Lesser Prairie-Chicken Habitat Map for Portions of Eastern New Mexico

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Paul Neville, Teri Neville, and Kristine Johnson[2]

ABSTRACT

The purpose of this project was to provide a map depicting the extent and location of lesser prairie-chicken habitat in New Mexico. The 923,441 ha (2,281,868 ac) study area includes most of the remaining occupied habitat for the lesser prairie-chicken in the state. We used field data in conjunction with satellite imagery and aerial photography to create a vegetation map. We classified the map according to plant associations and subsequently regrouped it into map units that incorporated landforms, to reflect the habitat requirements of lesser prairie-chickens. We performed GIS analyses incorporating vegetation type, patch size, and fragmentation to identify areas of high quality lesser prairie-chicken habitat. These analyses demonstrate that only three places within the mapped area contain large patches of suitable habitat, and one of those is south of US 380, where LPCH populations are already sparse and scattered. The GIS analyses also indicate that the vast majority of high-quality vegetation types occur in patches smaller than 3200 ha, rendering them by most definitions below the minimum size required by LPCH. Used in combination with GIS analysis and current LPCH population data, the map represents a powerful management, planning, and monitoring tool.

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Introduction

The lesser prairie-chicken (LPCH, *Tympanuchus pallidicinctus)* is a prairie grouse found in upland shrubland and grassland habitats of the Great Plains. Aside from the Gunnison's sage-grouse (*Certrocercus mimimus*), it has the most restricted distribution and smallest population size of any native North American grouse species. Distribution has declined by over 90% since the 1800s (Giesen 1998). Significant reductions in population size and distribution during that time have been attributed to drought, excessive grazing of rangelands, conversion of native rangelands to croplands, and chemical control of sand sagebrush (*Artemesia filifolia*) and shin-oak (*Quercus havardii*). As a consequence, populations in all states within its range are now fragmented and isolated (Giesen 1998). The species is listed as threatened by the state of Colorado, and the US Fish and Wildlife Service (USFWS) classifies it as "warranted but precluded" for listing as threatened under the Endangered Species Act (ESA).

The LPCH occurs in habitats dominated by shin-oak or sand sagebrush with tall grass or mixed-grass species, in five states within the Southern Shortgrass Ecoregion (Bailey 1998, Hagen et al. 2004). The current distribution and breeding range of the LPCH is southeastern Colorado, southwestern Kansas, western Oklahoma, eastern New Mexico, the Texas Panhandle, and portions of Texas contiguous with the New Mexico range (Figure 1). This study focuses on occupied habitats in New Mexico.

Sand shinnery dunelands also provide habitat for the sand dune lizard (*Sceloporus arenicolus*), a species endemic to eastern New Mexico and western Texas. The sand dune lizard is restricted to sand dune blowouts within sand shinnery dunelands. Its distribution is highly fragmented. The lizard is listed as endangered under the New

Mexico Wildlife Conservation Act but has no state listing status in Texas. It is a candidate for listing under the ESA.

The purpose of this study was to create a map depicting the major LPCH habitat types in a large portion of the current range in New Mexico. Our approach to mapping LPCH habitat was to: (1) define suitable LPCH habitat by reviewing published literature and consulting experts; (2) identify variation in vegetation communities using satellite imagery and aerial photos, (3) collect abundance, floristic, and habitat suitability data on vegetation plots; (4) create map units relevant to the needs of the lesser prairie-chicken; and (5) analyze and map habitat quality using GIS. The map is intended for analysis of LPCH habitat preference and use; habitat management for LPCH, sand dune lizard, and other wildlife species; and monitoring of wildlife habitat condition. As such it is not a traditional vegetation map but instead emphasizes plant associations known to be important to the LPCH and, to a lesser extent, the sand dune lizard.

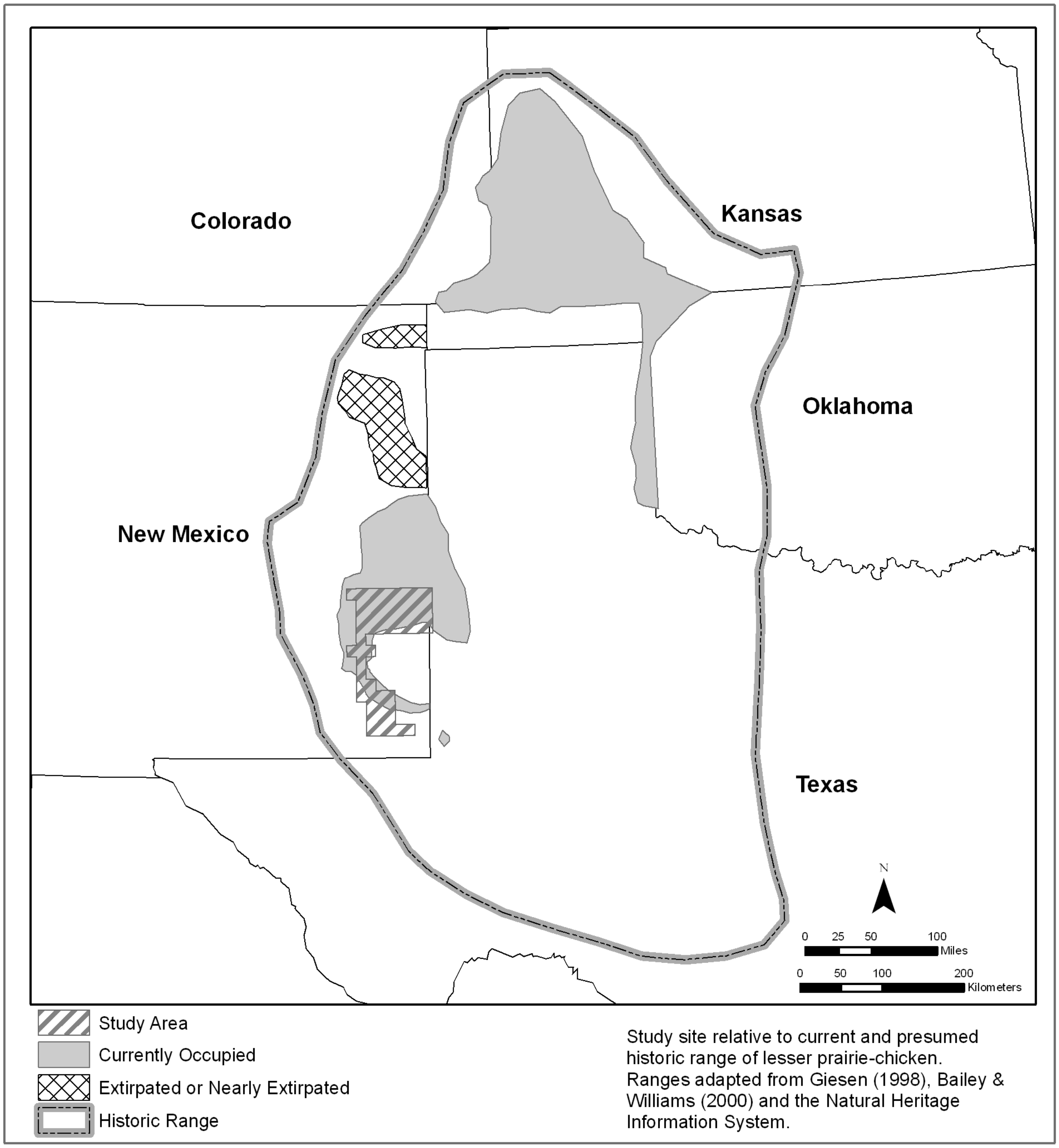

Figure 1. Current and historic range of the lesser prairie-chicken.

THE STUDY AREA AND THE LESSER PRAIRIE CHICKEN

Study Area

The study area comprises fifty-six 7.5' quads or approximately 923,441 ha (2,281,868 ac)[2] in portions of Chavez, Roosevelt, Eddy, and Lea counties in southeastern New Mexico (Figure 2). The block of quads is 50 km (32 mi.) south of Portales at its northernmost point and 60 km (36 mi.) east of Roswell at its westernmost point, runs along the state boundary at its easternmost point, and is due east of Carlsbad at its southernmost point.

The western edge of this region receives about 330 mm (12.97 in. in Roswell) of annual rainfall. It receives progressively more moisture eastward to the state line (450 mm, 17.9 in., in Clovis) but receives less moisture to the south (300 mm, 12 in., in Carlsbad). Most precipitation comes from convective thundershowers during the summer (Western Regional Climate Center 2005). Snow can occur from October to April, typically not more than 86.36 mm (3.4 in) of accumulation at any time and averaging about 254 mm (10 in.) for the year. Temperatures can range from as low as –22.8°C (-9°F) in winter to a high of 45.6°C (114°F) in summer. July is typically the warmest month, with average high temperatures of 33.3°C (92°F) in the north and 35.4°C (95.7°F) in the south. January is the coldest month, with average low temperatures of -4.4°C (24°F) in the north and –1.5° (29°F) in the south.

The study area runs along the margin of the Llano Estacado (the Staked Plains), the southernmost region of the Great Plains. Underlying the llano is the Ogallala Formation, a series of sands and gravels washed out from the Rocky Mountains over the last 12 million years (McLemore 1998); this material was cemented by calcrete precipitated out by groundwater, creating a hardened unit known as the "Caprock". On top of the Caprock, the soils are shallow and calcium carbonate-rich with a loam to clay texture.

In the northern third of the study area, the ancestral east-flowing Brazos River cut the broad Portales Valley through the Caprock. In the Pleistocene, the Pecos River captured most of the drainage, and the soils from the ancestral riverbed were reworked by wind into deep, well-drained sandhills characteristic of this area (McLemore 1998). These sandhills stretch along the whole Portales Valley, but on the margins of the valley and in large blow-out cells within the sandhills, the sands thin out and the llano soils dominate.

The central third of the study area borders the western margin of the llano. Along this area the Caprock attains its greatest relief, forming the west-facing cliffs of the Mescalero Ridge. Due to the tamping effect of the caprock ridgeline, the winds blowing off the

[2] Study area includes quads that extend into Texas. Area within New Mexico is approximately 876,799 ha (2,166,570 ac). We use the New Mexico area only for spatial analyses in the report

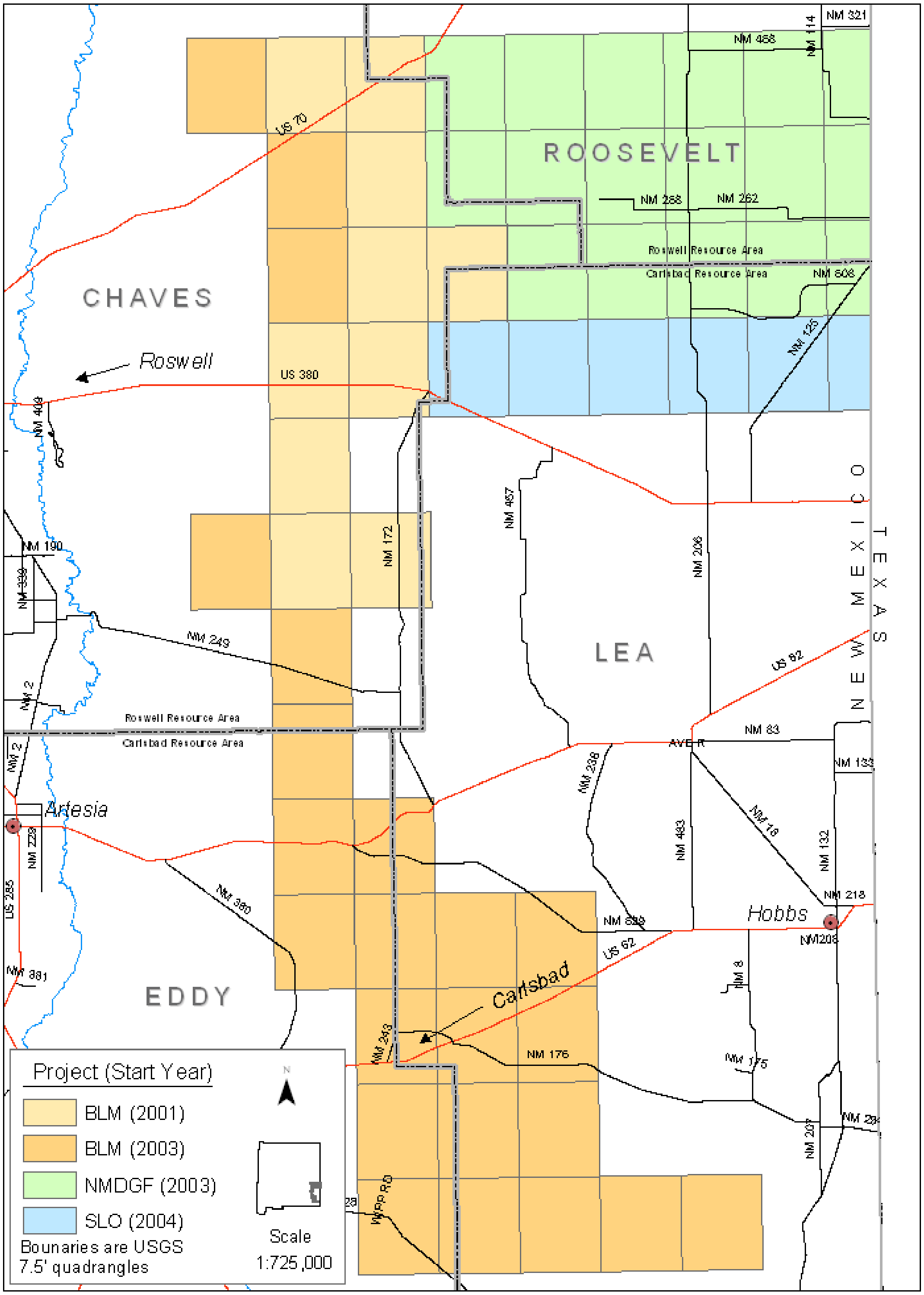

Figure 2. Study area.

Pecos River Valley slow and deposit their sediment loads to the west of the ridge (McLemore 1998). This forms the very deep, well-drained sands of the Mescalero Dunes. In the southern third, the Mescalero Ridge disappears and the dune fields blow out toward the east into wide, thin sand sheets intermingling with the shallow, calcium carbonate-rich soils covering the Caprock and older, limestone-dominated outcrops (McLemore 1998). Interspersed throughout this area are numerous large playas formed in the sinkholes of the karst landscape.

The distribution and depth of the sandsheets and underlying calcium carbon-rich soils are important factors in determining the growth, density, and distribution of the dominant plant, shin-oak, within the study area. The amount of clay and calcium carbonate accumulated within the subsoil affect the vertical height and density of shin-oak (Wiedeman and Penfound 1960, Pettit 1986). Shin-oak cover decreases as clay content of soil increases (Sullivan 1980, Pettit 1986). The relative depth to a calcic horizon is also a limiting factor for shin-oak (Wiedeman and Penfound 1960, Sullivan 1980, Peterson and Boyd 1998). Sullivan (1980) found that oak decreased dramatically when the accumulation of calcium carbonate was shallower than 101 cm (40 in). Mesquite may replace shin-oak in areas where the calcic horizon is within a meter (3.28 ft) of the soil surface (Sullivan 1980), and sand sagebrush may dominate where the subsoil is rich in carbonates or clay (Pettit 1978).

Sand shinnery communities are some of the least understood and most poorly described communities in the southwestern United States (Dhillion and Mills 1999). Much of the research on sand shinnery communities has occurred in Texas, and little is known about the extent of these communities in New Mexico. Most research has emphasized control of shin-oak using herbicides such as tebuthiuron to manage for increased grass cover favorable to livestock grazing (Scifres 1972, Pettit 1979, Sears et al. 1986). Other studies have concentrated on characterizing the sand shinnery plant community and structure (Sullivan 1980, Holland 1994, Peterson and Boyd 1998).

These highly-threatened communities (Dhillion et al. 1994) not only provide important habitat for the LPCH, but also harbor the sand dune lizard. In addition, the sand shinnery community supports a high diversity of raptors (up to 22 species, Bednarz et al. 1990). The geographic range of sand shinnery communities extends from eastern New Mexico, principally Chavez, Roosevelt, and Lea counties, across the Texas plains and Texas Panhandle, northward into western Oklahoma (Muller 1951, Everitt et al. 1993, Dhillion and Mills 1999). Shin-oak grows on deep, well-drained, nutrient-poor, Pleistocene-derived soils (Wiedman and Penfound 1960, Lenfesty 1980), which form dunes (Dhillion and Mills 1999) and sand sheets. The shin-oak of eastern New Mexico hydridizes with Mohr's oak (*Q. mohriana*) (Muller 1951; Correll and Johnson 1979; Vines 1982) and possibly with *Q. undulata* and *Q. gambelii* (Muller 1951). The height and density of plants increase toward the east, due to the deeper sandy horizon and higher precipitation (Sullivan 1980).

