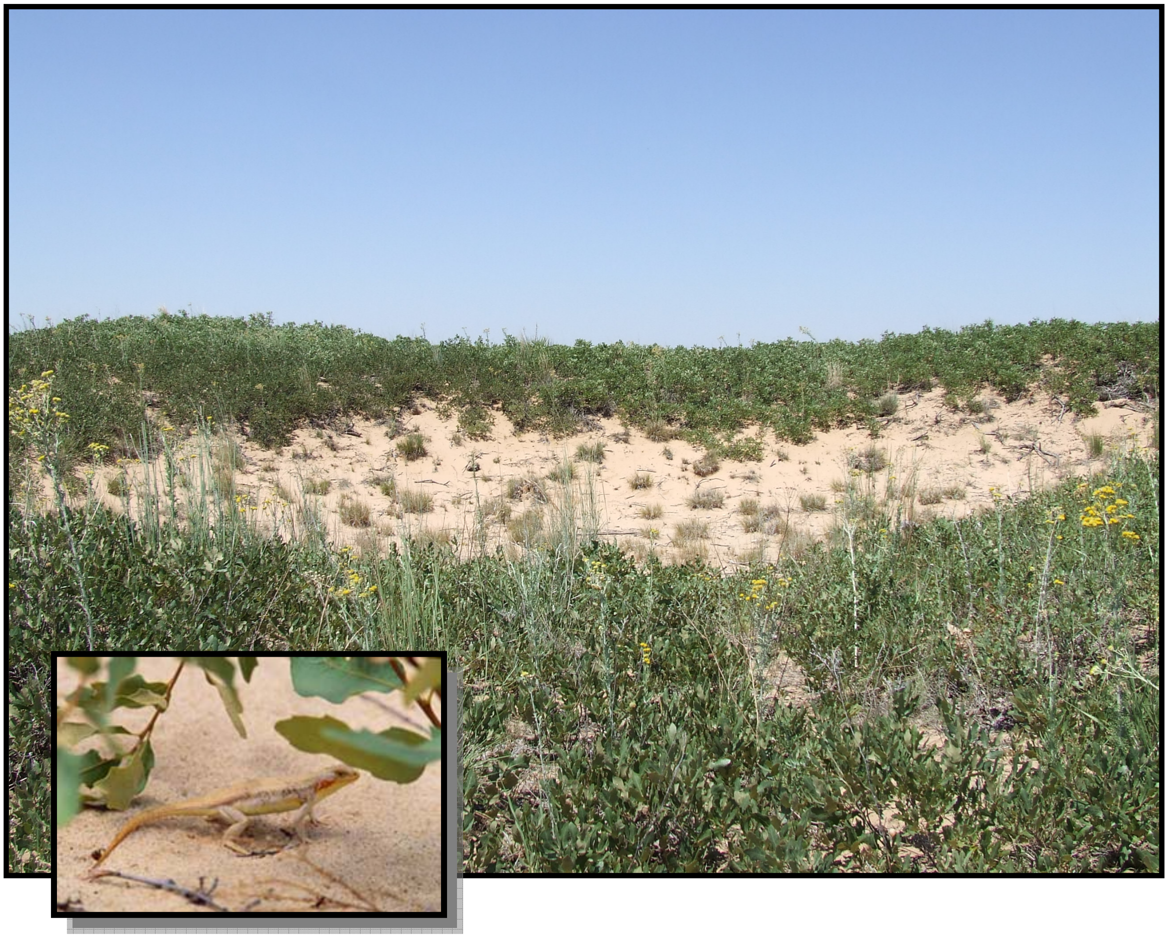
Map of a Portion of Potential Sand Dune Lizard Habitat in Southeastern New Mexico



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Map of a Portion of Potential Sand Dune Lizard Habitat in Southeastern New Mexico[1]

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ABSTRACT

The purpose of this project was to provide a map depicting the extent and location of a portion of sand dune lizard (*Sceloporus arenicolus*) habitat in southeastern New Mexico. Previous mapping projects (Johnson *et al*. 2006, Neville *et al*. 2005, Johnson *et al.* 2001) within the range of the sand dune lizard focused on lesser prairie-chicken (*Tympanuchus pallidicintus*) habitat, which overlaps to a great extent with that of the sand dune lizard. The study area lies within the southern portion of the lizard's range and covers approximately 81,328 ha (200,961 ac). We used field data in conjunction with satellite imagery and aerial photography to create a map based on plant associations, and we further modified the map units by landform. The result is a high spatial resolution dataset representing potential preferred sand dune lizard habitat of blowouts within dunes surrounded at the periphery by shin-oak (*Quercus havardii*). Other natural communities, as well as manmade disturbances and areas treated for shrub control are included in the mapped units. The overall accuracy of the map was 86.8%. When used in combination with GIS analysis and sand dune lizard population data, the map represents a useful management, planning, and monitoring tool.

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INTRODUCTION

The sand dune lizard (*Sceloporus arenicolus,* SCAR) is a small, terrestrial lizard endemic to sand shinnery habitat in portions of southeast New Mexico and adjacent areas in Texas. The known extent of its range in New Mexico covers portions of Chaves, Eddy, Lee, and Roosevelt counties while the extent within Texas is less well known (Figure 1). The Mescalero Sands of southeast New Mexico and the Monahan Sands of Texas are the known population centers for the lizard (New Mexico Department of Game and Fish 1988). The SCAR is currently listed by the U.S. Fish and Wildlife Service (USFWS) as a species of concern and by the Bureau of Land Management (BLM) as a sensitive species. It was recently uplisted to endangered by the New Mexico Department of Game and Fish (NMDGF).

***S. arenicolus* (photo: NMDGF)**

The purpose of this study was to create a map depicting the major SCAR habitat types within a narrow, occupied portion of the current range in New Mexico. Our approach to mapping SCAR habitat was to: (1) define suitable SCAR habitat by reviewing published literature and consulting experts; (2) identify variation in vegetation communities using satellite imagery and aerial photos, (3) conduct field reconnaissance on landcover types; (4) create map units relevant to the needs of the SCAR; and (5) analyze and map habitat quality using GIS. The map is intended for analysis of SCAR habitat preference and use, habitat management for the SCAR and other wildlife species such as the lesser prairie-chicken (*Tympanuchus pallidicintus*), 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 SCAR and offers a conservative delineation of potential habitat loss due to human use of these landscapes.

Study Area

The study area comprises five 7.5' U.S.G.S. topographic quads (Iron House Draw, Monument SW, Monument S, Hobb SW, and Hobb SE) or approximately 81,328 ha (200,961 ac)[3] within Lea County, New Mexico, with a portion of the easternmost quad falling within Gaines and Andrews Counties, Texas (Figure 1). The east-west block of quads lies nearly equidistant from between Hobbs to the north and Eunice to the south. Carlsbad is approximately 62 km (38.5 mi.) to the southwest of the western border of the mapped area.

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[3] Study area includes quads that extend into Texas. Area within New Mexico is approximately 72,966 ha (180,299 ac). We use the New Mexico area only for spatial analyses in the report.

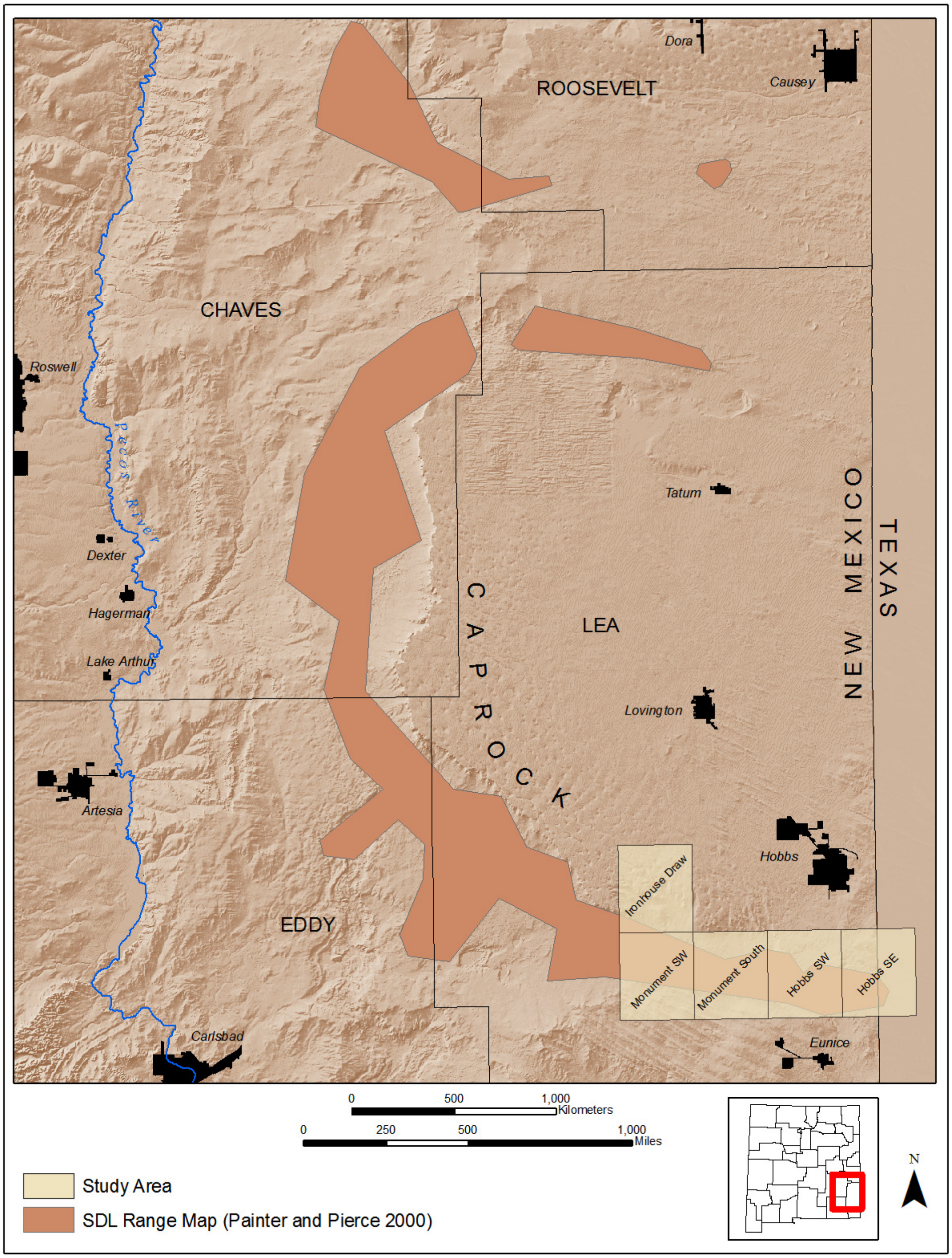


Figure 1. Study area south of Hobbs, New Mexico

Based on climate summaries from the Hobbs Station, New Mexico, approximately 9 km (5.5 mi) from the northern border of the study area, this region receives about 403 mm (15.9 in.) of annual rainfall. Most precipitation comes from convective thundershowers during the summer (Western Regional Climate Center 2006). Snow can occur from October to April, typically not more than 35 mm (1.4 in) of accumulation at any time and averaging about 129 mm (5.1 in.) for the year. Temperatures can range from as low as –21.6°C (-7°F) in winter to a high of 45.6°C (114°F) in summer. July is typically the warmest month, with an average high of 26.7°C (80.2°F). January is the coldest month, with average low temperatures of 5.6°C (42.2°F). At Clovis, the annual resultant drift direction (the vector sum of wind directions over the year weighted to wind speeds high enough to carry sand) is from the southwest (Muhs and Holliday 2001).

Much of the study area lies within the Mescalero Dunes, an eolian sand belt within the Pecos River valley that borders the physiographic feature known as the Llano Estacado or Caprock, as it is generally called locally. This escarpment marks the southernmost extension of the Great Plains. It is blanketed by the Pleistocene age Blackwater Draw formation, an eolian unit modified by pedogenesis and originally derived from wind-blown sediments from the Pecos River to the west (Holliday 1997). Underlying the Blackwater Draw is the older Miocene-Pliocene Age Ogallala Formation, a series of sands and gravels washed out from the Rocky Mountains over the last 12 million years (McLemore 1998) before the Pecos River became entrenched in its present position. The top layers of this unit have become highly cemented by calcium carbonate precipitated out by groundwater, creating the ledge-forming calcrete that gives the Caprock its name (Figure 1). Interspersed throughout this area are numerous large playas formed in the sinkholes of the karst landscape.

In the valley eroded out of the Ogallala by the Pecos River, dunes formed due to the tamping effect of the Caprock ridgeline. The winds blowing off the Pecos River Valley slow and deposit their sediment loads to the west of the ridge (McLemore 1998), forming the deep, well-drained sands of the Mescalero Dunes to the north of the study area. In the study area, the southerly dipping Caprock disappears into the sands and the dunes fields blow out toward the east into wide sand sheets and parabolic dunes intermingling with the shallow, calcium carbonate-rich soils of the underlying Caprock (McLemore 1998).

