Species Status Assessment for the Dunes Sagebrush Lizard

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Report Versions

Version 1.3 is a Species Status Assessment report containing the best available information used to inform the final listing determination.

Version 1.2 is a Species Status Assessment report used to inform the proposed listing determination for the dunes sagebrush lizard.

Version 1.1 is a draft Species Status Assessment report that incorporates feedback from peer and partner review.

Version 1.0 is a draft Species Status Assessment report completed exclusively for peer and partner review. As a preliminary draft document, this report should not be referenced or cited as an agency document.

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Executive Summary

Background

This Species Status Assessment (SSA) report documents our use of the best available information to characterize the biological status of the dunes sagebrush lizard (*Sceloporus arenicolus*). The purpose of this assessment is to inform the listing decision for the species under the Endangered Species Act and serve as an information source for conservation efforts.

Species Biology

The dunes sagebrush lizard (DSL) is a species of spiny lizard endemic to the shinnery oak dunelands and shrublands of the Mescalero and Monahans Sandhills in southeastern New Mexico and western Texas. This species is a habitat specialist that depends on shinnery oak duneland habitat to provide appropriate substrate for nests and cover for young and to provide food resources as juvenile lizards mature into adults. DSL form small, localized populations called "neighborhoods" that are inter-connected through dispersal. Since the Mescalero and Monahans Sandhills are dynamic ecosystems, appropriate habitat patches for DSL can shift over time. Long-term stability is maintained through inter-connected neighborhoods experiencing localized colonization and extirpation. The DSL is composed of three divergent and spatially discrete evolutionary lineages (Northern Mescalero, Southern Mescalero, and Monahans). These lineages are further subdivided into several genetically distinct groups that occupy discrete portions of the species' range.

Risk Factors

Due to their reliance on a very specific and restricted habitat within the Mescalero and Monahans Sandhills, DSL are highly susceptible to habitat loss and fragmentation. Removal of habitat can impair breeding, feeding, sheltering, dispersal, and survival, causing declines in abundance or even loss of populations. Habitat loss and fragmentation affect metapopulation dynamics by reducing dispersal and colonization dynamics. Degradation and fragmentation of shinnery oak dunelands may be non-reversible: once disturbed, they shift to alternative stable states and attempts to restore this habitat have been unsuccessful.

The entire range of the DSL overlaps with the Permian Basin, a geologic province known to contain rich oil and gas deposits. Since it has been a major oil producing region for over a century, the Permian Basin has experienced widespread development associated with the petroleum industry. The DSL experiences declines in abundance as density of oil well pads and associated infrastructure increases. A more recent threat to the DSL is mining of frac sand for use in hydraulic fracturing of oil and gas wells. Currently restricted to the Texas portion of the DSL range, extraction of frac sand results in the loss of shinnery oak duneland habitat and promotes the degradation of surrounding sand dune landforms. Although there are other sources of habitat loss, oil extraction and frac sand mining are the primary drivers of landscape change in this region.

There are conservation agreements that have been established to promote the conservation of DSL habitat. In New Mexico, a Candidate Conservation Agreement on federally owned land and a Candidate Conservation Agreement with Assurances on non-federally owned lands have been implemented since 2008. In Texas, the Texas Conservation Plan was established in 2012 to facilitate avoidance of DSL habitat by the oil industry. The plan was revised in 2020 and a new Candidate Conservation Agreement with Assurances was implemented the same year to include additional sources of habitat loss from sand mining activities.

Current Condition

We used geospatial analyses to assess the current condition of the DSL by estimating the current quantity and quality of available habitat. Our approach is rooted in the findings of numerous studies that the DSL experiences reductions in abundance and density as habitat is lost or becomes disturbed. Building upon previous attempts to map DSL habitat, we defined two classes of habitat important for the species viability. The first is Shinnery Oak Duneland, which is the core habitat composed of undulating sand dunes intermixed with blowouts and shinnery oak vegetation. The second is Shinnery Oak Supportive Habitat, which is composed of shinnery oak scrubland flats that help support the structure of sand dunes, buffer dunelands from impacts, allow for shifting habitat over time, offers habitat for species that DSL prey upon, and facilitates potential DSL dispersal. Along with mapping the distribution of these two habitat types, we also mapped the location of anthropogenic features, including oil well pads and sand mines. Based on the density of these features, we classified habitat as Minimally Disturbed, Disturbed, or Degraded, which, respectively, represent declining conditions for long-term DSL viability. For our assessment we defined 3 Representation Units that delineate the primary DSL phylogenetic lineages (Northern Mescalero, Southern Mescalero, and Monahans) and 11 Analysis Units that correspond to known genetic groups and/or significant landscape features.

The results indicate that across our analysis area there are 505,857 ha (1.25 million ac) defined as potential DSL habitat, with approximately 41 percent of that composed of Duneland (Figure ES-1). Our analysis found 47 percent of the analysis area is considered minimally disturbed by human development, whereas 39 percent of the area has been degraded to a state unable to support viable DSL populations. The remaining 14 percent has moderate levels of disturbance, where we anticipate there have been reductions in DSL viability. Levels of habitat degradation and disturbance were not equal across our 11 Analysis Units (Figure ES-2). Based on our ranking of condition categories, we found two Analysis Units are of High condition, five are Moderate, and four are Low. Using the total size of the Analysis Units we estimated the proportion of the total DSL range that fell into these different condition categories. Only 6 percent of the species range was estimated to be in High condition, whereas 47 percent was in Low condition. The remaining 47 percent was considered Moderate condition.

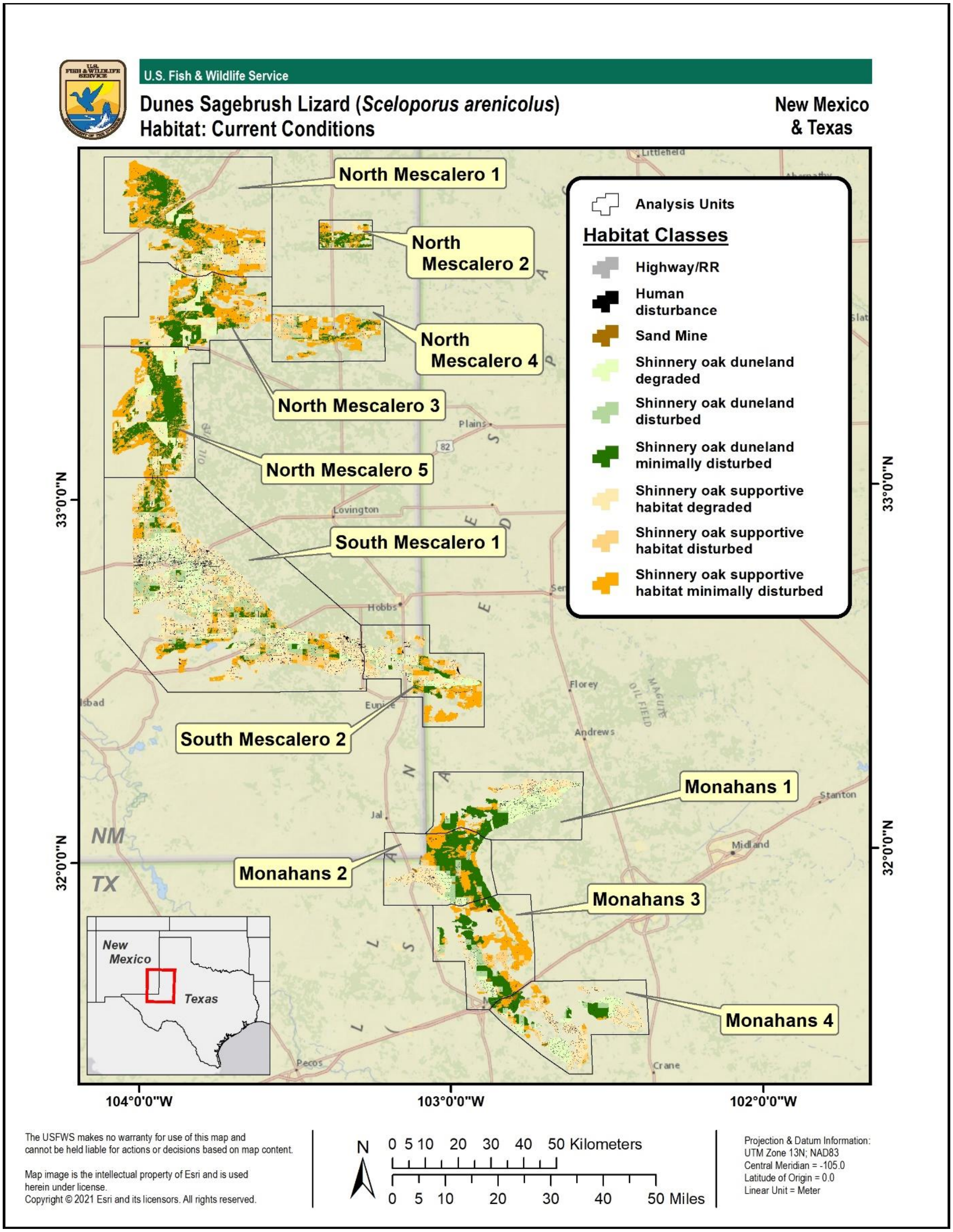

Figure ES-1 Map of habitat categories across the DSL range. The outlines delineate the 11 Analysis Units used to describe the condition of the DSL.

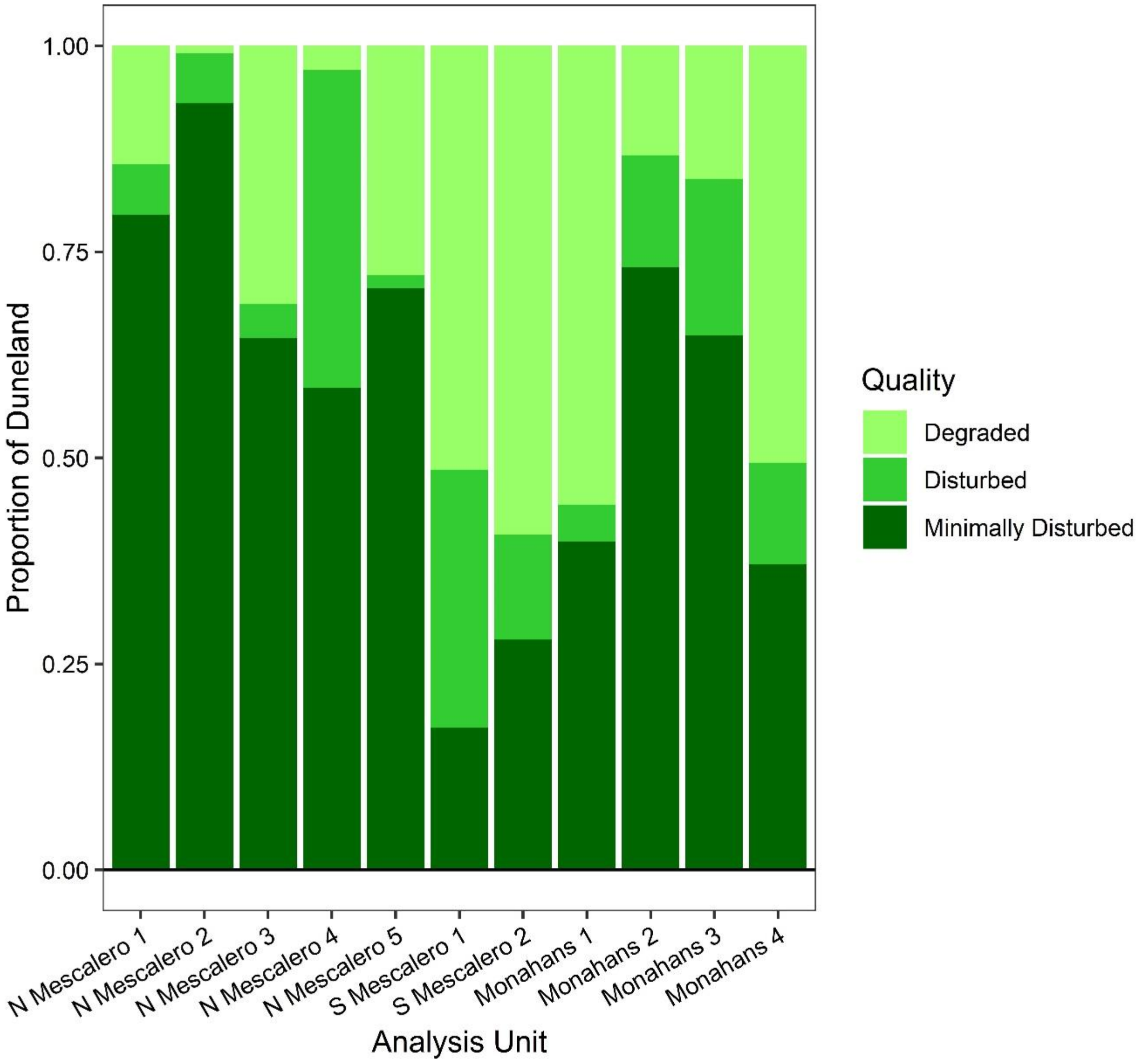

Figure ES-2 Proportion of Shinnery Oak Duneland habitat under the three categories of human disturbance by Analysis Unit.

Future Scenarios

Since we had an evaluation of current DSL habitat, those data served as the starting conditions for development of future scenario to project the status of the species into the future. Our scenarios were built around projections of future increases in oil well pad density and sand mine expansion out to 2050. We developed three scenarios (High, Medium, and Low) that represent plausible levels of impact to DSL habitat from these two factors.

In our assessment of current conditions, we found 47 percent of DSL habitat range-wide was Minimally Disturbed (Figure ES-3). Another 39 percent was Degraded or non-habitat and the remaining 14 percent Disturbed. In the Low future scenario, 42 percent remained Minimally Disturbed, whereas the proportion considered Degraded increased to 41 percent and Disturbed remained 14 percent. In the Medium scenario, 36 percent was considered Minimally Disturbed, 45 percent as Degraded, and 19 percent as Disturbed. With the High scenario, 25 percent was Minimally Disturbed, 53 percent Degraded, and 22 percent Disturbed. A similar trend was observed with the proportion of Duneland under the three scenarios. Projections of future resiliency varied spatially across the DSL range (Figure ES-4).

