foods of most of the raptors previously named; cumulatively, raptors probably equal the coyote in controlling rodent populations. However, only Swainson's and Harris' hawk diets have been studied in shinnery (Bednarz 1986a, 1986b).

Reptiles

Western box turtles (*Terrapene ornata*) are the only terrestrial turtles to inhabit shinnery regularly, although several aquatic turtles occur in water bodies. The turtles eat insects, plant material, and carrion (Degenhardt et al. 1996, Sievert and Sievert 1993).

About 25 snake species are recorded in shinnery, of which the plains hognose snake (*Heterodon nasicus*), night snake (*Hypsiglena torquata*), coachwhip (*Masticophis flagellum*), bullsnake or gopher snake (*Pituophis melanoleucus*), milksnake (*Lampropeltis triangulum*), massasauga (*Sistrurus catenatus*), and prairie rattlesnake (*Crotalus viridis*) are most common (Degenhardt et al. 1996, Sievert and Sievert 1993, Webb 1970, Wolfe 1978). These snakes eat rodents, lizards, snakes, and eggs. The larger snakes also eat cottontails. Smaller species and individuals eat centipedes, grasshoppers, and other arthropods (Degenhardt et al. 1996, Stebbins 1985).

Ten lizard species are in shinnery in southeastern New Mexico: prairie lined racerunner (*Cnemidophorus sexlineatus*), western whiptail (*C. tigris* or *C. marmoratus*), Great Plains skink (*Eumeces obsoletus*), leopard lizard (*Gambelia wislizenii*), lesser earless lizard (*Holbrookia maculata*), Texas horned lizard (*Phrynosoma cornutum*), roundtail horned lizard (*P. modestum*), prairie lizard (*Sceloporus undulatus*), and side-blotched lizard (*Uta stansburiana*) (Degenhardt and Jones 1972, Degenhardt et al. 1996, Gorum et al. 1995, Wolfe 1978). None of these species is limited to shinnery, but, the shinnery oak-mesquite habitat seems to be particularly suitable for side-blotched and western whiptail lizards (Wolfe 1978) and these 2 species are subjects of ecological studies in shinnery (Best and Gennaro 1984, 1985).

In addition, in 4 New Mexico and 4 Texas counties, occurs the sand dune lizard (*Sceloporus arenicolus*), the only reptile restricted to shinnery (figure 14; Degenhardt et al. 1996, Degenhardt and Jones 1972). This lizard occurs only in areas with open sand (especially in large, deep blow-outs), but it forages and takes refuge under shin-oak and is seldom more than 4 to 6 ft from the nearest plant. The sand dune lizard is lacking where blow-outs, topographic relief, or shin-oak are lacking and where 15% or more of the sand has a grain size less than .149 mm (Gorum et al. 1995). Because this reptile is listed as endangered by New Mexico and is under consideration for federal listing, its presence affects management of public lands. For instance, herbicidal treatment of shin-oak is forbidden on public lands in sand dune lizard habitat (USDI BLM 1997). Bailey and Painter (1994) are concerned about the possible extinction of the sand dune lizard where shinnery is managed for livestock and oil-and-gas production because of habitat lost to shin-oak control, well pads, roads, and pipelines.

We found no studies of reptiles in shinnery north of southeastern New Mexico. Of the species named previously, 6 are throughout the shinnery but the sand dune lizard, western whiptail, and leopard lizard are only in the southern part. The side-blotched and roundtail horned lizards are missing from the central shinnery and probably Oklahoma, though they are found in the Texas Panhandle (Dixon 1987). Regional inventories in Oklahoma record 9 lizard species from counties containing shinnery, but it is unknown which species are in shinnery. Species not listed previously are spotted whiptail (*Cnemidophorus gularis*), eastern collared lizard (*Crotaphytus collaris*), ground skink (*Lygosoma laterale*), and western slender glasslizard (*Ophisaurus attenuatus*) (Sievert and Sievert 1993, Webb 1970).

These lizards eat snails, insects, and other arthropods such as millipedes, scorpions, and spider. The larger species eat small rodents (pocket mice) and other lizards. Several include plant material in their diets (Best and Gennaro 1984, 1985, Degenhardt et al. 1996, Stebbins 1985).

Figure 14. A sand dune lizard on shin-oak litter.

Invertebrates

Lists of arthropod groups from Eddy County, New Mexico, come from the most complete study of invertebrates in shinnery, but identifications are not carried to the species nor often to the genus level. From one grass-rich shinnery site, Wolfe (1978) lists 6 families of Orthoptera, 1 of Psocoptera, 10 of Hemiptera, 8 of Homoptera, 19 of Coleoptera, 3 of Neuroptera, 4 of Lepidoptera, 17 of Diptera, and 19 of Hymenoptera plus members of Scorpionida, Solpugida, Acarina, Araneida, and Ostracoda. From sand sagebrush, Wolfe lists 17 families of insects, and from the stomachs of 2 lizard species in shinnery, 24 families. More detailed studies of arthropods, including termites, especially as they are involved in decomposition, were carried out at the same DOE site (Whitford 1982, Whitford et al. 1980).

Davis et al. (1979) identified insects from prairie-chicken crops in Chaves County, New Mexico, shinnery: cockroaches, mantids, crickets, walking sticks, treehoppers, scentless plant bugs, shield-backed bugs, short-horned and long-horned grasshoppers, robber flies, click beetles, darkling beetles, ground beetles, leaf beetles, scarab beetles, silken fungus beetles, snout beetles, weevils, caterpillars and moths, ants, and plant-gall insects (cynipid wasps, mainly).

Tucker (1970) lists 6 species of gall wasps (Cynipidae) from shin-oak and James Zimmerman (personal communiction 1997) adds *Xystoteras* sp. and *Xanthoteras eburneum*, the latter studied by Dodson (1987). Other insects that attack this host are discussed under Autoecology of Shin-oak.

Ants recorded at the Eddy County site are *Campanotus* sp., *Conomyrma insanum*, *Crematogaster* sp., *Iridomyrmex prunosum*, *Myrmecocystus dipilis*, *Pogonomyrmex apache*, *P. desertorum*, and *P. rugosus* (Whitford et al. 1980). Dhillion et al. (1994) recorded *Aphaenogaster cockerelli*, *Campanotus vicinis*, *Crematogaster punctulata*, *Myrmecocystus mimicus*, *Pheidole crassiconis*, *P. dentata*, and *Pogonomyrmex barbatus* in west Texas shinnery. Ant-plant-microbe interactions were studied by McGinley et al. (1994).

In 1996, the most frequently encountered short-horned grasshoppers in shinnery in New Mexico and adjacent Texas were (in descending order of frequency) *Schistocerca alutacea* subsp. *lineata* (which eats shin-oak), *Campylacantha olivacea*, *Melanoplus glaucipes*, *Mermiria bivittata*, *Dactylotum bicolor*, *Phlibostroma quadrimaculatum*, *Spharagemon cristatum*, *Melanoplus aridus*, *Paropomala wyomingensis*, *P. pallida*, *Melanoplus flavidus*, and *M. foedus*; 18 additional species were found at only 1 or 2 of 17 collection points (Peterson unpublished data).

An important and much-studied insect resident of shinnery in west Texas is the boll weevil (*Anthonomus grandis*), an introduced pest of cotton that overwinters in litter and then in spring infests cotton fields up to half a mile away (Rummel and Adkisson 1970). Shin-oak litter provides one of the best overwintering habitats for the weevil in the Rolling Plains and adjacent High Plains (Brown and Phillips 1989, Carroll et al. 1993). Mottes of taller oaks are particularly favorable to the weevils. Emergence from litter in mottes lasts a month longer than from low shinnery, which is long enough to ensure that some weevils live to infest fruiting cotton in late June and early July (Slosser et al. 1984).