Lesser prairie-chicken habitat

The LPCH typically nests on the ground under sand sagebrush or shin-oak shrubs, or in tall, residual bunchgrasses (e.g., *Aristida* spp., *Schizachyrium* spp., *Andropogon* spp.; Davis et al. 1979; Giesen 1994; Johnson and Smith 1998, 1999). Predation is the primary cause of nest failure (Davis et al. 1979; Riley et al. 1992; Johnson and Smith 1998, 1999, Johnson 2000), and nest depredation and abandonment rates are lower when vegetation height and residual tallgrass cover near nests are higher (Riley et al. 1992). In addition, survivorship has been shown to be higher for adults that choose microhabitat with higher cover of shrubs and grasses and higher vegetation density (Patten et al. in press). Although residual tall grass appears important for nesting cover, LPCH hens prefer to nest in pastures containing a mixture of grass and shin-oak over pastures in which shrubs have been eliminated (Haukos and Smith 1989, Johnson 2000, Johnson et al. 2004). LPCH in New Mexico need shin-oak for brood rearing (Riley and Davis 1993). The spring and summer diets of young birds are dominated by insects, particularly grasshoppers, which are found in shin-oak tallgrass community types (Davis et al. 1979). In southeastern New Mexico, acorns, galls, catkins, and new leaves of shin-oak were the most important year-round items in the diets of adult birds (Riley et al. 1993a).

LPCH habitat is apparently impacted by several agricultural practices. Conversion of native rangeland to croplands destroys and fragments the sand shinnery dune habitats crucial to nesting and winter survival of the species (Taylor and Guthery 1980). Grazing causes reduced vegetation height and reduced residual tallgrass cover, which in turn increases levels of predation, the primary cause of nest failure (Davis et al. 1979; Merchant 1982; Riley et al. 1992; Johnson and Smith 1998, 1999). Shin-oak competes with more desirable livestock forage plants, and its early-spring buds and leaves are toxic to livestock. Shrub removal, a common range management practice, degrades and fragments nesting, brood rearing, and wintering habitat (Peterson and Boyd 1998 and references therein). A landscape-level analysis showed that greater loss of shrub-dominated habitats was associated with a greater tendency for an LPCH population to be classified as declining (Woodward et al. 2001).

LPCH habitat must acommodate four main activities: mating, nesting, brood-rearing, and wintering. LPCH mate at traditional display grounds, where several males perform courtship displays to females. Lek sites are characterized by sparse vegetation (Davison 1940, Ahlborn 1980, Giesen 1998). Lek sites may occur in naturally bare areas or disturbed areas such as abandoned oil drilling pads, bare dunes, herbicide-treated areas, prairie-dog towns, or even old roads (Davis et al. 1979, Ahlborn 1980, Giesen 1998, Mote et al. 1999, Bidwell et al. 2002). A primary habitat requirement for lek sites appears to be visibility (Davis et al. 1979).

Nesting habitat is the principal limiting factor for the LPCH in New Mexico. It can be especially limited during droughts, when residual grass cover is reduced by grazing (Bailey and Williams 2000). In New Mexico, LPCH nested only in shin-oak/tallgrass habitats and avoided honey mesquite/shortgrass habitats (Davis et al. 1979). In one study on the Bureau of Land Management Caprock Wildlife Habitat Management Area

(CWHMA), ten of 14 nests occurred in duneland MUs (nest locations from Johnson 2000). Nests are typically found in plant communities dominated by shin-oak and having residual tall bunchgrasses from the previous growing seasons (Haukos and Smith 1989) that conceal nesting females laterally and overhead (Riley et al. 1992). Hens select nest sites with high visual obstruction (Robel et al. 1970) and horizontal cover (Giesen 1998) provided by tall, wide grass clumps with spreading stems (Riley et al. 1992). Nesting hens prefer shrubs and residual bunchgrasses over 40 cm tall that provide more than 75% vertical screening in the first 33 cm above ground and 50% overhead cover (Haukos and Smith 1989, Giesen 1994). In one on the CWHMA, hens nested in pastures having from 35.5-58.3% shrubs, 39.3-60% grasses, and 2.4-4.4% forbs. Plant height was typically greater within 3 m (10 ft) of nests than in the pasture as a whole (Johnson 2000). Nests are typically more successful within residual grass cover than under shrubs (Jamison et al. 2002 and references therein). The height, density, and species of grass have been found to be important in determining successful nesting sites, rather than percent shrub cover, which ranged from 31.3 to 66.2% for both successful and unsuccessful nest sites (Riley et al. 1992). Hens have been reported to nest on the north- or northest-facing sides of dunes (Davis et al. 1979), but a more recent study in the same area did now show such a strong tendency (Johnson unpublished).

Brood-rearing habitat is similar to nesting habitat. It must provide sufficient protection from climatic extremes and predators and provide an ample supply of food for broods. These areas are typically described as shrub-dominated with an open understory high in forbs and abundant in insects (Bidwell et al. 2002). Brood-rearing habitat has also been described as containing taller shrubs and having greater canopy cover than surrounding areas (Davis et al. 1979, Giesen 1994, Mote et al. 1999). Young chicks and juveniles eat almost exclusively insects, primarily grasshoppers (Davis et al. 1979). During the hot summer months, Frary (1957) observed LPCH moving to more dense cover in the vicinity of large, stabilized sand dunes. On cool evenings or when the wind was quite strong, the birds often chose a slight depression on the sheltered side of a dune (Frary 1957, field notes).

Autumn and winter habitat is similar to breeding habitat, but wintering LPCH may make greater use of small-grain agricultural fields in areas close to agriculture (Giesen 1998). However, not all birds make flights to grain fields in the winter. Frary (1957) noted that some Gallinas Wells Prairie Chicken Area (PCA) birds were observed throughout the fall and winter in the Gallinas Wells PCA area. Birds inhabiting the Milnesand area depended on waste grain during a “considerable” part of the winter (Frary 1957). From 1952-1955 the Gallinas Wells group held their numbers, while the Milnesand group declined. In a study on the CWHMA, which contains no agricultural fields, LPCH foraged almost exclusively in the Shin-Oak-Tallgrass vegetation type in the fall and winter (Davis et al. 1979). Fall and winter foraging habitat tended to be more grassy than the subtypes overall, and resting/roosting habitat was slightly more grassy than foraging habitat, apparently because grasses were used for cover (Davis et al. 1979). Grasses provide thermal covering in winter (Bidwell et al. 2002). In the Davis et al. (1979) study, LPCH used habitat containing 37% shrubs (32% shin-oak) and 63% grasses (*Aristida* spp., 23%; *Sporobolus* spp., 10%; *Andropogon scoparius[=Schizachyrium scoparium],* 8%;

Andropogon hallii, 7%) in autumn. LPCH wintered in habitat containing 41% shrubs (38% shin-oak) and 59% grasses, with the same four dominant species as in autumn (Riley et al. 1993b).

It is sometimes claimed that LPCH require a "mosaic" of habitats. However, neither the composition nor the size of "pixels" in such a mosaic is typically defined, and we know of no literature that does so. The belief that LPCH require habitat mosaics may come from the fact that LPCH are restricted during nesting to a few most favorable sites, but after nesting they naturally spread out because they need more resources than these small areas provide. (R. Peterson pers. comm.). Aside from lek sites, grassy sand shinnery appears to provide all that the birds need year-round (Davis et al. 1979, R. Peterson pers. comm.).

Fragmentation and conversion of sandhill landscapes have occurred at a broad scale in eastern New Mexico. Mechanisms that fragment the landscape are scale-dependent (Fuhlendorf et al. 2002) and differentially impact LPCH populations at local and regional scales. Regional scale (7,238 ha) landscape changes included conversions to cropland and tree encroachment. Local-scale (452-1,800 ha) impacts included edge density and patch size (Fuhlendorf et al. 2002). Braun et al. (1994 in USFWS 2004) suggest that grouse have short dispersal distances and specialized food habits that may make the genus relatively intolerant of extensive habitat fragmentation. Although no data exist on a minimum size of unfragmented landscapes for the LPCH, various studies have suggested necessary areas ranging from 500 ha to 7,200 ha (Jamison et al. 2002 and references therein). The area needed to sustain LPCH populations is expected to vary depending on environmental variables such as drought, which could increase the foraging area and intensify intraspecific competition for limited resources.

Methods

Data Sources

Satellite Imagery

We used two types of imagery over the study area, Landsat Enhanced Thematic Mapper$^+$ (ETM$^+$) satellite imagery and digital aerial photography. The satellite imagery, with its stable sensor platform, is relatively easy to geometrically correct to the known coordinate system of a base map. The height of the sensor above the earth (705 km. for Landsat) negates most parallax problems commonly found in aerial photography. (Parallax is the apparent change in positions of stationary objects affected by the viewing angle, creating greater distortions at greater distances from the center of an aerial photo.) Also, satellite data do not have the radiometric problems of air photos, such as hot spots, dark edges, or different contrasts for each photo due to sun-angle changes during the overflight.

The quantitative spectral and spatial aspects of ETM$^+$ imagery add particularly important dimensions to the mapping process. Multi-spectral satellite imagery records different reflectances of the variable natural radiation of surface materials such as rocks, plants, soils, and water. Variations in plant reflection and absorption due to biochemical composition produce distinct spectral "signatures" (Wickland 1991, Lillesand and Kiefer 1987). These signatures provide a quantitative measure of reflectance at specific wavelengths, which can be statistically analyzed to develop a vegetation map of spectrally similar plant communities.

Landsat ETM$^+$, with six spectral bands and one thermal band, provides the highest spectral discrimination of all commercially available space-based sensors. Each band represents a specific range of light wavelength (Table 1). ETM$^+$ bands 2, 3, 4, and 5 are particularly useful for vegetation mapping. ETM$^+$ bands 3, 5, and 7 are useful for detecting variations in surface geology. Surface geology and soil discrimination are important in developing mapping units of the vegetation communities that occur in sparsely vegetated areas within the study area. ETM$^+$ band 6 records a thermal response, which directly measures surface temperature. It indirectly indicates the moisture content and can be important for discriminating between different plant and soil types; however, it was not used because it has a much coarser spatial resolution (60 m x 60 m).

ETM$^+$ integrates the spectral characteristics of each band over the Instantaneous Field of View (IFOV), an area of approximately 30 m x 30 m (98 ft x 98 ft). This is the smallest area resolvable by the sensor, which is represented on the computer screen by individual pixels (picture elements). Individual occurrences of plants are not resolved by the sensor; therefore, ETM$^+$ is well suited for evaluating and quantitatively identifying more generalized vegetation community or plant association occurrence patterns and their associated surface substrate characteristics.

Table 1. Landsat band descriptions.

Landsat Band	Wavelength (µms)	Surface Response
Band 1	Visible Blue (0.45-0.52)	Absorption by most materials except saline or sandy soils.
Band 2	Visible Green (0.52-0.6)	Minor green vegetation reflectance peak.
Band 3	Visible Red (0.63-0.69)	Green vegetation absorption, but senescent vegetation reflectance and iron-stained soils reflect in these wavelengths.
Band 4	Near-Infrared (0.76-0.9)	Green vegetation reflectance peak.
Band 5	Mid-Infrared (1.55-1.75)	Woody vegetation has less reflectance than herbaceous vegetation due to shadowing.
Band 7	Mid-Infrared (2.08-2.35)	Hydrated vegetation, wet soil and clayey soils have strong absorption features in these wavelengths.

We acquired two ETM^+ scenes from May 27, 2000 and April 15, 2002. Although the two scenes were taken just over a month apart, they capture seasonal vegetation changes of deciduous shrub leaf-out, forb emergence, and transition from cool- to warm-season grasses.

Aerial Photography

Aerial photography was our other major data set. We combined Digital Ortho-photo Quarter Quads (DOQQs) to create one ortho-photo mosaic image. The 236 DOQQs from the USGS National Air Photo Program (NAPP) were acquired over the area at a 1:40,0000 scale from 1996 to 1997. These photographs provide a limited spectral profile (only one band representing an overall surface response in the visible wavelengths), but their 1-m spatial resolution provided spatial detail not found in the ETM^+ data.

Ancillary Map Geographic Information System (GIS) Layers

We used several additional data sets to develop the map, including GIS layers for roads, land status, and topography. Roads were digitized from aerial photography. The land status layers were created from the BLM 1:100,000 series of ownership maps available from the New Mexico Resource Geographic Information System (RGIS) website (http://rgis.unm.edu/). Raster data sets such as the USGS 1:24,000 Digital Raster Graphics (DRG, scanned topographic map sheets) and the National Elevation Dataset (NED) Digital Elevation Model (DEM, spatial resolution of 30 m or 96 ft) were also clipped to the area and used for the study.

We derived a dataset from the ETM^{+} to determine areas modified by herbicide treatments. We created additional layers from various datasets on locations of leks and nests of the LPCH (NHIS 2004, George Miksch Sutton Avian Research Center 2004).

Software and Hardware Used

We used primarily ERDAS Imagine, Version 8.7, software for mapping. All digital imagery and GIS layers were processed, manipulated, and used as overlays for analysis within the Imagine environment. The ERDAS Imagine software was loaded on a PC using a Windows2000 operating system. We used Arc/Info, Version 8.7, and ArcGIS 9.0 to create, import, and manipulate vector layers. We stored and manipulated all field data using Microsoft Access and Microsoft Excel 2000.

Image Processing

Geometric Correction

Although the ETM^{+} images were already geo-corrected, we rectified them again using the DOQQ photo mosaic as a base, to ensure that the images overlaid directly onto the same sites in the DOQQ. The ETM^{+} images were also resampled to 2 m, which would be the final image resolution during the classification process. The images were projected into the Universal Transverse Mercator, Zone 13, using the 1983 North American Datum and the 1980 Geodetic Reference System Spheroid.

Band Ratios

In addition to the spectral bands, we computed several vegetation indices to enhance various vegetation or ecosystem characteristics. The four indices used were the Normalized Difference Senescent Vegetation Index (NDSVI) [Eq. 1], the Normalized Difference Vegetation Index (NDVI) [Eq. 2], a moisture index [Eq. 3], and a canopy structure index [Eq. 4]. These were computed as follows:

$$\text{NDSVI} = ((\text{Band 7} - \text{Band 3}) / (\text{Band 7} + \text{Band 3}) + 1) * 100 \quad \text{(Eq. 1)}$$

$$\text{NDVI} = ((\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3}) + 1) * 100 \quad \text{(Eq. 2)}$$

$$\text{Moisture index} = ((\text{Band 5} - \text{Band 7}) / (\text{Band 5} + \text{Band 7}) + 1) * 100 \quad \text{(Eq. 3)}$$

$$\text{Structure index} = ((\text{Band 4} - \text{Band 5}) / (\text{Band 4} + \text{Band 5}) + 1) * 100 \quad \text{(Eq. 4)}$$

Band ratios, in general, are designed to divide a reflectance peak against an absorption low to distinguish unique surface features. Due to the potential differences between image data ranges, the difference between bands is normalized against the total data range of the image bands. The adding of “1” and multiplying by “100” in each equation takes the original result, which would be a positive or negative fractional value centered around 0, and turns it into a positive integer value centered around 100.

The NDSVI enhances the spectral characteristics of senescent vegetation (specifically grasses), which have a relatively low reflectance response in the red wavelengths (Band 3) and a high reflectance in the mid-infrared wavelengths (Band 7). The NDVI emphasizes vigorous green plant growth by comparing a strong chlorophyll reflectance in the near-infrared wavelengths (Band 4) against chlorophyll absorption in the visible red wavelengths (Band 3). The moisture index compares relatively high reflectance values in the shorter wavelengths of the mid-infrared (Band 5) against strong absorption at the longer wavelengths of the mid-infrared (Band 7) caused by water molecules found in soil and vegetation. Similarly, the structure index enhances shadowing and leaf water content in plants.

Texture Image

As noted above, DOQQs have limited spectral value, but they provide valuable spatial detail. One way to represent this spatial detail is to create a texture image that quantifies the amount of change in the brightness values between neighboring image cells. In this case, the texture image was created by averaging the variance of the DOQQ mosaic at 3 different scales or kernel sizes (3x3 cells - 36 m^2, 5x5 cells – 100 m^2, and 7x7 cells – 196 m^2). The variance was computed as shown in Equation 5:

$$\text{Variance} = \Sigma\ ((x - M)^2/(n-1)) \quad \text{(Eq. 5)}$$

where **x** is the value of a particular pixel, **M** is the mean value for the moving window kernel, and **n** is the kernel size.

Final Image Compilation

We then compiled the above images into one image resampled to 2-m spatial resolution. Little of the original spatial detail was lost from the DOQQs (1 m), but we gained considerable savings in disk space and processing time. The final image contained 18 image bands (Table 2) available to the classification process.

Table 2. Image file setup for images used in classification.