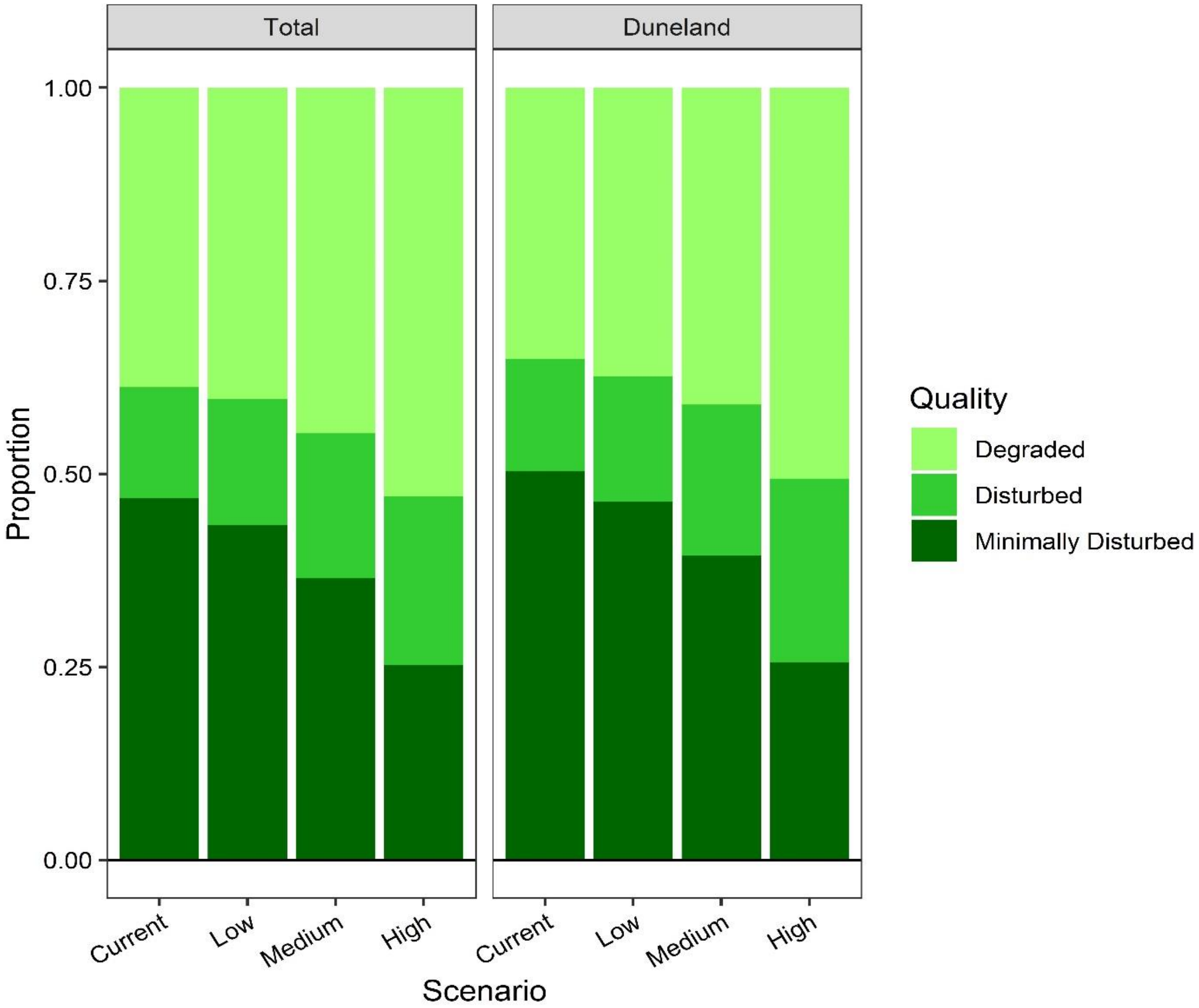

Figure ES-3 Comparison of the proportion of total DSL habitat (left panel) and Duneland habitat (right panel) currently and under the three future scenarios. Quality refers to the categories of human disturbance defined for this assessment.

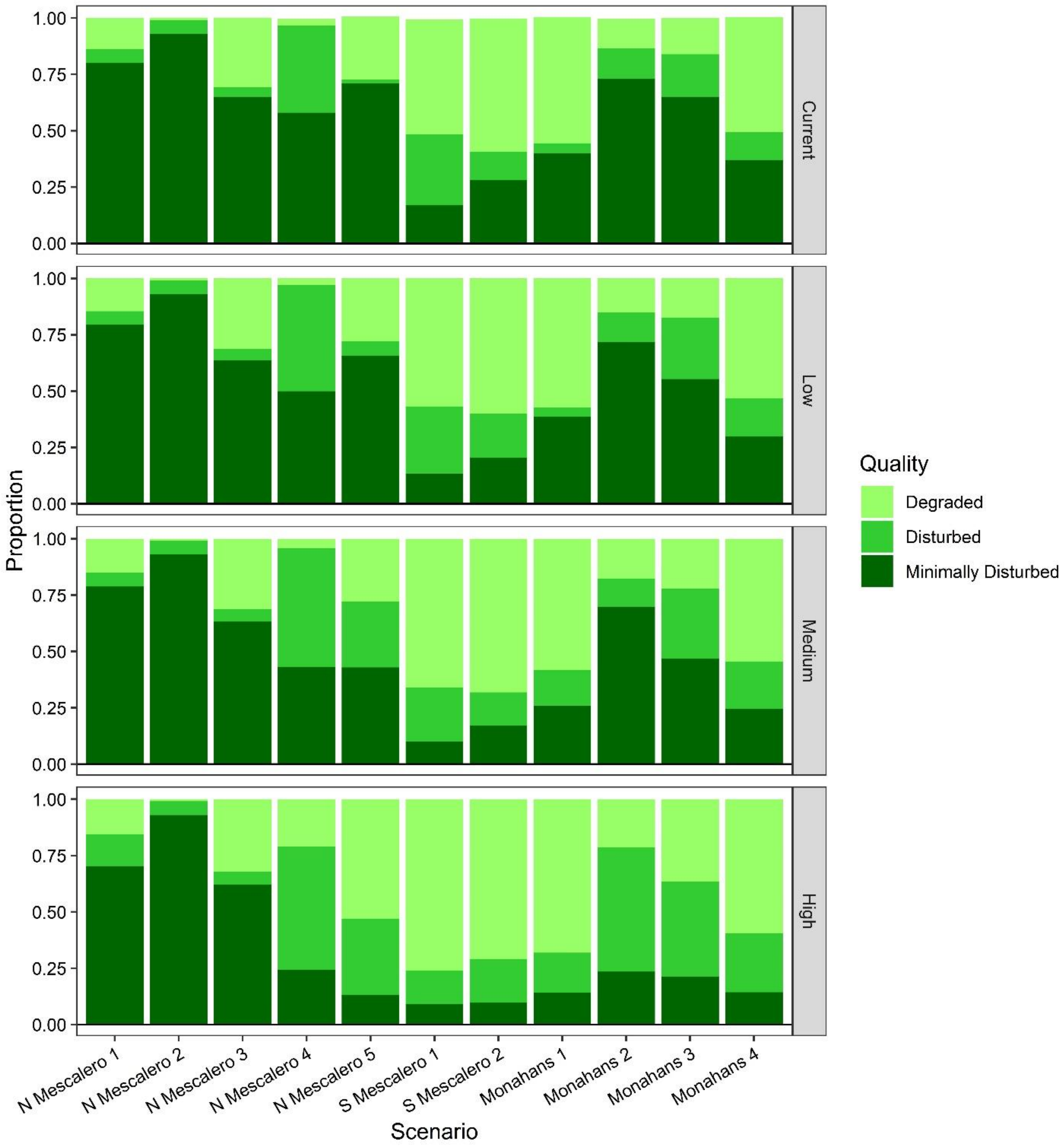

Figure ES-4 Current status of Duneland habitat by individual Analysis Unit and projections under the three future scenarios.

Some of these projections resulted in shifts in the condition category scores for the Analysis Units. None improved in score across the scenarios. Compared to current conditions, all Analysis Units maintained the same score in the Low scenario except for N. Mescalero 4, which dropped from High to Moderate condition (Table ES-1). Moving from the Low to Medium scenario resulted in Monahans 2 and 3 shifting to Low condition. Under the High scenario, N. Mescalero 5 changed from Moderate to Low condition (Table ES-1). All three scenarios projected that only

2 percent of the DSL range was projected to be in High condition by 2050. In contrast, under the Medium scenario 72 percent of the DSL range is projected to be in Low condition. This increases to 77 percent under the High scenario. With the Low scenario, 51 percent of the DSL range is projected to be in Moderate condition: this drops to 26 and 21 percent for the Medium and High scenarios, respectively. These projections indicate that the DSL will continue to experience declines in viability over the next 30 years.

Table ES-1 Results for the condition category scores and the overall resiliency condition for each Analysis Unit currently and under the three future scenarios.

Representation Unit	Analysis Unit	Current condition score	Projected condition under Low scenario	Projected condition under Medium scenario	Projected condition under High scenario
N Mescalero	N Mescalero 1	Moderate	Moderate	Moderate	Moderate
	N Mescalero 2	High	High	High	High
	N Mescalero 3	Moderate	Moderate	Moderate	Moderate
	N Mescalero 4	High	Moderate	Moderate	Low
	N Mescalero 5	Moderate	Moderate	Low	Low
S Mescalero	S Mescalero 1	Low	Low	Low	Low
	S Mescalero 2	Low	Low	Low	Low
Monahans	Monahans 1	Low	Low	Low	Low
	Monahans 2	Moderate	Moderate	Low	Low
	Monahans 3	Moderate	Moderate	Low	Low
	Monahans 4	Low	Low	Low	Low

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Chapter 1: Introduction

1.1 Introduction

The dunes sagebrush lizard (*Sceloporus arenicolus*) (DSL) is a species of spiny lizard that occurs in the shinnery oak dunelands and shrublands of the Mescalero and Monahans Sandhills ecosystems in southeastern New Mexico and western Texas. It is a habitat specialist that only occurs within shinnery oak duneland ecosystems, thus their survival is directly linked to the quality and quantity of available habitat. Over the past several decades, extensive loss, modification, and fragmentation of DSL habitat has prompted concern about the conservation status of the species. This report summarizes the Species Status Assessment (SSA) for the DSL, as the U.S. Fish and Wildlife Service (Service, our, we) has been periodically reviewing the status of the DSL for nearly two decades.

1.2 SSA Overview

The SSA framework (Figure 1-1; Service 2016, p. 6; Smith *et al.* 2018, entire) summarizes information compiled and reviewed by the Service to conduct an in-depth review of a species' biology, evaluate its biological status and influencing factors, and assesses the resources and conditions needed to maintain long-term viability. We have developed this SSA Report to summarize the most relevant information regarding life history, biology, and considerations of risk factors facing the DSL in the past, present, and future. The objective of the SSA is to evaluate the viability of the DSL based on the best scientific and commercial information available.

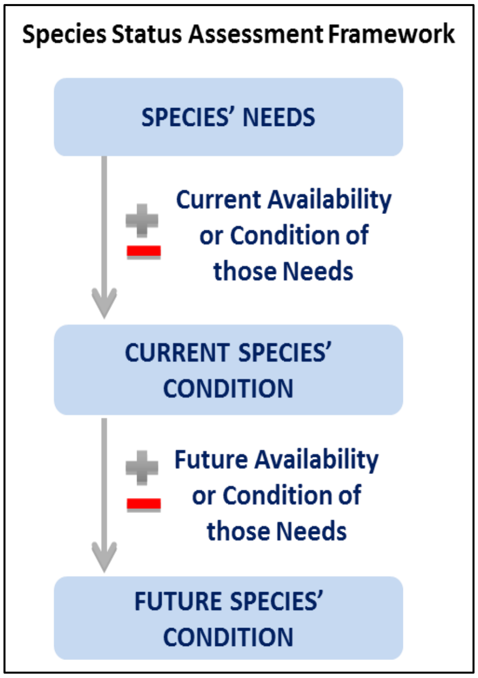

Figure 1-1 Species Status Assessment Framework

For this assessment, we consider viability to be a description of the ability of a species to sustain populations in the wild beyond a biologically meaningful timeframe. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (Service 2016, p. 9). Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its representation, resiliency, and redundancy (3Rs). Species with a high degree of the 3Rs are better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith *et al.* 2018, p. 306).

The definitions of the 3Rs are described below.

- **Representation** describes the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability, referred to as adaptive capacity, facilitates adaptation to continuously changing environments and thus promotes viability. Species adapt to novel changes in their environment by either [1] moving to new, suitable environments or [2] through changes in physical or behavioral traits (phenotypes) to adapt to new environmental conditions. Phenotypic changes progress through either plasticity or genetic change; the latter of which occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift.

- **Resiliency** is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction despite stochastic events.

- **Redundancy** is the ability of a species to withstand catastrophic events. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely. Redundancy is about spreading the risk and can be measured through the duplication and broad distribution of resilient populations which are connected across the range of the species. The larger the number of resilient populations the species has, distributed over a larger area, the better chances that the species can withstand catastrophic events.

1.3 Decision Context

The DSL was made a candidate for listing under the Endangered Species Act of 1973, as amended (hereafter Act; 16 U.S.C. 1531 et seq.), by the Service in 1982 (47 FR 58454). We proposed listing the DSL as an endangered species under the Act in December 2010 (75 FR 77801). However, in June 2012 (77 FR 36871), we formally declined to list the DSL under the premise that newly developed, voluntary conservation efforts would adequately protect the species. On May 8, 2018, the Service received a petition from the Center for Biological Diversity (CBD) and Defenders of Wildlife to list the DSL as threatened or endangered and for critical habitat to be designated for the species. On July 16, 2020, we published a 90-day petition finding that concluded that the petition to list the DSL provided substantial information that the petitioned action may be warranted (85 FR 43203). We developed this SSA for the DSL to inform a new 12-month petition finding to determine whether listing under the Act is warranted.

1.4 SSA Context

There is a substantial amount of scientific information available regarding the DSL. In this SSA report, we summarized the key findings of past research and publications, including information that informed our previous proposed rule to list the DSL as an endangered species (75 FR 77801) and information provided in the listing petition (CBD 2018, entire).

The conclusion of the SSA characterizes the viability of the DSL by considering the risks of extinction under a range of plausible future conditions. The decision whether to list a species is based not on a prediction of the most likely future for the species, but rather on an assessment of the species' overall risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. As a matter of practicality, the full range of potential future scenarios, and the range of potential future conditions for each potential scenario, are too large (virtually infinite) to individually describe and analyze. The scenarios we evaluate then do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. Consequently, the results of this SSA cannot fully describe all potential risks to the species. Recognizing these limitations, the results of this SSA nevertheless provide a framework for considering the overall risk to the species through a range of plausible scenarios.

1.5 ESA Determinations

Importantly, this SSA report does not result in, nor does it predetermine, any decisions by the Service under the Act. In the case of the DSL, the SSA report does not determine whether the DSL warrants the protections of the Act or whether it should be proposed for listing as a threatened or endangered species under the Act, nor does it establish recovery criteria or critical habitat should the species be listed. Those decisions will be made by the Service after reviewing this document, along with the supporting analysis, and all applicable laws, regulations, and policies. The results of any listing determinations under the Act will be published in the *Federal Register*, and, if appropriate depending on the determination, provide opportunity for public review and comment. This SSA report provides a strictly scientific, objective review and application of the available information related to the biological status of the DSL.

Chapter 2: Species Background

2.0 Summary

This chapter provides summary of the biology and ecology of the DSL. It is a unique species of spiny lizard endemic to shinnery oak duneland and shrubland landscapes of southeastern New Mexico and in western Texas, commonly referred to as the Mescalero and Monahans Sandhills ecosystem. Most adult DSL live for two to four years and reproduce in the spring and summer. Males are territorial and compete to attract and mate with females. Females establish nests underground in shinnery oak duneland vegetation, where they lay an average of five eggs and some will lay two clutches in a year. Hatchlings emerge approximately 30 days after eggs are laid. Eggs and young DSL are susceptible to natural mortality from environmental stress and predation. The appropriate shinnery oak duneland habitat is vital to provide appropriate substrate for nests and cover for young and to provide food resources as juvenile lizards mature into adults. In addition, DSL population dynamics are directly tied to the quality of sand dune blowout formation embedded within the shinnery oak duneland systems. DSL form small, localized populations called “neighborhoods” that are inter-connected through dispersal. Since the Mescalero and Monahans Sandhills are dynamic ecosystems, appropriate habitat patches for the DSL may shift over time. Long-term stability is maintained through inter-connected neighborhoods experiencing localized colonization and extirpation.