Soil microarthropods and nematodes are discussed but not identified beyond family by Elkins and Whitford (1982). Small fungus-eating mites (Pyemotidae, Lordalychidae, and Tarsonemidae) dominated soils in winter, and these were replaced by large predaceous mites (Rhodacaridae, Laelapidae) in spring and summer. Collembola and Psocoptera were present in buried litter but not in soil cores. Nematodes were common in buried litter. Only 3 families of mites were observed in surface litter: Nanorchestidae during summer and, sporadically, Nanorchestidae, Anystidae, and Bdellidae during non-summer months.

Management

Nearly all shinnery in Texas and Oklahoma is on private lands; the exceptions are: scattered parcels in highway rights-of-way and state parks; 13,000 acres in Black Kettle National Grassland (USDA Forest Service) in Roger Mills County, Oklahoma; and 16,000 acres in Packsaddle Wildlife Management Area (Oklahoma Department of Wildlife Conservation). In New Mexico, the BLM estimates its shinnery at 480,000 acres (USDI BLM 1979) to 1,200,000 acres (USDI BLM 1986, 1994); state trust lands include about 500,000 acres, and the New Mexico Department of Game and Fish (1984) manages 21,000 acres.

Nearly all of the shinnery is used for livestock (cattle) grazing and hunting. Recreational uses other than hunting are limited: birdwatching, especially prairie-chickens during their spring courting, and dune-hiking and dune-buggy-riding. Small areas are protected for scientific and wildlife purposes including BLM's Mescalero Sands Area of Critical Enviromental Concern and Mathers Research Natural Area in New Mexico (Peterson and Rasmussen 1986, USDI BLM 1997), and 21,000 acres protected as prairie-chicken habitat in tracts of 26 to 6,550 acres in 4 New Mexico counties (New Mexico Dept. Game & Fish 1984). In the Permian Basin (southeastern New Mexico and adjacent Texas), petroleum activities strongly affect shinnery management.

Hunting

From the abundance of both PaleoIndian and modern Indian artifacts, thought mainly to represent hunting camps, we know that game harvesting has occurred in the shinnery for millennia (Beckett 1976, Smith 1985). In the nineteeth century, harvests were large and provided food for explorers and settlers (Gregg 1844, Ligon 1927). Around 1900, railways ran special trains for sportsmen to towns in the Texas Panhandle and placed iced cars on sidings for preservation of the lesser prairie-chicken harvest (Jackson and DeArment 1963). Most game populations are now much smaller, but hunting is an important activity in shinnery and increasingly affects management of the rangeland.

Mule deer, pronghorn, and scaled quail are hunted in shinnery in New Mexico and Texas, white-tail deer and turkey in Texas and Oklahoma, feral hogs and Barbary sheep in Texas, and lesser prairie-chicken, bobwhite quail, mourning dove, and small game (rabbits and jackrabbits) in all 3 states. Trapping of coyotes, bobcats, foxes, skunks, and other mammals occurs in shinnery in all 3 states (Davis and Schmidly 1994, Duck and Fletcher 1944, NM Dept. Game & Fish 1967, D. A. Swepston personal communication 1997).

Management of shinnery has focused on livestock grazing, but unfavorable economics in that industry plus the increasing amounts that sportsmen are willing to pay for hunting privileges make management for wildlife attractive (Hamilton 1979, Holechek 1981, Knight 1985, Teer 1996). This is most true on the private-land ranches of Texas, Oklahoma, and the easternmost New Mexico shinnery. The BLM, which manages much of the New Mexico shinnery, is shifting toward active habitat protection for wildlife including restrictions on oil-and-gas activities and livestock grazing (USDI BLM 1997). Increased emphasis on wildlife can affect livestock stocking rates and grazing systems, brush control practices, revegetation, wildlife transplants, and the design of fences (Bryant et al. 1982, Bryant and Morrison 1985, Hanson 1957, Holechek 1981, Lamb and Pieper 1971, Taylor and Guthery 1980a, Teer 1996, Tharp 1971, Webb and Guthery 1982, Yoakum 1980).

Managing for livestock and big game can be beneficial to both, for instance, by preventing unwanted vegetation trends due to a single species' use (Bernardo et al. 1994, Holechek 1980). More frequently there are tradeoffs (discussed under Livestock Grazing below). For instance, hunting leases in bobwhite and whitetail country in central Oklahoma vary from $1 to $10/acr/yr, depending on habitat quality. The cost of achieving high habitat ratings in that non-shinnery area is higher for quail than for deer due to reductions in cattle numbers required to protect brood habitat and nesting cover (Bernardo et al. 1994, T. Bidwell personal communication 1997).

Livestock Grazing

Plants of the shinnery coevolved with grazing mammals. The larger indigenous herbivores included pronghorn antelope, bison, elk, mule deer, and white-tailed deer (Bailey 1905, Haines 1995, Smith 1971, Tyler and Anderson 1990, Yoakum et al. 1996). Today, cattle are grazed on nearly all of the shinnery range; sheep, horses, and goats are minor species. High stocking densities of cattle are thought to have transformed much of the shinnery from grass-oak communities to systems dominated by shin-oak (Dittemore and Blum 1975 and many other SCS publications, Duck and Fletcher 1944, Jackson and DeArment 1963, Litton et al. 1994, Pettit 1994, USDI BLM 1977, 1979), to have increased annual grasses and forbs at the expense of perennial grasses (Lenfesty 1983, Richardson et al. 1975), and to have increased bare ground, subjecting soils to wind erosion (Holland 1994). In 1970, the Forest Service estimated that 1.5% of the shinnery was in good condition, 92.3% in fair, and 6.2% in poor (USDA Forest Service 1972). These condition ratings were based on resemblance of current vegetation to the presumed original vegetation, and on its cover and vigor and on soil factors.

Evaluating the effects of livestock grazing on the structure of shinnery is problematic without at the same time considering the influence of fire and the interaction between historic fire and grazing in this system. In other systems, decreased fire frequency allowed woody vegetation to increase, often to the detriment of herbaceous species. Grazing may act to decrease fire frequency by reducing herbaceous fine fuels (Box 1967).

The herbaceous plants of ungrazed and heavily grazed areas differ. In ungrazed, there exist mostly perennial grasses, while in grazed areas there is a shift toward annual forbs and annual grasses and changes in perennial grass species. For example, in the southern shinnery, species in ungrazed or lightly grazed areas include bluestems, switchgrass, side-oats grama, plains bristlegrass, giant dropseed, and big sandreed; in heavily grazed areas species include mostly annual forbs and annual grasses (sandbur, purple sandgrass, fringed signalgrass, false buffalograss), and the main perennial grasses become three-awns, hooded windmillgrass, and red lovegrass. Hairy grama, sand muhly, and sand paspalum also increase in percentage under heavy grazing, while sand dropseed may increase or decrease (Lenfesty 1983, Pettit 1986, Richardson et al. 1975, USDI BLM 1977).

Holland (1994) examined the effects of grazing on plant species richness and distribution in shinnery in Yoakum County where shin-oak constituted 60% to 80% of plant cover. Using 2x2 m quadrats, she found that in ungrazed areas 252 m^2 of quadrats were needed to find 80% of the total 25 species present while in grazed areas only 115 m^2 of quadrats were needed to find 80% of the total 25 species present. A conclusion is that species are more evenly spread where grazed. The average number of species per 2x2 m quadrat was twice as high in the grazed treatment, although there was no difference in species richness between treatments. The density of herbaceous plants was almost twice as high in grazed (4.7 individuals per m^2) as in ungrazed treatments (2.5 individuals per m^2) due to cattle's creating open sites in the shin-oak litter for seedling establishment (Holland et al. 1994).

According to McIlvain (1954), "Grass growing in shinnery oak is much less nutritious than grass growing in open sunlight. The effect of shade is to increase fiber content and lower sugar content greatly. Consequently, livestock reluctantly graze these shaded grasses. Instead, they concentrate in open areas where the grass is weakened and often killed by heavy grazing use." There are no data to support these conclusions.