The lowest layer of these sands contains what Hall (2002) called Unit 1 red sands, formed during the warm early Wisconsinan (90,000 – 70,000 years ago) from eolian reworking of the sediments derived from the retreating Caprock. This unit is capped by an argillic horizon representing the next 55,000 years of moist, cooler climate that dominated the Wisconsinan Glacial, when the area was probably covered with a sagebrush grassland. The change back to a drier, warmer climate 9,000 – 5,000 years ago led to the deposit of the Unit 2 yellowish-red sands over the Unit 1 sands in what was probably a desert shrub grassland. The deposition of these units created the basic landforms found today, of the vegetated, parabolic dunes surrounded by the thinner sand sheets. In the last 150 years, probably due to human disturbance, the sands have become active again, with coppice dunes capping the parabolic dunes and sand sheets occurring throughout this area.

These well-drained sands typically overlie a petrocalcic horizon at varying depths. Hall (2002) identified these indurated layers below the sand sheets of the Mescalero Dunes as either red sand paleosols, spring-groundwater carbonates, or caliche. Near the Caprock, shallow sandy soils range from exposed bedrock to depths typically less than 50 cm (20 in). Further from the Caprock, soil depth to the indurated horizon is often greater than 147 cm (60 in). Other relatively deep sands have an indurated layer ranging between 50-147 cm (20-60 in) below the surface (Soil Survey Staff, SURGO). Surface sand grain sizes tend to be larger away from the Caprock as the sand sheets give way to the dunes. The color is white, probably due to Ogallala derivation or from the ancient springs deposits. South of the dunes, the grain size becomes smaller again and the sands become redder in color from the iron-oxide-rich clay coatings on the grains, which are derived from local reworking of the underlying red sands and deposition of wind-borne sands from the Pecos.

The most notable characteristic of these sands is the shin-oak (*Quercus havardii*) cover. The distribution and depth of the sandsheets and underlying calcium carbon-rich soils are important factors in determining the growth, density, and distribution of 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 (caliche) 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). Honey mesquite (*Prosopis glandulosa*) 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).

The current distribution of shin-oak occurred sometime after the Kansan glacial maximum of the middle Pleistocene (Tucker 1970). Sand shinnery communities are some of the least understood and most poorly described plant communities in the southwestern United States (Dhillion and Mills 1999). Much of the research on sand shinnery has occurred in Texas, and little is known about its extent 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 shin-oak 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 SCAR, but also provide nesting and foraging habitat for the lesser prairie-chicken. In addition, the shin-oak community supports a high diversity of raptors (up to 22 species, Bednarz *et al.* 1990). The geographic range of shin-oak 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 is a low, rhizomatous sub-shrub typically no more than 0.3 - 0.6 m (1-2 ft) in height. It grows on deep, well-drained, nutrient-poor, Pleistocene-derived soils (Wiedman and Penfound 1960, Lenfesty 1980) that 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).

Sand Dune Lizard Habitat

The SCAR is the only lizard species limited to the sand shinnery; other lizards that occur within shinnery in southeastern New Mexico are: Eastern collard lizard (Crotaphytus collaris), longnose leopard lizard (Gambelia wislizenii), lesser earless lizard (Holbrookia maculate), Texas horned lizard (Phrynosoma cornutum), roundtail horned lizard (P. modestum), Southern Plateau lizard (Sceloporus cowlesi), side-blotched lizard (Uta stansburiana), Great Plains skink (Eumeces obsoletus), six-lined racerunner (Aspidoscelis sexlineata), and western whiptail (A. tigris) (C.W. Painter personal communication). The SCAR occupies wind-eroded blowouts within shin-oak dunelands of southeastern New Mexico. It uses the shin-oak periphery of the blow-out for foraging and refuge (New Mexico Department of Game and Fish 2006). Behavioral studies aimed at thermoregulatory micro- and macro-site use by *S. arenicolus* and a more generalist lizard, *Uta stansburiana*, both species of the family Phrynosomatidae, found the SCAR used microsites with more vegetative cover (specifically shin-oak) than those of *U. stansburiana* (Sartorius *et al.* 2002). Within the blowouts, occupied sites tend to have coarser sand grains (Painter 2004). The SCAR feeds on ants and their pupae, small beetles and their larvae, crickets, grasshoppers, and spiders. They forage and hide within the deep sands under vegetated patches surrounding blowouts (Degenhardt *et al.* 1996).

The principal threats to the SCAR are habitat conversion due to shrub control through herbicides, oil and gas development, excessive livestock grazing, and agricultural conversion (New Mexico Department of Game and Fish 2006). Sias and Snell (1998) found 40% population reductions within 200 m (66 ft) of oil and gas activities compared to control sites. Oil and gas roads fragment habitat and create vehicle hazards (Dinerstein *et al.* 2000). The removal of shin-oak has caused reductions in SCAR populations (Snell *et al.* 1993) by as much as 70-94% in treated pastures compared to adjacent non-treated pastures (New Mexico Department of Game and Fish 2006). After herbicide treatment of shin-oak, the SCAR did not repopulate the treated pastures, despite nearby occupied habitat. Vegetation loss in occupied desert habitats has resulted in a decrease of lizard abundance (Fleischner 1994, Attum and Eason 2006). Attum and Eason (2006) found significant increases in another sand dune lizard species, *Acanthodactylus longpipes,* in less than two years following construction of livestock exclosures.

Due to the high rates of landscape change, loss of habitat, and geographically patchy occupied habitat, Chan *et al.* (2007) has begun DNA studies to characterize existing populations. This effort will help determine how environmental alterations to the SCAR's habitat may affect population genetic structure.

METHODS

Data Sources

Satellite Imagery

We used two types of imagery of 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 correct geometrically 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 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 analyzed statistically 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 sparse vegetation communities that occur in the study area. ETM$^+$ band 6 records a thermal response, which directly measures surface temperature. It indirectly indicates 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.

We acquired three ETM^+ scenes from April 15, 2002; June 18, 2002; and September 22, 2002. The multi-temporal scenes capture seasonal vegetation changes of deciduous shrub leaf-out, forb emergence, and transition from cool- to warm-season grasses.

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.

Aerial Photography

Aerial photography was our other major data set. We combined color Digital Ortho-photo Quarter Quads (DOQQs) to create one ortho-photo mosaic image. The 20, 3-band DOQQs from the New Mexico Statewide Orthophotography Project (Bohannan-Huston, Inc. 2005) were acquired over the area at a 1:12,000 scale in July of 2005. The color photographs provide the red, green, and blue portions of the electromagnetic spectrum with a 1-m spatial resolution.

Ancillary Map Geographic Information System (GIS) Layers

We acquired additional vector and raster data from various sources to use as background layers and objects for analyses. Roads (TIGER Line) were used on field maps to help identify established roads within the study area. We compiled and processed Soil Surveys Staff (SSURGO) digital GIS and tabular soil data to identify soil units that correspond to SCAR habitat types. We used accessioned specimen data and animal occurrence data from the New Mexico Department of Game and Fish and Natural Heritage New Mexico

(NHNM Species Information 2007) and to create a point GIS layer of occupied SCAR habitat.

Software and Hardware Used

We used Leica's ERDAS Imagine, Version 9.0, a pixel-based software, to process the raster imagery and develop the classification. We used Definien's Imaging (Baatz *et al.* 2004) Version 5.0, an object-oriented software, to develop the object primitives (or polygons) and ESRI's ArcGIS 9.2 to create topology for the vector map and refine the classification. All digital imagery and GIS layers were processed, manipulated, and used as overlays for analysis within both the Imagine and ArcGIS environments. We stored and manipulated all field data using Microsoft Access and Microsoft Excel 2003.

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 the images overlaid directly onto the same sites in the DOQQ. The ETM^+ images were also re-sampled 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

DOQQs 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, we created the texture image 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 re-sampled 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 34 image bands (Table 2) available to the classification process.

Table 2. Composite image file used in the classification.

Image Band	Band Description*
1	Air Photo - Blue
2	Air Photo - Green
3	Air Photo - Red
4	Air Photo - Texture
5	L7 04152002 - Blue
6	L7 04152002 - Green
7	L7 04152002 - Red
8	L7 04152002 - NIR
9	L7 04152002 – MIR I
10	L7 04152002 – MIR II
11	L7 06182002 - Blue
12	L7 06182002 - Green
13	L7 06182002 - Red
14	L7 06182002 - NIR
15	L7 06182002 – MIR I
16	L7 06182002 – MIR II
17	L7 09222002 - Blue
18	L7 09222002 - Green
19	L7 09222002 - Red
20	L7 09222002 - NIR
21	L7 09222002 – MIR I
22	L7 09222002 – MIR II
23	L7 04152002 - NDSVI
24	L7 04152002 - NDVI
25	L7 04152002 – Structure Ratio
26	L7 04152002 – Moisture Ratio
27	L7 06182002 - NDSVI
28	L7 06182002 - NDVI
29	L7 06182002 – Structure Ratio
30	L7 06182002 – Moisture Ratio
31	L7 09222002 - NDSVI
32	L7 09222002 - NDVI
33	L7 09222002 – Structure Ratio
34	L7 09222002 – Moisture Ratio

*L7 bands are from the Landsat ETM+, labeled with the acquisition date and wavelength or indice.

Field Data Surveys

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 field work was accomplished from July 24-26, 2006 (Figure 2). We used a total of 87 data points to construct the map. Of these, 7 were standard field plots and an additional 80 were map points. Due to our extensive, previous work within the sandhill ecosystem, we were less concerned about the vegetation classification. Therefore, we invested our limited field time in numerous, quick assessments of map units.

We chose plots based on homogeneity of floristics, physiognomy or physical structure, and known SCAR 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, and potential habitat use by the SCAR. 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). Exceptions included plots to characterize blowouts that varied in size.

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 the SCAR, such as agricultural lands, honey mesquite shrubland, and drainage areas. 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 a Garmin GPS 12 unit. The 12- channel receiver has an average accuracy of 7-15m (21 to 45 ft, Garmin Corporation 2001). The unit was 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.

Our second field trip to the study area occurred from May 29- June 1, 2007 (Figure 2). Prior to going into the field, we developed the draft vegetation map and identified questionable areas. We visited these sites, checked the draft map along our destination routes, and collected an additional 52 map points. The field data from the second trip were used to modify the draft map and further refine the classification and descriptions for the map units.

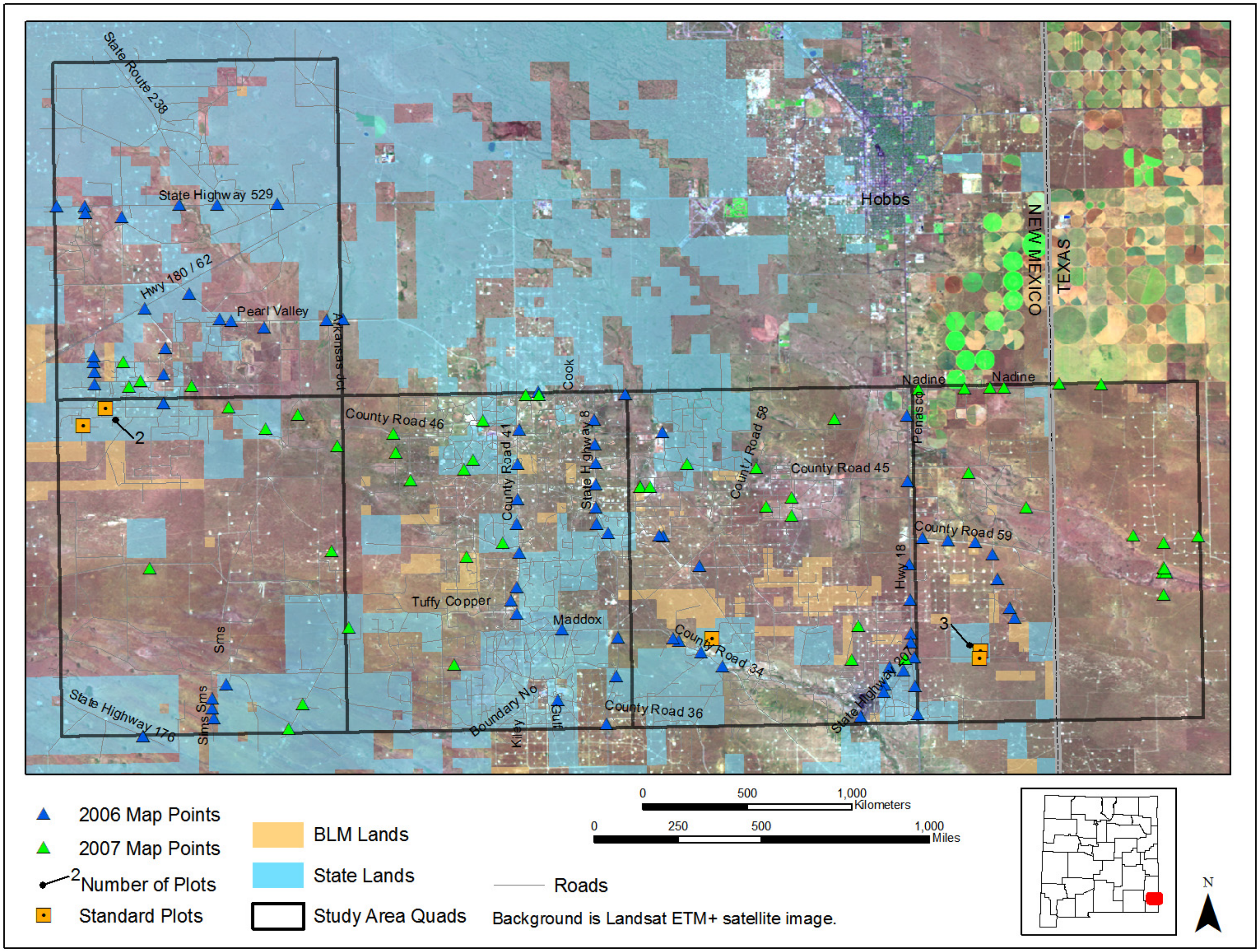


Figure 2. Locations of field surveys conducted in 2006 and 2007.