2.1 Description

The DSL is a small, light brown spiny lizard with a maximum snout-to-vent length (SVL) of 70 millimeters (mm) (2.8 inches[in]) (Figure 2-1; Degenhardt *et al.* 1996, p. 159; Hibbitts and Hibbitts 2015, p. 155). Its dorsal color matches that of sand and varies from a light tan to reddish tan. It also has grayish dorsolateral stripes (Hibbitts and Hibbitts 2015, p. 155). Females average 53.8 mm (2.12 in) SVL, whereas males average 54.5 mm (2.15 in) SVL (Degenhardt *et al.* 1996, p. 159). During breeding, females develop patches of orange along their head, neck, body, and tails, whereas males have paired blue patches on their belly (Figure 2-2; Degenhardt *et al.* 1996, p. 159; Hibbitts and Hibbitts 2015, p. 155).

Individual DSL have 41-52 scale rows around the midbody, granular scales on the back of its thighs, and more than 9 scale rows separating its femoral pores (i.e., small pores located on the ventral scales of the hind legs) (Hibbitts and Hibbitts 2015, p. 156). The DSL can be distinguished from a similar co-occurring species, the prairie lizard (*S. consobrinus*), by the presence of more than eight scales between the femoral pores (Fitzgerald and Painter 2009, p. 198).

Figure 2-1 Dunes sagebrush lizard (DSL). Credit: M. Hill.

Figure 2-2 Male DSL in breeding color. Credit: Department of The Interior.

2.2 Taxonomy

Kirkland L. Jones collected the holotype specimen (MSB 23621) on April 27, 1968 in eastern Chaves County, NM, after it was first recorded by Sabath in 1960 (Degenhardt *et al.* 1996, p. 159). Degenhardt and Jones (1972, entire) first recognized it as a subspecies of the broadly distributed sagebrush lizard (*S. graciosus arenicolus*). It was then recognized as a distinct species, *S. arenicolus,* by Collins 1991 (p. 43) and corroborated in Chan *et al.* 2013 (p. 316), who concluded it is morphologically, behaviorally, and ecologically distinct as well as geographically disjunct from the other taxa. Though commonly called the sand dune lizard, the accepted common name for *S. arenicolus* is the dunes sagebrush lizard (Crother and Moriarty 2008, p. 39). Phylogenetic analysis of mitochondrial DNA data estimated that the DSL diverged from the sagebrush lizard (*S. graciosus*) 2.55 million years ago and coalesced as a clade around 660,000 years ago (Chan *et al.* 2013, pp. 315-317). This predates the formation of the Monahans and Mescalero Sandhills, where the earliest estimates of sand accumulation date to 22-29,000 years ago (Rich and Stokes 2011, p. 238).

The DSL belongs to the family Phrynosomatidae, a diverse group of lizards with 7 genera and 22 species in New Mexico (Degenhardt *et al.*1996, p. 138; Stuart *et al.* 2019, entire), and 6 genera and 18 species in Texas (iNaturalist 2020, unpaginated). The DSL is in the genus *Sceloporus*, which are the spiny lizards. The species etymology is after the Latin noun “arena” meaning sand, and adjective “-cola” meaning dweller, referring to the habitat where the species lives (Reptile Database 2020, p. 1). The currently accepted classification is (Integrated Taxonomic Information System 2018):

Phylum: Chordata
Class: Reptilia
Order: Squamata
Family: Phrynosomatidae
Genus: *Sceloporus*
Species: *arenicolus*

2.3 Geographic range and distribution

The range of the DSL is limited to the shinnery oak duneland and shrubland landscapes in southeastern New Mexico and in western Texas, within an elevational range of 780-1400 meters (Painter *et al.* 1999, p. 1). Historically, it is estimated that the shinnery oak duneland and shrubland landscape covered 477,520 hectares (ha) (1,179,980 acres[ac]) in New Mexico and 398,583 ha (984,920 ac) in Texas (Figure 2-3). However, within this landscape the DSL’s distribution is naturally patchy and fragmented (Fitzgerald *et al.* 1997, p. 28) and the species is primarily associated with sand dune blowouts that occur within active sand dunes dominated by shinnery oak (*Quercus havardii*) and scattered sandsage (*Artemisia filifolia*) (see Section 2.6). DSL habitat is fragmented by both anthropogenic development and natural landscape barriers (Snell *et al.* 1997, p. 8; Painter *et al.* 1999, p. 23; Chan *et al.* 2009, p. 139, Fitzgerald *et al.* 2011, p. 2).

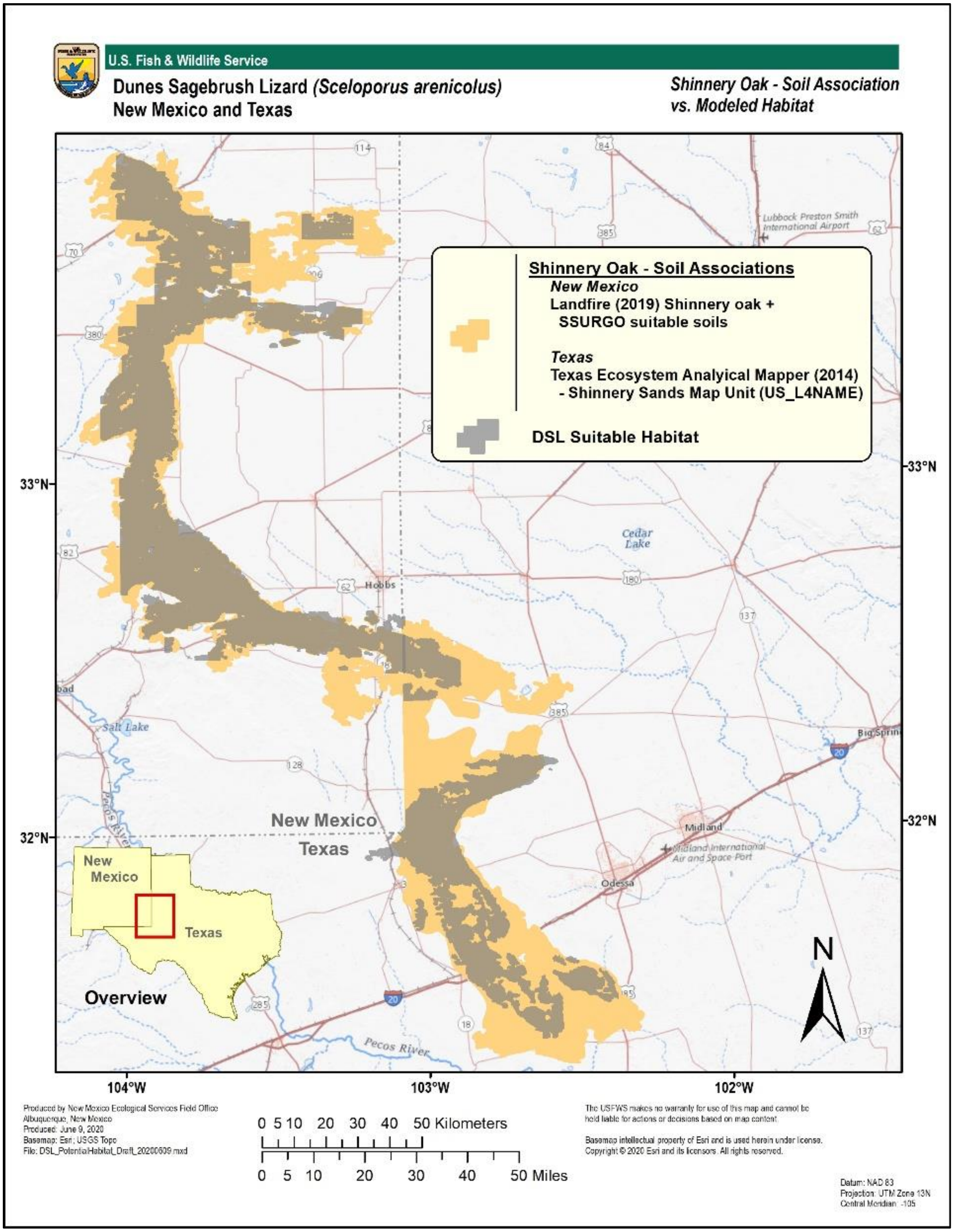

Figure 2-3 Potential range of the DSL in the Mescalero Sandhills of southeastern New Mexico and the Monahans Sandhills of west Texas based on shinnery oak vegetative cover and suitable soils.

2.4 Life History and Ecological Needs of Individual DSL

2.4.1 Life Cycle

DSL have a short lifespan, living only 2 to 4 years (Figure 2-4; Snell *et al.* 1997, p. 9; Fitzgerald and Painter 2009, p. 200), with a maximum reported age of 5 years (Leavitt and Acre 2021, p. 48). They have a reduced reproductive output compared to other Sceloporines, reproducing only once or twice in a season (Snell *et al.* 1997, p. 10; Ryberg *et al.* 2012, p. 583). They are active from April through October and dormant underground during the colder winter months (Sena 1985, p. 19, Sartorius *et al.* 2002, p. 1970; Painter 2004, p. 2; Ferguson *et al.* 2014, p. 60). Sexually mature males emerge in April (Sena 1985, p. 29), vitellogenesis (i.e., internal egg development) in females begins in late April (Sena 1985, p. 27), and mating occurs from May to early July (Fitzgerald and Painter 2009, p. 200; Hibbitts and Hibbitts 2015, p. 156).

Males are territorial and compete for females, whereas females are not territorial and have overlapping home ranges (Fitzgerald and Painter 2009, p. 200). Females lay one or two clutches of eggs annually, usually between June and August (Degenhardt and Jones 1972, p. 216; Cole 1975, p. 292; Fitzgerald and Painter 2009, p. 200; Hibbitts and Hibbitts 2015, p. 156). Clutches contain an average of five eggs (range three to six) and are laid underground in sand dunes dominated by shinnery oak (Hibbitts and Hibbitts 2015, p. 156, Hill and Fitzgerald 2007, p. 30; Ryberg *et al.* 2012, p. 583). The DSL has the smallest clutch size compared to other sympatric phrynosomatid lizards, with a potential lifetime reproductive output of between 6 and 20 eggs (Sena 1985, p. 6; Snell *et al.* 1997, p. 10; Hill and Fitzgerald 2007, p. 2). By comparison, females of the common side-blotched lizard (*Uta stansburiana*), a habitat generalist that is sympatric with the DSL, lay one to seven clutches of one to eight eggs annually, usually between March through August (Hibbitts and Hibbitts 2015).

Females dig burrows into sand dunes and sand dune blowouts at night and construct nest chambers at the soil moisture horizon (Ryberg *et al.* 2012, p. 583). DSL construct subterranean nests and pack eggs with moist sand from the surrounding substrate (Ryberg *et al.* 2012, p. 583; see below for further discussion). Data on DSL nesting behavior and ecology in the wild is limited to a few observations of nesting events described by Hill and Fitzgerald (2007, p. 2) and Ryberg *et al.* (2012, entire). One observation involved two females that nested in sand dune blowouts on west-facing, open sand slopes with little to no vegetation, up to 19 centimeters (cm) (7.5 in) below the sand surface (Hill and Fitzgerald 2007, p. 30). Another observation documented one female nesting in a sand dune blowout with little surrounding vegetation and no measurable slope, up to 20.5 cm (8 in) below the surface. All three females dug burrows below the surface to the soil moisture horizon where the nest chamber was then constructed (Hill and Fitzgerald 2007, p. 5; Ryberg *et al.* 2012, p. 583). Females may prefer sandy soils with large grain size composition and high moisture content relative to conditions available in the surrounding area (Ryberg *et al.* 2012, p. 584). Snell *et al.* (1997, p. 9) suggested that coarser sand may have properties that allow for adequate exchange of gas and water between eggs and the surrounding substrate. While females are gravid, particularly just prior to nesting, they are extremely susceptible to predation. Females tend to spend a high amount of time above ground, presumably basking more frequently to aid in egg development. Gravid females were also larger and slower due to the physical burden of carrying eggs (Sena 1985, p. 17).

Hatchlings emerge about 30 days after the eggs are laid, between July and September (Ryberg *et al.* 2012, p. 583; Fitzgerald and Painter 2009, p. 200). Hatchlings measure about 44 mm (1.7 in) in total length and grow rapidly, reaching sexual maturity by the following spring or summer (Degenhardt and Jones 1972, p. 216; Cole 1975, p. 292, Fitzgerald and Painter 2009, p. 200; Hibbitts and Hibbitts 2015, p. 157).

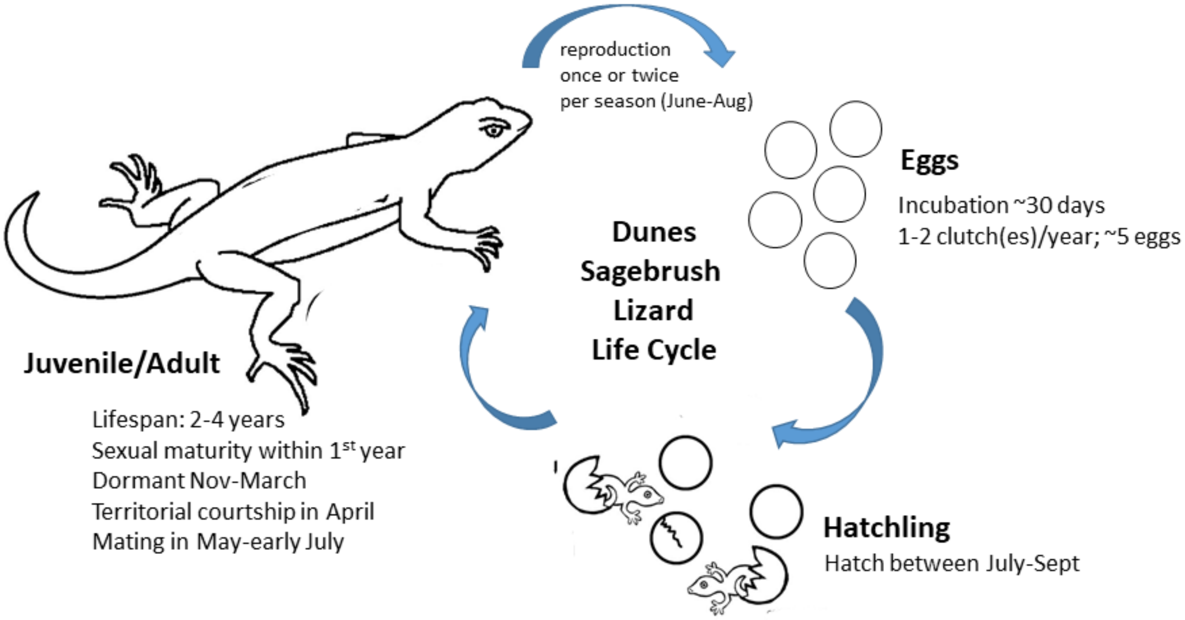

Figure 2-4 Dunes sagebrush lizard life cycle diagram.

2.4.2 Diet

The DSL is a sit-and-wait ambush forager and feeds on a variety of terrestrial invertebrates, including ants and their pupae, small beetles and their larvae, crickets, grasshoppers, and spiders (Degenhardt *et al.* 1996, p. 160; Degenhardt and Jones 1972, p. 217; Fitzgerald and Painter 2009, p. 199; TAMU 2016, p. 2).