Selection indices (relative amount eaten divided by relative amount available) were determined for cattle use of plants in shinnery in Eddy County, New Mexico. Dropseeds, sandbur, sand paspalum, plains bristlegrass, gyp phacelia, plains sunflower, evening primrose, and camphorweed had selection indices above 1; black grama, lovegrasses, and Schweinitz flatsedge had values about 1; shin-oak, sand sagebrush, mesquite, three-awns, false buffalograss, fall witchgrass, hairy grama, fringed signalgrass, *Pectis* species, leafflower, and crotons had values below 1, where summer cattle diets were 81% grasses, 17% forbs, and 2% shrubs (LaBaume et al. 1980).

It is sometimes claimed that cattle do not eat shin-oak or eat very little shin-oak when other forage is available (Villena-Rodriguez 1987), but this is not generally true. In Yoakum County, the relative frequency of shin-oak in cattle diets averaged 4.2%, 16.2%, 20%, 4.1%, and 9.5% at monthly intervals from June to October (Plumb 1984, Plumb and Pettit 1983). Roebuck (1982) reported that shin-oak had a relative frequency of 14% (spring through fall) in the diets of cattle grazing shinnery in northwestern Texas. However, in some studies oak was not eaten significantly during the period of study (LaBaume et al. 1980, Weir 1990). In Dickerson's (1987) study, cattle ate significant amounts of shin-oak (20% of diet) in only 1 mo of 13. Shin-oak "provides dependable forage during drought periods" (Holechek and Herbel 1982) and "is of much importance as forage" (Dayton 1931). "Shinnery oak provides safe forage during midsummer and fall, and receives heavy grazing pressure during drought years. A resilient shrub, its vigor and density are rarely harmed by heavy grazing" (USDI BLM 1979). Holland (1994) found that oak was significantly shorter in grazed areas compared with ungrazed, though not differing in density.

Cattle are generally removed from shinnery pastures during the 4-week period in spring following bud-break when shin-oak buds and immature leaves are poisonous to them (Allison 1994, Dollahite 1961). Livestock consumption of shin-oak buds and leaves during this time may lead to malaise, reduced conception rates, lower weight gains, and death (Jones and Pettit 1984). Several Texas counties have reported death due to shin-oak poisoning of more than 1,000 cows in a single year. Losses also occur due to chronic poisoning and increased management costs (moving cattle from shinnery pastures) (Dollahite 1961). The phenolic compounds responsible for the toxicity of shin-oak may have evolved as a defense against grazing animals; buds of grazed oak have been reported to contain higher phenoic levels that those of ungrazed (Vermeire and Boyd unpublished manuscript 1997). Ill effects resulting from shinnery consumption may be minimized by feeding protein-rich supplement containing 9% hydrated lime (Sperry et al. 1964).

Dowhower (1981) studied effects of trampling by human walking, vehicles, and (Dowhower et al. 1981) livestock. Forbs were most affected by trampling and grasses least; shrubs were intermediate. Livestock affected shin-oak more than 2 mi from centers of concentrated activity, but it quickly made up part of its losses by re-sprouting.

In west Texas, shinnery is sometimes converted to planted grass pastures, especially weeping lovegrass (*Eragrostis curvula*) (Goen et al. 1978). Plowing or disking is generally necessary, with plowing preferred to bury weed seeds, distribute nitrogen better, and to bury allelopathic residues from shin-oak and sandbur (Matizha and Dahl 1991). An attempt was made to plant weeping lovegrass in undisturbed shinnery; up to 17 seedlings/foot of row survived from May to August, but half were gone in September (Pettit et al. 1977).

Because cattle-grazing has the potential to decrease the productivity of shinnery and to decrease production of perennial grasses, there is considerable research to identify stocking rates and grazing systems that would produce a healthy ecosystem. Results are compared with traditional stocking of shinnery, which was continuous grazing averaging 45 acres (Pettit 1986) to 52 acres (USDA Forest Service 1972) per AU (animal unit, a cow-calf pair). In the dry years 1983 and 1984, Mosley et al. (1985b) found that stocking for 100% of proper use fell from an average of 19 acres/AU to 50 acres/AU in a highly productive area.

The efficacy of rotational grazing, in which certain pastures are rested during the various seasons has been evaluated in shinnery. In Yoakum County, Texas, Plumb (1984) found no difference in weaning weights or average daily gain of calves using a 3-herd, 4-pasture deferred rotation system stocked at 74 acres/AU relative to continuous grazing at 62 a/AU. The BLM mandated deferred grazing on 1,400,000 acres in 90 allotments in shinnery country of its Roswell District, with rest periods from 4 mos to 2 yrs (USDI BLM 1979), but the BLM has not enforced these decisions (USDI BLM 1997). Deferment during spring when shin-oak is poisonous to cattle is helpful but insufficient for grass recovery, since tillering and seed production come later in the season (USDI BLM 1977). Dahl (1986) stated that rotation and deferment are better tools to maintain rather than to improve range condition, but over several years they provide for about 25% more animals than does continuous year-long stocking.

Extensive tests have been made for short-duration grazing in shinnery in which a single herd is moved through 6 or more paddocks, with moves every 1 to 7 days. Dickerson (1985, 1987, summarized by Bryant et al. 1989) found that an 18-paddock system in Garza County, Texas, did not differ from continuous grazing with regard to herbage yield, forage digestibility or protein content, animal performance, animal production per acre, or vegetation composition, but it did permit higher stocking rates. In the same study, Mosley et al. (1985a) found 25% more crown death of little bluestem, sand dropseed, hairy grama, and fall witchgrass under continuous grazing. Shifting from 7 days in each pasture to flexible 0-to-14 day periods depending upon available herbage, did not improve results (Mosley and Dahl 1990). Plumb (1984, Bryant et al. 1989), working in Yoakum County, Texas, likewise found no difference in animal performance or production in a 6-paddock cell stocked at 35 acres/AU compared with continuous grazing at 62 acres/AU, though again, higher stocking was possible.

Weir (1990) evaluated cattle performance for 161 days in Roosevelt County, New Mexico, under continuous and short-duration grazing at the same stocking rates (19 to 26 acres/head) and found that daily weight gains were higher under continuous grazing than short-duration grazing; no differences appeared in quality or composition of diets. Working on the same ranch, Keesee (1992) measured physical and hydrologic properties of soils under continuous and short-duration grazing at the same stocking rate; he was unable to confirm the improvements claimed as a result of hoof action under short-duration grazing. Dahl (1986) discussed Texas Tech's experiments with short-duration grazing and concluded that it reduces sacrifice areas around range developments, provides opportunity for plants to recover from grazing, and, in large pastures, provides opportunity to increase stocking rates. However, short-duration grazing does not improve diet qualities, animal performance (at stocking rates equal to continuous grazing), infiltration of water into the soil, or revegetation of eroded gullies. Ethridge et al. (1987b) discussed the economics of an 8-paddock system in shinnery.

The only grazing system claimed to improve grass production in shinnery was the 1-herd, 4-pasture system described for Eddy County, New Mexico, by Moore (1954). Bunching cattle in 1 pasture had the advantage of forcing them to eat the less palatable grasses, which cost something in weight gains but, "we feel that the benefit to the range is greater than the loss to the stock" (Moore 1954). Moore offered no data to support his claim and there has been no controlled experiment to test it. However, this grazing system is probably closest to that used for thousands of years by bison, which moved through shinnery in close-knit groups in search of good forage (Shaw 1996), although they probably moved more than did Moore's cattle.

Rotational grazing is recommended for improvement of lesser prairie-chicken, bobwhite quail, scaled quail, and turkey habitat (Bryant et al. 1982, Holechek 1981, Taylor and Guthery 1980a). Ahlborn (1980) suggested a flexible strategy such as a best-pasture system (choice of pasture based on vegetative condition). Litton et al. (1994) recommended short-duration grazing for its hoof-action effect, believing that ground disturbance favors forbs that provide prairie-chicken food.