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, 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 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:

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

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:

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

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 shin-oak duneland community, which can be fairly heterogeneous due to numerous blowouts, as compared to a shin-oak shrubland community, 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 we detected a distribution problem with a seed, we rechecked the seed 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.

Object-oriented Classification

Concurrently, another technique was also applied to the imagery. This technique used an object-oriented method that segments the imagery into objects of similar color, contrast, and shape. The advantage of this approach is that these objects will preserve edge boundaries of detailed surface features such as roads, cliffs, and drainages – features that would be lost or misclassified in a pixel-based classification. These objects can then be classified based on their object-derived statistics or, as in this study, turned into polygons for editing and assigned a class values in a GIS by interpreting photos and referring to the pixel-based classification.

The level of detail is controlled by the scale parameter, an unit-less abstraction that considers each object based on its homogeneity of color and shape, each of which is weighted from 0 to 1. The smaller the scale factor, the more detail is represented and the more the image is segmented into objects, with a scale factor of 1 theoretically representing individual pixels. Depending on how much the shape factor is weighted, the shape's smoothness and compactness are also considered with each of those sub-factors receiving a weighting from 0 to 1. Through an iterative process of adjusting the scale parameter and the other factors, the resulting objects are assessed as to how well they map the features on the ground until a good result is obtained.

In this study, we used just the air photo bands, which had the best original spatial resolution and some spectral depth, in Definiens Imaging (Version 5) software to develop the object-oriented map. The color factor (0.9) was strongly weighted over the shape factor (0.1) and the shape sub-factors of smoothness and compactness were weighted equally (0.5). After experimenting with various scales, we decided that a scale factor of 50 best represented the detail of the features on the ground; this resulted in about 25,000 objects for each 7.5” Quad. These objects were then converted into polygons for use in the GIS.

Map Unit Designation

We grouped the 121 preliminary map classes from the supervised classification into nineteen map units (MUs) to represent groupings of vegetation assemblages and other significant surface features. 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 (Physiognomic 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 names indicate species less consistently found either in all associations of an alliance, or in all occurrences of an association.

The physiognomic class association with each association is determined by the relative percent cover of tree, shrub, dwarf-shrub, herbaceous, and nonvascular strata. The following values for physiognomic class, taken from Grossman *et al.* 1998 (Appendix A, p. 107) are used:

Forest – Trees with their crowns overlapping (generally forming 60-100% cover).

Woodland – Open stands of trees with crowns not usually touching (generally forming 25-60% cover). Canopy tree cover may be less than 25% in cases where it exceeds shrub, dwarf-shrub, herb, and nonvascular cover, respectively.

Shrubland – Shrubs generally greater than 0.5 m tall with individuals or clumps overlapping to not touching (generally forming more than 25% cover, trees generally less than 25% cover). Shrub cover may be less than 25% where it exceeds tree, dwarf-shrub, herb, and nonvascular cover, respectively. Vegetation dominated by woody vines is generally treated in this class.

Dwarf-Shrubland – Low-growing shrubs usually under 0.5 m tall. Individuals or clumps overlapping to not touching (generally forming more than 25% cover; trees and tall shrubs generally less than 25% cover). Dwarf-shrub cover may be less than 25% where it exceeds tree, shrub, herb, and nonvascular cover, respectively.

Herbaceous – Herbs (graminoids, forbs, and ferns) dominant (generally forming at least 25% cover; trees, shrubs, and dwarf-shrubs generally with less than 25% cover). Herb cover may be less than 25% where it exceeds tree, shrub, dwarf-shrub, and nonvascular cover, respectively.

Nonvascular – Nonvascular cover (bryophytes, non-crustose lichens, and algae) dominant (generally forming at least 25% cover). Nonvascular cover may be less than 25% where it exceeds tree, shrub, dwarf-shrub, and herb cover, respectively.

Sparse Vegetation – Abiotic substrate features are dominant. Vegetation is scattered to nearly absent and generally restricted to areas of concentrated resources (total vegetation cover is typically less than 25% and greater than 0%).

In addition to the mapped natural vegetation communities, we mapped planted/cultivated vegetation and modified/managed communities. Planted/cultivated areas are dominated by vegetation that has been planted or tilled, including agricultural areas and planted pastures. The modified/managed communities exist where the species composition and/or the structure of the vegetation has been altered through manmade disturbances, management, or modification of the natural/near natural vegetation. There may be no natural analogue known for these landscapes. To identify these areas, we either observed in the field remnants of the landscape before alteration (Figure 3) or discovered, through manipulation of the digital imagery and photo interpretive techniques, the altered landscapes expressed as abrupt textual changes (Figure 4). These landscapes may be restorable by management, time, or restoration of ecological processes. Examples of these communities within the study are represented as Converted Grassland (Treated Shin-oak) and Converted Shrubland (Treated Shin-oak). The existing, current condition of the managed landscape is represented by the physiognomic class assigned.

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.

Figure 3. Example of an herbicide treatment that left the dunal component relatively intact.

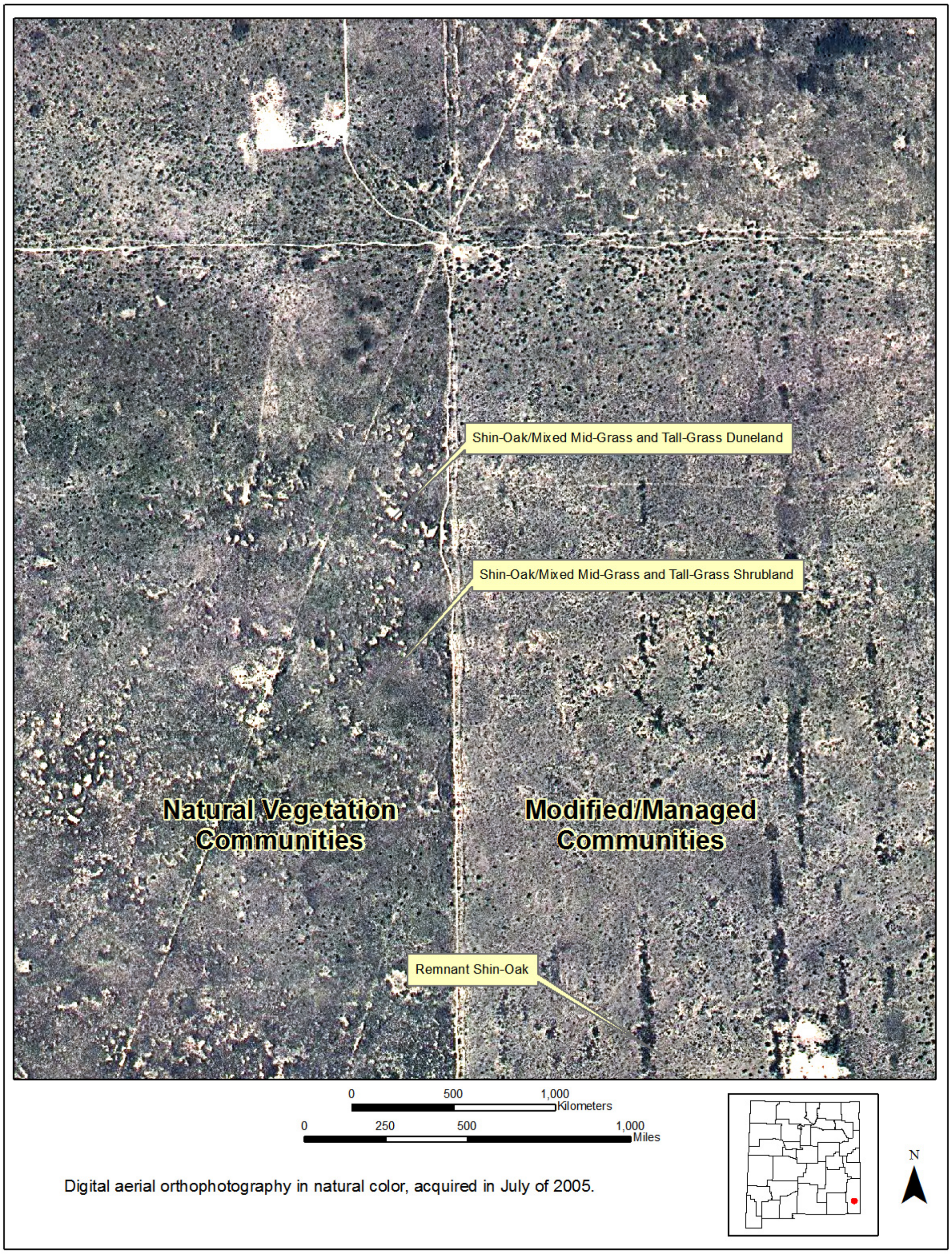


Figure 4. Digital aerial photography reveals abrupt changes to the landscape due to treatment by herbicides.

Final Map Classification and Ancillary layers

We imported the image object maps into a feature dataset polygon layer in ESRI ArcGIS (v. 9.2). After being cleaned for topological errors, they were overlain on to the supervised classified image, and the majority MU in each polygon was assigned to that polygon. The final layer was created by merging together the individual quads.

Based on the final field trip, we made changes to the map unit descriptions, the final designations of their aggregate community types, and their spatial distributions. We performed on-screen digitizing to modify map units based on field notes. It was challenging to distinguish in the field natural landscapes versus modified/managed landscapes, which can contain varying densities of native grasses, shin-oak, and in many cases honey mesquite.

Beyond the relatively long-term changes induced by grazing that we have designated "natural, transitional", other anthropogenic manipulations of the natural environment include "treatments" to eliminate or reduce shrub cover such as shin-oak and honey mesquite. In some cases these treatments are followed with successive modifications or a combination of manipulations such as further treatment using herbicides, and/or seeding with native or non-native grasses, and/or grazing. The study area is largely private or managed by the New Mexico State Land Office or Bureau of Land Management and therefore there are no additional data to corroborate these treated areas. Delineations of this map unit are based on field notes and distinctive, non-natural landscape changes identifiable using remote sensing classification methods and photo-interpretive techniques. Due to the variable nature of these converted landscapes in which the original community could be left relatively intact, they were only added to the classification where they were obvious. Otherwise, the original map unit class was left as it was; therefore, the resulting mapped area of treated lands is considered an underestimate.

We downloaded the Lea County soil (Soil Survey Staff, SSURGO 2007) spatial and tabular data from the NRCS website and used them in a GIS to identify the major soil map units that underlie areas dominated by shin-oak, as well as those areas occupied by the co-dominants mesquite and shin-oak. We aggregated soil map units based on the GIS analysis in combination with physical soil properties such as depth to petrocalcic horizon and ecological site designations. We used the results to interactively assist in determining vegetation map unit designations for individual polygons.

Map Accuracy Assessment

Due to time and monetary constraints, our assessment needed to be accomplished in four days. We assumed we could visit ten sites a day, giving us a maximum of 40 validation sites using a stratified random sampling method. To maximize the accuracy assessment of the map, stratification was based on a subset of the map units.

Following final changes to the map, a dissolve was run in ArcGIS to group all polygons of the same map unit together. Statistics were generated on the polygons to determine the percent of the study area covered by each map unit. Three of the map units to sample were too small to be given at least one sample plot. We therefore assigned a minimum of 3 sample plots per map unit for these MUs. The remaining map units were assigned samples proportional to their sum total area. Jurisidiction for 39% of the study area (within New Mexico) falls within federal and state lands, while the remaining 61% is under private ownership. Because we did not have access to polygons within private lands, we limited the validation sites to federal and state lands. After eliminating private lands from the selection, and polygons further than 30 meters from roads, a total of 1,210 polygons were then available to the random sampling generation software (Hawth's Tools 2007). To avoid revisiting sites used to develop the map, we eliminated polygons within 100 meters of our plots and map points. Our final stratification process selected polygons within 30 meters of roads to help ensure access to these sites. We used the U.S. Census Bureau TIGER Line roads (2000).

Maps were generated for the field validation showing all 40 polygons to be sampled as well as points within the polygon generated by the random sampling software. A list of the sample point coordinates were generated so that we could either orienteer to the particular site or choose a site within the polygon that appeared to be representative of the polygon.