Image Bands	Band Description
Band 1	May 27 2000 Visible Blue
Band 2	May 27 2000 Visible Green
Band 3	May 27 2000 Visible Red
Band 4	May 27 2000 Near-Infrared
Band 5	May 27 2000 Mid-Infrared
Band 6	May 27 2000 Mid-Infrared
Band 7	April 15 2002 Visible Blue
Band 8	April 15 2002 Visible Green
Band 9	April 15 2002 Visible Red
Band 10	April 15 2002 Near-Infrared
Band 11	April 15 2002 Mid-Infrared
Band 12	April 15 2002 Mid-Infrared
Band 13	May 27 2000 NSVDI
Band 14	May 27 2000 NDVI
Band 15	May 27 2000 Moisture
Band 16	May 27 2000 Structure
Band 17	April 15 2002 NSVDI
Band 18	April 15 2002 NDVI
Band 19	April 15 2002 Moisture
Band 20	April 15 2002 Structure
Band 21	Ortho-photo Mosaic
Band 22	Ortho-photo Texture

Field Data Survey

The mapping process used here depends on ground vegetation survey data. The goal of the field sampling was to capture the variation in distinct vegetation associations present in the study area. Initial work was accomplished from May 22-24, 2001 (Johnson et al. 2001). Rand French from the Roswell BLM Field Office assisted in choosing sampling areas representative of both vegetation and landform variation present in the Caprock Wildlife Habitat Management Unit study area (Figure 2). For example, shin-oak-dominated communities can be found both on dunes and within the flat, inter-dune plain. In March, June, and October of 2003 we surveyed portions of the Roswell BLM Field Office jurisdiction not previously mapped, along with areas within the Carlsbad Field Office area (Figure 2). In June, July, and October of 2004 we returned for surveys to all areas, including the addition of State Land Office areas (Figure 2). We spent more than five weeks in the field. We used a total of 239 data points to construct the map. Of these, 106 were full field plots and an additional 133 were map points.

We chose plots based on homogeneity of floristics, physiognomy or physical structure, and known LPCH habitat requirements. Plot data included the major vegetation plant associations, percent cover of dominant plants, bare ground, litter, basal cover, and canopy cover. General comments included occurrence size, landform characterization, potential habitat use by the LPCH, and nearby historical LPCH nest sites and leks. We placed plots in the center of stands of more or less uniform vegetation representing the dominant vegetation type. Stands were a minimum of 1 ha (2.5 ac) in size with plots covering an area 20 x 20 m (400 m^2, 4,306 sq. ft).

We collected map points by taking a GPS point in the field and recording the dominant plant association and percent cover of dominant species. Often this included indicating the extent of the occurrence on a map. This method was particularly useful when access to private lands was not possible; in these cases only the plant association was noted. This method was also useful for recording areas not utilized by LPCH, such as escarpment shrubland and agricultural lands. These areas are found within the mapped area and are delineated in the final map, but detailed plant species information was not required.

We collected GPS positions of plots using Garmin GPS 12 units. The 12- channel receiver has an average accuracy of 7-15m (21 to 45 ft, Garmin Corporation 2001). The units were preset to obtain averages for each position, thereby increasing positional accuracy. Positions were recorded in the Universal Transverse Mercator (UTM) coordinate system, North American Datum 1983 (NAD83), in Zone 13.

Image Classification

Supervised Strategy and Seeding

The image classification procedure synthesizes satellite image data, field plot data, and ancillary data derived principally from GIS layers. We adopted a supervised classification strategy to develop spectral classes based on ground locations with known characteristics such as vegetation composition and landscape context.

In a supervised classification strategy, the field data are applied to the image data through an interactive process called “seeding.” In the seeding process, a pixel at the field plot location was selected in the image and its spectral characteristics were used to gather other similar contiguous pixels to create a statistical model or “seed” of the field plot. The seeding algorithm (Eq. 6) searches around that point within user-defined parameters that contain a seed within: 1) a certain distance, 2) a certain area, and 3) a certain spectral distance defined as:

$$SD = \sqrt{\sum(\mu - X)^2} \;(\textbf{\textit{Eq. 6}}),$$

where **SD** is the spectral distance between a new pixel and the mean of the current seed group pixels across all bands, **μ** is the mean of the seed pixel group for each image band, and **X** is the spectral value of the new pixel for each band.

In an iterative process, we constructed the best seed models by adjusting the parameters and comparing the resulting pixel distributions against the terrain models and the original imagery. We developed a seed for each field plot using the plot GPS location and associated field information. The seed's maximum area was initially defined by the estimated size of the vegetation community occurrence as determined in the field. Often this is noted as a scalar, with small occurrences defined as 1-5 ha and large occurrences as greater than 5 ha. The actual seed was then defined by increasing the spectral distance iteratively until the spectral signature collected within the seed generated a covariance matrix that could be inverted, a requirement for the maximum likelihood decision rule used later in the actual classification.

We checked the seed shape and location against field notes and maps and by direct interpretation of the seed in the image on the screen, in conjunction with the terrain models. Each seed was saved in a signature file with its field plot number, mean values for each image band, variance, number of pixels that were used to create the seed, and minimum and maximum values.

Supervised Classification

We used statistics gathered in the seeding process to perform a supervised classification. Supervised classifications are based on a maximum likelihood decision rule containing a Bayesian classifier that uses probabilities to weight the classification toward particular classes. In this study the probabilities were unknown, so the maximum likelihood equation (Eq. 7) for each of the classes is given as:

$$D = [0.5\ln(cov_c)]-[0.5(X-M_c)^T * (cov_c^{-1})*(X-M_c)] \;(\textbf{\textit{Eq.7}}),$$

where **D** is the weighted distance, $\mathbf{cov_c}$ is the covariance matrix for a particular class, **X** is the measurement vector of the pixel, $\mathbf{M_c}$ is the mean vector of the class and $^{\mathbf{T}}$ is the matrix transpose function (ERDAS 2003). Each pixel is then assigned to the class with the lowest weighted distance. This technique assumes the statistical signatures have a normal distribution.

This decision rule is considered the most accurate, because it not only uses a spectral distance as the minimum distance decision rule, but it also takes into account the variance of each of the signatures. The variance is important when comparing a pixel to a signature representing, for example, a blue grama (*Bouteloua gracilis*)/hairy grama (*B.*

hirsuta) grass community, which might be fairly heterogeneous, to a water class, which is more homogeneous.

To locate problems, we performed informal accuracy checking based on field data, air photos, personal knowledge of a site, and other ancillary data. If a distribution problem with a seed was detected, the seed was rechecked to ensure it was properly modeling the vegetation type and landscape. The preliminary map had as many map classes as seeds used to develop it.

Map Unit Designation

We then grouped the preliminary map classes into map units (MUs) to represent groupings of vegetation assemblages and other significant surface features found repeatedly across the study area. The map units are based on a common dominant species in the upper-most canopy, with distinctions indicated by species composition and structure and typically unified by landscape features such as dunes. The plant association concept encompasses both the dominant species (those that cover the greatest area) and diagnostic species (those found consistently in some vegetation types but not others). These association types correspond to the U.S. National Vegetation Classification (USNVC) System. The USNVC System has been adopted by the Federal Geographic Data Committee as an information and classification standard to be used by federal agencies, with additional refinements to be adopted in the future in cooperation with the Ecological Society of America (Grossman et al. 1998). The USNVC System uses a hierarchical structure, beginning at the lowest level with growth form and structure (Class, e.g., tree, shrub, grass) to the highest level, the Association (or Community, e.g., *Quercus havardii*/*Schizachyrium scoparium* Shrubland), with various levels in between**.** A key to the nomenclature used to assign a plant association name follows:

- A hyphen ("-") indicates species occurring in the same Class (strata)
- A slash ("/") indicates species occurring in different strata.
- Species that occur in the uppermost stratum are listed first, followed successively by those in lower strata.
- Order of species names generally reflects decreasing levels of dominance, constancy, or indicator value.
- Parentheses around species name indicate species less consistently found either in all associations of an alliance, or in all occurrences of an association.

The USNVC System focuses on existing, rather than potential, vegetation, which provides a baseline standard for use in monitoring vegetation status and its response to management (Grossman et al. 1998). Many of the plant associations found within the study area are not previously described in the USNVC System for New Mexico and are therefore considered provisional.

Draft Final Map

To create the draft final map, we applied a filtering process to create a minimum map unit polygon size of 400 m^2 (4,306 sq. ft.). The procedure eliminates the "speckle" created by spatially solitary map units that have less than 100 contiguous pixels. The eliminated areas were then filled with the majority MU found in the surrounding cells.

No attempt was made to classify buildings, pavement, concrete, or lawns, due to heterogeneity of reflecting surfaces. Roads in vector format were placed directly onto the map to provide for their classification.

We grouped the 20 MUs in the draft final map based on floristic composition, landscape position, spatial contiguity and spectral similarity; i.e., floristically similar seed classes, which had similar landscape positions and were spatially close, were grouped into a map unit. This iterative computer-driven process based on informal accuracy checking continued until all seed classes were grouped into the most consistent and accurate map units.

Final Map Field Data Surveys

We took field trips in July and October 2004 to refine the vegetation map units and perform a qualitative check of the draft map accuracy. We developed a set of field maps using the draft LPCH habitat maps, with USGS 7.5' digital quadrangle maps and previous plot sites as overlays. Of particular interest were areas not previously visited. We also visited a set of predetermined locations where the accuracy of the map units was in question. We used map unit descriptions and a representative photograph of all the draft map units as a key for determining the map unit designation of each site visited.

We selected large areas of relatively homogeneous map units to visit in the field. Using a GPS unit to accurately locate each site, we performed a quick, qualitative assessment of the map unit by keying the site to the map unit descriptions. If the site visited did not exactly match the map unit descriptions, we either (a) adjusted the map unit description to accommodate elements missed in the previous field trip, or (b) in the case of an inaccurate map unit, took notes to create a new 'seed' to reclassify the map. In either case, we recorded a GPS point, annotated the map, and took notes.

Final Map Classification and Ancillary layers

Based on the final field trips, we made changes to the map unit descriptions, the designations of their aggregate community types, and their spatial distributions. We performed several iterations of reseeding, reclassifying, and aggregating, as well as on-screen digitizing to modify map units, based on personal knowledge and field notes.

In some cases, the automated method used in the classification of images is insufficient; e.g., agricultural fields may be in various stages that confound statistical averaging. Additionally, the range in dates from our aerial photography (1996, 1997), Landsat ETM+ (2000, 2002), and field data (2001-2004) were different enough to confound correct classification due to landscape changes over time.

Some of the landscape changes we identified were large area conversions from shin-oak-dominated communities to native grasslands (Figure 3). To aid in mapping the extent of the landscape changes, we developed an NDVI from a June 2002 image. The NDVI vividly discriminated between areas of little change compared to areas with major changes. We used this image in conjunction with a set of BLM Environmental Analysis records from 1981 to 1993 that described boundaries for approved herbicide treatments to be applied to BLM lands and contiguous private lands. To identify lands that were treated we screen digitized and annotated them as either: herbicide treatment, agricultural conversion, or unknown (Figure 4). If a match was made between the BLM documents and the NDVI, we added the document number to the associated vector record. The NDVI provides no indication of the date the landscape was modified; for those areas where we could positively identify agricultural conversion in the field and on the imagery, we used on-screen digitizing to correct the final map. For those areas where we could not field-confirm conversion of sand shinnery to rangeland, we did not modify the map.

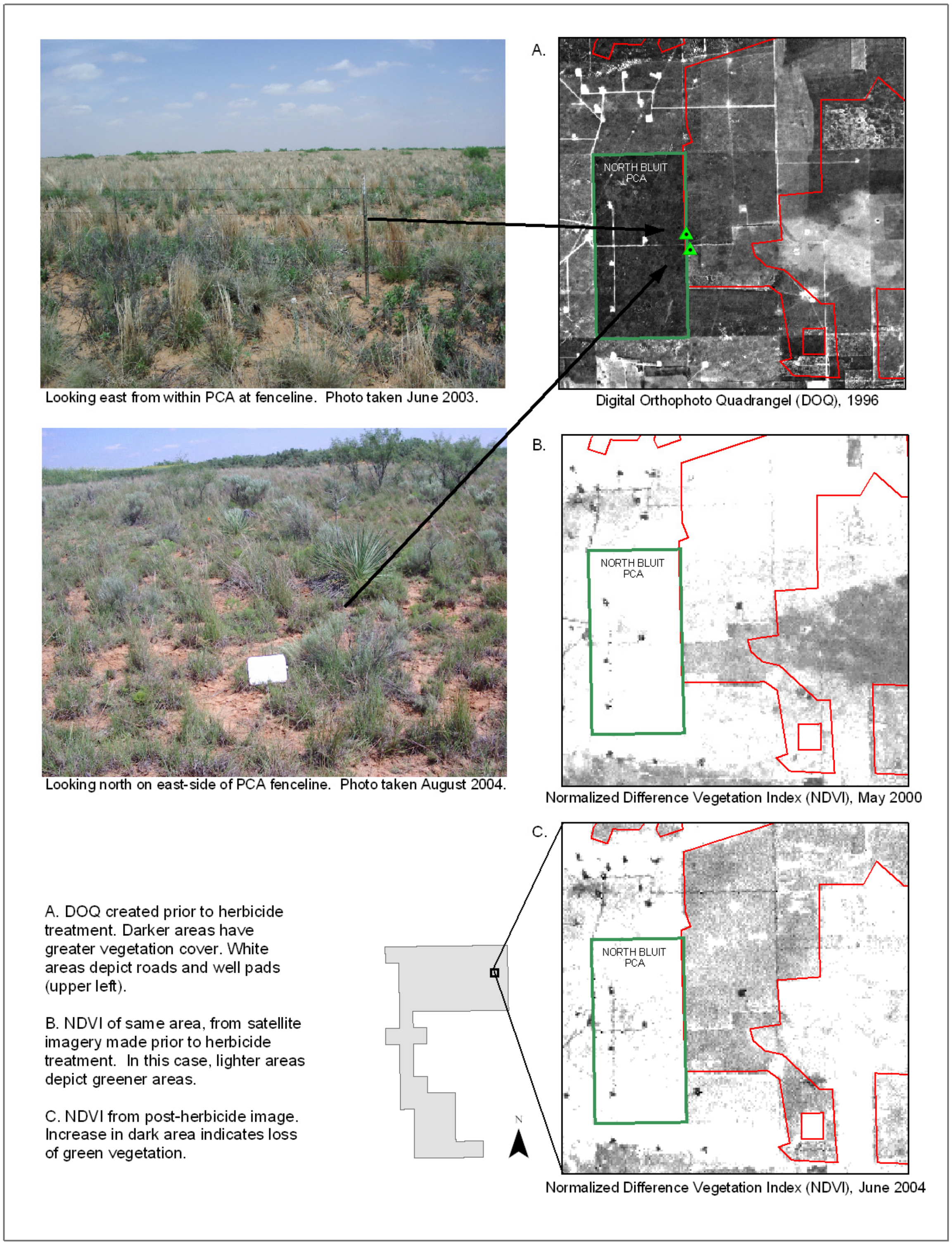

Figure 3. Landscape changes represented in the vegetation classification due to imagery acquisition dates.

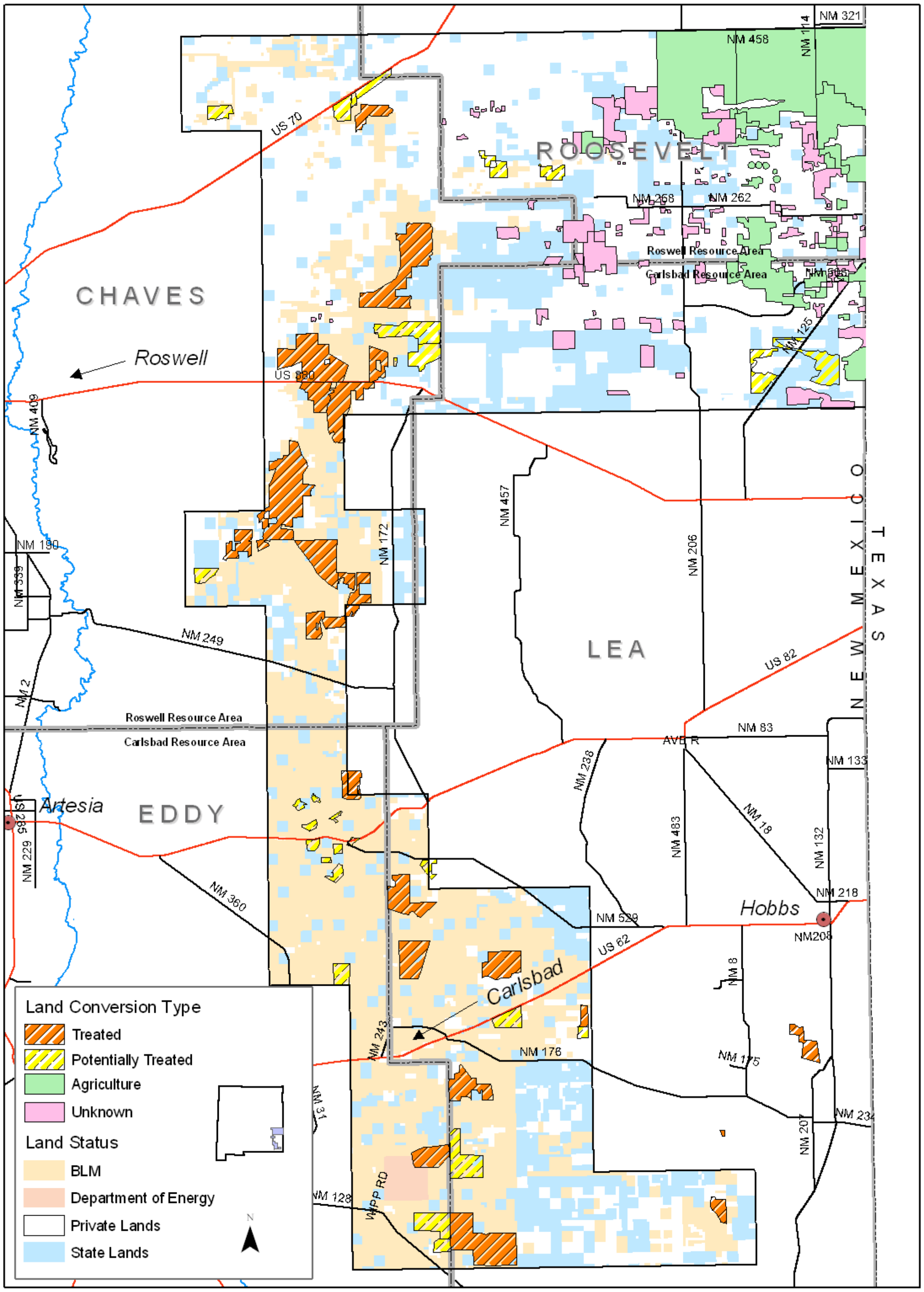

Figure 4. Landcover conversion within the study area.