More important than the grazing system for ground-nesting birds are stocking rates. Light to moderate grazing secures nesting cover for bobwhite quail (Guthery 1982), while serious reductions in prairie-chicken and scaled quail populations may follow overgrazing (Dixon and Knight 1993, Duck and Fletcher 1944, Litton et al. 1994). Haukos and Smith (1989) noted that prairie-chicken hens selected nest sites within lightly grazed shinnery with >75% vertical screening in the first 13 inches and 50% overhead cover. Riley et al. (1992) found, on average, 26-inch bluestem grasses at successful prairie-chicken nests and 14-inch grasses at unsuccessful ones. One important way to achieve this degree of cover is with livestock exclosures, which are discussed by Davis et al. (1979), Frary (1957), Sell (1979), Snyder (1967), and USDI BLM (1979) for prairie-chickens; by Dixon and Knight (1993) for scaled quail; by Holechek (1981) and Webb and Guthery (1982) for bobwhite habitat; by Bryant et al. (1982) and Holechek et al. (1982) for turkeys; and for all these species by Brown (1978).

Effects of grazing on other wildlife vary. Dietary overlap between deer and cattle in shinnery is minimal (Bryant and Demarais 1992, Bryant and Morrison 1985). Deer may avoid ranching operations and often select for deferred pastures over actively grazed areas (Holechek et al. 1982, Hood and Inglis 1974). The significance of this behavior to the well-being of deer populations is unclear. Shin-oak was the main item of dietary overlap between pronghorns and cattle in the Texas Panhandle but because there was plenty, the overlap posed no problem (Roebuck 1982).

Livestock grazing alters food and cover for non-game birds, particularly by altering the vertical structure of habitat. A few species benefit from grazing, while many species react unfavorably. However, species response varies drastically between sites and between years within sites so that lists of species are highly conditional (Knopf 1996).

Effects of livestock grazing on small mammal populations are variable and species-dependent. Plains pocket gophers are most abundant on moderately grazed range, preferring the varied vegetation of disturbed sites, whereas woodrats, cotton rats, and harvest mice prefer ungrazed range (Fagerstone and Ramey 1996). These generalizations are not based on studies in shinnery. Black-tailed jackrabbits have been variously reported to do best on ungrazed, moderately grazed, or overgrazed rangeland; dietary overlap is moderate as jackrabbits consume less grass and more shrubs than cattle (Fagerstone and Ramey 1996).

Effects of cattle-grazing on the sand dune lizard are unclear. In sites where most shin-oak had been killed, there were fewer lizards under heavy grazing than in lightly grazed areas, but heavily grazed untreated areas had slightly more lizards than those lightly grazed (Snell et al. 1993).

Management of Shin-oak

Shin-oak is often regarded as a noxious and undesirable weed for agriculture and livestock grazing: Shin-oak competes with better livestock forage and its buds and leaves are toxic to cattle for several weeks in spring (Dollahite 1961, Marsh 1919). In the last 25 yrs, an additional reason for control of shin-oak has developed. In 4 Texas counties where cotton is grown, boll weevils overwinter in shin-oak litter and infest nearby cotton fields in spring (Slosser et al. 1984, 1985). Most research and other human effort concerning shin-oak have been devoted to its eradication.

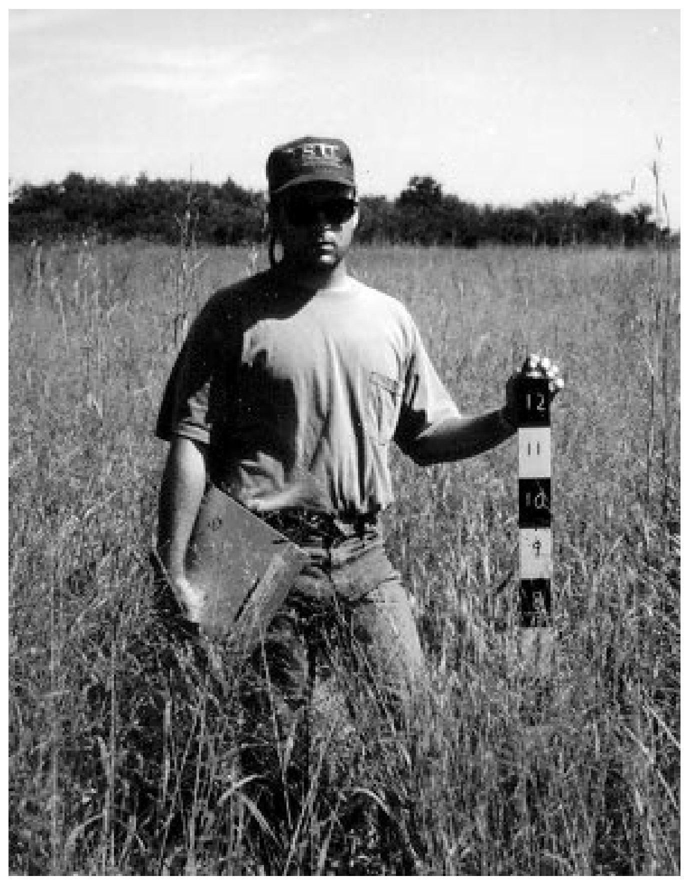
Mechanical Means

Plowing shinnery to create fields for crops is expensive but successful; almost 1 M acres have been cleared in Texas (Deering and Pettit 1972). The practice is ecologically questionable given the high regional potential for wind erosion (Lotspeich and Everhart 1962). Where improved rangeland for cattle is the goal, "Many different kinds of mowers, beaters, cutters, choppers, and other mechanical devices have been unsuccessfully used to control shinnery oak" (McIlvain 1954). Removal of aboveground shoots of the oak increases grass production primarily in the eastern shinnery, "where rainfall is high and potential production is good. However, the economics of the practice are questionable" (McIlvain 1954). Shredding above-ground parts of oaks weakens the plants, but they resprout and after a few months their levels of available carbohydrate have recovered (Bóo and Pettit 1975).

Fire

Control of shin-oak using prescribed fire is hampered because the oak typically resprouts vigorously in the growing season following fire, with regrowth reaching 3 to 4 ft within 2 or 3 growing seasons (McIlvain 1954). Although more research is needed, the use of annual or biennial prescribed fire may decrease the canopy height of shin-oak and increase production of perennial grasses. McIlvain (1954) speculated that annual fires were used to control shin-oak during early settlement in Oklahoma.

Figure 15. Prescribed fire moves through sand shinnery during the growing season in Ellis County, Oklahoma. The pole is 2 m high.



Figures 16. Plant growth during a wet year, 4 months after an April 29, 1997, prescribed fire in Ellis County, Oklahoma. Grasses dominate the post-fire community. The measuring board is marked in 10-cm increments to a height of 130 cm.

Given the resilience of shin-oak to fire, it is unlikely that annual fires would eliminate shin-oak from the community. Current research by Oklahoma State University (figures 15 to17) may help determine the use of annual and timed spring burns for managing shin-oak.

Herbivory

Goats have long been used in Texas for control of woody plants, including oaks, and there were early trials in southeastern New Mexico to control shin-oak with goats. In shinnery in west Texas where oak provided 79% of available forage, oak increased in the diets of Angora and Spanish goats from 31% in June to 51% in August, of which 85% was oak leaves and 15% stems. The increase was likely due to the goats' previous inexperience with oak and decreasing availability of forbs (Villena et al. 1987, Villena-Rodriguez 1987). Trials over 3 yrs in Black Kettle National Grassland (Roger Mills County, Oklahoma) used both meat-type and mohair-producing goats. The goats succeeded in shifting forage production from 95% oak and 5% grass and forbs to 50% oak and 50% grass and forbs without changing total production, and also greatly increased nitrogen, phophorus, and potassium in soil. Goats kept continuously on shin-oak lost weight. The authors recommended rotating goats out of target pastures when defoliation of shin-oak reaches 80% and returning them when regrowth leaves have attained one half of their mature size (Escobar et al. 1995). Control by goats is promising.

Figure 17. Plant growth during a wet year, 4 months after an April 29, 1997, prescribed fire in Ellis County, Oklahoma. Shin-oak resprouts form an understory 30-40 cm tall.