2.4.3 Activity Patterns and Thermoregulation

The DSL is ectothermic, meaning that it obtains its heat from its external environment (Pianka 1994, pp. 78-94). Ectothermic lizards must raise their body temperatures high enough to enable physical activity (e.g., feeding, breeding, and sheltering) and then must maintain their body temperatures within a range that optimizes physiological performance (metabolism, digestion, growth, etc.). Typically, ectothermic lizards exchange heat with their external environment via radiation, convection, and conduction, and regulate their body temperatures by making physiological and behavioral adjustments to dissipate (or avoid) excess body heat during warm periods and retain (or gain) heat during cooler periods (Pianka 1994, pp. 78-94).

Lizards of the genus *Sceloporus* are precise thermoregulators (Ferguson *et al.* 2014, p. 56). The DSL regulates its body temperature within a precise range that optimizes physical activity and physiological performance (Sartorius *et al.* 2002, p. 1970; Ferguson *et al.* 2014, p. 66). Sena (1985, p. 18) recorded DSL body temperatures in the field and reported an average body temperature of 33.4°C (92.1°F) and an average critical thermal maximum of 45.5°C (113.9°F). Sartorius *et al.* (2002, p. 1970) analyzed thermal preferences of DSL in the field and found they maintained body temperature within a narrow range of 34.1 ± 0.59°C (93.4 ± 1.1°F). The authors also analyzed thermal preferences of DSL in a laboratory setting and found a preferred body temperatures range of 33.9-37.2°C (93.0-99.0°F). Jacobson (2016, p. 4) analyzed thermal preferences of DSL in the field and found preferred body temperature for optimal performance to range from 23-38°C (73.4-100.4°F). Failure to regulate body temperatures within optimal ranges reduce the ability of lizards to feed, breed, or shelter, which ultimately may reduce survival (Jacobson 2016, p. 3).

Ectothermy in the DSL results in temporal patterns of activity that are restricted to warmer months and to warm parts of the day (Leavitt and Acre 2014, p. 800) (Figure 2-5; Leavitt 2019a, p. 9). DSL are active from April through October, with a peak in activity occurring from May through July. During this time, DSL establish and defend territories, mate and nest, and emerge from nests as hatchlings (TAMU 2016, p. 44). This seasonal peak in activity coincides with the warmest and wettest part of the year in the Mescalero and Monahans Sandhills (Leavitt 2019a, p. 11) and with the emergence of insects in the region (Longing *et al.* 2014, p. 18).

For daily activity patterns, thermoregulation in the DSL results in a bi-modal peak in lizard activity (Leavitt 2019a, p. 1). DSL are active primarily in the morning (08:00 – 12:00) and late afternoon (16:00-19:00) (Leavitt 2019a, p. 8), and less active in the middle of the day (12:00-16:00) when they confine their activity to shaded areas or retreat underground (Sartorius *et al.* 2002, p. 1970; Ferguson *et al.* 2014, p. 58; Leavitt 2019a, p. 8). During the morning, when ambient temperatures are low, DSL bask in sun-exposed dune blowouts to maximize the amount of heat gained and attain body temperatures high enough for activity and optimal physiological performance (Pianka 1994, pp. 78-94; Sartorius *et al.* 2002, p. 1968; Ferguson *et al.* 2014, p. 65). As ambient temperatures rise throughout the day, they seek shady habitats (e.g., shinnery oak, burrows, etc.) to minimize heat load, dissipate heat, and avoid overheating (Pianka 1994, pp. 78-94; Sartorius *et al.* 2002, p. 1970; Ferguson *et al.* 2014, p. 65). Ferguson *et al.* (2014) reported that individual DSL ceased aboveground activity and retreated underground from late morning until late afternoon on hot midsummer days (i.e., when air temperature exceeded 37°C (98.6°F). Such thermoregulatory behavior allows them to be active over a longer period; optimize feeding, breeding, and sheltering activities; and presumably compete and elude predators more effectively (Pianka 1994, pp. 78-94; Sartorius *et al.* 2002, p. 1975; Ferguson *et al.* 2014, p. 62). The survival of the DSL also depends on its ability to select microhabitats with temperatures that allow it to achieve body temperatures within its optimal performance range (Jacobson 2016, p. 3).

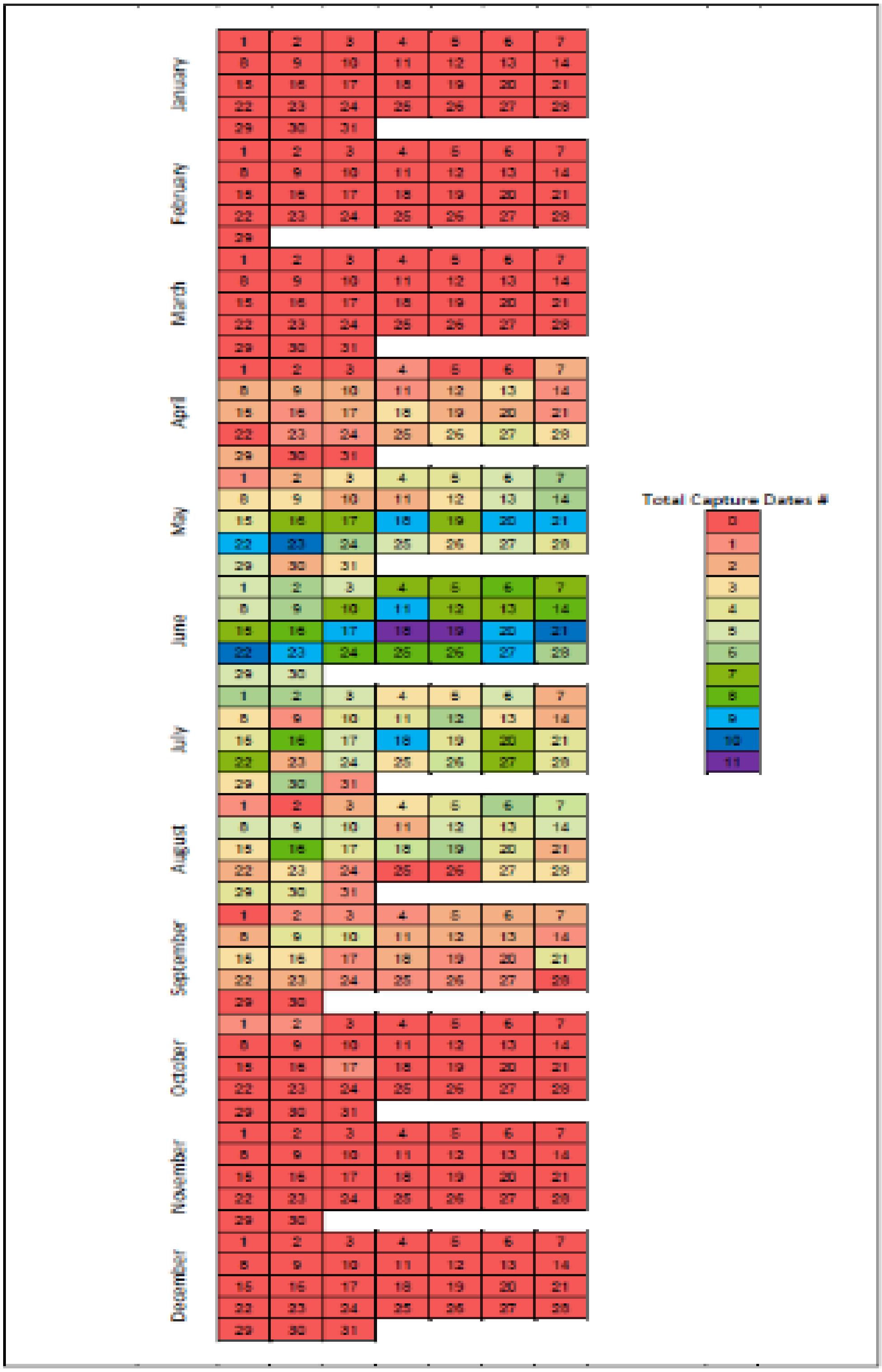

Figure 2-5 Dates of capture for field collected DSL from surveys conducted between 1938 and 2018. Colors represent the number of unique capture events across all surveys for that particular date. Credit: Leavitt (2019, p. 9).

2.4.4 Psammophilia

The DSL is psammophilic (i.e., sand-dwelling), spending the majority of its life on sandy substrates. It has evolved numerous adaptations for living in the sandy environment of the Mescalero and Monahans Sandhills (Ryberg and Fitzgerald 2015, p. 118). For example, DSL dive into sand to escape predators and can move several meters underneath sand, which is known as sand swimming. They also sleep buried underneath sand (Fitzgerald and Painter 2009, p. 199) and bury themselves in sand to thermoregulate (Snell et. al 1997, p. 9; Ferguson *et al.* 2014, p. 66). Female DSL dig burrows into sand dunes and inter-dune areas (i.e., dune blowouts) and construct subterranean nest chambers in sandy substrate (Ryberg *et al.* 2012, p. 583).

2.4.5 Predators

DSL predators include, but are not limited to, snakes (e.g., *Arizona elegans*, *Masticophis flagellum*, etc.), raptors (e.g., American kestrels [*Falco sparverius*]), and other birds (e.g., loggerhead shrikes [*Lanius ludovicianus*], greater roadrunners [*Geococcyx californianus*]) (Hill and Fitzgerald 2007, p. 5; Young *et al.* 2018, p. 908). About 25 species of snakes occur in shinnery oak communities of the Southern Great Plains as do many species of birds, including 22 raptor species reported from shinnery oak habitat in New Mexico (Dhillion and Mills 2009, p. 268). The DSL is also sympatric with other species of lizards that prey on lizards (e.g., common collared lizard [*Crotaphytus collaris*], long-nosed leopard lizard [*Gambelia wislizenii*]). Sand swimming constitutes the primary behavioral adaptation that allows DSL to avoid potential predators (Sena 1985, p. 33).

2.4.6 Home Range and Dispersal

Within shinnery oak duneland habitat, adult DSL have small home ranges, which are defined as the area used for normal daily feeding, breeding, and sheltering activities (Young *et al.* 2018, p. 906). Hill and Fitzgerald (2007, p. 5) reported an average home range of 436 square meters (m^2) (0.11 ac), whereas the largest home range documented was 2,799.7 m^2 (0.69 ac). Young *et al.* (2018, p. 907) found that average home ranges were larger in areas where habitat was fragmented (1,219 m^2 [0.3 ac]) compared to unfragmented areas (633 m^2 [0.16 ac]). They also observed larger average home ranges for males (1,000 m^2 [0.25 ac]) than for females (614 m^2 [0.15 ac]).

DSL movement includes dispersal of individuals from their birth site to their breeding site, as well as from one breeding site to another. Patterns of movement in DSL involve both the movements of juveniles and adults; however, data on DSL dispersal is limited, especially for juveniles (Painter *et al.* 1999, p. 37). Monitoring of pitfall traps (Painter and Fitzgerald, unpublished data, cited in Painter 2004, p. 5) indicate that interdune, shinnery oak flats (i.e., shinnery oak shrublands) that are at least 500 m (1,640 ft) wide and less than 2,000 m (6,562 ft) from occupied duneland habitat, are important as dispersal corridors for juveniles and for females seeking egg deposition sites (Fitzgerald *et al.* 1997, Appendix II; Painter 2004, p. 5; Johnson *et al.* 2016, p. 39; TAMU 2016, p. 2). Some females may leave their normal home range to nest in other dune blowouts (Fitzgerald *et al.* 2005, p. 12). One gravid female tracked with radio telemetry moved approximately 200 m (656 ft) through shinnery oak habitat to other dune blowouts (Fitzgerald *et al.* 2005, p. 11). It returned to the original capture site after it moved; thus, its movement was probably for egg laying. Another study found one gravid female moved greater than 150 m (492 ft) (Fitzgerald *et al.* 2005, p. 12). A third study documented a long-distance dispersal during a pitfall trapping study when a marked individual moved between trapping grids (843 m [2,766 ft]) in which the direct route would have required moving through shinnery oak shrublands and across a singular dirt (caliche) road (Leavitt *et al.* 2011 p. 8). However, no other similar long-distance dispersal events have been described with radio telemetry methods.

The following table presents a summary of resources needs for individual DSL at different life stages.

Life Stage	**Resources and/or circumstances needed for INDIVIDUAL DSLs to complete each life stage**	**Resource Function***	**Reference**
EGGS			
June-Aug	Dune blowouts with little to no vegetation - erosional microhabitat features, nested within shinnery oak sand dune landforms and landscapes	B, S	Hill and Fitzgerald 2007, p. 5, Ryberg *et al.* 2012, p. 583
	Appropriate medium/coarse sand grain size for burrows and nest chambers	B, S	Ryberg *et al.* 2012, p. 584
	Appropriate depth (e.g., ~21 cm below surface) at soil moisture horizon	B, S	Hill and Fitzgerald 2007, p. 5; Ryberg *et al.* 2012, p. 584
HATCHLINGS			
July-Sept	Abundant invertebrates (ants, ant pupae, small beetles and larvae, crickets, grasshoppers, spiders)	F	Degenhart *et al.* 1996, p. 160, Degenhardt and Jones 1972, p. 217, Fitzgerald and Painter 2009, p. 199
	Interdunal shinnery oak flats (i.e., shrublands); corridors between blowouts	D	Painter *et al.* 1999, p. 37, Fitzgerald *et al.* 2005, p. 11, Painter 2004, p. 5, Hill and Fitzgerald 2007, p. 5, TAMU 2016, p. 2, Johnson *et al.* 2016, p. 39, Hardy *et al.* 2018, p. 3-5, 21, 25-26
	Shinnery oak duneland complexes	S	Fitzgerald *et al.* 1997, p. 24
JUVENILES/ADULTS			
1-4 years	Mates	B	
	Abundant invertebrates (ants, ant pupae, beetles and larvae, crickets, grasshoppers, spiders, etc.)	F	Degenhardt *et al.* 1996, p. 160, Degenhardt and Jones 1972, p. 217, Fitzgerald and Painter 2009, p. 199, Leavitt and Acre 2014, p. 700
	Sand of appropriate grain size for burrowing for predator evasion, sand swimming, sleeping, thermoregulation, nest building, hibernating	B, S	Fitzgerald *et al.* 1997, p. 5 ; Peterson and Boyd 1998, pp. 6-7; Ryberg and Fitzgerald 2015, pp. 2-3;