RESULTS AND DISCUSSION

MUs

The final map has twenty MUs (Table 3, Figure 5). We defined MUs based on three kinds of information: 1. vegetation assemblages, as in a typical vegetation mapping process, 2. landscape features characteristic of habitat types required by LPCH, and 3. existing knowledge of LPCH use of various vegetation/habitat types. Detailed descriptions and a list of the dominant plant associations within each map unit are provided in Appendix A. A limited plant species list is provided in Appendix B.

Because of the focus on LPCH habitat needs, some mapping units (MUs) appear "lumped" and others "split," relative to more standard vegetation classification systems. For example, MU 1, Shin-Oak-Mixed Mid-Grass and Tall-Grass Duneland, and MU 3, Shin-Oak- Mixed Mid-Grass and Tall-Grass Shrubland, have similar species composition, but the primary difference in these two MUs is topographical rather than vegetative. We define these separately for several reasons. First, BLM personnel who funded the initial mapping effort requested that dunal MUs be separated from shrubland MUs. Sand dune lizards occur in dunes (Degenhardt et al. 1996); thus, differentiation of dune areas is potentially useful for sand dune lizard management. LPCH have been reported to preferentially nest in dunes (Davis et al. 1979). Finally, several previous vegetation classifications of the sand shinnery have differentiated dunes from areas lacking dunes (see references in Peterson and Boyd 1998, pp. 3-4).

Similarly, we have differentiated habitats that differ in overall vegetation cover and shrub versus grass density. Nest success has been shown to correlate with height, density, and abundance of residual grasses, especially bluestem, near nests (Riley 1978, Davis et al. 1979, Riley et al. 1992). Brood foraging sites have been described as having taller shrubs and greater canopy cover than surrounding areas (Davis et al. 1979, Giesen 1994). Thus, it is useful to differentiate habitats that differ in overall vegetation cover and shrub versus grass density. MUs designated as "sparse" (e.g., Shin-Oak/Sparse Duneland and Shin-Oak/Sparse Shrubland) contain lower grass cover than corresponding MUs not so designated.

In contrast, MUs 16, 23, and 13, Short-Grass, Mid-Grass, and Tall-Grass Grassland, respectively, each contain several grassland associations that might be grouped differently using a more traditional vegetation mapping methodology such as International Terrestrial Ecological Systems Classification (ITESC, Comer et al. 2003, see next paragraph), a mid-scale classification system, or the hierarchical, community-scale approach of the USNVC (Grossman et al. 1998). Because none of the plant associations individually contained in MUs 16, 23 or 13 constitutes preferred habitat for LPCH, our map combines structurally similar but compositionally different grassland associations. The structural components rather than the affinity to specific species dictate the use of these grasslands by the LPCH. As a result, this LPCH habitat map is different from other vegetation maps, but it is potentially more useful for addressing wildlife management and conservation concerns.

Another approach to aggregating plant associations at a broad scale is the ITESC System (Comer et al. 2003). The ITESC, now known as the International Vegetation Classification (IVC) was developed by NatureServe and its member programs for describing and assessing ecological diversity. It has been accepted as a standard approach to ecological classification by U.S. federal agencies and was adopted for the Southwest Regional Gap Analysis Project (SW ReGAP) to produce the land cover map that includes New Mexico. The system provides information about the co-occurrence of plant associations within a given landscape. Various diagnostic classifiers are used for these systems. Those important to our study area tend to be based on landform and biogeographic history. For example, areas historically and currently occupied by the lesser prairie-chicken from Kansas to Texas and New Mexico are predominantly found within three of the ecological systems described within the ITES: the Western Great Plains Sandhill Shrubland, the Western Great Plains Sand Prairie, and the Western Great Plains Tall Grass Prairie. In New Mexico, LPCH occupy the Western Great Plains Sandhill Shrubland system (SW ReGAP). This ecological system is characterized by excessively well-drained, deep sandy soils often associated with dune systems and ancient floodplains (NatureServe 2005). Within the southern reaches of this system, shin-oak is a dominant species.

Scale

We wish to include a word on the appropriate use of these maps. The minimum map unit size (resolution) is 20 X 20 m, meaning that the map units were designed to be optimally useful at the 1:24,000 scale. Use of the map at finer scales is not recommended. Future refinement of map unit categories at a larger scale might be possible but would not necessarily be appropriate for most natural resource management applications. Formal accuracy assessment and use of the map for management, planning, or scientific studies will reveal its strengths and weaknesses. While we expect the map to be useful for managing wildlife species other than the LPCH, MUs were designed with the LPCH in mind. Exactly how applicable the map will be for other species remains to be seen.

Soils

We looked at the distribution of soil map units from the State Soil Geographic (STATSGO) database, a series of digital maps developed at 1:250,000 scale and built from the more detailed soil surveys of Chaves, Roosevelt, Lea, and Eddy Counties (Ross and Bailey 1967, Chugg et al. 1971, Turner et al. 1974, Lenfesty 1980, Hodson et al. 1980, STATSGO 1994). Using the Official Soil Series Descriptions (OSD 2005) database, we derived some of the following distinctions for the vegetation and soil map units most utilized by the lesser prairie-chicken (Figure 6):

- MUs 1, 2, and 6 are on deep to very deep, well-drained eolian sands (Faskin, Roswell, Jalmar, Kermit, Berino, Nutivoli, Pyote, and Maljamar Series) representing the heart of the dunes and sand sheets.
- MUs 3 and 5 are on similar soil textures, but the sands begin thinning and are underlain by shallow, petrocalcic soils (Faskin, Roswell, Jalmar, Brownfield, Sharvana, Gomez, Duoro, Pyote, Springer, Nutivoli, and Arch series).
- MU 24 is on soils similar to those on MUs 3 and 5, but the soils have shallower sands, reflecting the location of this MU toward the margin of the sand sheets (Brownfield, Sharvana, Gomez, Duoro, Pyote, Springer, Nutivoli, and Arch series).
- MUs 13 and 23 are found predominantly on deep, well-drained eolian sands (Faskin, Roswell, and Jalmar), but MU 23 is found on more diverse soil textures, suggesting it is a more ubiquitous vegetation type less constrained by underlying soil conditions.
- MU 8 and 15 are found on many of the same soil textures as MUs 1, 2, and 6, but they can also be found on deep, mixed, alluvial-derived soil textures and not just on wind-derived sediments (Faskin, Roswell, Jalmar, Kermit, Berino, Nutivoli, Pyote, Maljamar, and Pajarito Series).

Habitat Analyses

Aggregation by Vegetation Type

At the request of the sand shinnery stakeholder group, we aggregated the map units into four landscape-scale units for application to conservation planning, population assessment, and restoration (Table 3).

Initially, the MUs were regrouped based on LPCH dependency on each of the units (Table 3, Figure 7). Group A MUs are considered occupied or suitable habitat and are based on MUs where shin-oak or sand sagebrush are dominant, with minor to no honey mesquite. Areas in Group B are considered to be seasonal-use to transitional areas and consist of MUs dominated by mid- or tall-grasses or grasslands with minor shin-oak components. Extensive areas of relatively homogeneous grasslands in Group B suggest that shrubs have been removed either mechanically or chemically. Areas in Group C are classified as potential restoration habitat. They contain altered vegetation types that were originally LPCH habitat and areas that have been impacted by invasive species but still contain enough suitable vegetation for restoration. All other MUs are considered unsuitable habitat.

There is evidence that CRP fields are used by LPCH in Kansas (Rodgers and Hoffman 2005) and New Mexico (Dawn Davis pers. comm.). It could be argued that CRP areas belong in Group C, potential restoration habitat. We chose not to designate CRP as Group C for this map, however, because several different grass communities are included in this MU, and these sub-types are indistinguishable on our map. By so doing we would risk classifying as restoration habitat communities that have not been shown to be used by LPCH or to offer restoration potential. Nevertheless, because CRP is mapped as a separate MU, it can easily be included in GIS habitat analyses. Distance to preferred LPCH habitat can be measured to determine potential for restoration. More research on LPCH use of CRP in New Mexico is warranted. Mapping of the plant communities that occur within CRP, information on how LPCH use these communities, and differential reproductive success in these versus native plant communities would all be useful information. If CRP proves to be productive LPCH habitat, lands enrolled in the CRP program could represent a management opportunity (Dawn Davis pers. comm.).

Areas with restoration potential are depicted in Figure 8. The mid- and tall-grass MUs can be a natural and integral component of the landscape, important for LCPH habitat, and as such can be considered Group B. However, where they exist as large, homogeneous patches, they indicate disturbance and therefore should be considered Group C. GIS analysis of treated areas within mid- and tall-grass MUs (13 and 23) revealed that at least 48% of these grasslands were likely created by human activities. This suggests that the native vegetation contained much lower percentages of these grasslands than currently exist. Additionally, Group C contains the MU with honey mesquite and shin-oak as co-dominants, which will require major restoration efforts focused on honey mesquite removal. These areas are found largely within the southern portion of the study area and may indicate mesquite invasion due to herbicide use or other disturbance. For example, the area north of Loco Hills is currently characterized by mesquite and bare ground, with a minor shin-oak component. Photography from the 1930s suggests that the area was dominated by shin-oak, prior to extensive oil and gas development.

Table 3. Vegetation map units and lesser prairie-chicken habitat suitability represented by land management groups. Group A – Occupied and suitable, Group B – Probable seasonal use and transitional areas, Group C – Potential restoration areas.[3] MUs 24, 23, and 13 comprise native grass species, but large sections of these MUs were created by herbicidal destruction of shin-oak. Because native and treated grasslands cannot be distinguished on the map, these areas are classified as B-C.

MU #	Group	MU Description	Hectares	Group Totals (ha)
1	A	Shin-Oak/Mixed Mid-Grass & Tall-Grass Duneland	82,642	
2	A	Shin-Oak/Sparse Duneland	73,894	
3	A	Shin-Oak/Mixed Mid-Grass & Tall-Grass Shrubland	26,232	
5	A	Shin-Oak/Mixed Mid-Grass & Short Grass Shrubland	139,591	
6	A	Shin-Oak/Sparse Shrubland	21,081	
15	A	Shin-Oak-Sand Sagebrush Shrubland	2,921	
8	A	Sand Sagebrush Shrubland	9,153	
24	B-C	Mixed Grasses/Shin-Oak Grassland	25,431	
23	B-C	Mid-Grass Grassland	21,602	
13	B-C	Tall-Grass Grassland	5,533	
		Total Group A habitat		**355,514**
		Total Group B habitat		**52,566**
		Total lesser prairie-chicken habitat	**408,080**	
7	C	Honey Mesquite-Shin-Oak/Short-Grass Shrubland	35,626	
10		Honey Mesquite Shrubland	55,321	
14		Honey Mesquite Sparse Shrubland	55,521	
11		Escarpment-Footslope Shrubland	2,515	
		Total Group C		**88,192**
		Total non shin-oak shrubland	**148,983**	
		Total shrubland	**504,497**	
16		Short-Grass Grassland	145,906	
25		Short-Grass/Honey Mesquite Grassland	61,259	
		Total grassland	**259,731**	
19		CRP Fields	13,482	
20		Agricultural Fields	19,198	
26		Playa Lakebed	2,278	
27		Barren/Sparsely Vegetated/Manmade Disturbance	77,612	
		Total Other	**112,570**	
		Study area total	**876,798**	

[3] Areas are calculated for New Mexico, exempting the area falling within Texas. Area is calculated using ERDAS Imagine. MU numbers are non-sequential because map versions have changed over time.

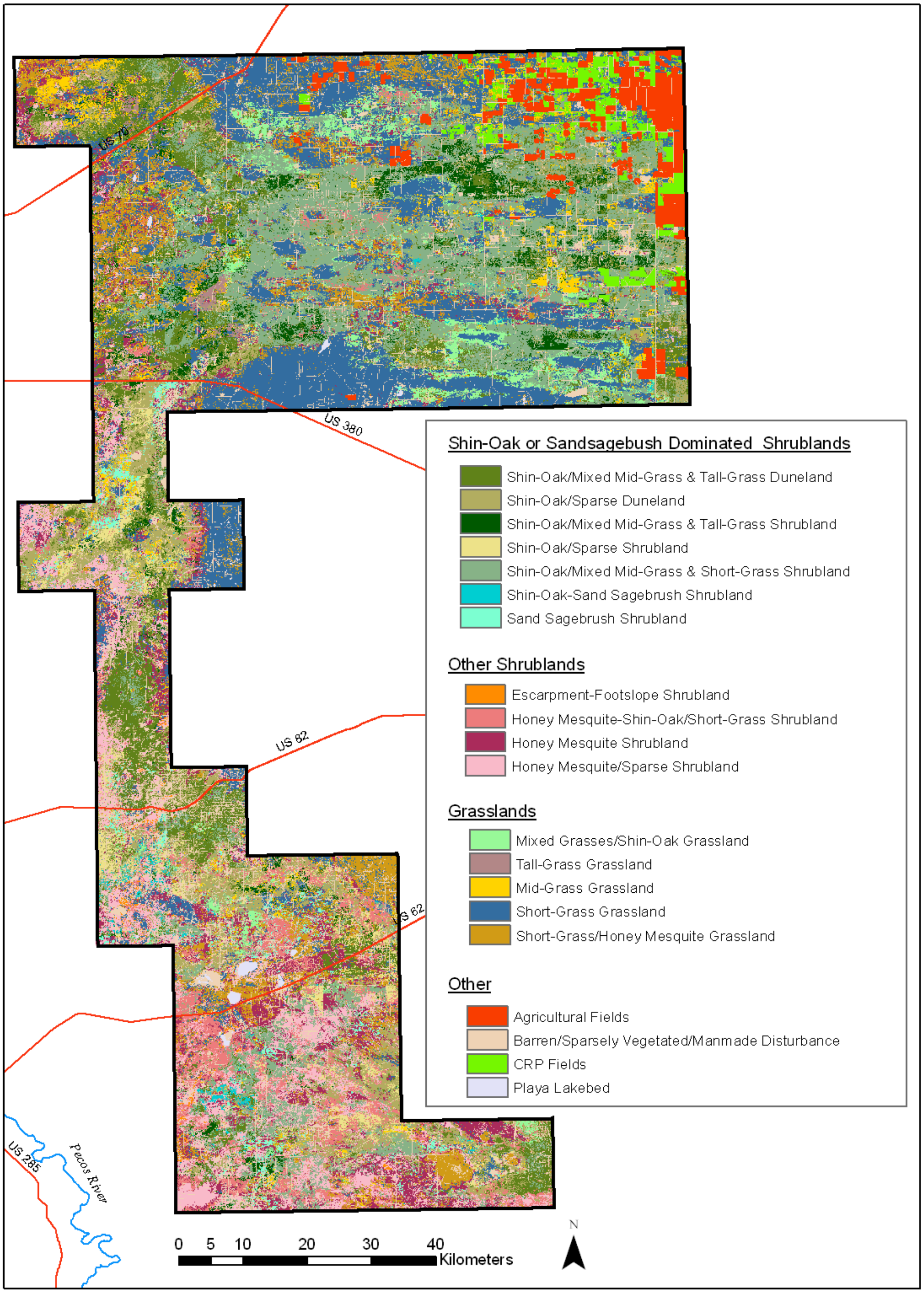

Figure 5. Vegetation map of the study area.