We recorded standard field data within 20 x 20 m plots within the validation polygon geographically represented on the field maps. The on-ground appearance had to be representative of the entire validation polygon. We conducted reconnaissance initially from the road and observed those portions of the polygon that were contiguous to the road to get an overall, general idea of the floristics, physiognomy, and landform. In many cases, where the software generated point did not occur within disturbed sites, or were reasonably accessible, we orienteered to the point. Plot data included the major vegetation plant associations, percent cover of dominant plants, bare ground, litter, basal cover, and canopy cover. General comments included landform characterization and potential habitat use by the SCAR. We also made an initial assignment to map unit.

Habitat Type Analysis

We performed a GIS analysis to delineate occupied, potential, and marginal habitat types for the SCAR. The known point locations where SCAR have either been observed or collected (New Mexico Department of Game and Fish data) were placed on the map and analyzed. Occupied Habitat was assigned to the individual polygons that overlaid these sites. All other habitat types were created by aggregating the polygons according to map units based on these results and the literature review of SCAR habitat requirements.

Results and Discussion

Map Units

The final map has nineteen MUs (Figure 5, Table 3). We defined MUs based on vegetation assemblages, as in a typical vegetation mapping process, and landscape features characteristic of habitat types utilized by the SCAR. Detailed descriptions and a list of the dominant plant associations for selected map units are provided in Appendix A.

Because of the focus on SCAR habitat, some MUs appear "lumped" and others "split," relative to more standard vegetation classification systems. For example, **Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland** and **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 the following reasons. Sand dune lizards occur in dunes (Degenhardt *et al.* 1996); thus, differentiation of dune areas is potentially useful for SCAR management. In addition, several previous vegetation classifications of sand shinnery have differentiated dunes from areas lacking dunes (*see* references in Peterson and Boyd 1998, pp. 3-4). Shrublands within the study area often occur on undulating sand sheets with small blowouts scattered throughout. Later we discuss the underlying substrate that may be useful in distinguishing suitable and potential SCAR habitat (*see* Soils).

We have also delineated **Active Duneland** and **Duneland Blowout** (wind-formed hollows). These types are mentioned repeatedly in the literature as important habitats, and when surrounded by shin-oak they are thought to be the central focus of SCAR habitat. We have not captured each individual blowout that occurs within both the duneland and shrubland shin-oak dominated map units, nor have we mapped all active dunes. However, many of the larger blowouts and active dunes have been captured in the Active Duneland and Duneland Blowout MUs. We consider the following four map units to be potential SCAR habitat: Active Duneland; Duneland Blowout; Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland; and Shin-Oak/Mixed Mid-Grass and Tall-Grass Shrubland.

Due to natural transitions along an environmental gradient, varying species composition and structure are expected within what we consider to be a natural plant community. For example, shin-oak dominated communities are typically associated with loose sands found within parabolic dunelands and on relatively deep sandsheets. At the margins of these deep sands, we find natural transitions determined by lower cover values of shin-oak and higher grass cover values or an increase of honey mesquite and short grasses. Neville *et al.* (2005, p. 61) designated a map unit (Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland) comprised of several plant associations characteristic of transitional grasslands found on flat to rolling eolian plains within this region.

Other examples of natural, transitional communities found within the study area are shrublands dominated by honey mesquite with shin-oak or co-dominate with shin-oak and having an understory herbaceous cover of native grasses. In the past 100 years, deflation of the sand sheets and expansion of honey mesquite from historical habitats of playas and arroyos (Virginia *et al.* 1992, Gadzia and Ludwig 1983) into desert grasslands and shrublands, likely due to localized land-use changes such as grazing, have occurred throughout the region (Hall 2002). Establishment of honey mesquite within these sand sheets has resulted in the formation of coppice dunes in which mesquite forms the nucleus. Gadzia and Ludwig (1983) determined that 62% of the mesquite in coppice dunes germinated in the period ca. 1931 to 1941. Coppice dunes are circular mounds of sand formed at the base of shrubs such as honey mesquite where reduced winds deposit sand grains. This landform is more likely to develop at the margins of the shin-oak dominated parabolic dunes and sandsheets where the indurated calcic soil layer can be less than one meter below the surface (Hall 2002). These shrublands were found repeatedly within the study area, previously identified in the contiguous study area by Neville *et al.* (2005) and designated a map unit (Honey Mesquite-Shin-Oak/Short-Grass Shrubland).

In contrast, map units such as Short-Grass Grassland and Seasonally Flooded Mixed Grassland 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), 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 these map units constitutes preferred habitat for SCAR, our map combines structurally similar but compositionally different grassland associations. As a result, this SCAR potential habitat map is different from other vegetation maps, but it is potentially more useful for addressing wildlife management and conservation concerns for the lizard.

Most of the landscapes converted by herbicidal or mechanical treatment to reduce or eliminate shin-oak within the study area have natural analogues. However, we aggregated all classes that fell in these modified/managed landscapes into two MUs based on their dominant physiognomic class: Converted Mixed Grassland (Treated Shin-oak) and Converted Mixed Shrubland (Treated Shin-oak). We have been conservative in our estimate of treated landscapes, designating only those landscapes where we found evidence in the field of manipulation. If we determined an area was treated and is currently under cultivation, we classified it as Agricultural Fields. Signs of manipulation include any of the following or combinations thereof:

- shin-oak found along the fencerow of a field and not found within the field
- shin-oak found along the fencerow of a field and remnant patches covering dunes within the field (Figure 6)
- extensive shin-oak cover stopping at a field boundary and no evidence of shin-oak within the adjacent field
- extensive shin-oak cover stopping at a field boundary and found within the field in irregular, very minor patches
- introduced grasses within undulating sand sheets (Figure 7)
- remnant shin-oak patches within developing honey mesquite coppicing dunes (Figure 8).

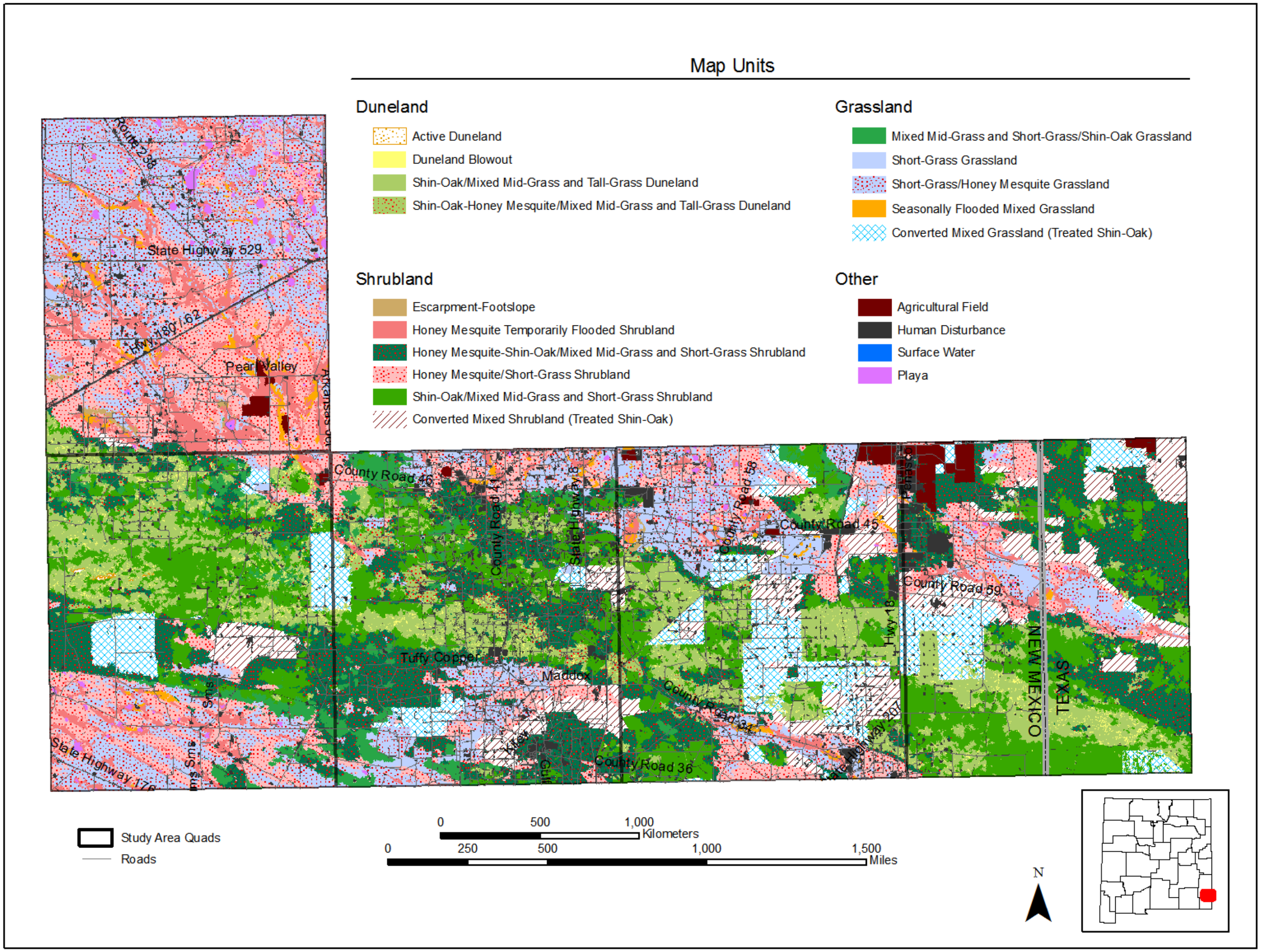


Figure 5. Vegetation and potential habitat map for the sand dune lizard.

Table 3. Map units for the study area.

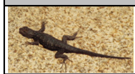
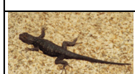
Suitable	Map Unit Description	Ha	Ac
	Duneland Map Units		
	Active Duneland	24	59
	Duneland Blowout	604	1492
	Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland	8526	21068
	Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland	962	2377
	Shrubland Map Units		
	Converted Mixed Shrubland (Treated Shin-Oak)	4474	11055
	Escarpment-Footslope	112	277
	Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland	13166	32533
	Honey Mesquite/Short-Grass Shrubland	12563	31043
	Honey Mesquite Temporarily Flooded Shrubland	4468	11040
	Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland	11586	28629
	Grassland Map Units		
	Converted Mixed Grassland (Treated Shin-Oak)	4699	11611
	Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland	2313	5715
	Seasonally Flooded Mixed Grassland	596	1473
	Short-Grass Grassland	2082	5145
	Short-Grass/Honey Mesquite Grassland	13092	32350
	Other Map Units		
	Agricultural Fields	1107	2735
	Human Disturbance	5821	14384
	Playa	543	1342
	Surface Water	2	5
	Total Area	86740	214333

Figure 6. Herbicide treatment on left-side of fenceline with relatively intact shin-oak shrubland on right.

Figure 7. Herbicide treatment within a shin-oak duneland. Honey mesquite coppicing is evident.

Figure 8. Non- native grasses dominate the understory of scattered shin-oak and mesquite.

Map Accuracy Assessment

Forty validation sites were used in a stratified random sampling method (Figure 9). The subset of the map units chosen for validation were based on their greatest potential to be suitable habitat for the lizard or marginal units that had a significant, natural shin-oak component (Duneland Blowout, Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland, Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland, and Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland).

In addition to these map units, we added a potentially marginal type (Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland) and another transitional type generally found at the margins of the shin-oak dominated systems (Honey Mesquite-ShinOak/Mixed Mid-Grass and Short-Grass Shrubland). These were added to provide an assessment of map-to-ground validation and as a means to collect additional information on cover values and plant associations found within these map units. SCAR has been found within shin-oak dunelands that contain honey mesquite at low densities (C.W. Painter personal communication); however, it is unclear at what point encroachment of honey mesquite becomes a limiting factor for SCAR use. The extensive invasion of honey mesquite into shin-oak dominated dunelands and shrublands within the study area is greater than we have observed in the rest of the lizard's range.

The proportion of samples per map unit was generated using the total study area totals for each map unit sampled (Table 4). The three map units with total areas to small to be given at least one sample plot were assigned 3 sample plots per map unit. The remaining map units () were assigned samples proportional to their sum total area (Table 4, Total of Large Sample Areas). The MUs Honey Mesquite-Shin-Oak Shrubland and Shin-Oak/Mixed Mid-Grass & Tall-Grass Shrubland had the greatest number of samples, 12 and 11, respectively.