Herbicides

Chemical-control trials by the Agricultural Research Service began at Woodward, Oklahoma, in 1947 (McIlvain 1954). In 50 yrs, a great deal of effort at Woodward, Texas Tech, and Texas A & M has gone into herbicidal control of shin-oak. This effort has resulted in about 75 articles and theses on how and when to control, another 40 on the effects of control on vegetation and soils, and others on the effects on mammals, birds, and reptiles.

Most early trials involved phenoxy herbicides including 2, 4-D and 2, 4, 5-T and Silvex (2-(2,4,5-T) propionic acid), benzoic acids, including dicamba, and a picolenic acid, picloram (Tordon), which are applied as liquids and absorbed through foliage. At a pound or more per acre of active ingredient, these herbicides top-killed 85% to 95% of the oak and root-killed a small percentage (Greer et al. 1968, NM Inter-Agency Comm. 1970, Pettit 1977). Lighter application of herbicide was usually recommended because of adverse effects on forbs. Control was expensive but effective. Spray applications that killed 10% of the oak doubled grass production, which was measured 3 yrs later. At 20% kill, production was tripled 2 yrs after the second annual spraying. A 90% kill, resulting from 3 annual sprayings, quadrupled production a year after the third spraying, although grass production declined to the level of twice the original production within a few years (Greer et al. 1968, McIlvain and Armstrong 1959). Much higher application rates, 2.7 to 7 lb/acre of picloram, killed oak with 1 spraying but desirable forbs and seedlings of perennial grasses had scarcely reentered the sprayed plots 6 yrs later (Pettit 1976, 1977).

Beginning in 1974, a pellet form of tebuthiuron (Spike or Graslan, a thiadiazol combined with dimethlyurea and dimethylethylene), which acts through the soil and is absorbed by roots, was tested on shin-oak. Tebuthiuron defoliates the oak, which then leafs out repeatedly with decreasing vigor, followed by death in the second, third, or later years after treatment (Jones and Pettit 1984). At 2.7 lb active ingredient/acre, the oak was killed and many non-target forbs and grasses were set back (Pettit 1979). At .36 lb active incredient/acre, oak canopy was reduced 95% and grass yield was 2.5 times the control after 3 yrs. At .54 to .9 lb/acre all oak was killed (figure 18). At .72 lb/acre, the maximal grass yield of 4 times the control was obtained (Jones 1982, Jones and Pettit 1984).

Total production was generally constant. The herbicide shifted its composition from oak toward grass, which increased from 26% to 700% following control depending on the degree of oak cover, percentage kill, initial grass cover, soil type, and precipitation (Gribble 1981, Jacoby et al. 1983, Jones and Pettit 1982, 1984, Pettit 1979, 1986, Plumb 1984). Much of the increase was annual grasses and undesirable sandbur (Jacoby et al. 1983, Plumb 1984). Grasses begin growth from 3 to 6 weeks earlier in treated pastures than in untreated (Biondini et al. 1986, Plumb 1984). In the 4 grass species sampled, crude protein was 28% higher in treated than in untreated shinnery in the treatment year, but the effect was gone a year later (Biondini et al. 1986). Plumb (1984) found that cows on treated pasture were above protein maintenance levels in all seasons except winter. On untreated pastures, cows required protein supplement in all seasons except summer.

Forb response to tebuthiuron is uneven but generally after 1 or 2 yrs of depleted production, the variety and yield of forbs become greater than in untreated pastures (Doerr and Guthery 1983b, Jacoby et al. 1983, Jones and Pettit 1982, Olawsky and Smith 1991, Pettit 1986, Willig et al. 1993). Bare soil plus litter decreased from 35% in untreated plots to 20% in treated, while the percentage of living-plant cover increased (Jacoby et al. 1983). By 1995, 320,000 acres of shinnery had been treated with tebuthiuron in Texas (Johnson and Ethridge 1996). From 1981 to 1993, the BLM sprayed 100,000 acres in New Mexico (USDI BLM 1997).

Figure 18. This treated sand shinnery is a rich mix of grasses and forbs; little bluestem, sand bluestem, annual wild buckwheat, and fall witchgrass are visible.

In the eastern two-thirds of the shinnery region, the economics of shinnery conversion can be favorable on livestock ranches, though very sensitive to rainfall, depth of fine sand, herbicide price, and beef prices (Etheridge et al. 1987a, 1987b, Jones 1982, Neal 1983, Pettit 1986, Richardson and Badger 1974). By extension of the calculations of Etheridge et al. (1987a) it appears that shin-oak control loses money farther west, including New Mexico, where precipitation is less and forage increases are smaller, or where wildlife values should be included in the calculations.

Pettit (1983a) reported that brownspine prickly pear was indirectly controlled by tebuthiuron: after shin-oak is defoliated the cactus gains vigor or at least remains static, but as grasses begin to dominate the cactus shows signs of stress. Within 2 yrs, many cactus pads are infested with borers and scale insects, and Pettit estimated that the cacti would die about 10 yrs after herbicidal treatment.

Herbicidal treatment alters the distribution of biomass in shinnery. Sears et al. (1986a) reported that 3 yrs after tebuthiuron treatment, total above-ground biomass decreased by 2% relative to control plots, which is the result of a 17% decrease in oak and litter and a 266% increase in herbaceous vegetation. Six yrs following treatment, above-ground biomass had decreased by 29% (41% decrease in oak, 32% decrease in litter, and 161% increase in herbaceous vegetation). Surprisingly, the ratio of above-ground to below-ground biomass was the same in controls and in 6-yr treated shinnery, 1: 5.7 (Sears et al. 1986a). Litter can cover 100% of the soil under oak. This decreases after control but is partly compensated by an increase in herbs (Sears 1982). Soil organic matter increases with the decay of oak (Sears et al. 1986b).

Soil nutrient and water relations are changed by herbicidal control. Nitrogen (nitrate + ammonium) concentrations were higher in soils of treated shinnery than in untreated and increased for years after control (Kyrouac 1988, Sears et al. 1986b). Phosphorus may also have increased in soils after control but the effect was not as long-lasting (Kyrouac 1988). Removal of oak adds little to soil moisture if herbs are allowed to flourish, nor does removal of herbs add much to soil moisture since the oaks will use more (Pettit and Holder 1973, Pettit and Small 1974). Galbraith (1983) did find some increase in soil water after treatment but mainly found water differently distributed; the increase was from 35 to 100 inches depth due to death of the deep oak roots. Test (1972) also found more soil water in treated plots than untreated (37% more in July, 9% in wetter September soils) but most of the increase was at depths less than 30 inches.

Small differences between treated and untreated areas in development of vesicular-arbuscular mycorrhizae on little bluestem and purple three-awn grasses were likely due to increases in soil nutrients and moisture due to treatment (Kyrouac 1988).

Experimenters with tebuthiuron treatment have issued several cautions: shin-oak should not be treated in drought years, in areas of large dunes, or where perennial grasses are few, and treated pastures should not be burned or summer-grazed for at least 2 yrs after treatment (Doerr and Guthery 1980b, McIlvain and Armstrong 1959, N. M. Inter-Agency Comm. 1970). "These herbicides are not recommended for application to an oak community in poor range condition. These lands are perhaps the most fragile of all ecosystems on the southern High Plains of Texas and the landowner cannot afford to abuse them" (Pettit 1979). A year after shin-oak treatment, a pasture "supporting a midgrass prairie" was many times more susceptible to wind erosion than untreated shinnery (Thurmond et al. 1986). Even where surface cover increased from 60% to 65% due to herbicidal treatment, there was an 80% increase in wind-blown sediment (Zobeck et al. 1989). Because of the fine fuel load, treated land also becomes more susceptible to wildfire. In sand dune habitat, Petit (1985) reported that 50% of grasses were killed by fire or by blowing sand and over 3 inches of sand were removed. The biggest danger from herbicide-based control is erosion following drought. The grasses and forbs that replace oak are not as resistant to drought as is shin-oak, and their death would leave the soil exposed.