			Fitzgerald and Painter 2009, p. 199; Snell *et al.* 1997, p. 9; Ferguson *et al.* 2014, p. 65
	Deep (>3m) and long (~33m) dune blowouts with northerly or easterly exposures in shinnery oak dune complexes (although they can survive in smaller blowouts, just at lower abundances)	B, F, S	Degenhardt *et al.* 1996 p. 160; Snell *et al.* 1997, pp. 3, 8-9; Sias and Snell 1998, pp. 1, 8, 25, Fig 5 and 6; Fitzgerald *et al.* 1997, pp. 2, 25, 27; Painter 2004, pp. 3-5; Fitzgerald and Painter 2009, pp. 199-200; Fitzgerald *et al.* 2011, p. 3, 10, 14, and 24; Ryberg *et al.* 2013, pp. 2, 5-6; Chan *et al.* 2014, pp. 30-31 and 38-41; Hibbitts and Hibbitts 2015, p. 157; Ryberg *et al.* 2015, pp. 888, 890-891, 895-896; Johnson *et al.* 2016, pp. 3, 26-27, 34, 36, 39, 80; Chan *et al.* 2017, pp. 7-8, 22; Hardy *et al.* 2018, pp. 10, 21-25, 27; TAMU 2016, pp. 7, 18, 38; TAMU 2016 pp. 3-4, 7, 18, 38, 56
	Sun for basking (thermoregulation, which enables foraging and other essential physical activities) & egg development	B, F, S	Sena 1985, p. 17; Sartorius *et al.* 2002, pp. 1970, 1972-1973; Hill and Fitzgerald 2007, p. 6; Ferguson *et al.* 2014, pp. 56-57, 63, 66; Leavitt and Acre 2014, p. 700
	Shady habitats and leaf litter for refuge, foraging, thermoregulation	B, F, S, D	Pianka 1994, pp. 78-94, Sartorius *et al.* 2002, p. 1970, Ferguson *et al.* 2014, p. 66, Machenberg 1984, pp. 16 and 20-21; Degenhardt *et al.* 1996 p. 160; Snell *et al.* 1997, pp. 1, 8-9; Fitzgerald *et al.* 1997, p. 26; Peterson and Boyd 1998, p. 21; Painter *et al.* 1999, pp. 1, 27; Sartorius *et al.* 2002, pp. 1972-1975; Painter 2004, pp. 3-4; Dhillion and Mills 2009, p. 264; Leavitt and Acre 2014, p. 700; Hibbitts and Hibbitts 2015, p. 157
	Interdunal shinnery oak flats (i.e., shrublands); corridors	D	Fitzgerald *et al.* 1995, p. 10, Table 2, Painter *et al.* 1999, p. 37, Painter 2004,

			p. 5, Fitzgerald *et al.* 2005, p. 11, Hill and Fitzgerald 2007, p. 5, Chan *et al.* 2014, p. 2, 30-33, 35-38, TAMU 2016, p. 2, Johnson *et al.* 2016, p. 39, Hardy *et al.* 2018, p. 3-5, 21, 25-26
	Adequate home range (Avg 0.11 acre) [Mean (±SD) 0.15±0.08 acre (Female); 0.23±0.22 acre (Male); 0.16±0.09 acre (Unfragmented); 0.30±0.26 acre (Fragmented); Range 0.01-0.69 acre; Range 0.03-0.88 acre]	B, F, S, D	Hill and Fitzgerald 2007, p. 5, TAMU 2016, p. 12; Young *et al.* 2018, p. 3
	Optimal body temperature 23-28 ˚C (73.4 -100.4 ˚f); maximum is 45.5 ˚C (113.9 ˚F)	B, F, S, D	Sena 1985, p. 38, Jacobson 2016, p. 4
*B=Breeding, F=Feeding, S=Sheltering, D=Dispersal			

2.5 Habitat

The Mescalero and Monahans Sandhills ecosystems, located in southeastern New Mexico and adjacent West Texas, are composed of ancient sand dune fields maintained by wind, moving sand, and partially stabilized by shinnery oak (as referenced in Walkup *et al.* 2017, p. 2). These ecosystems are characterized by a patchy arrangement of narrow, almost linear sand dunes embedded in a matrix of shinnery oak shrubland flats (Figure 2-6; Fitzgerald and Painter 2009, p. 199, Ryberg *et al.* 2015, p. 890). Within the sand dunes themselves, open dune blowouts (bowl-shaped depressions) form when disturbance removes stabilizing vegetation. There are complex feedbacks between wind, sand, and shinnery oak that make this a "unique, irreplaceable landform" (Ryberg *et al.* 2015, pp. 888, 893).

The DSL is considered a habitat specialist due to its restricted range and dependence on shinnery oak duneland habitat (Fitzgerald *et al.* 1997, p. 4; Hibbitts *et al.* 2013, p. 104; Hardy *et al.* 2018, p. 10, Fitzgerald *et al.* 2022, p. 6). Within the duneland complexes, the DSL further selects for areas with open dune blowouts and uses the interface of the shinnery oak and sand (Walkup *et al.* 2021, pp. 13-14; Walkup *et al.* 2022, pp. 350, 352, 356). The DSL will traverse other habitats, such as shinnery oak shrublands (flats), open dunes, and barren sand areas, when such habitats are in contact with, or embedded within, the shinnery oak duneland landscape (Snell *et al.* 1997, p. 9; Johnson *et al.* 2016, p. 11; Hardy *et al.* 2018, p. 2; Walkup *et al.* 2022, pp. 358).

Figure 2-6 Dunes sagebrush lizard habitat. Mescalero Sandhills, New Mexico. Credit: US Fish and Wildlife Service.

2.5.1 Shinnery Oak Duneland

Shinnery oak duneland habitat represents active and semi-active stable dune complexes where shinnery oak is in contact with the sand dune landform at the margins or as embedded vegetation within the larger open dune area (Machenberg 1984, p. 1, 3, 9, 16, 23-24, 29-31, Plate 1;

Fitzgerald *et al.* 1997, p. 8; Holliday 2001, p. 102; Hardy *et al.* 2018, p. 21, 25-27). Dune complexes in Texas are larger and more open than those found in New Mexico. These open dune fields are dynamic in terms of interannual vegetation coverages especially when viewed over decadal periods (Dzialak *et al.* 2013, entire). Historical and current survey data have documented DSL in these open dune fields in the absence of vegetation as well as in contact with shinnery oak (Hardy *et al.* 2018, p. 21; Walkup *et al.* 2021, pp. 13-14; Walkup *et al.* 2022, pp. 355, 358). Shinnery oak duneland may also be co-dominated by honey mesquite (*Prosopis glandulosa*). As noted in Johnson *et al.* (2016, p. 20), when dunelands are invaded by mesquite, the area will eventually lose the dune structure and become degraded as DSL habitat. Hardy *et al.* (2018, p. 25) saw decreased detections of DSL at 5 percent mesquite cover.

2.5.2 Sand Dune Blowouts

Within shinnery oak dunelands themselves, DSL select for areas containing what are referred to as sand dune blowouts (Fitzgerald *et al.* 2022, p. 8). These erosional features occur throughout many dune fields of the Mescalero and Monahans Sandhills. Dune blowouts form where stabilizing vegetation is removed from a localized area by some abiotic or biotic disturbance. Winds then scour out sand from the disturbed area until a more consolidated, erosion resistant soil layer becomes exposed, creating a sparsely vegetated, bowl-like depression among the sand dunes (Figure 2-7; Machenberg 1984, p. 16; Snell *et al.* 1997, p. 3; Dhillion and Mills 2009, p. 264). Blowout depth depends on the presence of the local indurated soil layer (e.g., clay or caliche), or the local water table, below which the sands are more consolidated and erosion-resistant (Machenberg 1984, p. 16; Dhillion and Mills 2009, p. 264).

Figure 2-7 Sand dune blowout within shinnery oak duneland habitat. Credit: Johnson *et al.* (2016, p. 29).

Sand dune blowouts are essential to support the life history needs of DSL, particularly breeding. DSL prefer relatively large (>3 m [9.8 ft]) deep and 32.9 m [107.9 ft] long) blowouts (Fitzgerald *et al.* 1997, p. 17; Hibbitts *et al.* 2013, p. 108; TAMU 2016, p. 3; Walkup *et al.* 2022, pp. 352, 356). All known DSL nests have been located within blowouts, in which the female digs perpendicular to the blowout surface down to the moisture horizon, approximately 18 cm (7 in) below the surface (Hill and Fitzgerald 2007, p. 5). These large, deep blowouts with higher rugosity (bumpiness of topography) provide superior habitat with more edge for cover, more open sand, and steeper slopes (TAMU 2016, p. 9 ; Walkup *et al.* 2021, pp. 13-14; Walkup *et al.*2022, pp. 352, 356). Deeper blowouts may also present a larger three-dimensional surface area from which DSL may choose microsites that combine their thermoregulatory needs with those of foraging, protection from predators, territorial interactions, and mate seeking (Fitzgerald *et al.* 1997, p. 25). Along with the size of blowouts, DSL also choose blowouts with more northerly and easterly exposure. The destruction of dune blowouts or the alteration of blowout topography and edaphic features preferred by DSL leads to decreases in abundance and local extirpation (Sias and Snell 1998, p. 12; Hibbitts *et al.* 2013, p. 110).

2.5.3 Shinnery Oak

Shinnery oak is a deciduous, low-growing shrub, that occurs on sandy soils in southeastern New Mexico, western Texas, and western Oklahoma (Figure 2-8; Peterson and Boyd 1998, p. 1; Gucker 2006, p. 2; Dhillion and Mills 2009, p. 264). Shinnery oak is also known as sand shinnery, Havard oak, sand scrub oak, or panhandle oak (Peterson and Boyd 1998, p. 5). The common name shinnery oak is derived from the French word *chenneire*, indicating “shin-high” vegetation (Peterson and Boyd 1998, p. 5). Sandy plains, sand dunes, and sand hills are typical shinnery oak habitat (Gucker 2006, p .7). Maximal densities of shinnery oak occur where the soil surface is sand, especially where the sand layer is relatively thick, permitting water infiltration to greater depths. The permeability of sandy soils that support shinnery oak is generally high and water erosion very low (Peterson and Boyd 1998, p. 7). As the soil clay content increases, shinnery oak cover decreases. Shinnery oak density is negatively correlated with percentage clay, runoff, and water retention (Peterson and Boyd 1998, p. 7). Additionally, shinnery oak does not occur regularly where there is much calcium carbonate (i.e., caliche) in the soil (Peterson and Boyd 1998, p. 7). Shinnery oak typically dominates or co-dominates the local vegetation community with shrubs, grasses, forbs, and succulents (Peterson and Boyd 1998, p. 2). In heavier soils (i.e., soils with higher clay contents) shinnery oak is replaced by mesquite and grasses as the dominant vegetation (Peterson and Boyd 1998, pp. 7, 12).

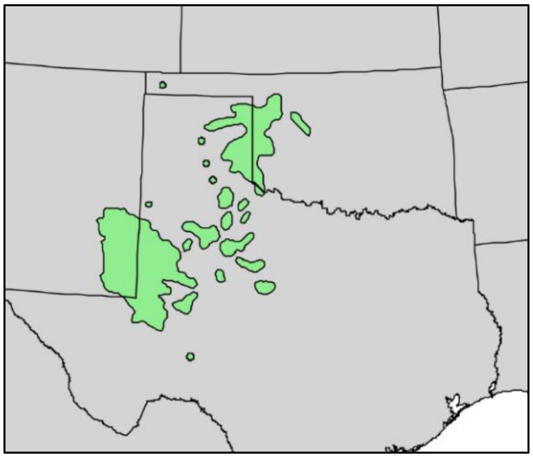

Figure 2-8 Shinnery oak distribution map. Credit: USGS 1999.

The root and rhizome system of mature shinnery oak is extensive and is concentrated in the top 50 cm (20 in) of soil for uptake of precipitation; however, the taproot of shinnery oak can extend 4.5-9 m (15-30 ft) deep in search of groundwater and soil moisture (Figure 2-9; Gucker 2006, p. 6, Peterson and Boyd 1998, p. 5). Shinnery oak is thicket-forming and spreads underground by lateral rhizomatous growth. Rhizome growth is slow, thus shinnery oak growth spreads slowly. Consequently, shinnery oak does not readily colonize open sites nor does it regrow easily if removed from a site (Gucker 2006, p. 7). In one study, reestablishment of a disturbed open space by adjacent clones was measured at just 9 m (30 ft) in 50 years (Pettit 1986, p. 1). Shinnery oak rhizomes spread laterally, commonly forming individual plants 3 to 15 m (10 to 50 ft) or more in diameter (Peterson and Boyd 1998, p. 50; Gucker 2006, p. 7).

Figure 2-9 Shinnery oak exposed root system. Credit: Peterson and Boyd (1998, p. 5).

Dzialak *et al.* (2013, entire) documented the dynamic nature of shinnery oak ecosystem in New Mexico and Texas. They found that spatial distribution, patch size, and patch isolation of the shinnery oak changed over decadal periods, responding to prevailing wind patterns, moisture and elevation gradients, sand availability, and anthropogenic disturbance. Shinnery oak is slow growing and long-lived (Gucker 2006, p. 5). Individual plants average 1 m (3.3 ft) in height, but may grow to 2 m (9.8 ft) tall, and canopy coverage can be as high as 90 percent, but averages 20 to 30 percent throughout its range (Gucker 2006, p. 5). Differences in depth of the sandy soil, sand content of the soil, and the amount of precipitation causes shrubs to be taller and denser in the eastern compared to the western portion of the range (Dhillion and Mills 2009, p. 263). Shinnery oak growth rates also increase with higher moisture levels (Gucker 2006, p. 7). Although above ground stems live only 11 to 15 years, clones may live for hundreds to thousands of years (Gucker 2006, p. 5; Dhillion and Mills 2009, p. 263).

The presence of shinnery oak is important for both the maintenance of the dune fields themselves and for the life history of DSL. These shinnery oaks, with large root and stem masses and extensive underground system of horizontal rhizomes, support dynamic sand dune systems. Shinnery oak acts as a soil stabilizer in sandy areas and influences dune formation (Machenberg 1984, p. 23; Gucker 2006, p. 14; Dhillion and Mills 2009, p. 264). Aboveground stems and leaves trap windblown sand, while the extensive root and rhizome system holds subsurface sand in place and prevents wind erosion. The upward growth of shinnery oak continues during sand deposition as the size of the sand dune grows (Machenberg 1984, p. 16; Dhillion and Mills 2009, p. 264). Peterson and Boyd (1998, p. 5) reported that the stem system of shinnery oak may grow to 9 m (30 ft) or more during sand deposition and dune formation. Ninety percent or more of shinnery oak biomass occurs underground where its root and rhizome system is typically 10 to 16 times greater than aboveground stems (Gucker 2006, p. 6).

Many species of insects utilize shinnery oak as a food source and can inhabit the shrub in high abundances (Peterson and Boyd 1998, pp. 21-22; Gucker 2006, p. 13). For example, thousands of species of insects were collected in one shinnery oak area in southeastern New Mexico (Peterson and Boyd 1998, p. 13). Densities of ants as high as 1,600 colonies per hectare of shinnery oak habitat have also been reported. Beetles have also been estimated to have a biomass of 5 kilograms (kg) per hectare in shinnery oak (Dhillion and Mills 2009, p. 269). DSL forage for insects within shinnery oak vegetation and leaf litter (Bailey and Painter 1994, p. 22; Peterson and Boyd 1998, p. 21) and take refuge from predators within shinnery oak vegetation (Peterson and Boyd 1998, p. 21). They also utilize shinnery oak vegetation for thermal refugia (i.e., shade) to minimize heat load, optimize physiological performance (i.e., feeding, breeding, and sheltering activities), and escape potentially lethal or physically damaging surface temperatures (Bailey and Painter 1994, p. 22; Fitzgerald *et al.* 1997, p. 25; Sartorius *et al.* 2002, p. 1972; Ferguson *et al.* 2014, p. 66). Significant reductions in DSL population abundance are associated with the removal of shinnery oak vegetation (Snell *et al.* 1997, p. 6).

2.5.4 Sand

Sand grain size is an important factor influencing the distribution of the DSL. The species is more abundant in areas where sand particles are larger (Fitzgerald *et al.* 1997, p. 25, Snell *et al.* 1997, p. 9). Soils with fine-grained particles (< 250 µm) may interfere with breathing physically (e.g., inhaling sand) and prevent gas exchange necessary for lizards to breathe while buried (Fitzgerald *et al.*1997, p. 25; Snell *et al.* 1997, p. 9; Ryberg and Fitzgerald 2015, p. 118). Ryberg and Fitzgerald (2015, p. 119) demonstrated that fine-grained sand collected from locations where DSL were absent had lower oxygen diffusion rates than samples with coarse sand at locations where DSL were present. Fine-grained sand may also be too compact for the DSL to bury itself, inadequate for nest excavation and egg incubation (Ryberg *et al.* 2012, p. 584), and have properties that prevent adequate exchange of gasses and water between eggs and the substrate surrounding subterranean nest chambers (Snell *et al.* 1997, p. 9). Laboratory and field experiments determined that DSL select sites with more medium-grained sand (250-354 µm) and do not use fine-grained sands (Fitzgerald *et al.*1997, p. 12). Sand grain size may also be important in the establishment of dune blowouts and can influence the dune structure and vegetation (Fitzgerald *et al.* 1997, p. 5).