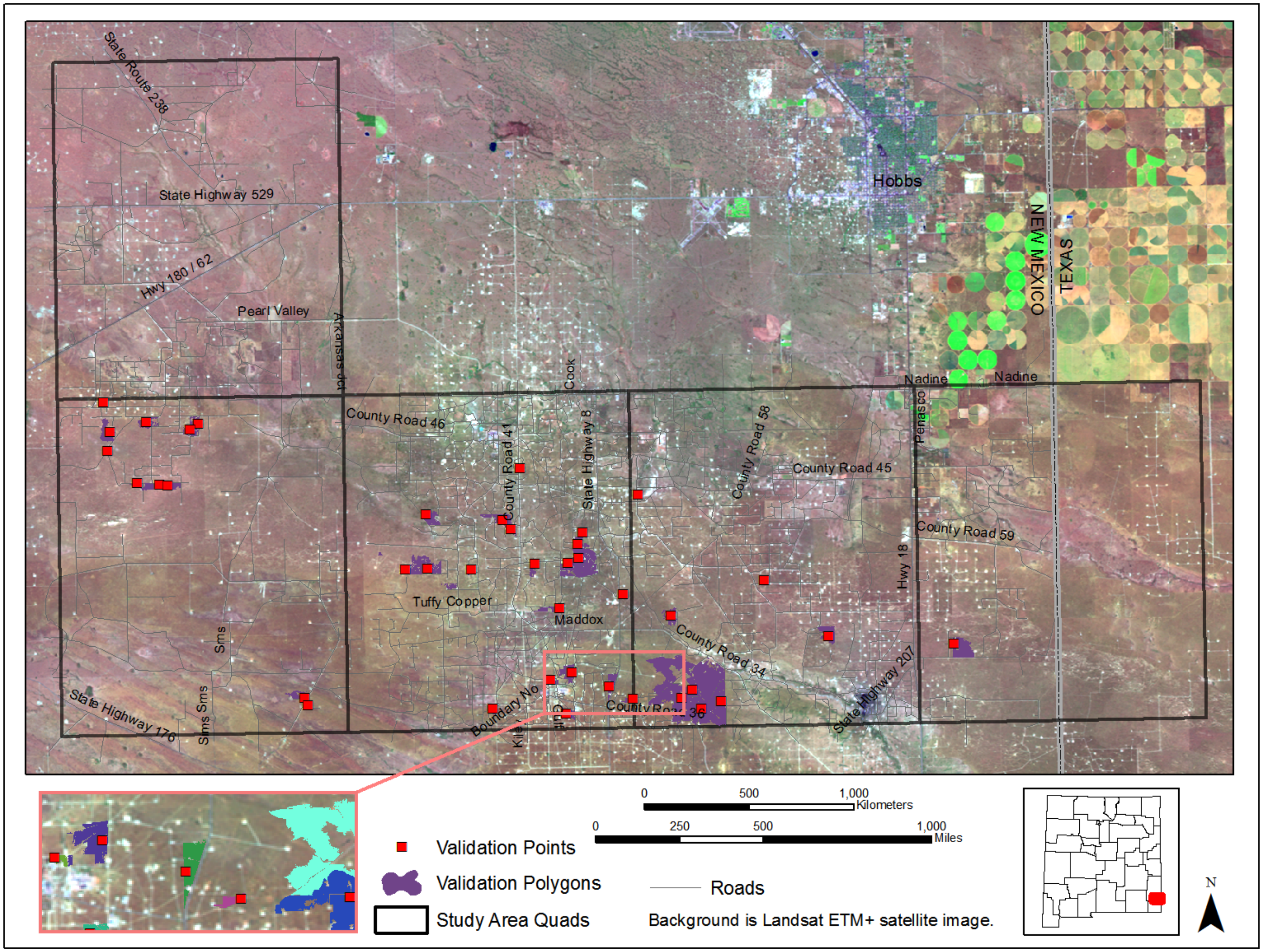


Figure 9. Accuracy assessment validation polygons.

Table 4. Sample map units and their proportionate sample area.

Sample Map Units	Hectares Study Area	% Area	Number Sample Plots
Duneland Blowout	604.4	1.6	3
Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland	961.7	2.5	3
Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland	13166.1	35.4	12
Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland	2312.6	6.2	3
Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland	8525.9	22.9	8
Shin-Oak/Mixed Mid-Grass and Tall-Grass Shrubland	11586.2	31.1	11
Total Sample Area	37157.2		
Total of Large Sample Areas	33278.3		

In the end, we could not make it to two inaccessible validation polygons (a Duneland Blowout polygon and a Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland polygon). Therefore, of the thirty-eight remaining validation polygons, thirty-three matched their designation as on the map, for an overall accuracy of 86.8% (Table 5). On an individual basis, most of the classes validated at a 100% producer's accuracy (the probability that the class on the map is correctly classified). The two exceptions were a 33% omission error (the probability that the class is omitted on the map) for Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland (a Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland polygon was mapped as a Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland) and an 11% omission error for Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland (a Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland polygon was mapped as a Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland).

Likewise most of the classes validated with a 100% user's accuracy (the probability that the class on the ground matches the mapped class). The two exceptions were a 33% commission error (the probability that the class on the map will be different that the one on the ground) for Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland (a Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland was classified as a Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland) and a 36% commission error for Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland (three Converted Mixed Shrubland polygons were classified as Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland). In the latter case, each of the validation polygons was Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland prior to being treated.

Because of our conservative assignment to the treated classes, the error is not unexpected. The pre-treatment class was correctly identified in all cases (Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland). This is a marginal class at best for the SCAR and minimizes the effect of this error for identifying potential habitat. This does show that in these units, especially south of the main dune field where all of these errors occurred, more converted landscapes exist than shown on the map.

Table 5. Error matrix for the accuracy assessment.

		Field									
Map		2	3	4	6	9*	10	11	Row Totals	Users Accuracy %	Error of Comission %
	2	2	0	0	0	0	0	0	2	100.0	0
	3	0	8	0	0	0	0	0	8	100.0	0
	4	0	1	2	0	0	0	0	3	66.7	33.3
	6	0	0	1	7	3	0	0	11	63.6	36.4
	9*	0	0	0	0	0	0	0	0	NA	NA
	10	0	0	0	0	0	11	0	11	100.0	0
	11	0	0	0	0	0	0	3	3	100.0	0
Column Totals		2	9	3	7	3	11	3	33		
Producers Accuracy %		100.0	88.9	66.7	100.0	NA	100.0	100.0	Overall Accuracy %	86.8	
Error of Omission %		0	11.1	33.3	0	NA	0	0			

*The Converted Mixed Shrublands MU was not validated; however, some of the field plots classified as this MU.

2 Duneland Blowout
3 Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland
4 Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland
6 Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland
9 Converted Mixed Shrubland (Treated Shin-Oak)
10 Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland
11 Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland

Habitat Types for the Sand Dune Lizard

For the GIS analysis, we made the following habitat designations for each of the map units (Figure 10:

- **Occupied Habitat** (based only on occurrence records, a subset of the following map units):
  - Blowouts
  - Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland
  - Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland
- **Potential Habitat** (based on occurrence records, literature review, and personal communication with Lee Fitzgerald. L. Fitzgerald states SCAR can be found within 5 km of its known range [Figure 1]). This was divided into two sub-categories:
  - **Duneland**
    - Active Duneland
    - Duneland Blowout
    - Shin-oak/Mixed Mid-Grass and Tall-Grass Duneland
  - **Shrubland**
    - Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland
- **Marginal/Unknown Habitat** (SCAR's use of these MUs is not well-defined and are included as they contain shin-oak. Marginal habitat may include the duneland map unit listed; no information is known on the remaining two map units):
  - Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland
  - Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland
  - Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland

Approximately 3% of the study area is Occupied Habitat under these strict conditions. Known occupied habitat may be larger for a specific area, but we only had a single point location to use and we selected the mapped polygon that it overlaid. The actual extent of occupied habitat may be larger for any of these areas, but they are likely separated by roads from other suitable, potentially occupied habitat and therefore not included. Occupied Habitat covers 2,931 ha (7,242 ac). Nine hectares (22 ac, 0.32%) are mapped within blowouts, 442 ha (1,092 ac, 15%) are within shin-oak dominated shrublands, and 2,479 ha (6,126 ac) are in shin-oak dominated dunelands, which account for 84% of the occupied sites.

Combining both occupied and potential habitat, approximately 24% of the study area is suitable habitat for the SCAR (Table 6). Potential Habitat was divided into Duneland and Shrubland sub-categories. Although both are considered good SCAR habitat, the majority of known SCAR occurrences fall within duneland areas. Therefore, SCAR may be more abundant in Potential Habitat – Duneland than Potential Habitat - Shrubland. Excluding habitat that is unsuitable, Occupied Habitat covers 6% and potentially suitable habitat covers 38%. The habitat that has been converted covers about a fifth of this total area. This is an undercount of the actual area that has been treated. However, most, if not all, of the unmapped treated areas are expected to occur in the Marginal/Unknown Habitat (*see discussion in* Map Accuracy Assessment).

Table 6. Sand dune lizard habitat types within the study area.

Habitat Type	Area (ha)	Area (%)	% Habitat of Total Habitat
Converted	9,173	10.58	19.79
Marginal/Unknown Habitat	16,441	18.95	35.47
Not Suitable Habitat	40,386	46.56	NA
Occupied Habitat	2,931	3.38	6.32
Potential Habitat - Duneland	6,666	7.68	14.38
Potential Habitat - Shrubland	11,144	12.85	24.04
Total Study Area	86,741		

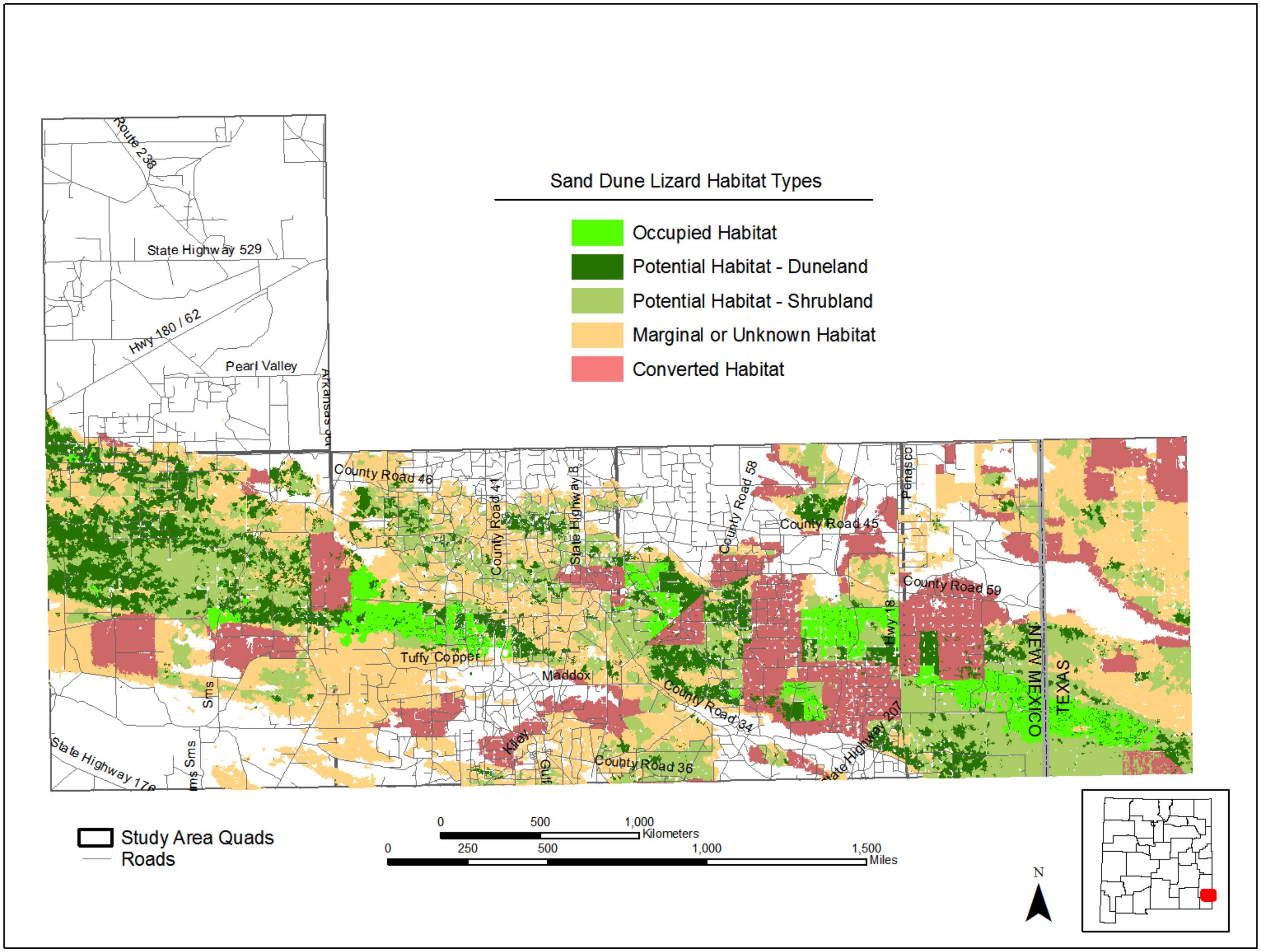


Figure 10. Sand dune lizard habitat types.