The usefulness of shin-oak as livestock feed during drought, as well as erosion control, indicate that preserving some oak is beneficial. "Research results in Oklahoma show greater forage production when shinnery makes up part of the vegetation than when grasses are alone on these soil types" (N. M. Inter-Agency Comm. 1970). According to McIlvain and Armstrong (1963), on steep dunes the goal for brush control should be 25% kill, on low dunes without thick grass stands kill should be less than 50%, on gently rolling or nearly flat areas that support dense grasses kill should be 70% to 80%.

On multiple use land, the question of treatment becomes more complex, especially regarding the lesser prarie-chicken. Jackson and DeArment (1963) claimed that large-scale brush control produces communities that the prairie-chicken does not readily adjust to. Even a 25% kill prevented acorn production for 2 yrs and the effects were apparent in lower prairie-chicken populations. Copelin (1963) discussed the difficulties of determining whether brush control helped or hurt prairie-chicken populations. But Donaldson (1966, 1969) claimed benefits from shin-oak control. He counted birds for 1 season where 75% of shin-oaks had been killed, forb production had decreased, and grass production had doubled. He found 10 times as many prairie-chickens in treated areas as in untreated areas. However, shin-oak was the plant that the birds used most, especially in the treated areas, and he proposed supplemental winter feeding to make up for loss of acorns.

In the 1960s, the New Mexico Department of Game and Fish negotiated an understanding with the BLM prevening shin-oak control in federal prairie-chicken areas (Sands 1968). The BLM (USDI BLM 1984) later abrogated the memorandum and from 1981 through 1993 treated 100,000 acres. There is no evidence from Texas or New Mexico indicating that shin-oak treatment with tebuthiuron benefits prairie-chickens. Two studies used paired plots to compare prairie-chickens in treated and untreated shinnery: Olawsky (1987, Olawsky et al. 1988) found little change in populations but in treated areas there was a decrease in lipid levels that indicated worse overall condition, which he tentatively blamed on lack of acorns. Martin (1990) found 86% fewer prairie-chickens in treated areas than in untreated areas but seeing the birds in grass was a problem. A third study used radiotelemetry to track females and found that they preferred nesting in untreated rather than treated shinnery (Haukos and Smith 1989b). If shin-oak control benefited prairie-chickens it would do so by creating a mosaic of small blocks of vegetation (Davis et al. 1979, Sell 1979, Taylor and Guthery 1980a). "Because of the importance of shinnery oak grassland to prairie-chickens for both food and cover, broad-scale eradication of this community should be avoided" (Riley et al. 1993a, Olawsky and Smith 1991). Use of picloram to treat 150 to 300 ha blocks was recommended by Doerr and Guthery (1980b) to improve nesting cover, providing that control was partial and admitting that these large blocks were a compromise between the habitat requirements of the birds and the economics of treatment.

Control of shin-oak affects other wildlife species variously. For mule deer habitat, "Any mechanical or chemical treatments should be avoided where damage to skunkbush sumac, wild plum, or sand-shinnery oak is a possibility" (Bryant and Morrison 1985). Javelina presumably do better in untreated shinnery because of the importance to them of shin-oak and prickly pear (Bryant et al. 1982). Bryant and Demarais (1992) emphasized white-tailed deer use of acorns and browse. They thiought that opening up dense browse can be beneficial if openings are less than 300 yards wide, ideally 50 to 100 yards wide. Darr and Klebenow (1975) discouraged treatment of shinnery, especially oak mottes.

In Eddy County, New Mexico, Bednarz (1987) found lagomorph populations depressed the year following complete elimination of shin-oak, with some recovery in the second and third years following spraying. In Cochran County, Texas, rodent populations were 41% higher on untreated plots than where the shin-oak had been 75% removed by tebuthiuron (Doerr and Guthery 1980a). In Yoakum County, Texas, where treatment removed 90% of the oak, populations of Ord's kangaroo rat more than doubled on treated plots; northern grasshopper mouse populations were lower in winter and spring on treated plots but higher in fall, plains pocket mice prospered on treated plots, and deer mice were fewer on treated plots (Colbert 1986, Willig et al. 1993). In Eddy County, Fischer (1985) also found larger Ord's kangaroo rat populations on treated areas; other species seemed unaffected.

Davis et al. (1974) reviewed the effects of brush control on bird species in Eddy County. They thought that any control should be in swaths. When control was in large blocks in Eddy County, Bednarz (1987) found that the success of raven nesting "crashed" following treatment although populations did not change. He hypothesized that lack of suitable foods was the cause. On plots in Chaves County, New Mexico, where shin-oak was reduced 90% by treatment and grasses doubled, numbers of birds and bird species were not significantly different from untreated plots. Cassin's sparrows may have increased slightly on treated plots, only prairie-chickens sharply decreased (Martin 1990). Bobwhite quail use of treated areas was almost double that of untreated areas where control was in 20-ft wide strips (Webb and Guthery 1982). In Eddy County, scaled quail populations fell following treatment, while bobwhite quail and most other bird species were unaffected and loggerhead shrike populations increased (Bednarz 1987). Meadowlark populations may double in treated shinnery (Olawsky et al. 1987).

In Chaves County, 6 of 7 species of lizard censused were more common in untreated than in treated shinnery, the endangered sand-dune lizard was 5 to 6 times more common. The fence lizard, lesser earless lizard, side-blotched lizard, western whiptail, and six-lined racerunner were significantly more common in untreated areas. The Great Plains skink was significantly more common in treated areas (Gorum et al. 1995, Snell et al. 1997).

A possible compromise between tebuthiuron treatments that destroy shin-oak and no control is to use the foliar herbicides of the 1960s that merely defoliate the oak, giving its herbaceous competitors a period of time in which to regain dominance. The use of goats and of fire are also promising control methods that may not affect wildlife unduly. Most studies (e.g. Bednarz 1987, Harmel 1979) suggest interspersing untreated areas with treated so that shin-oak can provide food and cover.

Conclusions

Shaped by a balance between an extremely long-lived shrub and grasses and forbs that come and go with climatic and human-caused changes, the shinnery is an unusual biological community with unusual problems. Problems concern sand shin-oak, whose virtues are tempered by its negative effects on livestock grazing. Shin-oak is targeted because it is seasonally poisonous to cattle, because grass production can be increased by herbicidal treatment, and because of the erroneous beliefs that it has invaded and increased. Conversion to cultivated land or to seeded pasture destroys the shinnery ecosystem. Loss of tallgrasses to livestock or of shin-oak to herbicides destroys the integrity of the ecosystem. Only small samples resembling undisturbed shinnery remain.

The shinnery is rich habitat for wildlife compared with the surrounding short grass plains. Protecting sandy soils from wind erosion, maintaining wildlife habitat, and improving vegetation for livestock grazing are often in conflict and should be carefully considered before undertaking control of shin-oak.

More research is needed especially to: 1) identify grazing management to help restore and maintain grasses of the shinnery, 2) explore the role of fire in restoring and maintaining the shinnery ecosystem, and 3) examine the effects of different methods and configurations of shin-oak control on wildlife species.

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Appendix

Plants of Shinnery Communities

Plants are listed that were recorded in shinnery by Sullivan (1980) for 6 counties of western Texas adjacent to New Mexico, by R. Peterson (unpublished) for the Mescalero Sands of Chaves County, NM, and by C. Boyd (unpublished) for Black Kettle National Grassland (Roger Mills County) and southern Ellis County, OK. Plant lists for shinnery of the Texas Panhandle such as that of Sears (1982) resemble Boyd's list. Nomenclature largely accords with the Great Plains Flora (1986) except in *Bothriochloa, Digitaria, Elymus, Schizachyrium, Vulpia, Brickellia, Dimorphocarpa, Heterotheca*, and *Mimosa*.