2.5.5 Groundwater

Sand dunes derive soil moisture primarily from precipitation and groundwater. Groundwater intersects the soil column at the base of the dune (Garza and Wesselman 1959, pp. 23-24; White 1971, p. 17; Kocurek and Havholm 1993, pp. 394, 398-400, 407; p. 4; Newton and Allen 2014, pp. 1, 4; Forstner *et al.* 2018, p. 4) or is pulled upward into the soil column of the dune by capillary potential (Newton and Allen 2014, pp. 17, 28-31). The water table underlying sand dune formations often exhibits a relationship to surface topography, forming a dome in sand dune accumulations (Pye 2009, pp. 333-334, 363-364).

Soil water affects sand dune stability and geomorphology (Machenberg 1984, pp. 6, 19; Kocurek and Havholm 1993, pp. 394, 398-400, 407, Newton and Allen 2014, pp. 1, 4). Soil water gives dune sands cohesiveness as capillary action holds sand grains in place, allowing dunes to resist wind erosion (White 1971, p. 17; Machenberg 1984, p. 19; Kocurek and Havholm 1993, pp. 394, 398; Newton and Allen 2014, p. 17). Similarly, soil water enables sand dunes to support vegetation, which reduces wind shear and erosion (Machenberg 1984, pp. 9, 16, 19, 20-22; Pye 2009, pp. 333-334; Dhillion and Mills 2009, pp. 264, 270-271). The formation and morphology of interdunal blowouts is also influenced by the depth of the local water table, below which sand is consolidated and resistant to wind erosion (Machenberg 1984, p. 16; McCord and Stephens 1987, pp. 236-237; Newton and Allen 2014, pp. 3, 24, 26-27, 46).

Water availability is a limiting factor for the establishment and growth of shinnery oak (Peterson and Boyd 1998, pp. 8, 11). Shinnery oak, like other phreatophytes, is a deep-rooted plant that obtains a portion of its water supply from the water table (Robinson 1958, pp. 9-10; Machenberg 1984, pp. 20-21, 34; Peterson and Boyd 1998, p. 5; Gucker 2006, p. 6; Pye 2009, pp. 333-334). Shinnery oak has a shallow root system near the soil surface for uptake of precipitation, and a taproot that extends deep below ground for the absorption of water (Peterson and Boyd 1998, p. 5; Gucker 2006, p. 6). Its deep growing tap root allows shinnery oak to access groundwater in arid and drought prone environments where precipitation may be unable to sustain plants year-round (Robinson 1958, pp. 9-10; Machenberg 1984, pp. 20-21; Peterson and Boyd 1998, p. 5; Gucker 2006, p. 6). The combination of groundwater and vegetation produces what is referred to as a “stabilized aeolian system” in which groundwater and shinnery oak vegetation stabilizes the structure of the sand dunes (Kocurek and Havholm 1993, pp. 401-402). This facilitates the formation of irregular, erosional sand dune blowouts that are preferred by the DSL.

2.5.6 Shinnery Oak Shrublands and Other Habitats

Shinnery oak shrublands (flats) occur throughout the Mescalero and Monahans Sandhills as flat-to-low rolling plains in which blowouts are somewhat deflated (i.e., reduced vertical dimensions) and limited to smaller scattered patches (Johnson *et al.* 2016, p. 87; Hardy *et al.* 2018, p. 24). Although they are also characterized by shinnery oak-sand substrate, they do not possess the rugosity and topographic complexity of duneland (Walkup *et al.* 2021, p. 20). Thus, these areas do not possess the critical attributes to support robust DSL populations. However, that does not mean these areas are entirely unused by DSL. Although most DSL detections are located within

dunelands (Hardy *et al.* 2018, p. 18), individual DSL have been found in shrublands and flats adjacent to dunelands in multiple studies (Fitzgerald *et al.* 2005, p. 12, Hardy *et al.* 2018, pp. 19, 21, 25-26, Painter 2004, p. 5). This is because fine-scale environmental conditions result in local variation in habitat quality, and studies have demonstrated intermittent use of less suitable habitat in areas occupied by DSL through time (Walkup *et al.* 2022, pp. 358). Hardy (*et al.* 2018, p. 19) found that 98 percent of DSL observations in New Mexico were found within dunelands. Shrublands adjacent to dunelands may support DSL feeding and sheltering and may occasionally possess blowouts that are adequate to support limited reproduction. Importantly, shinnery oak shrublands may be dispersal corridors for juvenile and adult DSL that connect patches of duneland habitat. Indeed, studies of DSL demography and movement suggest that areas of highly suitable habitat with robust reproduction sustains areas of less suitable habitat with low or no reproduction through movement of individuals (Walkup *et al.* 2022, p. 358).
Shinnery oak-honey mesquite shrublands dominated by mesquite, but with some shinnery oak inclusions, also occur in the Mescalero and Monahans Sandhills. When adjacent to, or embedded within shinnery oak dunelands, shinnery oak-honey mesquite shrublands can function as dispersal corridors for the DSL (Hardy *et al.* 2018, p. 21). Grasslands, when interspersed with blowouts and adjacent to shinnery oak dunelands, can also function as dispersal corridors (Hardy *et al.* 2018, p. 21). Based on guidelines developed by Painter (2004), Johnson *et al.* (2016) indicated that the scale of the dispersal habitat corridors was 500 m (1,640 ft) wide connecting patches of shinnery oak dunelands within 2,000 m (6,562 ft) (Hardy *et al.* 2018, p. 26).

Shinnery oak shrublands and flats also buffer dunelands from impacts, allow for shifting habitat over time, and offer habitat for species that DSL prey upon (Painter 2004, p. 3524; CPA 2012, p. 76; Dzialak *et al.* 2013, p. 1371, 1379-1383; Johnson *et al.* 2016, p. 39; TAMU 2016, p. 2; Hardy *et al.* 2018, p. 21, 25-27).

2.5.7 Dynamic Shinnery Oak Duneland Ecosystem

The landscape created by the shinnery oak duneland ecosystem is a spatially dynamic system (Dzialak *et al.* 2013, entire). Shinnery oak duneland habitat moves slowly with natural process like wind, rain, and disturbance. Areas that are currently large deep blowouts with preferred grain size, steepness and cover to support populations of DSL may not always be such suitable habitat and likewise areas that are currently shinnery oak flats could build into dune complexes that could support the species. However, these changes typically occur over long-time scales (centuries to millennia). DSL populations will move across the landscape tracking sand dune blowouts, which is the obligate habitat for the species. Areas that are currently unoccupied may become occupied with shift in dunes over time, influenced by the rate of landscape change and low dispersal capability of the DSL (Fitzgerald *et al.* 1997, p. 28; Dzialak *et al.* 2013, p. 1371-1372, 1379-1383; Hardy *et al.* 2018, p. 27).

Dzialak *et al.* (2013, entire) examined changes in shinnery oak dunelands in eastern New Mexico and west Texas using aerial photography from 1986-2011. Their research showed that smaller, isolated patches of shinnery oak dunelands on the periphery of the system were more likely to be lost over time (Dzialak *et al.* 2013, p. 1377). Emergence of duneland was most likely to be associated with larger, less isolated existing patches relatively close to the geographic center of the systems. While the Mescalero Sandhills showed an overall decrease in area and Monahans Sandhills an overall increase, the range of DSL showed an overall decline of 10.3 percent of the duneland system during the 25-year window. This translates into a 0.41 percent loss of dunelands annually. Additionally, this research showed a 13.1 percent decrease in patch sizes and a 27.3 percent increase in patch isolation over the entire region (Dzialak *et al.* 2013, p. 1377).

2.6 Population Dynamics

2.6.1 Demographics

As a temperate lizard species, DSL experiences seasonal birth pulses. The age structure of these types of species corresponds to a yearly breeding phenology with relatively high proportions of adults and young-of-year at the beginning of the breeding season, a peak in the proportion of adults during the middle of the breeding season as juveniles mature, and a peak in the proportions of juveniles near the end of the breeding seasons as hatchlings emerge (Walkup *et al.* 2017, p. 2). Over time, the age structure is expected to be stable, despite seasonal changes. Population simulations based on trapping data in New Mexico suggests that population growth rates are most sensitive to juvenile and adult survival, although percentage of females breeding and fecundity of older individuals was also important (Leavitt and Acre 2021, pp. 20-28)

However, spatial heterogeneity in habitat quality, within habitat patches, can also drive regional population dynamics by shaping the movement, behavior, and habitat selection of DSL (Figure 2-10; Ryberg *et al.* 2015, p. 888). For example, studies of DSL demography and movement suggest that areas of highly suitable habitat with robust reproduction sustains areas of less suitable habitat with low or no reproduction through movement of individuals (Walkup *et al.* 2022, pp. 358).

Vital rates of DSL population growth are affected by the shape of blowouts: the importance of juvenile survival and fertility on population growth rates increases and the importance of adult survival on population growth rates decreases with more complex blowout shape (Ryberg *et al.* 2015, p. 888; Johnson *et al.* 2016, p. 10). Further, the spatial layout of blowouts in continuous habitat regulates the size of DSL neighborhoods, which is positively related to recruitment (Ryberg *et al.* 2013, p. 4; Johnson *et al.* 2016, p. 10). Given that DSL is territorial, the presence of adult lizards in ideal source habitat (i.e., regularly shaped blowouts with less edge) leads to dispersal of juveniles into less ideal, unoccupied territories (i.e., irregularly shaped blowouts with lots of edge) (Ryberg *et al.* 2015, p. 893). Based on data collected in Chaves County, New Mexico, annual adult survival rates were nearly three times as high as juvenile survival rates (0.67 versus 0.26, respectively) (Ryberg *et al.* 2013, p. 4). Although Ryberg *et al.* (2015, p. 895) documented DSL populations with on average increasing growth rates (population growth rate [λ]=1.18), they did note other studies indicated that DSL populations decline with only minor disturbances to the system, and populations disappear from fragmented areas even where degraded dune blowouts remain (Leavitt and Fitzgerald 2013, p. 9).

2.6.2 Population structure

The DSL exhibits a dynamic population structure at localized scales, wherein a series of subpopulations are patchily distributed throughout areas of contiguous habitat. These subpopulations or concentrations of DSL are referred to as “neighborhoods” (Ryberg *et al.* 2013, p. 1). Individual neighborhoods can be small and depend on the configuration of dune blowouts (Figure 2-10). Ryberg *et al.* (2013, p. 6) found that DSL neighborhoods distributed within a contiguous patch of shinnery oak duneland habitat and separated by distances ranging from 0.6 to 3.6 km (0.4 to 2.2 mi) had their own distinct recruitment patterns. Larger neighborhoods act as net exporters of individuals (sources) and smaller neighborhoods as net importers (sinks), via movement of individuals (Ryberg *et al.* 2013, p. 4; Walkup *et al.* 2022, pp. 358). Larger neighborhoods exhibit higher recruitment and population diffusion rates, acting as sources for smaller neighborhood sinks with negligible recruitment. It is important to recognize that a DSL population, even within a contiguous patch of habitat, is itself composed of aggregations of localized neighborhoods that interact with each other.

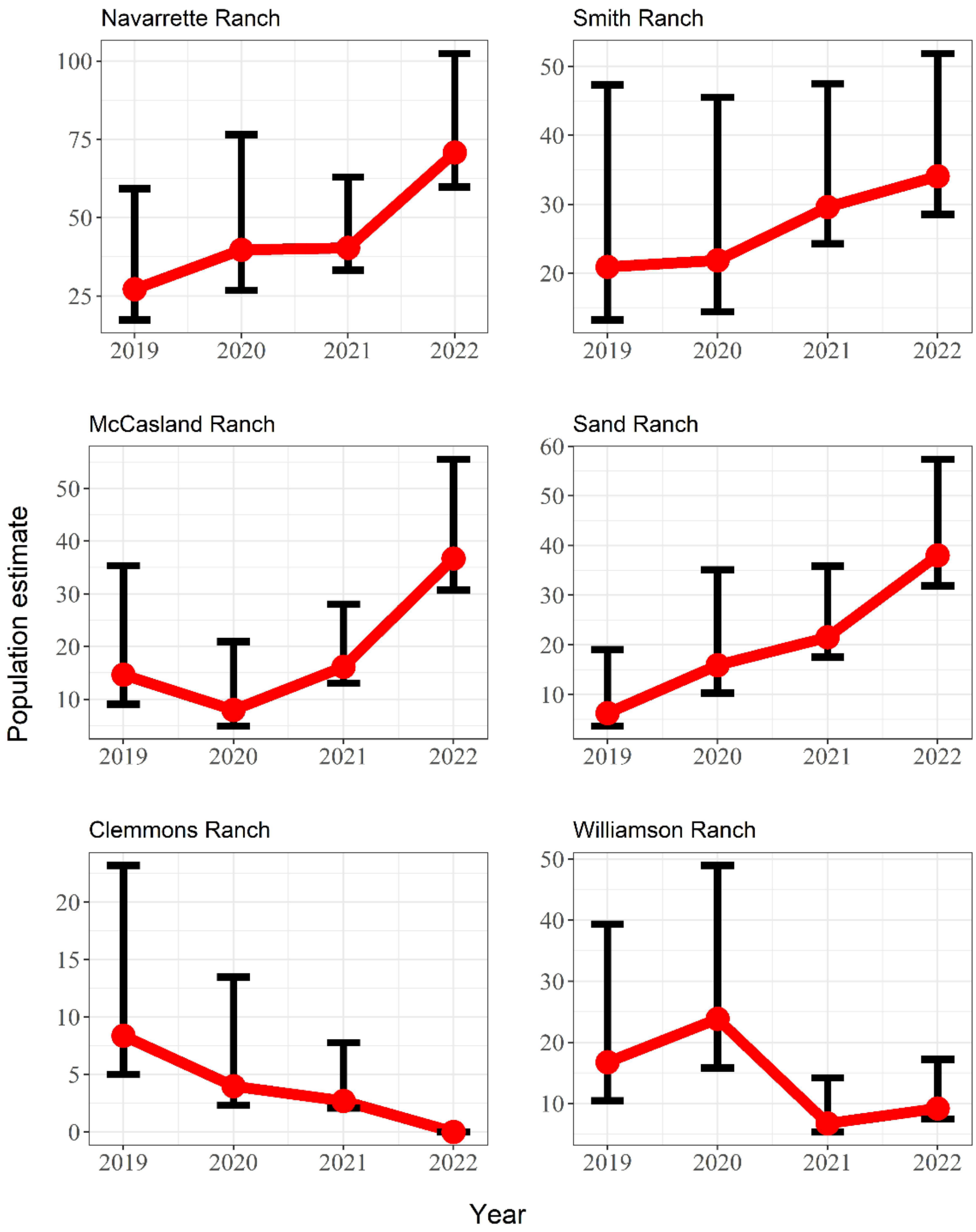

Figure 2-10 Population estimates of DSL from most recent surveys from 2019-2022 survey at 6 sites in the Mescalero Sandhills, New Mexico. 2022 surveys appear to show a potential extirpation at one of the long-term monitoring sites. Credit: Acre and Hill 2023, p. 11.