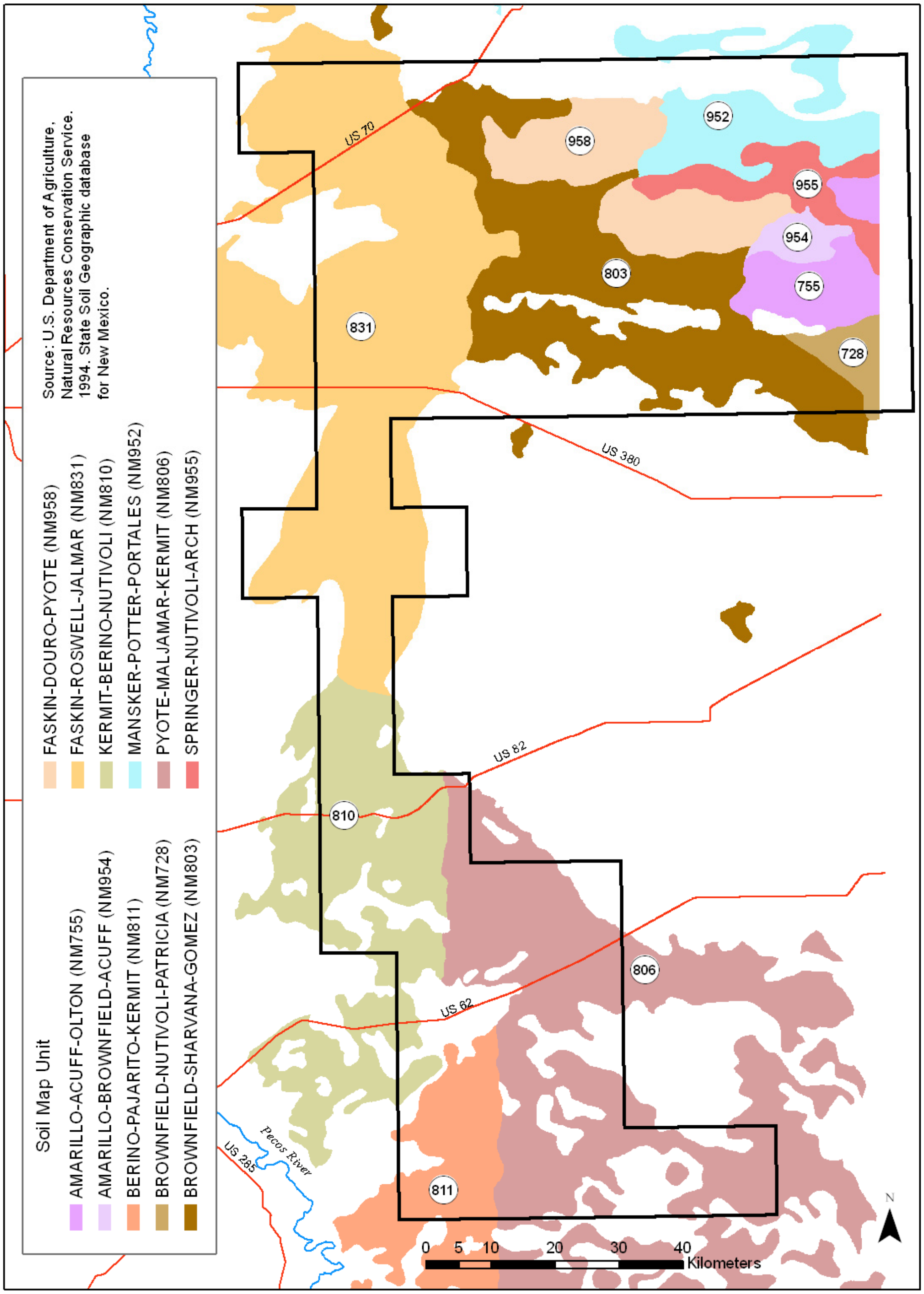

Figure 6. Generalized soil map units within the study area associated with lesser prairie-chicken habitat.

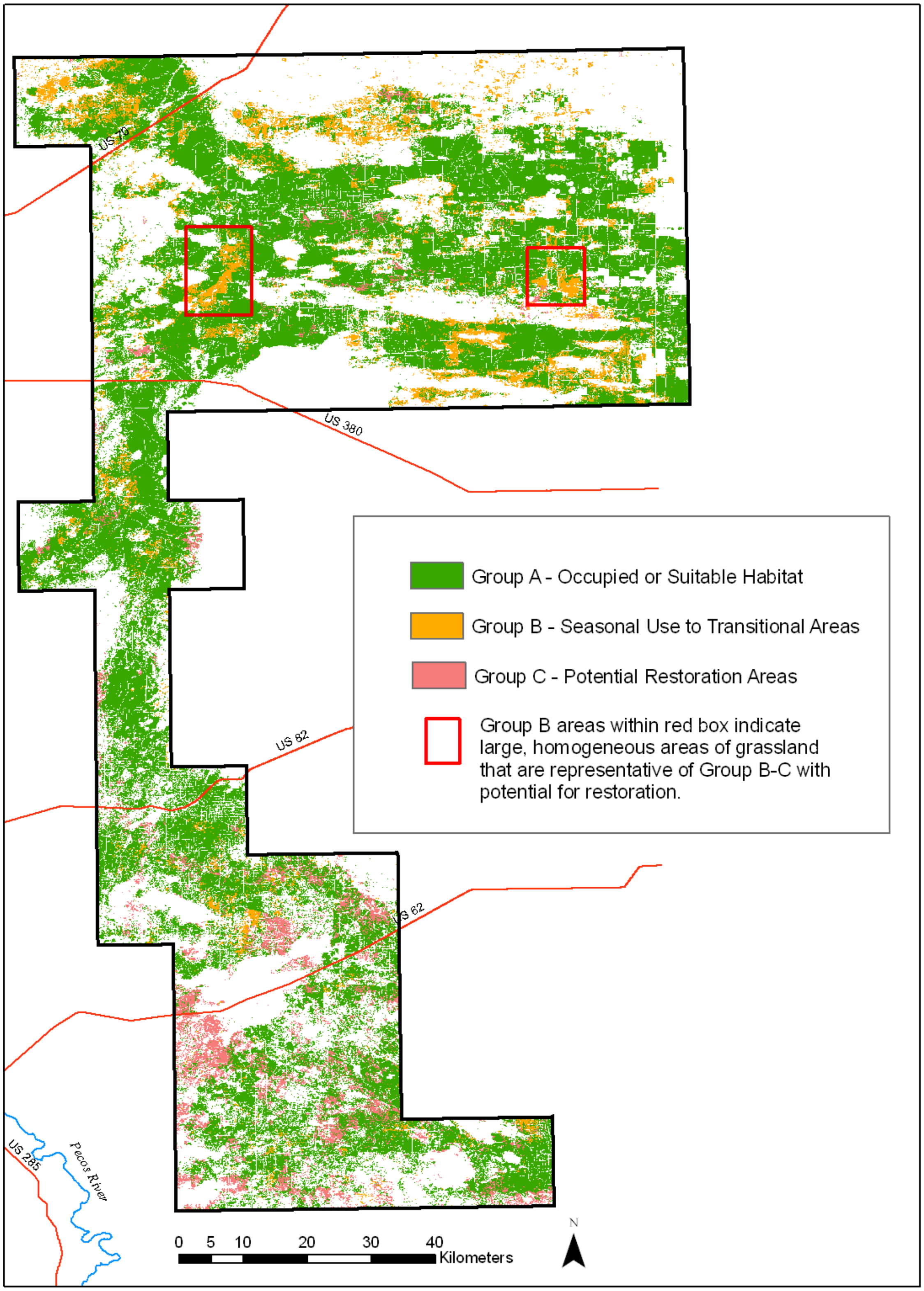

Figure 7. Landscape scale aggregation of map units for management.

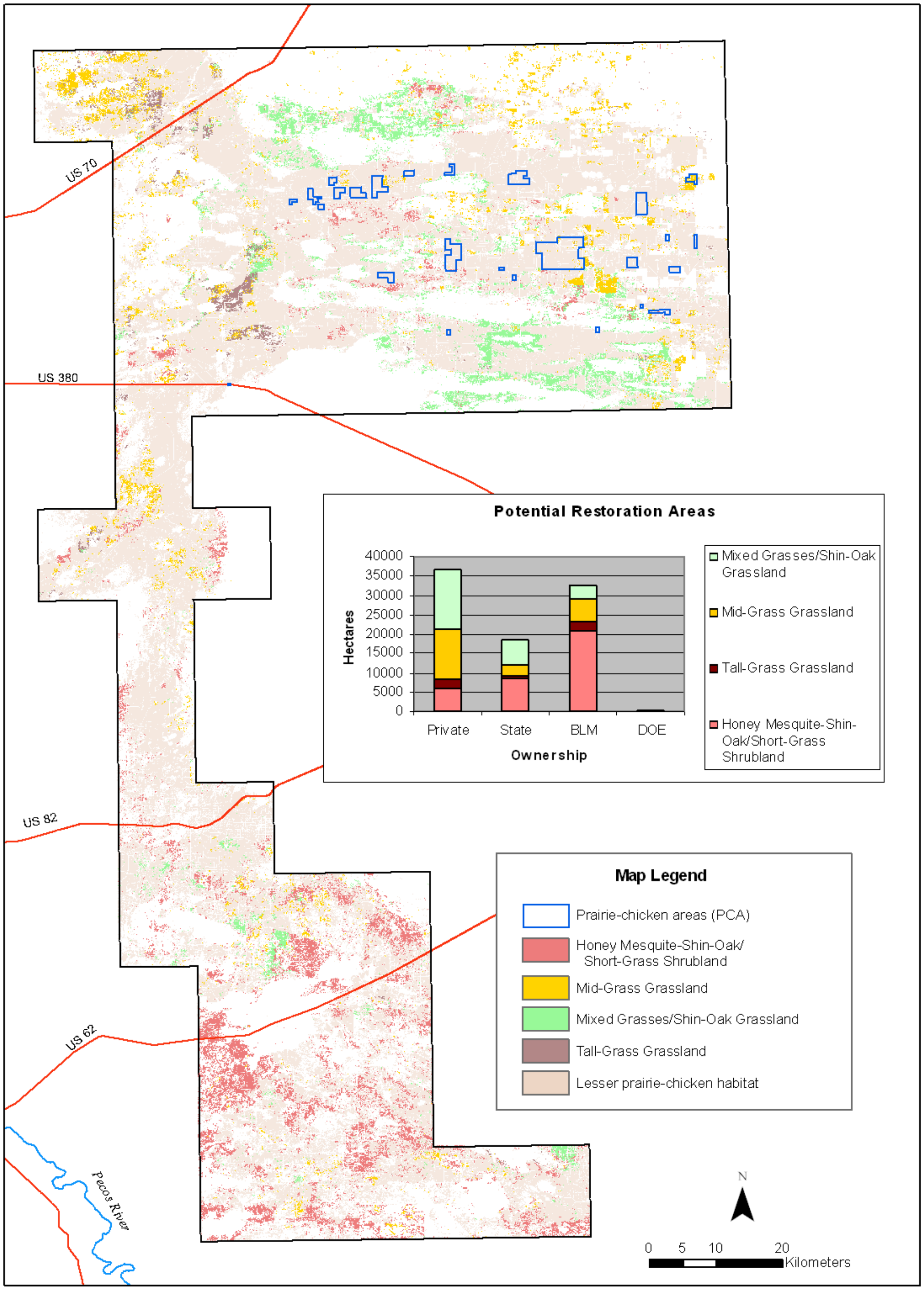

Figure 8. Potential LPCH habitat restoration areas. Graph shows restoration potential by landowner.

Patch Size Analysis

The minimum habitat patch size required to support LPCH is unclear, but research has focused on two patch sizes: ~3200 ha (7907 ac) and ~7200 ha (17,991 ac). These two patch sizes represent areas with approximately two and three mile radii, respectively, around a point (typically a lek). Taylor and Guthery (1980a,b) proposed an area of suitable habitat with radius of 3.2 km centered around a lek (equivalent to 32 km^2, 3,200 ha, or a 2 mi radius) as the minimum patch size for maintenance of a "lek population," because 90% of activity occurs within this limit. This distance was consistent with earlier studies by Copelin (1963) and Campbell (1972) and corroborated by our studies on the CWHMA (Johnson et al. 2004). Giesen (1994) found that the mean distance from lek of capture to nest site was 1.8 km (1.13 mi, range 0.2-4.8 km). Thus, a two-mile radius of a lek is an estimate of the minimum breeding-season patch size around a lek that is needed by the majority of LPCH hens attending that lek.

In addition, Taylor and Guthery (1980a,b) proposed 72 km^2 as the optimum patch size needed for maintaining healthy LPCH populations, based on the observation that virtually all detections of LPCH were within 4.8 km (3 mi) of the display ground. This observation was originally made by Copelin (1963) and corroborated by Giesen (1994). The 3 mi/7200 ha patch size was subsequently used by Woodward, Fuhlendorf and co-authors, who found that landscapes in which LPCH populations declined were characterized by greater rates of landscape change and greater rates of shrub loss within 4.8 km of leks than landscapes in which populations did not decline (Woodward et al. 2001). An investigation of the scale-dependence of habitat loss and fragmentation on LPCH populations found that general landscape changes, amount of cropland, and number of trees impacted LPCH populations at the 4.8 km (7238 ha) scale (Fuhlendorf et al. 2002).

Both of these frequently-cited patch sizes have biological significance, but both are based on distances smaller than observed dispersal distances (Giesen 1998 and references therein). Thus, they represent only minimum requirements, and conservation planning based on even the 7200 ha patch size will not guarantee LPCH population stability. The analysis we performed using these two patch sizes should therefore be considered useful primarily to identify areas where minimum patch sizes of suitable LPCH habitat remain.

To identify areas of suitable habitat, we performed a patch size analysis including patches of 2 and 3 mi radius (3200 and 7200 ha, respectively). We included only Group A MUs as suitable habitat because Group B could include chemically- or mechanically-treated, marginal, or otherwise unsuitable habitat (Figure 7). The analysis revealed 56,986 ha of Group A MUs (16%) distributed in patches of at least 3200 ha (3200-7237 ha in area). We found 38,122 ha distributed in patches over 7238 ha. All other patches of Group A MUs were smaller than 3200 ha, comprising a total of 260,406 ha (Figure 9). Thus, the vast majority of "suitable" LPCH habitat occurred in patches too small to support LPCH, as defined by current literature (see references above). Patches of at least 3200 ha occurred primarily on private land (45%), followed by BLM (36%), state (20%), and

DOE (0). Patches of over 7238 ha also occurred primarily on private land (39%), followed by BLM (37%), state (25%), and DOE (0).

For the final habitat analysis, we delineated large (3200 ha) patches of the highest quality habitat (Figure 10). For this analysis, we included only the three MUs most often used by LPCH, MUs 1, 2, and 3. MUs 1 and 2 are dunelands that provide protection to the LPCH from winds and summer heat and are used by LPCH for nesting, foraging, and brood-rearing. MU 3, usually found in conjunction with MUs 1 and 2, is a high-quality sand shinnery shrubland with potential for necessary residual cover of mid- and tall-grasses for nesting, foraging, and brood rearing. The analysis revealed 46,558 ha of high-quality habitat distributed in patches of 3200 ha or larger. BLM manages the majority of these large, high-quality habitat patches (51%), followed by private landowners (31%) and the state (18%).

Although these high-quality patches are smaller in size than the optimal patch size of 7200 ha suggested by several authors (see references above), they offer opportunity for habitat improvement through expansion of patch size. We therefore chose to use the smaller patch size in our analysis, to include substantial areas of moderately-sized patches of the best LPCH habitat.

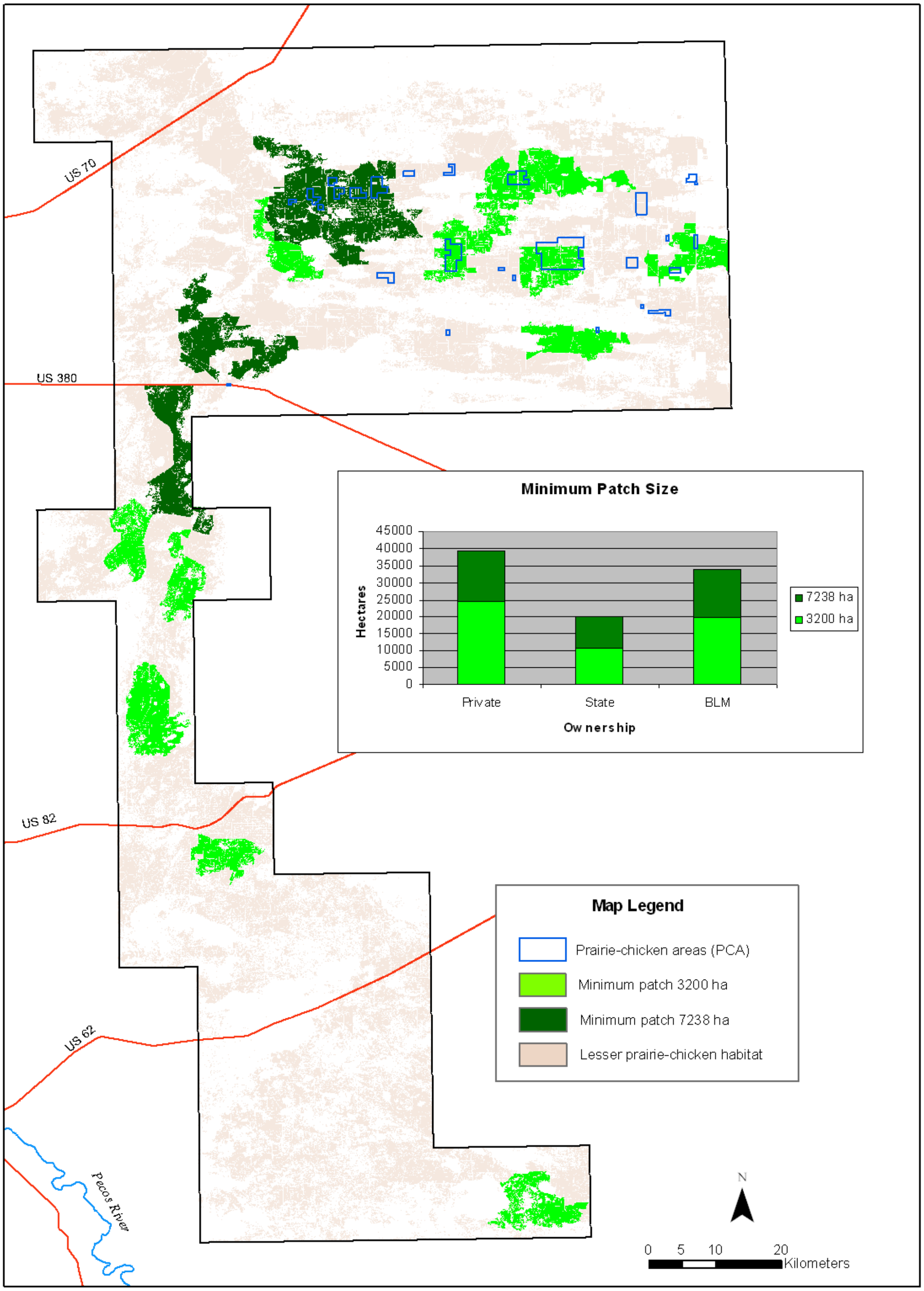

Figure 9. Patch sizes of LPCH habitat within the study area.