The Role of Soil in the Habitat

Although the relationship between the SCAR and soil texture has already been established (Sena 1984), it can be difficult to use existing soil maps to identify SCAR habitat because these map units typically represent complexes of soil groups. One component series of a soil map unit may have characteristics more suitable to SCAR habitat requirements than other components. When these data are used in conjunction with our classification, certain patterns emerge. We used the shin-oak related units from the Soil Survey (SSURGO) Geographic database, a digital map based on the soil survey of Lea County (Turner *et al.* 1974) and the Official Soil Series Descriptions (Soil Survey Staff OSD 2005) database, to aggregate soil map units with SCAR requirements in mind (Figure 11, Appendix B). Some of the notable items of interest from this analysis are:

- Approximately 48% of the study area is dominated by sandy soils where shin-oak occurs.
- Four units cover 97% of the occupied habitat: Kermit soils and dune land (KM, 71%), Pyote and Maljamar fine sands (PU, 19%), Kermit-Palomas fine sands (KD, 4%), and Tivoli-Brownfield fine sands (TB, 3%).
- Three of the soil map units listed above also occur in potential habitat (KM-14%, PU-8%, and TB-<1%), along with three others: Pyote soils and dune land (PY, 5%), Wink fine sand (WF, 2%), Brownfield-Springer association (BO, 2%). In addition, Active dune land (Aa) comprises less than 1%, but the entire Aa unit is found in potential habitat.
- The problem with using the soil units to identify the deep sands preferred by the SCAR, is illustrated by the dominant soil types found in the marginal/unknown habitat type. This is the habitat that includes (1) honey mesquite as a co-dominant in the shrublands and dunelands and (2) the shinnery grasslands. Some of the same types found in potential habitat types are also found within the marginal types: PU (32%), PY (13%), and WF (11%). Also, Berino-Cacique loamy fine sands association (BE) accounts for 20% of the area, but the unit itself seems to define the mesquite-shin-oak units south of the main dune field.
- The PU and PY soils units' strong membership in both the occupied/potential habitat and the marginal/unknown habitat suggests that two different soil types have been mapped together in these units. We assume the indurated layers characteristic of PU may be expressed in higher mesquite cover.
- Also, the WF unit is strongly associated with the shin-oak-honey mesquite/mixed mid-grass and tall-grass duneland class.

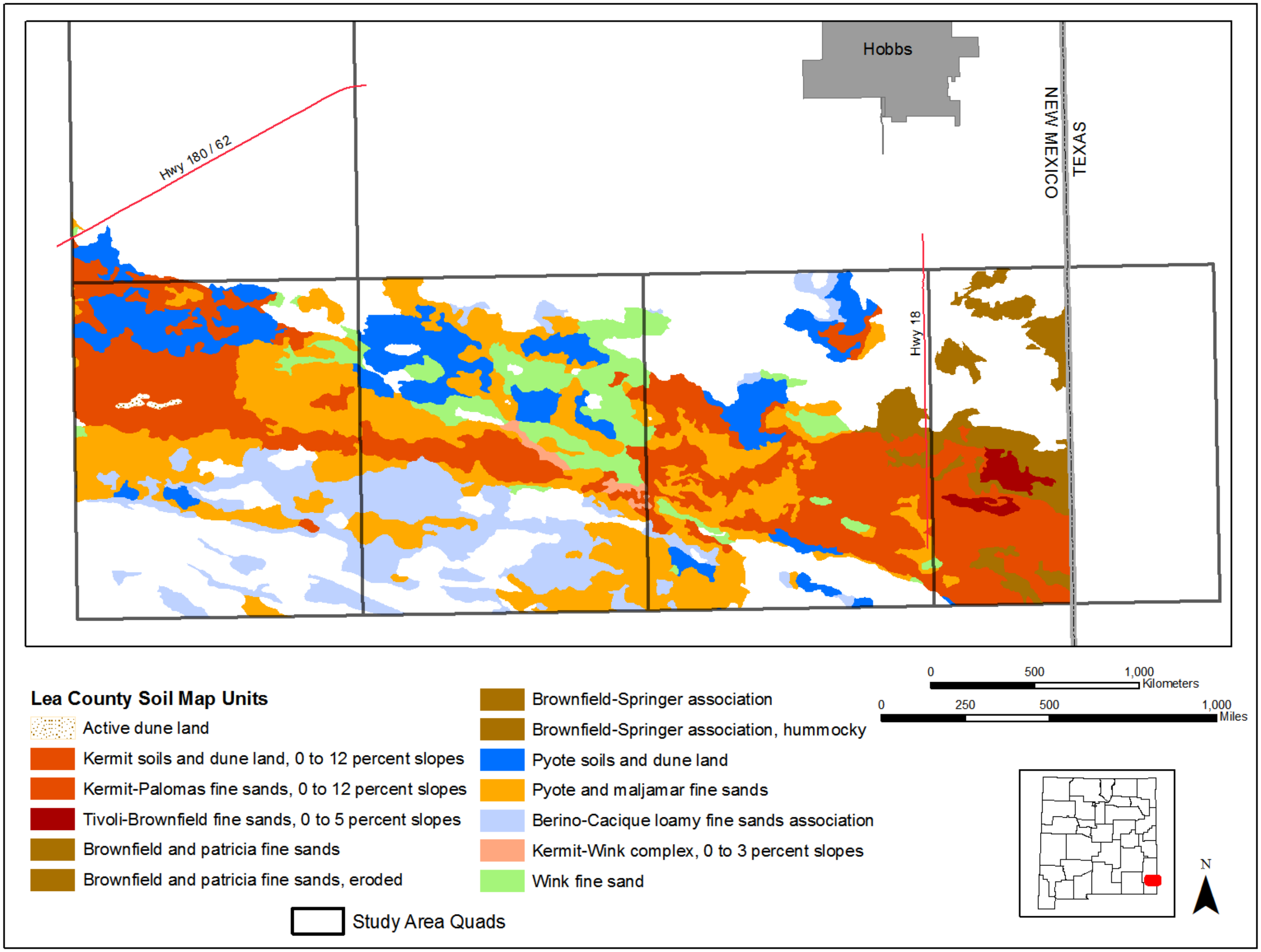


Figure 11. Soil map units that underlie shin-oak communities.

The Role of Honey Mesquite in the Habitat

That playas and drainages provide avenues for invasion of honey mesquite into grasslands and shrublands is well documented in various studies within the Chihuahuan Desert (Virginia *et al.* 1992, Gadzia and Ludwig 1983) but less so within the Pecos Valley. In his studies of the Mescalero Dunes, Hall (2002) suggests that the expansion of honey mesquite is largely due to overgrazing. Another potential corridor for encroachment within the study area occurs where the drainages cross and are superimposed by the sands. It is notable that the map unit Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland is primarily found where Ironhouse Draw (Monument Draw on some maps) crosses the dunes. This suggests that if honey mesquite was in these drainages originally, it may have moved into the shallow sands surrounding the shinnery dunelands in the course of natural propagation, as opposed to being spread through grazing.

We do not know whether honey mesquite is an aggressive encroachment problem or part of a relatively stable ecological dynamic. Our field observations within the shin-oak dunelands suggest that mesquite first establishes itself within the blowouts (Figure 12). The invasion of mesquite into the blowouts is plausible since these areas are lower than the surrounding dunes and therefore closer to indurated substrates.

In the absence of shin-oak, it is possible honey mesquite would aid in stabilizing the dunes, indicating a different succession for stabilization within the dunes. Campbell (1929) suggests that interspaces between mesquite that are bare, due typically to grazing pressures, will follow a succession from various annual and perennial forbs, to snakeweed, to *Sporobolus* spp., and then finally to reestablishment of short grasses. His observations were within the Jornada to the west, but we may be seeing evidence of this progression in the Shin-Oak-Honey Mesquite Mixed Mid-Grass and Tall-Grass Dunelands. The filling of blowouts is largely by short-grasses and mesquite, with few of the mid- and tall-grasses remaining on the tops and shoulders of the dunes (Figure 13).

The effects of different densities of honey mesquite on the SCAR's habitat suitability are unknown. Dense honey mesquite is considered detrimental for the sympatric lesser prairie-chicken because it provides raptor roosts. The repercussions of high mesquite cover may be likewise detrimental to the SCAR, due to their requirements for sparsely vegetated blowouts (C.W. Painter personal communication). Blowouts with a high vegetative cover including grasses and honey mesquite are not suitable SCAR habitat (Figure13). Grass and mesquite invasion is a threat that has not been mentioned in previous literature and may be impacting the decline of the SCAR and contributing to the further isolation of individuals.

Figure 12. Large blowout duneland occupied by sand dune lizards. Honey mesquite has invaded the low deflation area.

Figure 13. Blowout with high grass cover in a shin-oak-mesquite duneland. This is probably not suitable sand dune lizard habitat.

CONCLUSIONS

Prior to this mapping effort, we created a similar map covering the sand shinnery communites to the north and west for habitat mapping for the lesser prairie chicken (Neville *et al.* 2005). This study was to build on those efforts. Due to improvements in spatial technology and data sets, the mapping in this project was done at a far greater level of detail. We extended much of the classification scheme to this contiguous area and were able to refine some of the map units. For example, this map better isolates dunes and dunal complexes. In addition, we added a new class for blowouts.

Of the nineteen MUs, we consider four to be SCAR habitat (Active Duneland, Duneland Blowout, Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland, and Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland), based on the literature and known SCAR occurrences. Three other MUs represent shinnery communites (Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland, Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland, and Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland), but their role as suitable SCAR habitat is not known. The mapped classes were found to have an overall accuracy of 86.8%.

An appropriate scale at which to view the map is 1:12,000. 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. While we expect the map to be useful for managing wildlife species other than SCAR, the MUs were designed to identify potential habitat for SCAR.

Our examination of the relationship between soil types, SCAR occurrences, and suitable habitat confirms the suggestion of other authors that SCAR rely on sandy soils. However, the scale of available soil maps is more general than the scale of our vegetation-based classification. Thus, we cannot conclusively tie specific soil types to all of the specific MUs used by the SCAR.

Within the Shin-Oak-Honey Mesquite Mixed Mid-Grass and Tall-Grass Dunelands MU, blowouts were very grassy. Grassy blowouts are not used by SCAR. The Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland MU appears indicative of the thinning out of sands with an indurated substrate close to the surface. In the field we observed silty soil textures for this map unit and the Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland MU, indicating grain sizes smaller than in the dunes. This may have negative implications for the SCAR. Nonetheless, all these units could potentially provide SCAR corridors to quality habitat, especially the Honey Mesquite Mixed Mid-Grass and Tall-Grass Dunelands MU.

The impact of honey mesquite on SCAR is not well understood. Mesquite is ubiquitous throughout the shinnery community, so SCAR apparently can co-exist with a certain density of mesquite. Large mesquite thickets occur near known SCAR occurrences, but whether or not these are avoided is unknown. Honey mesquite may provide an advantage for SCAR predators, such as the loggerhead shrike (*Lanius ludovicianus*), which has been observed to impale lizards on its thorns (C.W. Painter personal communication).

Previous studies have found that oil and gas development has a negative impact on SCAR, particularly when disturbances impact dunes (Sias and Snell 1998). Within the study area, oil and gas disturbance fragments suitable habitat, but some of the highest density of oil and gas development occurs within Occupied Habitat. The long-term persistence of SCAR in these heavily impacted areas is uncertain. Further GIS analysis coupled with lizard monitoring studies might shed light on these questions.

Conversely, large areas of habitat we classified as potential habitat in the western part of the mapped area are apparently not occupied. These areas appear to include dunes and shinnery habitats with limited oil and gas activity (Figure 10). It is puzzling that these apparently suitable habitats are not occupied. Although data suggest sand grain size may be a limiting factor in these areas. Some of these areas may be occupied but un-surveyed. All potential habitat areas have not been thoroughly surveyed (Charlie Painter personal communication). A comprehensive management program for this species would include thorough surveys and monitoring in the potential habitats we have identified.

Converted landscapes appear to have an obvious negative impact on SCAR within the study area. Typically the landscapes are altered to increase grass for grazing. We observed either an increase in herbaceous cover throughout or the opposite, barren, sparsely vegetated lands. Shin-oak was either dramatically reduced or eliminated in all cases. Dunal features were often eroded due to lack of vegetative cover and grazing impacts. Some converted landscapes with relict shinnery communities have restoration potential, and these areas should not be written off.

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Shin-Oak Mott

APPENDIX A – MAP UNIT DESCRIPTIONS

The nineteen map units are grouped by physiognomic group: Duneland, Shrubland, Grassland, and Other. Within the groupings the map units are found in alphabetical order. Links to the descriptions are provided. Map unit descriptions include:

1. A descriptive name for the map unit, e.g. Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland
2. Representative photo taken within the study area.
3. Short description of the map unit. In some cases the plant associations that comprise the unit are given.

Duneland Map Units

Shrubland Map Units

Grassland Map Units

Other Map Units

Active Duneland

Active sand dunes within the study area range in size from 0.5 ha to 13.5 ha (1.3 ac to 34.3 ac) and have little or no vegetation. They occur within the dunelands at the western edge of the study area. Shin-oak dominated dunelands typically surround the active dune fields. This map unit provides essential habitat for the sand dune lizard. Areas within the active duneland most likely utilized by the lizard are generally within 1.2 to 1.8 m (4 - 6 ft) from the nearest shin-oak (Peterson and Boyd 1998). These dunes are composed of white sands.