		TX	NM	OK
Woody Plants				
Amorpha canescens	leadplant			+
Artemisia filifolia	sandsage	+	+	+
Baccharis texana	prairie baccharis	+		
Celtis reticulata	netleaf hackberry	+	+	+
Chrysothamnus pulchellus	Southwest rabbitbrush	+	+	
Coryphantha (Mammillaria) vivipara	pincushion, ball cactus		+	
Ephedra antisyphilitica	vine ephedra	+		
Ephedra sp.	ephedra		+	
Ferocactus wislizenii	barrel cactus	+		
Gutierrezia sarothrae	broom snakeweed	+	+	+
Lycium berlandieri	wolfberry	+		
Mimosa biuncifera	catclaw mimosa	+		
Opuntia imbricata	cholla		+	
Opuntia leptocaulis	tasajillo	+		
Opuntia macrorhiza	plains pricklypear			+
Opuntia phaeacantha	brown-spine pricklypear		+	
Opuntia polyacantha	plains pricklypear	+	+	
Populus fremontii subsp. *wislizenii*	Rio Grande cottonwood		+	
Prosopis glandulosa	honey mesquite	+	+	+
Prunus angustifolia	Chickasaw plum			+
Prunus gracilis	Oklahoma plum	+		+
Quercus havardii	sand shin-oak	+	+	+
Rhus aromatica	skunkbush, squawbush	+	+	+
Salix exigua	coyote willow		+	
Salix nigra (*S. gooddingii*)	Goodding's willow	+		
Sapindus saponaria	soapberry	+	+	
Tamarix spp.	tamarisk, saltcedar	+	+	
Yucca campestris	plains yucca	+		
Yucca glauca	soapweed yucca	+	+	+
Ziziphus obtusifolia	lotebush	+		
Graminoids				
Andropogon gerardii	big bluestem	+		
Andropogon hallii	sand bluestem	+	+	+
Aristida divaricata var. *havardii*	Havard's three-awn	+	+	
Aristida purpurea (4 varieties)	purple three-awn	+	+	+
Bothriochloa barbinodis	cane bluestem	+	+	
Bothriochloa laguroides	silver bluestem	+	+	+
Bothriochloa springfieldii	bluestem		+	
Bouteloua curtipendula	side-oats grama	+	+	+
Bouteloua eriopoda	black grama	+	+	
Bouteloua gracilis	blue grama	+	+	+

		TX	NM	OK
Graminoids (Cont'd.)				
Bouteloua hirsuta	hairy grama	+	+	+
Bouteloua rigidiseta	Texas grama	+		
Brachiaria ciliatissima	fringed signalgrass	+		+
Bromus tectorum	cheatgrass			+
Buchloe dactyloides	buffalograss			+
Calamovilfa gigantea	giant sandreed	+	+	
Cenchrus incertus	sandbur	+	+	+
Chloris cucullata	hooded windmillgrass	+	+	
Chloris verticillata	tumble windmillgrass	+	+	+
Cyperus onerosus	flatsedge	+		
Cyperus schweinitzii	Schweinitz flatsedge	+	+	+
Cyperus uniflorus	one-flower flatsedge	+		
Dichanthelium oligosanthes	rosette-grass			+
Digitaria (*Leptoloma*) *cognata*	fall witchgrass	+	+	+
Elymus canadensis	Canada wild rye			+
Elymus longifolius	squirreltail grass		+	
Enneapogon desvauxii	spike pappus-grass		+	
Eragrostis cilianensis	stinkgrass		+	
Eragrostis curtipedicellata	gummy lovegrass	+	+	+
Eragrostis curvula	weeping lovegrass			+
Eragrostis lehmanniana	Lehmann lovegrass	+	+	
Eragrostis secundiflora	red lovegrass	+	+	+
Eragrostis spectabilis	purple lovegrass			+
Eragrostis sessilispica	tumble lovegrass	+	+	
Eragrostis trichodes	sand lovegrass		+	+
Erioneuron (*Dasychloa*) *pulchellum*	fluffgrass		+	
Juncus scirpoides	needlepod rush	+		
Lycurus phleoides (*L. setifolia*)	wolftail	+		
Muhlenbergia arenacea	ear muhly		+	
Muhlenbergia porteri	bush muhly		+	
Munroa squarrosa	false buffalograss	+	+	
Panicum capillare	witchgrass		+	
Panicum hallii	Hall's panicum		+	
Panicum havardii	Havard panicum	+	+	
Panicum obtusum	vine-mesquite	+		
Panicum virgatum	switchgrass		+	
Paspalum setaceum	sand paspalum	+	+	+
Schedonnardus paniculatus	tumble-will		+	
Schizachyrium scoparium	little bluestem	+	+	+
Scirpus acutus	hardstem bulrush	+		
Scleropogon brevifolius	burrograss		+	
Setaria leucopila (*S. macrostachya*)	plains bristlegrass	+	+	
Setaria (*Panicum*) *ramisetum*	bristle panicum	+		
Setaria viridis	green foxtail			+
Sorghastrum nutans	Indiangrass		+	+
Sporobolus contractus	spike dropseed		+	
Sporobolus cryptandrus	sand dropseed	+	+	+
Sporobolus flexuosus	mesa dropseed	+	+	
Sporobolus giganteus	giant dropseed	+	+	
Sporobolus vaginiflorus	poverty grass			+
Stipa comata	needle-and-thread	+	+	
Triplasis purpurea	purple sandgrass		+	
Vulpia octoflora	six-weeks fescue	+	+	+
Forbs				
Abronia fragrans	snowballs, sandverbena	+	+	
Achillea millefolium	yarrow			+

		TX	NM	OK
Forbs (Cont'd.)				
Allionia incarnata	trailing four-o'clock, windmills		+	
Allium drummondii	wild onion			+
Amaranthus retroflexus	redroot pigweed	+		
Ambrosia psilostachya	western ragweed	+	+	+
Aphanostephus skirrhobasis	sleepydaisy		+	
Apocynum cannabinum	dogbane		+	+
Argemone polyanthemos	prickly poppy			+
Argemone sp.	prickly poppy		+	
Artemisia caudata	threadleaf sagewort	+		
Artemisia frigida	estafiata, prairie sagewort		+	
Artemisia ludoviciana	white sage			+
Asclepias arenaria	sand milkweed	+	+	
Asclepias asperula	antelopehorns			+
Asclepias engelmanniana	Engelmann milkweed	+		
Asclepias pumila	plains (or dwarf) milkweed	+	+	
Asclepias subverticillata	poison milkweed		+	
Asclepias tuberosa	butterfly milkweed			+
Asclepias verticillata	whorled milkweed			+
Asclepias viridiflora	green antelopehorns	+		+
Aster ericoides	white aster			+
Aster patens	aster			+
Astragalus mollissimus	woolly loco	+	+	+
Baptisia australis	blue false indigo			+
Berlandiera lyrata	greeneyes, chocolate flower	+		
Brickellia (*Kuhnia*) *eupatorioides*	false boneset	+	+	
Caesalpinia jamesii	James' rushpea	+	+	
Callirhoe involucrata	poppy mallow			+
Calylophus berlandieri	sundrops			+
Calylophus hartwegii	sundrops		+	
Calylophus serrulatus	halfshrub sundrops	+	+	+
Cassia chamaecrista	partridgepea			+
Chenopodium album	lamb's quarters			+
Chenopodium leptophyllum	slimleaf goosefoot	+		
Cirsium ochrocentrum	yellow-spine thistle	+	+	+
Cirsium undulatum	wavy-leaf thistle			+
Cnidoscolus texanus	Texas bull-nettle	+		
Comandra umbellata subsp. *pallida*	bastard toadflax	+		
Commelina erecta	dayflower	+	+	+
Conyza canadensis	horseweed	+		
Corispermum hyssopifolium	tickseed, bugseed		+	
Corispermum nitidum	tickseed, bugseed	+	+	
Croton dioicus	hierbo del gato		+	
Croton pottsii	leatherweed croton	+	+	
Croton texensis	Texas croton	+	+	+
Cryptantha cinerea	hiddenflower	+	+	
Cryptantha minima	small hiddenflower	+		
Cuscuta glabrior	dodder		+	
Cycloloma atriplicifolium	tumble ringwing	+	+	
Dalea aurea	golden prairie-clover			+
Dalea candida	white prairie-clover		+	
Dalea lanata	woolly dalea	+	+	
Dalea nana	dwarf dalea	+	+	
Dalea purpurea	purple prairie-clover		+	+
Dalea tenuifolia	slimleaf prairie-clover	+		
Dalea villosa	silky prairie-clover	+		+
Datura quercifolia	oak-leaf thornapple		+	
Datura stramonium	jimsonweed	+		