These diffusion-dispersal, source-sink dynamics of DSL neighborhoods result in a pattern of natural extinction and re-colonization of habitat over time, producing a patchwork of occupied and unoccupied areas across a landscape of otherwise suitable habitat (Fitzgerald *et al.* 1997, p. 28; Fitzgerald *et al.* 2005, p. 1; Walkup *et al.* 2022, pp. 358; Acre and Hill 2023, p. 11, Figure 2-10). That is, DSL may not occur in all areas of suitable habitat due to natural extinction-colonization dynamics (Fitzgerald *et al.* 1997, p. 28; Painter *et al.* 1999, p. 51; Fitzgerald *et al.* 2005, p. 1) and the current state of occupancy may not necessarily reflect the future state at a site (Walkup *et al.* 2018, p. 503). Thus, it is important to include the consideration of currently unoccupied but potentially suitable habitat patches within the range of the DSL, especially since dispersal rates and their mechanisms are not well-understood (Painter *et al.* 1999, p. 36; Hardy *et al.* 2018, p. 20).

Scaling up to the species range, genetic research has identified nine to ten groupings of DSL that occupy spatially distinct, contiguous patches of duneland habitat (Chan *et al.* 2014, pp. 15-28; Chan *et al.* 2020, entire). These groups correspond to notable breaks and pinch points in the dune formations found in both the Mescalero and Monahans Sandhills (see Chapter 3). Within these groups themselves, the DSL exhibits patterns of isolation by distance and resistance, meaning the combination of both sheer spatial distance and landscape features influence gene flow (Chan *et al.* 2014, pp. 33-41; Chan *et al.* 2017, pp. 9-22). Patches of duneland habitat that support these aggregations may be connected via shrubland or other habitats that support dispersal. Given that DSL have only been documented dispersing limited distances through these habitats (Fitzgerald *et al.* 1997, Appendix II; Painter 2004, p. 5; Johnson *et al.* 2016, p. 39), the spatial orientation of duneland patches relative to surrounding habitat is important for determining whether populations may interact. These findings, and the results of the home range and dispersal studies, suggest that gene flow among DSL populations is maintained by cumulative short distance movements of individuals across many generations with long-range, inter-dune field movements being rare (Chan *et al.* 2009, p. 137; Ryberg *et al.* 2013, p. 6).

2.6.3 Population abundance data

Because of the dynamic nature of DSL populations and differences in sampling methods (Smolensky and Fitzgerald 2010, entire), estimating metrics such as population size and range-wide occupancy have proved challenging (but see Leavitt and Acre 2021, entire). There is no range-wide population size estimate for the DSL due to differences in land access, survey protocols, and survey intensity across the range in New Mexico and Texas. However, several studies have attempted to make inferences about population trends. An analysis by Johnson *et al.* (2016, p. 38) suggested that in New Mexico DSL numbers have declined in areas with decreased habitat quality, and Leavitt and Hill (2020, entire; Acre and Hill 2023, p. 11) also note that some high-quality habitat locations that formerly had high DSL abundance are now showing declining DSL numbers. More recently, Leavitt and Acre (2021, entire) used trapping data to estimate DSL densities in relation to environmental variables and then extrapolate population totals for the New Mexico portion of the range (Figure 2-11). They estimated a population size of 1,015,945 individual DSL with the 95 percent confidence interval ranging from 225,766 to 4,363,797 individuals (Table 2-1). Densities were predicted to be highest in the North Mescalero 3 and 5 Analysis Units (see Chapter 5).

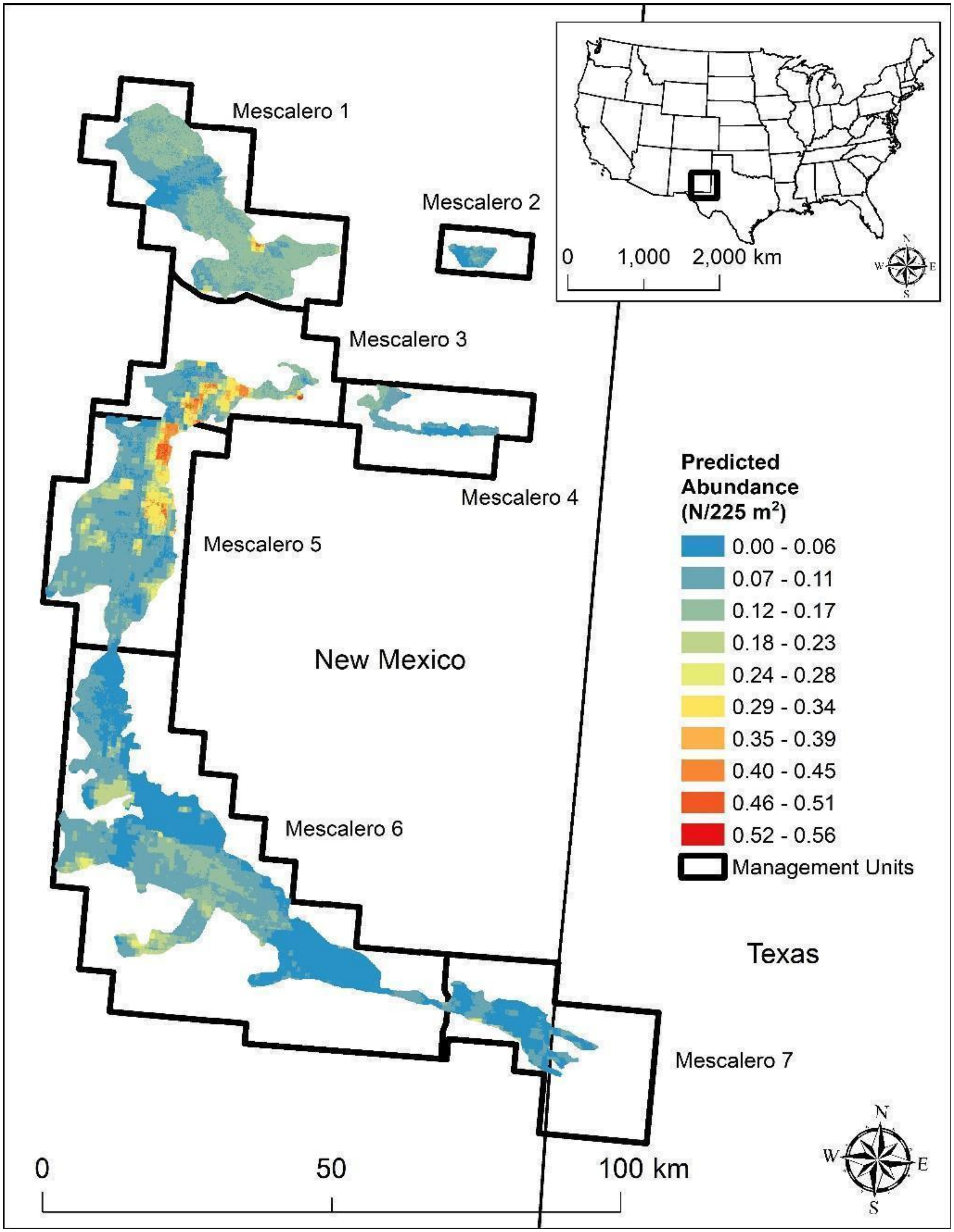

Figure 2-11 Density estimates of DSL per 225 m^2 in New Mexico based on trapping grid data. Credit: Leavitt and Acre (2021, p. 20).

Table 2-1 Estimates of total DSL population size from Leavitt and Acre (2021, p. 21) for each Analysis Unit in New Mexico. LCL is the lower bounds of the 95 percent confidence interval of the population estimate and UCL the upper bounds of the 95 percent confidence interval. Note that Leavitt and Acre (2021, entire) had a different naming convention for their analysis units (see Figure 2-11). The Analysis Unit names in this table are those developed for this SSA.

Representation Unit	Analysis Unit	Total population estimate	LCL	UCL
N Mescalero	N Mescelaro 1	236,687	52,597	1,35,447
	N Mescelaro 2	6,851	1,522	38,364
	N Mescelaro 3	117,158	26,035	656,087
	N Mescelaro 4	20,887	4,642	116,917
	N Mescelaro 5	284,084	63,130	1,590,871
S Mescalero	S Mescalero 1	317,513	70,559	1,778,075
	S Mescalero 2	32,765	7,281	183,483

During the public comment period for the proposed listing rule, we also received unpublished data on genetic effective size for all ten Analysis Units (Chan pers. comm. 2023)(Table 2-2). These effective sizes were estimated using the microsatellite data and DSL samples published in Chan *et al.* (2020, entire). There are several caveats to these estimates. First, sample sizes for some of the Analysis Units are low to accurately estimate effective sizes. Also, estimates with confidence intervals or point estimates of infinity or negative values may violate the assumptions of the method. Considering those facts, only two Analysis Units had point estimates above 500, and six were below 50. The largest effective sizes corresponded with the largest Analysis Units by area in Mescalero Sandhills, while none of units in the Monahans Sandhills with above 50. There are no species-specific estimates of effective to census size ratio for DSL that could be used to extrapolate overall abundance. The general guidance for vertebrates is to use a ratio of 0.1 (Hoban *et al.* 2020, p. 7) and for a related species (*Sceloporus olivaceus*) the ratio was estimated at 0.22. Again, considering all the caveats mentioned above regarding the effective size estimates, using those ratios would result in abundance estimates below 10,000 for each Analysis Unit.

Table 2-2 Estimates of N_e for groups delineated in Chan et al. (2020). Reported are corresponding SSA Analysis Unit, sample size (N), estimate of effective population size (N_e), and 95% confidence intervals (CI) under parametric and jackknife approaches.

Group from Chan et al. 2020	**Analysis Unit (SSA)**	**N**	N_e	**95% CI (Parametric)**	**95% CI (Jack-knife)**
AA	North Mescalero 1	22	437.0	115.9-infinite	58.6-infinite

AB	North Mescalero 2	10	12.3	8.4-19.6	2.7-infinite
BA	North Mescalero 3	42	658.4	286.7-infinite	150.8-infinite
BB	North Mescalero 4	6	16.5	4.0-infinite	2.6-infinite
C	North Mescalero 5	20	988.8	148.9-infinite	108.8-infinite
DA	South Mescalero 1	76	401.1	291-632.0	225.9-1448.4
DB	South Mescalero 2	16	39.8	27.1-69.5	12.4-infinite
EA	Monahans 1	27	-2701.4	305.3-infinite	196.0-infinite
EB	Monahans 2	10	39.0	20.0-209.9	13.2-infinite
EC	Monahans 3/4	8	27.2	11.8-infinitie	2.8-infiite

2.6.4 Occurrence data

Rather than estimating population numbers or densities, most surveys have primarily been oriented toward documenting the occurrence of DSL. When the distribution of the species was first defined in New Mexico, there were 72 sites where DSL was verified to occur. Thirty of these sites are in Chaves County, 8 in Eddy County, 4 in Roosevelt County, and 30 in Lea County (Fitzgerald *et al.* 1997, Appendix 1). The Bureau of Land Management (BLM) conducted surveys in conjunction with applications to drill for oil and gas, and a habitat suitability study in 2006-2007. During these surveys DSL were found at 36 sites, 8 of which were not within the previously known geographic range of the species but were in either shinnery oak duneland, blowouts, along pipelines, or in shinnery oak shrubland within 2.8 km (1.7 mi) of the known geographic range (Bird 2007, p. 1). All distribution surveys or surveys in conjunction with applications to drill have been presence/absence surveys and did not attempt to estimate population size. In areas where DSL are observed early in the survey process, it was assumed that DSL are relatively abundant in that given location. Conversely, in areas where DSL were only found after a long, intensive survey, it could be an indication of lower numbers or a difference in detection probability.

In 2006 and 2007 surveys were conducted in the Monahans Sandhills to determine the distribution of the DSL in Texas. Thirty-two standardized surveys were conducted at 27 sites where shinnery oak vegetation was present in Andrews, Crane, Cochran, Ector, Ward, and Winkler counties. Of the 27 sites surveyed, only DSL were found at only 3 sites (Laurencio *et al.* 2007, p. 8). In these areas, the search time to find DSL was over 68 person-minutes and up to 115 person-minutes; comparatively, for sites in New Mexico 74 percent of DSL are found within 31 person-minutes (Laurencio *et al.* 2007, p. 10). In the north and western sectors of Crane County, shinnery oak duneland habitat exists but no DSL were found. This area has been fragmented with oil and gas development and off-highway vehicle use (Laurencio *et al.* 2007, p. 10). Two of the three sites containing lizards in Texas were in a large band of sand dunes in shinnery oak located in Ward, Winkler, and Andrews Counties. One DSL was found at a site in

Gaines County that is technically the eastern-most portion of the Mescalero Sandhill complex that extends from New Mexico into Texas (Laurencio *et al.* 2007, p. 11). Survey data remains limited in parts of the species range in Texas and other parts of the range remain completely un-surveyed due to limited access to private lands (Walkup *et al.* 2021, p. 13). Furthermore, because DSL absence was not consistently confirmable across many surveys, non-detection of DSL during surveys may not equate to species absence in surveyed areas (Walkup *et al.* 2022, pp. 354, 357).

One location where the DSL has been documented multiple times in Texas is Monahans Sandhills State Park, which overlaps a portion of Ward and Winkler Counties. Monahans Sandhills State Park is a well-known historical locality that is the only known area where DSL has been found on public land in Texas, with confirmed records from 2010, 2015, 2016, 2019, and 2020 (Fitzgerald 2010, entire; iNaturalist community 2022.).

In Texas, there have been several efforts to develop occurrence maps for DSL. In June 2011, Texas A&M AgriLife Research (TAMU) conducted surveys in the Permian Basin in Texas. Fifty sites were surveyed in Andrews, Crane, Ector, Ward, and Winkler Counties. Most surveys were conducted in Andrews (37 percent) and Ward (39 percent) Counties; fewer surveys were conducted in Crane (10 percent), Ector (4 percent), and Ward (10 percent) Counties. DSL were found at 27 of the 50 survey sites. Nineteen and eight DSL were detected in Andrews and Winkler Counties, respectively. One DSL was detected in Ward County and none in Crane and Ector Counties (Fitzgerald *et al.* 2011, pp. 9-14). Texas A&M AgriLife Research utilized the results of these surveys and aerial photography to develop a likelihood of occurrence map that was used to define DSL Habitat for purposes of the Texas Conservation Plan for the DSL. This map is referred to as the TCP Permit Area/Likelihood of Occurrence Map or Hibbitts Map (TCP 2012, Figure 1.2).

From May 2014 to August 2016, TAMU conducted 339 DSL surveys at 100 sites in Texas (Walkup *et al.* 2018, entire). They estimated occupancy and extinction probabilities for the DSL for part of its range in Texas, to increase understanding of the distribution of the species and to evaluate the Hibbitts map that identifies areas according to Very High, High, Low, and Very Low categories of likelihood-of-occurrence (Walkup *et al.* 2018, p. 497). In total, they selected 100 sites for surveys in four of the six counties with historical records of DSL (Andrews County, n = 50 sites; Crane County, n = 20 sites; Ward County, n = 13 sites; Winkler County, n = 17 sites). The study concentrated sites in areas of Very High likelihood of occurrence (n =119) and areas outside of suitable habitat (n = 50), with fewer surveys in the other categories of occurrence (Low, n = 13; Very Low, n = 24). They only found DSL in areas that were classified as Very High likelihood-of-occurrence under the Hibbitts map (Walkup *et al.* 2018, p. 500).