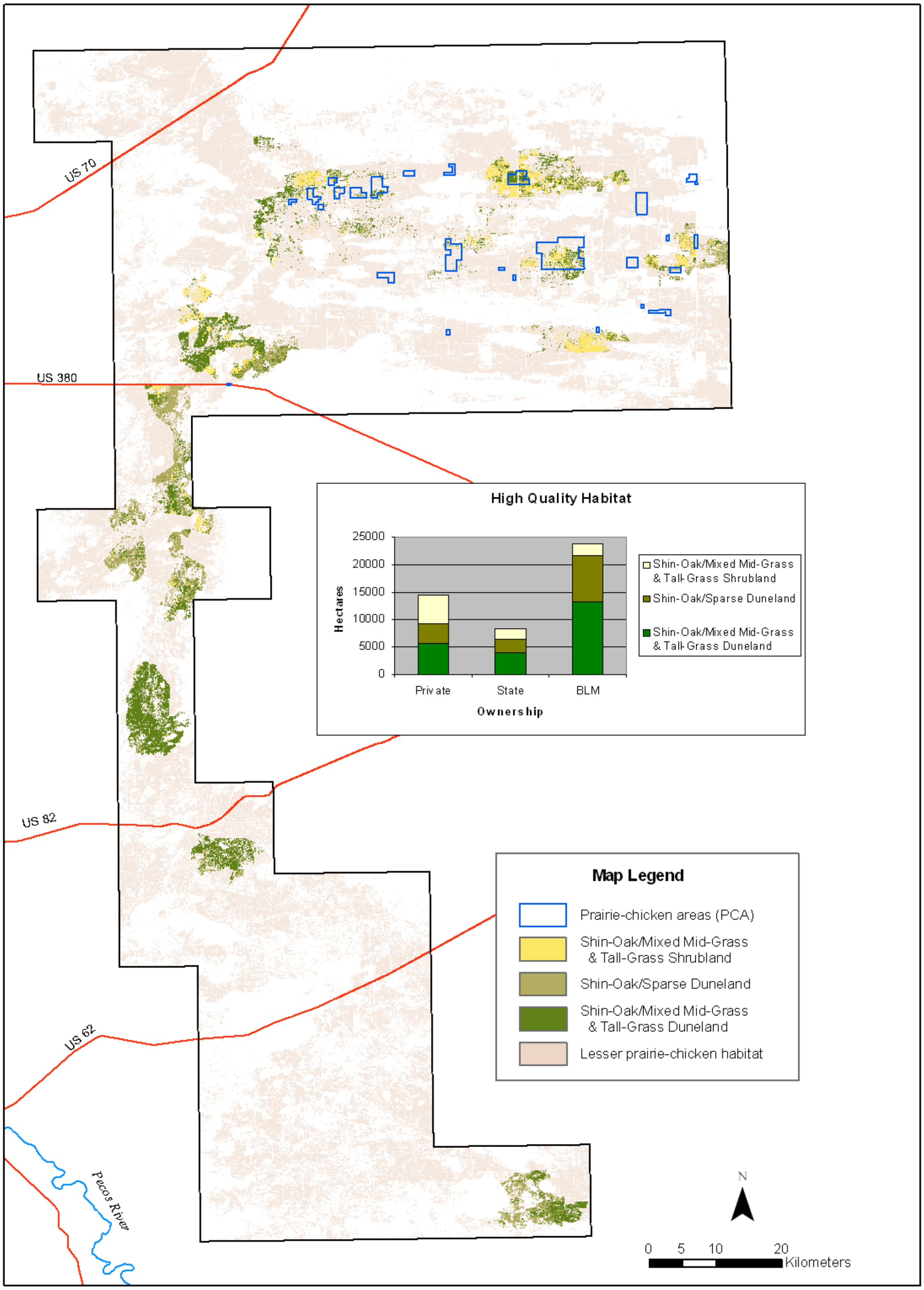

Figure 10. High quality LPCH habitat in moderately large patch sizes.

CONCLUSIONS

Although the exact nature of ideal LPCH habitat is under debate, existing literature (e.g., Davis et al. 1979, Giesen 1998, Woodward et al. 2001, Fuhlendorf et al. 2002, Johnson 2000, Johnson et al. 2004) suggests that sand shinnery communities are critical because they are heavily used for nesting, brood rearing, and wintering (see The Study Area and the Lesser Prairie-Chicken, above, for additional references and review).

Our habitat classification contains six shin-oak-dominated MUs (MUs 1-3, 5, 6, 15). These MUs differ in the relative composition of shin-oak and grass, topography (dunes versus flat areas), and grass species. In contrast to a standard vegetation map, we considered grass species to be less important than structure provided by the grasses. MUs with mid- and tall-grasses provide better cover than MUs with low- to mid-grasses, which were considered lower quality. In addition, percent composition of grasses, grass height, and cover value of grasses can vary in the study area, depending on livestock stocking rates and rainfall amounts. For this map, grass composition is most important in the sand shinnery communities preferred by LPCH. Therefore, in MUs rarely used by the birds (Short-Grass Grassland and Short-Grass/Honey Mesquite Grassland), we lumped some grassland communities.

Pasture-scale treatment with the herbicide tebuthiuron occurred in the study area from the 1980s until the early 1990s. Treated areas contain substantially lower shinoak cover than untreated areas and were therefore of interest to the mapping effort (Johnson et al. 2004). Nearly twenty years after treatment, differences in vegetation composition between treated and untreated pastures remain, providing further rationale for distinguishing shrub-dominated from grass-dominated habitats. The effects of treatment varied with timing of treatment, quantity of herbicide used, and subsequent management practices. Thus, a single signature for all treatment areas was not evident on the imagery, and treatment areas were not readily seen in the initial map. We therefore created a separate layer of the treatment areas (Figure 4). This layer will be useful for analyses of the effects of herbicide treatment on LPCH, SDL, and other wildlife habitats. For example, we found that at least 48% of the area covered in mid- and tall-grass MUs resulted from human activities, which suggests that the original community composition was much lower in grassland vegetation types.

The greatest utility of this effort is perhaps found not in the map itself, but in the associated GIS analyses. We present analyses showing potential restoration areas, highest-quality habitats, and largest patch sizes of high-quality habitat, all of which have obvious usefulness for those charged with implementing LPCH conservation. These analyses demonstrate that only three places within the mapped area contain large patches of suitable habitat, and one of those is south of US 380, where LPCH populations are already sparse and scattered (Figure 9). The GIS analyses also indicate that the vast majority of patches of high-quality MUs occur in patches smaller than 3200 ha (Figure 10 and Results and Discussion), rendering them by most definitions below the minimum size required by LPCH.

Many additional important GIS habitat analyses could be performed. Indeed, it is difficult to envision implementation of the plan or LPCH habitat management in general without additional habitat analysis to identify what activities should be conducted where. The map, GIS analyses, and updated LPCH population information will also be crucial to monitoring the effects of conservation and management actions on these focal species.

ACKNOWLEDGEMENTS

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APPENDIX A. VEGETATION MAP UNIT DESCRIPTIONS

Twenty map unit descriptions are provided in the following pages. Each descriptions includes :

1. Map unit number that corresponds to the unique number for the map.

2. Short descriptive name for the map unit, e.g. Mid-grass Grassland.

3. Area in hectares (ha) and acres (ac) for the entire study area included in New Mexico and Texas.

4. Represenative photo taken within the study area.

5. Short description of the map unit that includes dominant shrub and grass percentages, topographic features, and importance to the lesser prairie-chicken.

6. A list of plant associations that would be found aggregated within the map unit.

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
1	Shin-Oak/Mixed Mid-Grass & Tall-Grass Duneland	86,182	212,961

This MU contains semi-stabilized, 2-10 m- (6-32 ft) tall dunes dominated by shin-oak. These eolian soils are excessively well-drained fine sands. Total vegetative, litter, and soil cover varies greatly due principally to land management practices. Total shrub cover ranges from 20 to 70% and grasses cover between 6 and 42%. Median total cover for shrub and grass is 38 and 15%, respectively, or a relative shrub to grass cover of 71% shrubs to 29% grass. Litter was found to vary from 13-90% cover. Little bluestem is typically the dominant grass in both the northern (north of Hwy 380) and southern part of the study area. Sand bluestem is regularly found within this map unit in the north, and giant dropseed is found in the south. Soapweed yucca (*Yucca glauca*) and sand sagebrush, making up less than 5% of total cover, are also found consistently within this map unit, although in areas it can be the co-dominant shrub. This MU provides important nesting, brood-rearing, and foraging habitat for the lesser prairie-chicken and protection from the sun, wind, and storms.

Plant Associations:
Shin-Oak/Little Bluestem Duneland
Shin-Oak/Sand Bluestem Duneland
Shin-Oak/Giant Dropseed Duneland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
2	**Shin-Oak/Sparse Duneland**	76,511	189,063

This MU is a transition community between MU #1 and barren dunelands. These eolian soils are also excessively well-drained, fine sands. It consists of dunelands dominated by shin-oak, with a shrub component between 22 and 62%, and a grass component typically less than 5%. A relative shrub to grass cover of 95% shrubs to 5% grass is found within this map unit. This significant decrease in grass cover separates this MU from MU #1. Soapweed yucca, sand sagebrush, fall witchgrass, and purple threeawn are regularly found within this map unit. This transitional community is found scattered throughout the study area, but it is concentrated along the western edge of the study area, within herbicide-treated areas, and to the south (below Hwy 380). The complex terrain has a variety of vegetation types, often containing pockets of nearby plant community types. This MU is used by the LPCH for nesting and brood-rearing, particularly because it contains early successional plant species utilized by broods. Under proper management, mid- and tall-grasses could increase, improving nesting habitat for LPCH.

Plant Associations:
Shin-Oak/Sparse Duneland
Shin-Oak/Giant Dropseed Duneland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
3	**Shin-Oak/Mixed Mid-Grass & Tall-Grass Shrubland**	26,409	65,258

This MU is similar to the Shin-Oak/Mixed Mid-Grass & Tall-Grass Duneland, but the terrain consists of undulating sand sheets to nearly level plains. The shrub component ranges between 23 and 60%, and grass from 5 to 40%. A relative shrub to grass cover of 63% shrubs to 37% grass is found in this map unit. Bare soil ranges from 20 to 80%. In the north, the dominant grass is little bluestem with less, but locally-dominant, cover of various grasses, including hairy grama, sand bluestem, and purple threeawn. The southern portions of the study area are typically dominated by dropseed species. The height of shin-oak on the sand sheets is often half that in the nearby dunelands. This MU provides good nesting, brood-rearing and foraging habitat and is heavily used by the LPCH.

Plant Associations:
Shin-Oak/Sand Bluestem Shrubland
Shin-Oak/Little Bluestem Shrubland
Shin-Oak/Sparse Shrubland
Shin-Oak/Giant Dropseed Shrubland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
5	**Shin-Oak/Mixed Mid-Grass & Short-Grass Shrubland**	143,005	353,372

This community is found on flat to rolling eolian sandy plains with few dunes. Soils are typically fine and loamy fine sands. The shrub component ranges between 20 and 45%, and grasses vary between 1 and 30%. A relative shrub to grass cover of 86% shrubs to 14% grass is found in this map unit. Bare soil ranges from 15 to 40%. Grasses are dominated by little bluestem, black grama (*Bouteloua eriopoda*), or New Mexico needlegrass (*Stipa neomexicana*) but local dominance of other grasses such as dropseed species or hairy grama occurs. Soapweed yucca and sand sagebrush are found as minor components throughout this unit. This MU is used by the LPCH for nesting and foraging.

Plant Associations:
Shin-Oak/Black Grama Shrubland
Shin-Oak/Little Bluestem
Shin-Oak/New Mexico Needlegrass
Shin-Oak/Fall Witchgrass

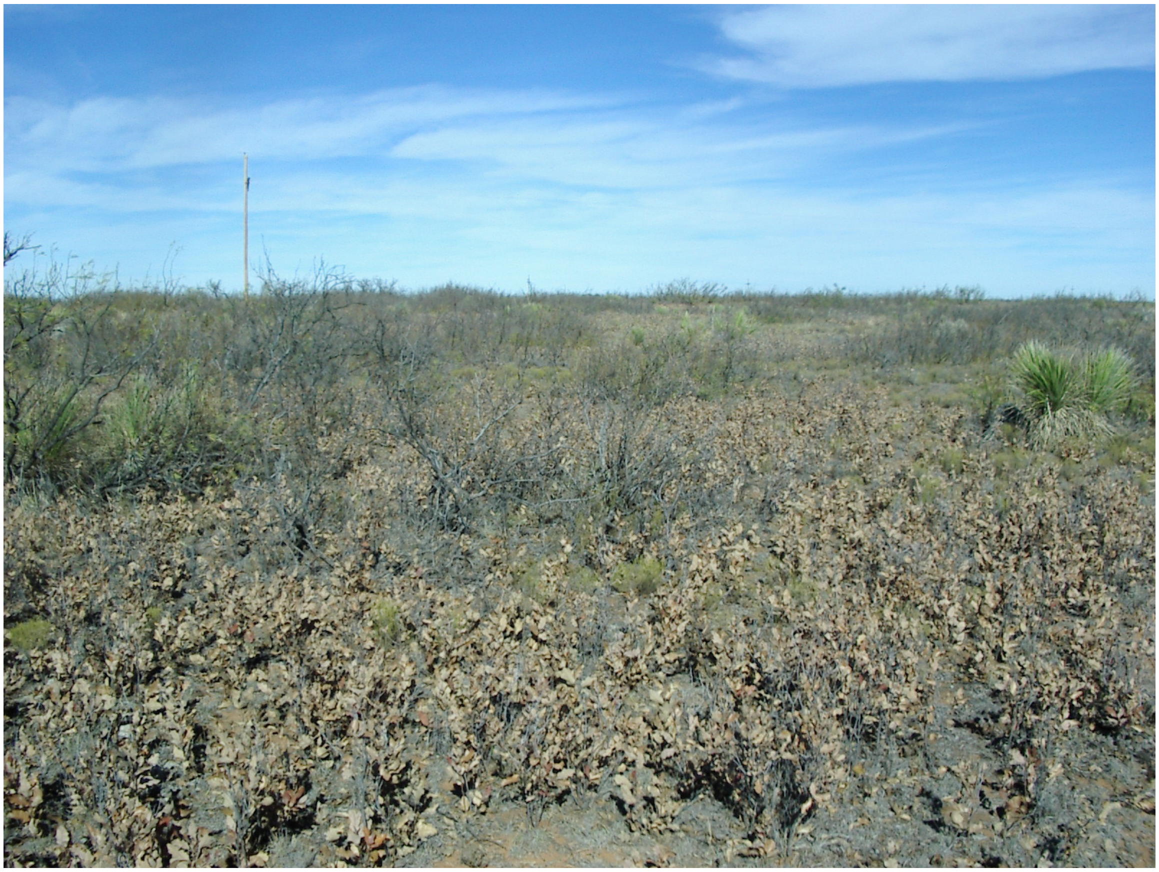
MU#	MU DESCRIPTION	HA	AC
6	**Shin-Oak/Sparse Shrubland**	21,217	52,429

This MU tends to be found on the fringes of the other shinnery communities, especially in the southern part of the study area. Soils are fine and loamy fine sands. The shrub component comprises approximately 12 to 45%, and a grass component ranges from 5 to 19%. A relative shrub to grass cover of 71% shrubs to 29% grass is found in this map unit. There is no evidence that LPCH utilize this MU for nesting, possibly due to the absence of residual grasses such as little bluestem and sand bluestem. If contiguous to other areas important to the LPCH, there may be significant utilization of the early successional species for foraging, and it may be used as a dispersal corridor to better habitat.