Duneland Blowout

This unit represents some of the larger, sparsely vegetated blowout (wind-formed hollows) patches principally found within the Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland and Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland. These deflation areas accumulated episodically in the late Pleistocene and Holocene; however, some have developed due to human disturbance such as pipelines, roads, and oil development activity. Due to active deflation, very little on-ground litter remains. Grass and forbs are dominant rather than shrubs of the contiguous dunes. Grasses tend to clump at the base and margins of the blowouts and can either be dominated by tall grasses such as giant sacaton and sand bluestem or mid-grasses such as little bluestem and sand dropseed. If the surrounding dunelands are dominated by short grasses such as three-awn, the blowouts will contain these short grasses. Forbs tend to vary considerably and range in cover from 1% to 16% while grasses average 10% and shrubs 2%. Total cover averaged less than 20%; however, notable exceptions occurred. The mapped patches range in size from a few square meters to 3.0 ha (7.6 ac). It is composed of white to tan sandy soils. This map unit, surrounded by shin-oak duneland or shrubland is essential habitat for the sand dune lizard.

Plant Associations:

Sand Bluestem-Giant Sacaton/Sparse	*Andropogon hallii-Sporobolus giganteus/Sparse*
Little Bluestem-Thin Paspalum/Sparse	*Schizachyrium scoparium-Paspalum setaceum/ Sparse*
Purple Threeawn/Sparse	*Aristida purpurea/Sparse*
Honey Mesquite/Sparse	*Prosopis glandulosa/Sparse*

Shin-Oak/Mixed Mid-Grass and Tall-Grass Duneland

This map unit contains semi-stabilized, 2-10 m- (6-32 ft) tall dunes dominated by shin-oak, a low-growing shrub (<1 m). These eolian soils are excessively well-drained, fine sands. Total vegetative, litter, and soil cover varies greatly due principally to land management practices. Total shin-oak cover ranges from 30% to 45% and grasses cover between 3% and 10%. Mean total cover for shin-oak and grass is 36% and 7%, respectively, or a relative shin-oak to grass cover of 83% shrubs to 16% grass. Giant sacaton was found throughout this unit with other grasses such as sand bluestem, little bluestem, sand dropseed, and purple threeawn. Soapweed yucca (*Yucca glauca*) and sand sagebrush (*Artemesia filifolia*), making up less than 5% of total cover, are also found consistently within this map unit. The dunelands trend from the southeast to the northwest corner of the study area and are bound on either side by honey mesquite dominated landscapes. The soils range from white sands in the northern dunes to tan sands along the southern dunes. This map unit, in close proximity to wind-created blowouts, provides essential habitat for the sand dune lizard.

Plant Associations:

Shin-Oak/Giant Sacaton Duneland	*Quercus havardii/Sporobolus giganteus*
Shin-Oak/Sand Bluestem Duneland	*Quercus havardii/Andropogon hallii*
Shin-Oak/Sparse Duneland	*Quercus havardii/Sparse*

Shin-Oak-Honey Mesquite/Mixed Mid-Grass and Tall-Grass Duneland

This duneland is a transitional landscape and indicative of either nearby disturbances or close proximity to seasonally flooded drainages such as Ironhouse Draw, Monument Draw, and their tributaries. The shallow drainages act as a dispersal corridor for honey mesquite into the nearby parabolic dunelands. Coppicing dunes dominated by honey mesquite occur along the margins of the main dunelands and can be indicative of heavy grazing or other large-scale disturbances. The shin-oak-mesquite habitat is particularly suitable for both the side-blotched and western whiptail lizards (Wolfe 1978 in Peterson and Boyd 1998). Sand dune lizards have been found within shin-oak-dominated dunelands with honey mesquite (Charlie Painter personal communication); however, it is unclear at which point encroachment of honey mesquite becomes a factor limiting sand dune lizard use of the landscape. We found the majority of blowouts within this unit to have a high cover of grasses (see additional photo). This unit is dominated by white sandy soils.

Plant Associations :

Shin-Oak-Honey Mesquite/Giant Sacaton Duneland	*Quercus havardii-Prosopis glandulosa/ Sporobolus giganteus*
Shin-Oak-Honey Mesquite/Sparse Duneland	*Quercus havardii-Prosopis glandulosa/Sparse*
Honey Mesquite/Sparse Duneland	*Prosopis glandulosa/Sparse*

Escarpment-Footslope

These are diverse, sparsely vegetated xeric grasslands, dwarf-shrublands, and shrublands found on the outcrops of cemented or indurated caliche generally found at the edges of the Caprock escarpment. This map unit is relatively narrow within the study area, compared to its overall size. This portion of the Caprock is at its most southern end and plunges beneath the sands thereby providing little relief displacement along its edges. The escarpment boundary can be masked by migrating sands overlaying the caliche.

Plant Associations :

Sideoats Grama/Javelina Bush Grassland	*Bouteloua curtipendula/Condalia ericoides*
Sideoats Grama/Four-wing Saltbush Grassland	*Bouteloua curtipendula/Atriplex canescens*
Sideoats Grama/Featherplume Grassland	*Bouteloua curtipendula/Dalea formosa*
Creosotebush/Sparse Shrubland	*Larrea tridentata/Sparse*

Honey Mesquite-Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland

This shrubland contains co-dominant honey mesquite and shin-oak on nearly flat to undulating or coppicing eolian plains at the margins of the dunelands. Honey mesquite ranges in cover values from 3% to 26% and averages 10% cover for the map unit. Shin-oak ranges from 22% to 50% cover and averages 32% overall. Grasses average 17% and typically have both mid- and tall grasses within occurrences; however, short grasses tend to be more characteristic. These landscapes are generally heavily grazed, leaving the less desirable short grasses such as threeawn. Sand sagebrush can be dominant in some areas and is typically found throughout. These areas are transitional and often indicative of shallow sands with an underlying indurated soil horizon. These soils tend to be siltier than the dunelands and are white in the north and red in the south.

Plant Associations:

Honey Mesquite-Shin-Oak/Sand Dropseed	*Prosopis glandulosa-Quercus havardii/Sporobolus cryptandrus*
Honey Mesquite-Shin-Oak/Needle-and-Thread Grass	*Prosopis glandulosa-Quercus havardii/Herperostipa comata*
Honey Mesquite-Shin-Oak/Purple Threeawn	*Prosopis glandulosa-Quercus havardii/Aristida purpurea*
Honey Mesquite-Shin-Oak/Sparse	*Prosopis glandulosa-Quercus havardii/Sparse*

Honey Mesquite/Short-Grass Shrubland

This map unit is dominated by honey mesquite and is found at the margins and scattered within the short-grass grasslands of the Caprock. Soils are well-drained, fine, sandy loams on gently sloping alluvial material and shallow sandsheets. Honey mesquite ranges in cover between 20% and 24%, and grasses range between 16% and 20%. Bare soil averages 45%. The dominant grasses found in association with honey mesquite are blue grama (*Bouteloua gracilis*), black grama (*Bouteloua eriopoda*), tobosa (*Pleuraphis mutica*), and bush muhly (*Muhlenbergia porteri*). Soapweed yucca and snakeweed are minor shrub components found consistently in this map unit. The more degraded sites have an increase in purple threeawn (*Aristida purpurea*), snakeweed, and four-wing saltbush. Catclaw mimosa (*Mimosa aculeaticarpa* var. *biuncifera*) will replace honey mesquite or occur with honey mesquite on the Grama Ridge within the southwest corner of the study area.

Plant Associations:

Honey Mesquite/Blue Grama Shrubland	*Prosopis glandulosa/Bouteloua gracilis*
Honey Mesquite/Blue Grama-Black Grama Shrubland	*Prosopis glandulosa/Bouteloua gracilis-Bouteloua eriopoda*
Honey Mesquite/Blue Grama-Tobosa Shrubland	*Prosopis glandulosa/Bouteloua gracilis-Pleuraphis mutica*
Honey Mesquite/Black Grama Shrubland	*Prosopis glandulosa/Bouteloua eriopoda*
Honey Mesquite/Buffalograss-Blue Grama Shrubland	*Prosopis glandulosa/Buchloe dactyloides-Bouteloua gracilis*
Honey Mesquite/Sparse Shrubland	*Prosopis glandulosa/Sparse*
Honey Mesquite/Threeawn Shrubland	*Prosopis glandulosa/Aristida purpurea*
Honey Mesquite-Four-wing Saltbush/Sparse Shrubland	*Prosopis glandulosa-Atriplex Canescens/Sparse*
Catclaw Mimosa/Blue Grama Shrubland	*Mimosa aculeaticarpa var. biuncifera/Bouteloua gracilis*

Honey Mesquite Temporarily Flooded Shrubland

This unit occupies bottomlands that are subject to periodic flooding throughout the study area. The soils consist largely of mixed alluvium from adjacent slopes scattered thoughout the Caprock in swales and drainages. Off the Caprock they can be found in major drainages such as Ironhouse Draw, Monument Draw, and their tributaries. Plant assocations found within these drainages can be represented in upland sites; however, due to the greater availability of moisture within these depressions, they have a higher cover value and can contain a high diversity of forbs. Although there is a variety of plant assemblages listed below, the dominant plant association is Honey Mesquite – Blue Grama Shrubland. The more mesic sites will have a dense grass understory while the more xeric sites can either be sparsely vegetated or have a diverse forb understory. Western soapberry within this map unit is a minor inclusion. It is the tallest tree and is found in small groves.

Plant Associations:

Honey Mesquite/Blue Grama Shrubland	*Prosopis glandulosa/Bouteloua gracilis*
Honey Mesquite/Blue Grama-Buffalograss Shrubland	*Prosopis glandulosa/Bouteloua gracilis-Buchloe dactyloides*
Honey Mesquite/Tobosa Shrubland	*Prosopis glandulosa/Pleuraphis mutica*
Honey Mesquite/Purple Threeawn Shrubland	*Prosopis glandulosa/Aristida purpurea*
Honey Mesquite/Sparse Shrubland	*Prosopis glandulosa/Sparse*
Honey Mesquite-Four-wing Saltbush/Tobosa Shrubland	*Prosopis glandulosa-Atriplex canescens/Pleuraphis mutica*
Four-wing Saltbush/Sparse Shrubland	*Atriplex canescens/Sparse*
Western Soapberry Woodland	*Sapindus saponaria*

Converted Mixed Shrubland (Treated Shin-Oak)

On flat to rolling eolian plains, formerly shin-oak dominated landforms are now a highly variable landscape that can sometimes emulate native plant communities. Generally they appear to be transitional communities grading toward shrublands dominated by honey mesquite or sand sagebrush with scattered or solid patches of shin-oak suggesting its previous composition. These areas have been converted using varying amounts of herbicides to remove the shin-oak in favor of an increase in grass cover. At times the areas have been seeded with non-native grasses or may have a significant four-wing saltbush (*Atriplex canescens*) component. Typically the inter-shrub spaces are relatively barren with a sparse herbaceous cover of mid- and/or short-grasses and snakeweed. Mechanical removal of shin-oak may also have occurred.

Shin-Oak/Mixed Mid-Grass and Short-Grass Shrubland

This community is found on flat to rolling eolian sandy plains with scattered blowouts. Shin-oak averages 27% cover, and grasses vary between 10% and 30%. Grasses are typically dominated by little bluestem, sand dropseed, thread-and-needle grass, or threeawn. Soapweed yucca and sand sagebrush are found as minor components. This map unit provides essential habitat for the sand dune lizard. Painter (2004) suggests the shinnery oak "flats" provide important dispersal corridors for juvenile sand dune lizards and egg deposition sites for females. Shrublands containing blowouts or in close proximity to dunelands are more likely to provide suitable habitat for dispersal of the sand dune lizard. These tend to vary from white sandy soils to silty sands.

Plant Associations:

Shin-Oak/Little Bluestem Shrubland	*Quercus havardii/Schizachyrium scoparium*
Shin-Oak/Needle-and-Thread Grass	*Quercus havardii/Hesperostipa comata*
Shin-Oak/Sand Dropseed	*Quercus havardii/Sporobolus cryptandrus*
Shin-Oak/Purple Threeawn	*Quercus havardii/Aristida purpurea*

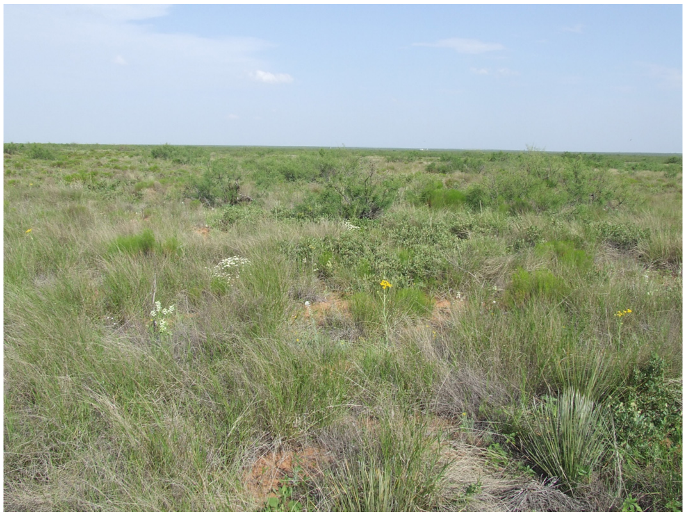
Mixed Mid-Grass and Short-Grass/Shin-Oak Grassland

This grassland is found within varying terrain from flat or rolling eolian plains to interdune swales and stabilized deflation plains. At the edges of shin-oak-dominated dunelands and shrublands, these grasslands overlie shallow sandy soils where caliche is close to the surface. Soils are fine and loamy fine sands. The shin-oak component ranges from 3% to 10%. Grass cover averages 17% and can range from 5% to 25%. Honey mesquite and sandsage are typically found within this map unit. Sandsage may be the locally dominant shrub cover. The shrub cover is typically too low to consider these areas suitable habitat for the sand dune lizard and deflation plains instead of blowouts were generally observed. These soils tend to be siltier than the dunelands and vary from being white in the north to reddish brown in the south.