		TX	NM	OK
Forbs (Cont'd.)				
Delphinium virescens	plains larkspur		+	+
Desmodium sessilifolium	sessile-leaved tickclover			+
Dimorphocarpa (*Dithyrea*) *candicans*	spectaclepod			+
D*imorphocarpa* (*Dithyrea*) *wislizenii*	spectaclepod	+	+	
Erigeron bellidiastrum	fleabane		+	
Erigeron modestus (broad sense)	plains fleabane	+	+	+
Erigeron spp.	fleabane	+		
Eriogonum annuum	annual wild buckwheat	+	+	+
Erodium texanum	Texas stork's-bill		+	
Erysimum capitatum	wallflower	+		
Euphorbia carunculata	spurge		+	
Euphorbia fendleri	spurge	+	+	
Euphorbia geyeri	spurge		+	
Euphorbia micromera	spurge		+	
Euphorbia missurica	spurge	+	+	
Euphorbia parryi	spurge		+	
Euphorbia prostrata	spurge			+
Euthamia gymnospermoides	viscid euthamia			+
Evolvulus alsinoides	ojo de víbora		+	
Evolvulus nuttallianus	hairy evolvulus	+		+
Evolvulus sericeus	silky evolvulus		+	
Froelichia floridana	snakecotton	+	+	+
Froelichia gracilis	snakecotton		+	
Gaillardia pinnatifida	yellow blanketflower			+
Gaillardia pulchella	firewheel, Indianblanket	+	+	+
Gaillardia suavia	rayless gaillardia			+
Gaura coccinea	scarlet gaura	+	+	+
Gaura suffulta	gaura			+
Gaura villosa	woolly gaura	+	+	
Gnaphalium sp.	cudweed	+		
Guilleminea lanuginosa	woolly cottonflower	+		
Gutierrezia dracunculoides	annual broomweed			+
Haplopappus spinulosus	goldenweed, ironplant	+	+	+
Hedyotis humifusa	mat bluets	+	+	
Helianthus annuus	annual sunflower	+	+	+
Helianthus petiolaris	plains sunflower	+	+	
Heliotropium convolvulaceum	bindweed heliotrope	+	+	
Heterotheca canescens	golden aster	+		
Heterotheca latifolia	camphorweed	+	+	+
Heterotheca villosa	golden aster			+
Hoffmanseggia drepanocarpa	sicklepod rushpea	+	+	
Hymenopappus flavescens	yellow woollywhite	+	+	
Hymenopappus tenuifolius	woollywhite			+
Hymenoxys acaulis	bitterweed		+	
Hymenoxys odorata	bitterweed			+
Hymenoxys scaposa	bitterweed	+		
Ipomoea leptophylla	bush morning-glory		+	
Ipomopsis (*Gilia*) *longiflora*	blue trumpets	+	+	
Krameria lanceolata	trailing ratany	+	+	+
Lactuca ludoviciana	western wild lettuce			+
Lechea mucronata	pinweed	+		
Lepidium virginicum	peppergrass			+
Lespedeza stuevei	tall-bush lespedeza			+
Lesquerella fendleri	bladderpod		+	
Leucelene ericoides	baby aster, sand aster		+	
Liatris punctata	gayfeather	+		+
Linaria canadensis	toadflax			+

		TX	NM	OK
Forbs (Cont'd.)				
Linum aristatum	yellow flax		+	
Linum pratense	Norton's flax			+
Linum rigidum	stiffstem flax	+	+	
Linum sulcatum	grooved flax			+
Lithospermum arvense	puccoon			+
Lithospermum carolinense	puccoon			+
Lithospermum incisum	gromwell, puccoon	+	+	+
Lygodesmia juncea	rush skeletonplant	+		
Machaeranthera canescens	daisy (lavender, white forms)		+	
Machaeranthera tanacetifolia	Tahoka daisy	+	+	
Maurandya antirrhiniflora	snapdragon vine		+	
Melampodium leucanthum	blackfoot daisy	+	+	
Mentzelia nuda	blazingstar	+		+
Mentzelia perennis	blazingstar		+	
Mentzelia strictissima	blazingstar		+	
Mimosa (*Schrankia*) *quadrivalvis*	sensitive brier	+	+	+
Mirabilis (*Oxybaphus*) *carletonii*	four-o'clock			+
Mirabilis (*Oxybaphus*) *glabra*	four-o'clock		+	
Mirabilis (*Oxybaphus*) *linearis*	four-o'clock	+	+	+
Mollugo cerviana	carpetweed		+	
Mollugo verticillata	Indian chickweed, carpetweed	+		
Monarda citriodora	lemon beebalm	+		
Monarda pectinata	plains beebalm	+		
Monarda punctata	dotted beebalm			+
Oenothera albicaulis	evening primrose		+	
Oenothera engelmannii	evening primrose		+	
Oenothera rhombipetala	evening primrose	+		+
Orobanche ludoviciana	broomrape		+	
Palafoxia sphacelata	palafoxia	+	+	
Paronychia jamesii	nailwort	+	+	
Pectis angustifolia	limoncillo		+	
Pectis papposa	chinchweed	+		
Penstemon albidus	white beardtongue			+
Penstemon ambiguus	plains penstemon	+	+	
Penstemon buckleyi	Buckley penstemon	+	+	+
Phacelia integrifolia	scorpionweed		+	
Phyllanthus abnormis	leaf-flower	+	+	
Physalis viscosa	groundcherry	+	+	
Physalis sp.	groundcherry			+
Plantago patagonica	Indianwheat	+	+	+
Polanisia dodecahedra	clammyweed		+	
Polanisia jamesii	clammyweed		+	
Polygala alba	white milkwort	+		
Portulaca mundula	chisme, wild purslane	+	+	
Portulaca oleracea	purslane	+	+	
Psilostrophe villosa	hairy paperflower	+		
Psoralea tenuiflora	scurfpea	+		+
Pyrrhopappus multicaulis	false dandelion			+
Ratibida columnifera	prairie coneflower	+	+	+
Reverchonia arenaria	sand reverchonia	+	+	
Ruellia humulis	fringe-leaf ruellia			+
Salsola iberica	Russian thistle	+	+	
Salvia azurea	blue sage			+
Senecio flaccidus (*2 varieties*)	threadleaf groundsel	+	+	
Senecio riddellii	Riddell ragwort			+
Senecio spartioides	broom groundsel	+	+	
Solanum elaeagnifolium	horsenettle, nightshade	+	+	+

		TX	NM	OK
Forbs (Cont'd.)				
Sphaeralcea coccinea	scarlet globemallow	+	+	
Stillingia sylvatica	queen's-delight	+	+	+
Streptanthus hyacinthoides	twistflower			+
Talinum calycinum	rockpink	+		
Talinum parviflorum	fame-flower		+	
Tephrosia virginiana	goat's rue			+
Teucrium laciniatum	germander		+	
Thelesperma filifolium	gray greenthread			+
Thelesperma megapotamicum	greenthread, Navajo tea	+	+	
Tidestromia lanuginosa	tidestromia	+	+	
Townsendia exscapa	Easter daisy	+	+	
Tradescantia occidentalis	prairie spiderwort	+	+	+
Tragia ramosa	noseburn			+
Tribulus terrestris	puncturevine			+
Triodanis perfoliata	Venus looking-glass			+
Verbena bracteata	prostrate vervain		+	
Verbesina encelioides	cowpen daisy; crownbeard	+		
Vernonia baldwinii	western ironweed			+
Xanthisma texanum	sleepydaisy	+		+
Xanthium strumarium	cocklebur	+	+	
Zinnia grandiflora	wild zinnia	+		

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of forests and rangelands. Research is designed to meet the needs of National Forest managers, federal and state agencies, public and private organizations, academic institutions, industry, and individuals.

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