Plant Associations:
Shin-Oak/Sparse Shrubland
Shin-Oak/Purple Threeawn
Shin-Oak/Hairy Grama

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
7	**Honey Mesquite-Shin-Oak/Short-Grass Shrubland**	35,832	88,542



This shrubland is dominated by honey mesquite and shin-oak on nearly flat eolian plains, although in areas it can include dunelands. Shrubs range from 13 to 31% cover, with an understory of grasses ranging from 9 to 38%. Bare soil is relatively high at 40 to 80%. This MU is found throughout but is concentrated on the western extent of the study area and south of Hwy 380. These areas are transitional between fine sandy soils dominated by shinn-oak and heavier soils with honey mesquite. Despite the presence of shin-oak, LPCH are thought to avoid these areas due to the presence of honey mesquite, which can be used by avian predators as perches.

Plant Associations :
Honey Mesquite-Shin-Oak/Blue Grama Shrubland
Honey Mesquite-Shin-Oak/Black Grama Shrubland
Honey Mesquite-Shin-Oak/Bush Muhly Shrubland
Honey Mesquite-Shin-Oak/Sparse

MU#	MU DESCRIPTION	HA	AC
8	**Sand Sagebrush Shrubland**	9,179	22,681

This MU is found on flat to rolling eolian plains on the edges of barren dunelands and in shin-oak habitat that has been treated with herbicides. Sand sagebrush is the dominant shrub component within this MU, comprising 10 to 50% of the vegetative cover. A relative shrub to grass cover of 82% shrubs to 18% grass is found in this map unit. This MU has a high percentage of bare ground (ca. 60%) and low litter (7 to 10%) in comparison to sand shinnery shrublands, which have approximately 30% bare ground and 20 to 35% litter. Soapweed yucca can be found scattered within this MU and can approach 10% of the total cover. Although sand sagebrush can provide wintering habitat for the LPCH (R. French, pers. comm.), no nesting has been observed within this MU in New Mexico.

Plant Associations:
Sand Sagebrush / Purple Threeawn Shrubland
Sand Sagebrush/Little Bluestem Shrubland
Sand Sagebrush/Sparse Shrubland
Sand Sagebrush/Honey Mesquite Shrubland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
10	**Honey Mesquite Shrubland**	55,754	137,771

This MU is dominated by honey mesquite and is found on the western edge of the study area, west of the shin-oak habitats, the toe slopes of the Caprock escarpment, at the margins and scattered within the short-grass grasslands, and throughout the southern portion of the study area. Soils are typically deep, well-drained, fine, sandy loams on gently sloping alluvial material. Shrub cover ranges between 20 and 56%, and grasses range between 6 and 60%, although grass cover is typically closer to 30%. Bare soil averages 52% but can be as low as 6% and as high as 70%. The dominant grasses found in association with honey mesquite are black grama, blue grama, vine mesquite (*Panicum obtusum*), and bush muhly (*Muhlenbergia porteri*). Soapweed yucca and snakeweed are minor shrub components found consistently in this MU. This is not suitable nesting habitat, and LPCH avoid honey mesquite/short grass areas (Davis et al. 1979).

Plant Associations:
Honey Mesquite/Black Grama Shrubland
Honey Mesquite/Blue Grama Shrubland
Honey Mesquite/Vine Mesquite Shrubland
Catclaw Mimosa/Dropseed Shrubland
Honey Mesquite-Creosotebush/Burrograss Shrubland
Honey Mesquite/Buffalograss Shrubland
Javelina Bush/Bush Muhly Shrubland
Honey Mesquite/Bush Muhly Shrubland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
11	**Escarpment - Footslope Shrubland**	2,536	6,266

This MU aggregates plant communities along the Caprock escarpment and foothill slopes. Most of the Caprock was not sampled so we refer to Lenfesty (1980) and Rand French (pers. comm. 2001) who indicate steep slopes may include the following shrubs and grasses: *Yucca* spp., honey mesquite, littleleaf sumac (*Rhus microphylla*), wavyleaf oak (*Quercus undulata*), skunkbush sumac (*Rhus trilobata*), and catclaw acacia (*Acacia neovernicosa*), blue grama, black grama, sideoats grama (*Bouteloua curtipendula*), bush muhly, three-awn, and sand dropseed. Junipers (*Juniperus* sp.) are scattered throughout the steep slopes. Javalina Bush/Mariola Shrubland and Creosotebush/Bush Muhly are found on the shoulder slopes of the caprock. Creosotebush/Tarbush Shrubland was found near the dissected footslopes in heavier soils.

Plant Associations:
Javalina Bush/Mariola Shrubland
Creosotebush/Bush Muhly Shrubland
Creosotebush/Tarbush Shrubland
Caprock Escarpment Shrubland (unsampled)

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
13	**Tall-Grass Grassland**	5,575	13,776

This grassland is found on flat and rolling eolian plains naturally interspersed within shin-oak-dominated areas or at their periphery. Where soils are very deep, sand bluestem will be locally dominant and shallower sandy areas will have a higher cover of little bluestem. Soils are fine and loamy fine sands. More often this MU is a result of herbicide-treated areas where shin-oak is almost completely absent. Instead of forming small patches interspersed among shin-oak (< 1 ha), large expanses covering several hundred hectares are found. Within these treated tall-grass areas, soapweed yucca tends to be the dominant shrub, in some places approaching 20% cover. Giant dropseed may replace sand bluestem south of Hwy 380. As patches within shin oak dominated areas, tall grasses provide good thermal cover in winter (Bidwell et al. 2002) and provide the most protection from predators, thereby increasing the likelihood of successful nests (Davis et al. 1979). These tall grass prairies are an essential seedbank but may be most utilized by the LPCH as corridors to their principal habitat in shin-oak-dominated areas.

Plant Associations:
Sand Bluestem/Soapweed Yucca Grassland
Sand Bluestem-Little Bluestem/Soapweed Yucca Grassland

MU#	MU DESCRIPTION	HA	AC
14	**Honey Mesquite Sparse Shrubland**	55,978	138,325

Honey mesquite and fourwing saltbush are found on rolling eolian to dramatically high coppicing dunelands. Shrub cover ranges between 40 and 45% with only 1 to 3% cover of grasses that include predominantly black grama, bush muhly and mesa dropseed. The inter-shrub spaces are mostly barren with values ranging from 70 to 85%. With the exception of agricultural conversion, these landscapes are the most altered within the study area.

Plant Associations:
Honey Mesquite/Fourwing Saltbush
Honey Mesquite/Fourwing Saltbush/Sparse

MU#	MU DESCRIPTION	HA	AC
15	**Shin-Oak-Sand Sagebrush Shrubland**	2,949	7,287

This MU is found within undulating sand sheets to small dunes having a nearly equal dominance of shin-oak and sand sagebrush. Shrubs on average comprise 37% of cover with grasses ranging between 10 and 20%. A relative shrub to grass cover of 75% shrubs to 25% grass is found in this map unit. Dominant grasses are dropseed species, fall witchgrass, and purple threeawn. Soils are very loose and mobile with a high percent of exposed bare soil ranging from 60-70%. There is no evidence these areas are used for nesting; however, they may be important for the LPCH by providing cover from seasonal events such as thundershowers, intense sun and winds. This MU may also provide imporant foraging due to the relatively high cover of shin-oak and large barren interspaces for early successional plant species.

Plant Associations :
Shin-Oak-Sand Sagebrush Shrubland

MU#	MU DESCRIPTION	HA	AC
16	**Short-Grass Grassland**	148,101	365,964

This grassland community is principally dominated by black grama and in some areas, blue grama. The unit is found in large inter-dune plains or swales and on the Caprock. Although they represent different landscape positions, both of these areas are on flat terrain with shallow, calcareous soils. Black grama and blue grama grasslands within the inter-dune plains or swales originated in calcareous alluvial and lacustrine sediments, often found in depressions (Lenfesty 1980). The upland grasslands on the Caprock are moderately calcareous soils that overlay indurated caliche (Lenfesty 1980). Black grama, which dominates the typical Chihuahuan Desert grassland, increases in dominance further to the south and below the Caprock. Blue grama, which dominates the typical Great Plains grassland, becomes more dominant to the north and may be dominant on top of the Caprock, but this area was not sampled. Snakeweed and honey mesquite are consistently found scattered throughout this MU. Tobosa grass (*Hilaria mutica*) dominates in more clay-rich playas and drainage areas formed in alluvium and underlain by strongly calcareous clay and clay loams (Lenfesty 1980). Prairie dog towns and leks can be found in this MU.

Plant Associations:
Black Grama-Blue Grama/Soapweed Yucca Grassland
Black Grama-Bush Muhly Grassland
Black Grama-Purple Threeawn Grassland
Black Grama-Vine Mesquite Grassland
Blue Grama-Black Grama Grassland
Blue Grama-Little Bluestem Grassland
Ear Muhly-Blue Grama Grassland
Hairy Grama/Soapweed Yucca Grassland
Blue Grama-Purple Threeawn Grassland
Blue Grama-Sand Dropseed Grassland

MU#	MU DESCRIPTION	HA	AC
19	**Conservation Reserve Program (CRP) Fields**	16,,274	40,215

US Department of Agriculture CRP is a volunteer program between private landowners and the USDA to provide yearly compensation over 10-15 years to place idle or highly erodible lands previously in agricultural production into conservation. The lands were seeded with either native or non-native grasses or a combination of both. They often appear very monotypic. There is evidence that some types of mixed CRP may support LPCH (Rodgers and Hoffman 2005, Dawn Davis pers. comm.); more information on this MU and its subtypes may support a future classification change to Group C.

MU#	MU DESCRIPTION	HA	AC
20	**Agricultural Fields**	29,524	72,956

A variety of agricultural crops are grown within the study area, including cotton, milo, corn, and alfalfa to name a few. This MU includes active and fallow agricultural fields.

MU#	MU DESCRIPTION	HA	AC
23	**Mid-Grass Grassland**	21,931	54,194

This MU is dominated by little bluestem, probably the most ubiquitous herbaceous plant of the sandhills. Little bluestem occurs throughout the study area and is likely found within all of the map units important to the LPCH. These mid-grasses typically occur naturally within shin-oak dominated areas in patches of less than 5 ha; whereas, areas that have been treated with an herbicide to remove woody species will occupy areas greater than 5 ha. In some cases CRP lands were seeded with native mid-grasses that comprise this map unit. Soils are fine and loamy fine sands on relatively flat plains. Tobosa grass increases in depressions, with soapweed yucca occurring on sandier soils. Honey mesquite and sand sagebrush are also components of this community and can be locally dominant. When found near areas dominated by shin-oak, LPCH may utilize these areas for nesting (Dawn Davis, pers. comm.). Otherwise, they may provide functional corridors and foraging areas.

Plant Associations:
Little Bluestem/Soapweed Yucca Grassland
Little Bluestem-Treated Grassland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
24	**Mixed Mid-Grass & Short-Grass/Shin-Oak Grassland**	25,670	63,432

This grassland is found within varying terrain from flat or rolling eolian plains to interdune swales and deflation plains. These areas have a high diversity of short- and mid-grasses. Soils are fine and loamy fine sands. The shin-oak component ranges from 1 to 12%. Grass cover ranges from 11 to 42%. A relative shrub to grass cover of 33% to 67% is found in this map unit. Honey mesquite or catclaw mimosa invades in all areas except interdune swales. Large patches of this MU indicate landcover changes, probably due to herbicide treatment. Although shin-oak cover is low, these areas may have restoration potential if they are adjacent to occupied habitat or are large and near occupied habitat. Restoration potential is reduced by encroachment of large woody shrubs such as mesquite.

Plant Associations:
Purple Threeawn/Shin-Oak Grassland
Purple Threeawn-New Mexico Needlegrass/Shin-Oak Grassland
Little Bluestem-Purple Threeawn/Shin-Oak Grassland
Sideoats Grama/Shin-Oak Grassland
Fall Witchgrass/Shin-Oak Grassland

APPENDIX A

MU#	MU DESCRIPTION	HA	AC
25	**Short-Grass/Honey Mesquite Grassland**	61,830	152,785

This map unit contains a high diversity of short grasses and ranges between 5 and 16% cover of either honey mesquite or catclaw mimosa. This unit is transitional between the short-grass grasslands and honey mesquite shrublands. Where condition is adversely affected by overgrazing, soils begin to move and settle beneath the shrubs and form coppicing dunes. Since honey mesquite is an invasive species, the grassland can transition into higher shrub cover. This map unit is found within large inter-dune plains or swales and on the Caprock. Within the inter-dune plains the relatively high percentage of forbs (15%) is dominated by collegeflower (*Hymenopappus flavescens* var. canotomentosus). On the Caprock, the unit can have a high occurrence of snakeweed and cholla.

Plant Associations:
Tobosa grass-Blue Grama/Honey Mesquite Grassland
Blue Grama-Black Grama/Honey Mesquite Grassland
Black Grama-Bush Muhly/Honey Mesquite Grassland
Blue Grama-Black Grama/Catclaw Mimosa Grassland

MU#	MU DESCRIPTION	HA	AC
26	**Playa Lakebed**	2,282	5,638

Topographically low areas within the landscape that are seasonally flooded.

MU#	MU DESCRIPTION	HA	AC
27	**Barren/Sparsely Vegetated/Manmade Disturbance**	79,162	195,615

This MU is largely composed of dune fields, escarpment outcrops, barren swales, roads and drill pads. Although vegetation is sparse to non-existent, it can include scattered canopies of trees such cottonwood and elm in the dunelands, along roads, surrounding wells, and old home sites. Eliminating all categories within this map unit, with the exception of areas falling within shin-oak dominated areas, may be helpful in locating blowouts that are important to the sand dune lizard.

APPENDIX B

APPENDIX B. PLANT SPECIES LIST

The list contains plant species found within the study area as part of the vegetation survey by NHNM and EDAC from 2001-2004. Table B-1 is ordered by lifeform and then alphabetically by scientific name. Table B-2 is ordered by lifeform and family. Lifeform categories are: Tree = greater than 3 m; Shrub = tall shrubs 0.5 to 3 m; Sub-shrub = woody sub-shrubs less than 0.5 m; Grass = grasses and graminoids (rushes, sedges, etc.); and Forb = herbaceous forbs.

APPENDIX B

Table B-1. Species list by lifeform and scientific name.

Lifeform	Scientific Name	Common Name	Family
Tree	Juniperus monosperma	oneseed juniper	Cupressaceae
Shrub	Acacia spp.	acacia	Fabaceae
	Artemisia filifolia	sand sagebrush	Asteraceae
	Atriplex canescens	fourwing saltbush	Chenopodiaceae
	Baccharis spp.	baccharis	Asteraceae
	Chrysothamnus pulchellus	southwestern rabbitbrush	Asteraceae
	Condalia ericoides	javelina bush	Rhamnaceae
	Ephedra spp.	mormontea	Ephedraceae
	Ephedra torreyana	Torrey's jointfir	Ephedraceae
	Ericameria spp.	heath goldenrod	Asteraceae
	Flourensia cernua	tarbush	Asteraceae
	Koeberlinia spinosa	crown of thorns	Koeberliniaceae
	Larrea tridentata	creosotebush	Zygophyllaceae
	Mimosa aculeaticarpa var. biuncifera	catclaw mimosa	Fabaceae
	Opuntia imbricata	tree cholla	Cactaceae
	Opuntia leptocaulis	Christmas cactus	Cactaceae
	Opuntia spp.	pricklypear	Cactaceae
	Prosopis glandulosa	honey mesquite	Fabaceae
	Quercus havardii	shin-oak	Fagaceae
	Rhus microphylla	littleleaf sumac	Anacardiaceae
	Sapindus saponaria	wingleaf soapberry	Sapindaceae
	Yucca glauca	soapweed yucca	Agavaceae
	Ziziphus obtusifolia	lotebush	Rhamnaceae
Sub-shrub	Croton dioicus	grassland croton	Euphorbiaceae
	Croton pottsii	leatherweed	Euphorbiaceae
	Dalea formosa	featherplume	Fabaceae
	Escobaria vivipara var. vivipara	spinystar	Cactaceae
	Ferocactus hamatacanthus	turk's head	Cactaceae
	Gutierrezia microcephala	threadleaf snakeweed	Asteraceae
	Gutierrezia sarothrae	broom snakeweed	Asteraceae
	Krameria grayi	white ratany	Krameriaceae
	Opuntia phaeacantha	tulip pricklypear	Cactaceae
	Opuntia polyacantha	plains pricklypear	Cactaceae
	Parthenium incanum	mariola	Asteraceae
	Paronychia jamesii	James' nailwort	Caryophyllaceae
	Thymophylla acerosa	pricklyleaf dogweed	Asteraceae
	Zinnia grandiflora	Rocky Mountain zinnia	Asteraceae
	Zinnia spp.	zinnia	Asteraceae
Grass	Andropogon hallii	sand bluestem	Poaceae
	Aristida divaricata	poverty threeawn	Poaceae
	Aristida purpurea	purple threeawn	Poaceae
	Bothriochloa laguroides	silver beardgrass	Poaceae
	Bothriochloa laguroides ssp. torreyana	silver beardgrass	Poaceae