Plant Associations:

Sand Dropseed/Shin-Oak Grassland	*Sporobolus cryptandrus/Quercus havardii*
Needle-and-Thread Grass/Shin-Oak Grassland	*Hesperostipa comata/Quercus havardii*
Blue Grama/Shin-Oak Grassland	*Bouteloua gracilis/Quercus havardii*
Purple Threeawn/Shin-Oak Grassland	*Aristida purpurea/Quercus havardii*
Hooded windmillgrass/Shin-Oak Grassland	*Chloris cucullata/Quercus havardii*

Mixed Grassland (Treated Shin-Oak)



Large patches of this map unit indicate landcover changes, likely due to herbicide treatment or mechanical removal of shin-oak. This grassland is found in varying terrain from flat or rolling eolian plains to interdune swales and deflation plains. Depending on the original landform and soil type, we see either a dominance of mid- or short-grass. Deeper soils within undulating landforms have blowouts and potential habitat for the sand dune lizard and tend to have mid-grasses. Other landforms such as the nearly level plains with more calcareous soils and/or a relatively short depth to indurated layer may not have been sand dune lizard habitat. In all cases, some residual shin-oak exists. The top and center photos are examples of what was potentially suitable habitat; sandy soils and occasional blowouts are evident. The bottom photo represents areas that may not have been suitable due to more calcic soils. In some cases introduced grasses such as Lehman's lovegrass (*Eragrostis lehmanii*) were planted and now dominate these areas.

Seasonally Flooded Mixed Grassland

This unit occupies bottomlands subject to seasonal and periodic flooding throughout the study area. The soils consist largely of mixed alluvium from adjacent slopes found scattered thoughout the Caprock in swales and drainages. Off the Caprock they can be found in major drainages such as Ironhouse Draw, Monument Draw, and their tributaries. Plant associations in these drainages can be represented in upland sites; however, due to the greater availability to moisture within these depressions, they have a higher herbaceous cover value, can be more monotypic with regard to plant diversity, and have sedges in the more mesic sites. Characteristic species of this grassland are Tobosa (*Pleuraphis mutica*), blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), and inland salt grass (*Distichlis spicata*).

Plant Associations:

Blue Grama-Tobosa Grassland	*Pleuraphis mutica-Bouteloua gracilis*
Alkali Sacaton Monotypic Grassland	*Sporobolus airoides*
Blue Grama-Buffalo Grass Grassland	*Bouteloua gracilis-Buchloe dactyloides*

Short-Grass Grassland

This grassland community is dominated by either black grama or blue grama, and in some places co-dominant. The unit is found on the Caprock and along the shoulders of both Ironhouse Draw and Monument Draw. It is typically found on flat terrain with shallow, calcareous soils that overlay indurated caliche (Turner *et al.* 1974). Snakeweed, honey mesquite, and cholla are consistently found scattered throughout this map unit.

Plant Associations:

Black grama/Monotypic Grassland	*Bouteloua eriopoda/Monotypic*
Blue grama/Monotypic Grassland	*Bouteloua gracilis/Monotypic*
Blue grama-Black grama Grassland	*Bouteloua gracilis-Bouteloua eriopoda*

Short-Grass/Honey Mesquite Grassland

This map unit contains a high diversity of short grasses ranging in cover from 12% and 32% and typically dominated by either black grama or blue grama. Either honey mesquite or catclaw mimosa (*Mimosa aculeaticarpa var. biuncifera)* occurs consistently at relatively low cover values, typically less than 10%. This unit is transitional between the short-grass grasslands and honey mesquite shrublands. The condition of the grassland can be adversely affected by overgrazing, resulting in higher forb cover and an increase of honey mesquite and snakeweed (*Gutierrezia* spp.). This map unit is found within large inter-dune plains or swales and on the Caprock. On the Caprock, the unit can have a high occurrence of snakeweed and cholla.

Plant Associations:

Black Grama/Honey Mesquite Grassland	*Bouteloua eriopoda/Prosopis glandulosa*
Blue Grama/Honey Mesquite Grassland	*Bouteloua gracilis/Prosopis glandulosa*
Blue Grama-Buffalograss/Honey Mesquite Grassland	*Bouteloua gracilis-Buchloe dactyloides/Prosopis glandulosa*

Agricultural Fields

Active and fallow agricultural fields, as well as small, managed pastures comprise the majority of this map unit. These fields are typically on or at the edges of the Caprock.

The photo presented here is an agricultural field that was previously a shin-oak shrubland ; note the remnant shin-oak in the foreground.

Human Disturbance

This map unit is largely composed of roads, drill pads, pipelines, land farms, farmsteads, town sites, industrial sites, and borrow pits. Although vegetation is sparse to non-existent, it can include scattered canopies of trees such as cottonwood and elm along roads, disturbances surrounding wells and home sites, and irrigated grasses.

Playa

These undrained, topographically low areas within the landscape are seasonally flooded for short periods and consist largely of silt and clay sediments. Playas are numerous and found throughout the study area. They are concentrated within the northwest section of the Ironhouse Draw Quadrangle associated with the Caprock where these caliche-bearing units surface within the sandy plains.

Playas are highly diverse where the vegetation changes in type and density due to water availability. They vary from drier, sparsely vegetated or to forb-rich to more mesic types dominated by water-tolerant grasses and sedges to thick patches of mesquite shrubland. These areas are often altered due to human activities such as grazing and oil development.

Surface Water

There are no perennial streams found within the study area. This map unit identifies a few of the larger stock tanks, but many more exist within the study area.

APPENDIX B – LEA COUNTY SOIL MAP UNITS WITHIN THE STUDY AREA

Map Unit Symbol	Lea County Map Unit Name	Ecological Site	Top of Petrocalcic Horizon (cm)	Petrocalcic Thickness (cm)	Petrocalcic Hardness	Shin-oak Dominance / Co-Dominance
Aa	Active dune land	Active Dune Land				Shin-oak
AB	Amarillo-Arvana loamy fine sands association	Sandy Plains				
Ad	Amarillo loamy fine sand, 0 to 3 percent slopes	Sandy Plains				
Ae	Amarillo loamy fine sand, 0 to 3 percent slopes, eroded	Sandy Plains				
Af	Amarillo fine sandy loam, 0 to 1 percent slopes	Sandy				
Ag	Amarillo fine sandy loam, 1 to 3 percent slopes	Sandy				
Ah	Amarillo loam, 0 to 1 percent slopes	Sandy				
AL	Amarillo-Arvana fine sandy loams, association	Sandy				
Am	Arch loam	High Lime				
An	Arvana loamy fine sand, 0 to 3 percent slopes	Sandy Plains				
Ao	Arvana loamy fine sand, 0 to 3 percent slopes, eroded	Sandy Plains				
Ap	Arvana fine sandy loam, 0 to 1 percent slopes	Sandy				
Ar	Arvana fine sandy loam, 1 to 3 percent slopes	Sandy				
AS	Amarillo-Arvana association, eroded	Sandy Plains				
AV	Arch-Drake association	High Lime				
AW	Arvana-Lea association	Sandy				
BE	Berino-Cacique loamy fine sands association	Loamy Sand	51-102	10-42	Indurated	Mesquite - Shin-oak
BF	Berino-Cacique fine sandy loams association	Sandy				
BH	Berino-Cacique association, hummocky	Loamy Sand				
BO	Brownfield-Springer association	Deep Sand				Mesquite - Shin-oak
Bp	Brownfield and patricia fine sands	Deep Sand				Mesquite - Shin-oak
Br	Brownfield and patricia fine sands, eroded	Deep Sand				Mesquite - Shin-

Map Unit Symbol	Lea County Map Unit Name	Ecological Site	Top of Petrocalcic Horizon (cm)	Petrocalcic Thickness (cm)	Petrocalcic Hardness	Shin-oak Dominance / Co-Dominance
						oak
BS	Brownfield-Springer association, hummocky	Deep Sand				Mesquite - Shin-oak
CLP	Caliche pit	Caliche Pit				
Dr	Drake loamy fine sand	Sandy Plains				
Go	Gomez loamy fine sand	Sandy Plains				
GP	Gravel pit	Gravel Pit				
JA	Jal association	Limy				
Kb	Kimbrough loam, 0 to 1 percent slopes	Shallow Sandy				
Kc	Kimbrough loam, 1 to 3 percent slopes	Shallow Sandy				
KD	Kermit-Palomas fine sands, 0 to 12 percent slopes	Deep Sand				Shin-oak
KE	Kermit-Wink complex, 0 to 3 percent slopes	Deep Sand			Moderately cemented	Mesquite - Shin-oak
Kg	Kimbrough gravelly loam, 0 to 3 percent slopes	Very Shallow				
Kh	Kimbrough-Lea complex	Very Shallow				
KM	Kermit soils and dune land, 0 to 12 percent slopes	Sandhills				Shin-oak
KN	Kimbrough loam, 0 to 3 percent slopes	Shallow Sandy				
KO	Kimbrough gravelly loam, 0 to 3 percent slopes	Very Shallow				
KU	Kimbrough-Lea complex	Very Shallow				
La	Lea fine sandy loam	Sandy				
Le	Lea loam	Loamy				
LP	Largo-Pajarito complex	Loamy				
Ma	Mansker loam, 0 to 1 percent slopes	Loamy				
Me	Mansker loam, 1 to 3 percent slopes	Loamy				
MM	Midessa loam	Loamy				
MN	Midessa and wink fine sandy loams	Loamy				
MU	Mixed alluvial land	Mixed Alluvial Land				
MW	Mobeetie-Potter association, 1 to 15 percent slopes	Sandy				

Map Unit Symbol	Lea County Map Unit Name	Ecological Site	Top of Petrocalcic Horizon (cm)	Petrocalcic Thickness (cm)	Petrocalcic Hardness	Shin-oak Dominance / Co-Dominance
PC	Portales loam, 0 to 3 percent slopes	Loamy				
Pe	Portales fine sandy loam, 0 to 1 percent slopes	Loamy Sand				
PG	Portales and gomez fine sandy loams	Loamy Sand				
Ph	Portales loam, 0 to 1 percent slopes	Loamy				
Po	Portales loam, 1 to 3 percent slopes	Loamy				
PS	Portales-Stegall loams	Loamy				
PT	Pyote loamy fine sand	Loamy Sand				
PU	Pyote and maljamar fine sands	Loamy Sand	98-147	10-24	Indurated	Mesquite - Shin-oak
PY	Pyote soils and dune land	Loamy Sand				Shin-oak
RE	Reeves loam	Loamy				
SA	Sharvana loamy fine sand	Sandy Plains				
SD	Sharvana fine sandy loam	Sandy				
SE	Simona fine sandy loam, 0 to 3 percent slopes	Shallow Sandy				
Sh	Sharvana fine sandy loam	Sandy				
Sm	Simona fine sandy loam, 0 to 1 percent slopes	Shallow Sandy				
Sn	Simona fine sandy loam, 1 to 3 percent slopes	Shallow Sandy				
So	Slaughter loam	Loamy				
SR	Simona-Upton association	Shallow Sandy				
SS	Stegall and slaughter soils	Loamy				
St	Stegall loam	Loamy				
Su	Stegall silty clay loam	Loamy				
SY	Stony rolling land	Shallow				
TB	Tivoli-Brownfield fine sands, 0 to 5 percent slopes	Deep Sand				Shin-oak
TE	Tonuco fine sand, hummocky	Deep Sand				
TF	Tonuco loamy fine sand	Shallow Sandy				
To	Tonuco loamy fine sand	Shallow Sandy				
WF	Wink fine sand	Sandy				Mesquite – Shin-oak

Map Unit Symbol	Lea County Map Unit Name	Ecological Site	Top of Petrocalcic Horizon (cm)	Petrocalcic Thickness (cm)	Petrocalcic Hardness	Shin-oak Dominance / Co-Dominance
WK	Wink loamy fine sand	Loamy Sand				
Zf	Zita fine sandy loam	Sandy				
Zt	Zita loam	Loamy				