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Lifeform	Scientific Name	Common Name	Family
	Bouteloua curtipendula	sideoats grama	Poaceae
	Bouteloua eriopoda	black grama	Poaceae
	Bouteloua gracilis	blue grama	Poaceae
	Bouteloua hirsuta	hairy grama	Poaceae
	Buchloe dactyloides	buffalograss	Poaceae
	Cenchrus spp.	sandbur	Poaceae
	Chloris crinita	false Rhodes grass	Poaceae
	Chloris cucullata	hooded windmill grass	Poaceae
	Chloris spp.	windmill grass	Poaceae
	Cyperus esculentus	chufa flatsedge	Cyperaceae
	Cyperus retroflexus	oneflower flatsedge	Cyperaceae
	Digitaria californica	Arizona cottontop	Poaceae
	Digitaria cognata	fall witchgrass	Poaceae
	Elymus elymoides	bottlebrush squirreltail	Poaceae
	Eragrostis curtipedicellata	gummy lovegrass	Poaceae
	Eragrostis spp.	lovegrass	Poaceae
	Eragrostis lehmanniana	Lehmann's lovegrass	Poaceae
	Eragrostis secundiflora	red lovegrass	Poaceae
	Eragrostis sessilispica	tumble lovegrass	Poaceae
	Erioneuron pilosum	hairy woollygrass	Poaceae
	Erioneuron pulchellum	fluffgrass	Poaceae
	Hilaria jamesii	galleta	Poaceae
	Hilaria mutica	tobosa	Poaceae
	Lycurus phleoides	common wolfstail	Poaceae
	Muhlenbergia porteri	bush muhly	Poaceae
	Muhlenbergia torreyi	ring muhly	Poaceae
	Munroa squarrosa	false buffalograss	Poaceae
	Panicum obtusum	vine mesquite	Poaceae
	Paspalum setaceum	thin paspalum	Poaceae
	Schizachyrium scoparium	little bluestem	Poaceae
	Scleropogon brevifolius	burrograss	Poaceae
	Setaria spp.	bristlegrass	Poaceae
	Setaria leucopila	streambed bristlegrass	Poaceae
	Sporobolus contractus	spike dropseed	Poaceae
	Sporobolus cryptandrus	sand dropseed	Poaceae
	Sporobolus flexuosus	mesa dropseed	Poaceae
	Sporobolus giganteus	giant dropseed	Poaceae
	Sporobolus spp.	dropseed	Poaceae
	Stipa comata	needle-and-thread grass	Poaceae
	Stipa neomexicana	New Mexico needlegrass	Poaceae
	Urochloa ciliatissima	fringed signalgrass	Poaceae
	Vulpia octoflora	sixweeks fescue	Poaceae
Forb	Acourtia nana	desert holly	Asteraceae
	Ambrosia psilostachya	Cuman ragweed	Asteraceae
	Ambrosia spp.	ragweed	Asteraceae
	Aphanostephus ramosissimus	plains dozedaisy	Asteraceae

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Lifeform	Scientific Name	Common Name	Family
	Asclepias latifolia	broadleaf milkweed	Asclepiadaceae
	Berlandiera lyrata	lyreleaf greeneyes	Asteraceae
	Caesalpinia jamesii	Rushpea	Fabaceae
	Calylophus spp.	sundrops	Onagraceae
	Chaetopappa ericoides	rose heath	Asteraceae
	Chamaesyce spp.	sandmat	Euphorbiaceae
	Chenopodium spp.	goosefoot	Chenopodiaceae
	Cirsium spp.	thistle	Asteraceae
	Commelina erecta	whitemouth dayflower	Commelinaceae
	Commelina spp.	dayflower	Commelinaceae
	Croton texensis	Texas croton	Euphorbiaceae
	Croton spp.	Croton	Euphorbiaceae
	Cryptantha cinerea	James' catseye	Boraginaceae
	Cryptantha crassisepala	hiddenflower	Boraginaceae
	Cryptantha minima	little cryptantha	Boraginaceae
	Dalea lanata	woolly prairieclover	Fabaceae
	Dalea purpurea	purple prairieclover	Fabaceae
	Delphinium spp.	larkspur	Ranunculaceae
	Dimorphocarpa wislizeni	spectacle pod	Brassicaceae
	Echinacea angustifolia	prairie coneflower	Asteraceae
	Eriogonum annuum	annual buckwheat	Polygonaceae
	Erigeron bellidiastrum	western daisy fleabane	Asteraceae
	Erigeron spp.	fleabane	Asteraceae
	Gaillardia spp.	gaillardia	Asteraceae
	Gaillardia pulchella	firewheel	Asteraceae
	Gaura coccinea	scarlet beeblossom	Onagraceae
	Gaura parviflora	velvetweed	Onagraceae
	Gaura spp.	beeblossom	Onagraceae
	Glandularia spp.	vervain	Verbenaceae
	Hedyotis spp.	starviolet	Rubiaceae
	Helianthus annuus	common sunflower	Asteraceae
	Heliotropium convolvulaceum	phlox heliotrope	Boraginaceae
	Helianthus spp	common sunflower	Asteraceae
	Hoffmannseggia spp.	rushpea	Fabaceae
	Houstonia humifusa	matted bluet	Rubiaceae
	Hymenoxys spp.	rubberweed	Asteraceae
	Hymenopappus flavescens	collegeflower	Asteraceae
	Hymenopappus flavescens var. canotomentosus	collegeflower	Asteraceae
	Ipomoea leptophylla	bush morningglory	Convolvulaceae
	Krameria lanceolata	trailing krameria	Krameriaceae
	Lappula occidentalis	flatspine stickseed	Boraginaceae
	Lesquerella gordonii	Gordon's bladderpod	Brassicaceae
	Lesquerella spp.	bladderpod	Brassicaceae
	Linum spp.	flax	Linaceae
	Machaeranthera pinnatifida	lacy tansyaster	Asteraceae
	Marrubium vulgare	horehound	Lamiaceae

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Lifeform	Scientific Name	Common Name	Family
	Mentzelia albicaulis	whitestem blazingstar	Loasaceae
	Mirabilis glabra	smooth four o'clock	Nyctaginaceae
	Mirabilis linearis	narrowleaf four o'clock	Nyctaginaceae
	Monarda pectinata	pony beebalm	Lamiaceae
	Monarda punctata	spotted beebalm	Lamiaceae
	Nama hispidum	bristly nama	Hydrophyllaceae
	Palafoxia rosea	rosy palafox	Asteraceae
	Penstemon spp.	beardtongue	Scrophulariaceae
	Phacelia integrifolia	gypsum scorpionweed	Hydrophyllaceae
	Plantago spp.	plantain	Plantaginaceae
	Plantago patagonica	woolly plantain	Plantaginaceae
	Polygala alba	white milkwort	Polygalaceae
	Polygonum spp.	knotweed	Polygonaceae
	Psilostrophe tagetina	woolly paperflower	Asteraceae
	Senna bauhinioides	twinleaf senna	Fabaceae
	Senecio flaccidus var. flaccidus	threadleaf ragwort	Asteraceae
	Senecio spartioides var. multicapitatus	broomlike ragwort	Asteraceae
	Solanum elaeagnifolium	silverleaf nightshade	Solanaceae
	Stephanomeria pauciflora	brownplume wirelettuce	Asteraceae
	Stillingia sylvatica	queen's-delight	Euphorbiaceae
	Teucrium laciniatum	lacy germander	Lamiaceae
	Thelesperma megapotamicum	Hopi tea greenthread	Asteraceae

APPENDIX B

Table B-2. Species list by lifeform and family.

Lifeform	Scientific Name	Common Name	Family
Tree	Juniperus monosperma	oneseed juniper	Cupressaceae
Shrub	Yucca glauca	soapweed yucca	Agavaceae
	Rhus microphylla	littleleaf sumac	Anacardiaceae
	Artemisia filifolia	sand sagebrush	Asteraceae
	Baccharis spp.	baccharis	Asteraceae
	Chrysothamnus pulchellus	southwestern rabbitbrush	Asteraceae
	Ericameria spp.	heath goldenrod	Asteraceae
	Flourensia cernua	tarbush	Asteraceae
	Opuntia imbricata	tree cholla	Cactaceae
	Opuntia leptocaulis	Christmas cactus	Cactaceae
	Opuntia spp.	pricklypear	Cactaceae
	Atriplex canescens	fourwing saltbush	Chenopodiaceae
	Ephedra spp.	mormontea	Ephedraceae
	Ephedra torreyana	Torrey's jointfir	Ephedraceae
	Acacia spp.	acacia	Fabaceae
	Mimosa aculeaticarpa var. biuncifera	catclaw mimosa	Fabaceae
	Prosopis glandulosa	honey mesquite	Fabaceae
	Quercus havardii	shin-oak	Fagaceae
	Koeberlinia spinosa	crown of thorns	Koeberliniaceae
	Condalia ericoides	javelin bush	Rhamnaceae
	Ziziphus obtusifolia	lotebush	Rhamnaceae
	Sapindus saponaria	wingleaf soapberry	Sapindaceae
	Larrea tridentata	creosotebush	Zygophyllaceae
Sub-shrub	Gutierrezia microcephala	threadleaf snakeweed	Asteraceae
	Gutierrezia sarothrae	broom snakeweed	Asteraceae
	Parthenium incanum	mariola	Asteraceae
	Thymophylla acerosa	pricklyleaf dogweed	Asteraceae
	Zinnia grandiflora	Rocky Mountain zinnia	Asteraceae
	Zinnia spp.	zinnia	Asteraceae
	Escobaria vivipara var. vivipara	spinystar	Cactaceae
	Ferocactus hamatacanthus	turk's head	Cactaceae
	Opuntia phaeacantha	tulip pricklypear	Cactaceae
	Opuntia polyacantha	plains pricklypear	Cactaceae
	Paronychia jamesii	James' nailwort	Caryophyllaceae
	Croton dioicus	grassland croton	Euphorbiaceae
	Croton pottsii	leatherweed	Euphorbiaceae
	Dalea formosa	featherplume	Fabaceae
	Krameria grayi	white ratany	Krameriaceae
Grass	Cyperus esculentus	chufa flatsedge	Cyperaceae
	Cyperus retroflexus	oneflower flatsedge	Cyperaceae
	Andropogon hallii	sand bluestem	Poaceae
	Aristida divaricata	poverty threeawn	Poaceae

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Lifeform	Scientific Name	Common Name	Family
	Aristida purpurea	purple threeawn	Poaceae
	Bothriochloa laguroides	silver beardgrass	Poaceae
	Bothriochloa laguroides ssp. torreyana	silver beardgrass	Poaceae
	Bouteloua curtipendula	sideoats grama	Poaceae
	Bouteloua eriopoda	black grama	Poaceae
	Bouteloua gracilis	blue grama	Poaceae
	Bouteloua hirsuta	hairy grama	Poaceae
	Buchloe dactyloides	buffalograss	Poaceae
	Cenchrus spp.	sandbur	Poaceae
	Chloris crinita	false Rhodes grass	Poaceae
	Chloris cucullata	hooded windmill grass	Poaceae
	Chloris spp.	windmill grass	Poaceae
	Digitaria californica	Arizona cottontop	Poaceae
	Digitaria cognata	fall witchgrass	Poaceae
	Elymus elymoides	bottlebrush squirreltail	Poaceae
	Eragrostis curtipedicellata	gummy lovegrass	Poaceae
	Eragrostis lehmanniana	Lehmann's lovegrass	Poaceae
	Eragrostis secundiflora	red lovegrass	Poaceae
	Eragrostis sessilispica	tumble lovegrass	Poaceae
	Eragrostis spp.	lovegrass	Poaceae
	Erioneuron pilosum	hairy woollygrass	Poaceae
	Erioneuron pulchellum	fluffgrass	Poaceae
	Hilaria jamesii	galleta	Poaceae
	Hilaria mutica	tobosa	Poaceae
	Lycurus phleoides	common wolfstail	Poaceae
	Muhlenbergia porteri	bush muhly	Poaceae
	Muhlenbergia torreyi	ring muhly	Poaceae
	Munroa squarrosa	false buffalograss	Poaceae
	Panicum obtusum	vine mesquite	Poaceae
	Paspalum setaceum	thin paspalum	Poaceae
	Schizachyrium scoparium	little bluestem	Poaceae
	Scleropogon brevifolius	burrograss	Poaceae
	Setaria leucopila	streambed bristlegrass	Poaceae
	Setaria spp.	bristlegrass	Poaceae
	Sporobolus contractus	spike dropseed	Poaceae
	Sporobolus cryptandrus	sand dropseed	Poaceae
	Sporobolus flexuosus	mesa dropseed	Poaceae
	Sporobolus giganteus	giant dropseed	Poaceae
	Sporobolus spp.	dropseed	Poaceae
	Stipa comata	needle-and-thread grass	Poaceae
	Stipa neomexicana	New Mexico needlegrass	Poaceae
	Urochloa ciliatissima	fringed signalgrass	Poaceae
	Vulpia octoflora	sixweeks fescue	Poaceae
Forb	Asclepias latifolia	broadleaf milkweed	Asclepiadaceae
	Acourtia nana	desert holly	Asteraceae
	Ambrosia psilostachya	Cuman ragweed	Asteraceae

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Lifeform	Scientific Name	Common Name	Family
	Ambrosia spp.	ragweed	Asteraceae
	Aphanostephus ramosissimus	plains dozedaisy	Asteraceae
	Berlandiera lyrata	lyreleaf greeneyes	Asteraceae
	Chaetopappa ericoides	rose heath	Asteraceae
	Cirsium spp.	thistle	Asteraceae
	Echinacea angustifolia	prairie coneflower	Asteraceae
	Erigeron bellidiastrum	western daisy fleabane	Asteraceae
	Erigeron spp.	fleabane	Asteraceae
	Gaillardia pulchella	firewheel	Asteraceae
	Gaillardia spp.	gaillardia	Asteraceae
	Helianthus annuus	common sunflower	Asteraceae
	Helianthus spp	common sunflower	Asteraceae
	Hymenopappus flavescens	collegeflower	Asteraceae
	Hymenopappus flavescens var. canotomentosus	collegeflower	Asteraceae
	Hymenoxys spp.	rubberweed	Asteraceae
	Machaeranthera pinnatifida	lacy tansyaster	Asteraceae
	Palafoxia rosea	rosy palafox	Asteraceae
	Psilostrophe tagetina	woolly paperflower	Asteraceae
	Senecio flaccidus var. flaccidus	threadleaf ragwort	Asteraceae
	Senecio spartioides var. multicapitatus	broomlike ragwort	Asteraceae
	Stephanomeria pauciflora	brownplume wirelettuce	Asteraceae
	Thelesperma megapotamicum	Hopi tea greenthread	Asteraceae
	Cryptantha cinerea	James' catseye	Boraginaceae
	Cryptantha crassisepala	hiddenflower	Boraginaceae
	Cryptantha minima	little cryptantha	Boraginaceae
	Heliotropium convolvulaceum	phlox heliotrope	Boraginaceae
	Lappula occidentalis	flatspine stickseed	Boraginaceae
	Dimorphocarpa wislizeni	spectacle pod	Brassicaceae
	Lesquerella gordonii	Gordon's bladderpod	Brassicaceae
	Lesquerella spp.	bladderpod	Brassicaceae
	Chenopodium spp.	goosefoot	Chenopodiaceae
	Commelina erecta	whitemouth dayflower	Commelinaceae
	Commelina spp.	dayflower	Commelinaceae
	Ipomoea leptophylla	bush morningglory	Convolvulaceae
	Chamaesyce spp.	sandmat	Euphorbiaceae
	Croton spp.	Croton	Euphorbiaceae
	Croton texensis	Texas croton	Euphorbiaceae
	Stillingia sylvatica	queen's-delight	Euphorbiaceae
	Caesalpinia jamesii	Rushpea	Fabaceae
	Dalea lanata	woolly prairieclover	Fabaceae
	Dalea purpurea	purple prairieclover	Fabaceae
	Hoffmannseggia spp.	rushpea	Fabaceae
	Senna bauhinioides	twinleaf senna	Fabaceae
	Nama hispidum	bristly nama	Hydrophyllaceae
	Phacelia integrifolia	gypsum scorpionweed	Hydrophyllaceae
	Krameria lanceolata	trailing krameria	Krameriaceae

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Lifeform	Scientific Name	Common Name	Family
	Marrubium vulgare	horehound	Lamiaceae
	Monarda pectinata	pony beebalm	Lamiaceae
	Monarda punctata	spotted beebalm	Lamiaceae
	Teucrium laciniatum	lacy germander	Lamiaceae
	Linum spp.	flax	Linaceae
	Mentzelia albicaulis	whitestem blazingstar	Loasaceae
	Mirabilis glabra	smooth four o'clock	Nyctaginaceae
	Mirabilis linearis	narrowleaf four o'clock	Nyctaginaceae
	Calylophus spp.	sundrops	Onagraceae
	Gaura coccinea	scarlet beeblossom	Onagraceae
	Gaura parviflora	velvetweed	Onagraceae
	Gaura spp.	beeblossom	Onagraceae
	Plantago patagonica	woolly plantain	Plantaginaceae
	Plantago spp.	plantain	Plantaginaceae
	Polygala alba	white milkwort	Polygalaceae
	Eriogonum annuum	annual buckwheat	Polygonaceae
	Polygonum spp.	knotweed	Polygonaceae
	Delphinium spp.	larkspur	Ranunculaceae
	Hedyotis spp.	starviolet	Rubiaceae
	Houstonia humifusa	matted bluet	Rubiaceae
	Penstemon spp.	beardtongue	Scrophulariaceae
	Solanum elaeagnifolium	silverleaf nightshade	Solanaceae
	Glandularia spp.	vervain	Verbenaceae