Natural Heritage New Mexico (Johnson *et al.* 2016, p. 17) used field data in conjunction with satellite imagery and aerial photography to create a range-wide map for New Mexico based on plant associations and further modified by landform. The result was a high spatial-resolution habitat map with focus on blowouts within dunes and surrounded by shinnery oak (Johnson *et al.* 2016, Appendix B). Texas State University (Hardy *et al.* 2018, p. i; Jensen and Hardy 2021, entire) created a DSL habitat model depicting the spatial distribution and suitability of DSL habitat within Texas. Development of the map relied on an extension of the analytical approach taken in development of the DSL map by Natural Heritage New Mexico. Hardy *et al.* (2018, entire) relied on aerial photography and remote sensing techniques for image classification to create a map based on land cover attributes within the context of landscape scale features. Habitat categories targeted landscape level features such as shinnery oak dune complexes, shinnery oak flats, dunes, etc., derived from defined habitat types in the New Mexico model (Hardy *et al.* 2018, p. 36). However, it important to note that these models did not incorporate presence/absence data to calibrate the models. Instead, they are based on known habitat associations to make inferences about the location and abundance of potentially suitable DSL habitat across the landscape.

Walkup *et al.* (2022, entire) used DSL presence data gathered from several surveys conducted in Texas to develop a probability of occurrence model based on environmental variables. Using 67 presence points collected from 1998 to 2019, they found that DSL probability of occurrence was positivity related to mean maximum rugosity and negatively associated with percent cover of shinnery oak. They then generated a species distribution model of DSL occurrence probability, revealing a patchy and disjunct distribution across the species range in Texas (Walkup *et al.* 2021, pp. 16-20; Walkup *et al.* 2022, pp. 354-356). The authors were unable to survey parts of the species range, such as southwestern Andrews County, northern Winkler County, and much of the northeastern part of Ward County due to lack of access to private land. They also had limited survey data from Ector County, western Winkler County, and north and central Crane County (Walkup *et al.* 2022, pp. 354, 357). Furthermore, because DSL absence was not consistently confirmable across many surveys, non-detection of DSL did not necessarily equate to species absence in surveyed areas (Walkup *et al.* 2022, pp. 352, 354, 357). As a result of the abovementioned limitations, the authors recommend caution when interpreting low predicted probabilities of occurrence produced by their model (Walkup *et al.* 2022, p. 357).

Chapter 3: Species Viability

3.0 Summary

The key requirement for long-term DSL viability is large, intact shinnery oak duneland ecosystems to complete their life history and maintain healthy populations (TAMU 2016, p. 3). We present these ecological requirements at the species and populations scales in terms of representation, redundancy, and resiliency that contribute to overall species' viability.

Within the DSL, there are three divergent and spatially discrete evolutionary lineages: we consider the three lineages and the areas they occupy (northern Mescalero, southern Mescalero, and Monahans) as Representative Units to capture potential adaptive capacity. Each Representation Unit is composed of several genetically distinct groups, which also correspond to natural and anthropogenic breaks in the shinnery oak duneland landscape (Chan *et al.* 2020, entire). We have designated these groupings as our Analysis Units for this SSA. The northern Mescalero contains five Analysis Units, the southern Mescalero contains two Analysis Units, and the Monahans contains four Analysis Units. Maintaining multiple, highly resilient populations (i.e., Analysis Units) within the three Representation Units is essential to promote redundancy and overall species viability.

For the populations themselves to remain resilient, they require large, intact, functioning shinnery oak duneland and shrubland habitat with large dune blowouts and rugose terrain, with limited anthropogenic disturbance. Shinnery oak duneland habitat provides the primary features necessary to support neighborhoods of DSL, whereas both duneland and shrubland habitat facilitate dispersal to maintain source-sink dynamics.

3.1 Representation

Representation describes the species ability to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. It is characterized by the breadth of genetic and environmental diversity within and among populations that may facilitate adaptation (Smith *et al.* 2018, p. 304). The more representation, or adaptive capacity, the species has, the higher its potential of adapting to future changes, whether caused by nature or humans, in its environment.

3.1.1 History of the Mescalero and Monahans Dune Fields

The Mescalero and Monahans Sandhills are a northwest-southeast trending series of dune fields and sand sheets located within the Pecos River Valley in New Mexico and Texas (Figure 3-1; Holliday 2001, p. 91). They are adjacent to the western escarpment of the Southern High Plains, or Llano Estacado, which is a broad plateau covering approximately 130,000 km^2 (50,193 mi^2) of eastern New Mexico and Western Texas. Altitudes range from 1,700 m (5,577 ft) in the northwest to 750 m (2,460 ft) in the southeast (Holliday 2001, p. 89). Sand dune and sand sheet deposits cover only about 10 percent of the Southern High Plains and the Mescalero and

Monahans Sandhills are one of three dune fields in this region (Holliday 2001, p. 89). From north to south, the four major dune fields of the Southern High Plains are the Muleshoe, Lea-Yoakum, Mescalero, and Monahans dune fields (Figure 3.1 below, Holliday 2001, p. 91; Rich and Stokes 2011, p. 222-224). The Mescalero Sandhills encompass an area in New Mexico in Chaves, Roosevelt, Lea, and Eddy County as well as a small section on the border of Gaines and Andrews County in Texas. The Monahans Sandhills encompass an area in Texas, covering portions of Andrews, Crane, Cochran, Ector, Ward, and Winkler Counties.

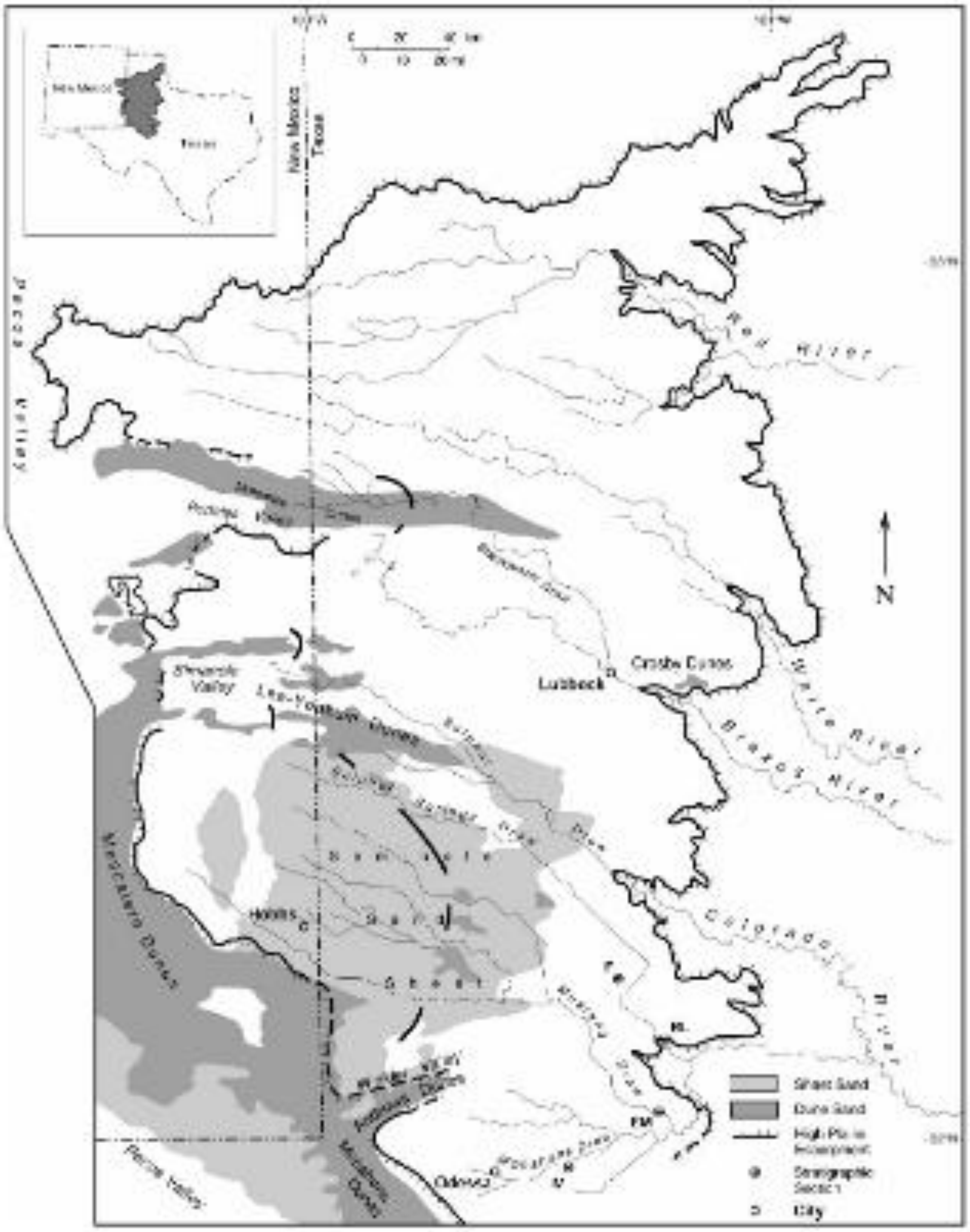

Figure 3-1 Map of the dune fields of the Southern High Plains. Credit: Holliday (2001, p. 91).

The dune fields of the Mescalero and Monahans Sandhills consist of windblown sand that began accumulating several thousand years ago in the late Pleistocene-early Holocene periods (Machenberg 1984, p. 4; Muhs and Holliday 2001, p. 75; Rich and Stokes 2011, entire). The sandy source material for these landforms was originally derived from erosion of igneous and sedimentary rocks in the southern Rocky Mountains and transported to Pecos River Valley by fluvial processes via ancestral streams and waterways (Machenberg 1984, p. 8). As the climate dried at the end of the Pleistocene, streams that once flowed permanently became ephemeral, leaving sand and silt unconsolidated in floodplains and exposed to the elements (Machenberg 1984, p. 6). Eolian (i.e., wind driven) processes then concentrated this sand along the western escarpment of the Southern High Plains, creating the dune fields and sand sheets present today (Machenberg 1984, p. 3, Holliday 2001, p. 89; Muhs and Holliday 2001, p. 78; Rich and Stokes 2011, entire). Stratigraphic analysis, radiocarbon ageing, and optical dating indicate that eolian dune building began during the late Pleistocene (>10,000 years before present) and occurred thereafter in several phases throughout the Holocene (<10,000 years ago). Most sand dune and sand sheet formations of the Mescalero and Monahans dune fields are late Holocene age, dating mostly before 1,500 years before present (Holliday 2001, p. 88; Rich and Stokes 2011, p. 238). This windblown sand was derived from the Pleistocene Blackwater Draw Formation, an older, extensive eolian deposit that crops out east of the region (Jones 2004a, p. 121).

The Mescalero and Monahans Sandhills experience a regime of strong winds, which exert control over dune morphology and movement (Machenberg 1984, p. 3). In general, the dune fields of the Southern High Plains are known to be affected by wind erosion, especially during periods of drought and loss of vegetation cover (Holliday 2001, p. 102). However, the Mescalero and Monahans Sandhills are currently in a state of equilibrium, stabilized by vegetation and groundwater (Machenberg 1984, p. 29; Muhs and Holliday 2001, p. 75). Muhs and Holliday (2001, p. 75) considered the Mescalero and Monahans Sandhills to be a sediment availability limited system. That is, sediment is mostly stabilized by vegetation cover and not available for wind transport.

3.1.2 Climate of the Mescalero and Monahans Sandhills

The Mescalero and Monahans Sandhill region is located along the margins of the Chihuahuan Desert and has a climate consistent with a semi-desert system (Breckle *et al.* 2008, p. 441). Indeed, Muhs and Holliday (2001, p. 77) considered the Monahans Sandhills, to be part of the Chihuahuan Desert instead of the southern Great Plains. As such, the climate of the Mescalero and Monahans Sandhills is semiarid (i.e., dry) and characterized by low precipitation, high evaporation rates, large variations in daily temperature, and high winds (Machenberg 1984, p. 3; Boghici 1998, p. i; Holliday 2001, p. 88).

Rainfall averages approximately 39.9 cm (15.7 in) per year with most precipitation falling during the spring and summer (Machenberg 1984, p. 3; Leavitt 2019a, p. 6). Furthermore, rainfall is highly variable from year to year and the region is subject to severe droughts (Machenberg 1984, p. 3; Holliday 2001, p. 102). Season-long and multi-year droughts are common in the Mescalero and Monahans Sandhills. In any 10-year period, it is common for the region to experience 2 or 3 years with less than 75 percent of the average annual precipitation (Peterson and Boyd 1998, p.

14). Long term average precipitation decreases with latitude; thus, the Monahans Sandhills receive less precipitation than the Mescalero Sandhills (Figure 3-2; Leavitt 2019a, p. 8).

The Mescalero and Monahans Sandhills have an average annual temperature of 16.3°C (61.3°F), an average maximum temperature of 24.7°C (76.4°F), and an average minimum temperature of 7.9°C (46.2°F). The average daily temperature range is 16°C (30.2°F) and extreme seasonal highs and lows are common during warmer and cooler months (Machenberg 1984, p. 3; Levitt 2019, p. 6). For example, summertime temperatures often exceed 37°C (99°F) (Ferguson *et al.* 2014, p. 65).

A latitudinal gradient in precipitation and temperature exists from north to south within the Mescalero and Monahans Sandhills. In general, moving 1° latitude from north to south results in a 1.1°C (2°F) mean annual maximum temperature increase and a 5 cm (2 in) decrease in total annual precipitation (Figures 3-2, 3-3; Levitt 2019, pp. 7-8). Potential evapotranspiration also increases from north to south (Holliday 2001, p. 101).

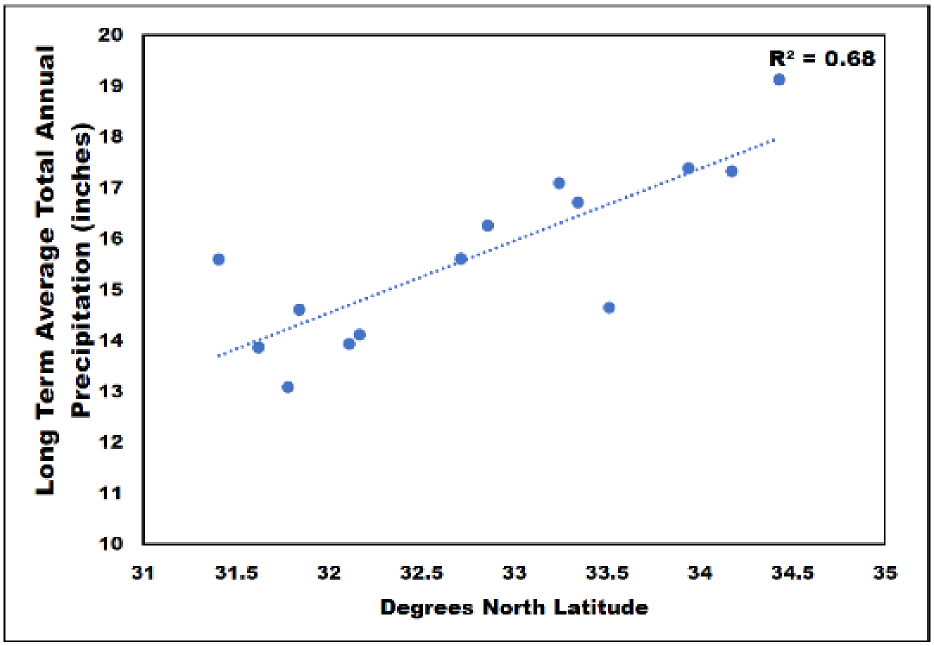

Figure 3-2 Long term average annual precipitation in relation to latitude within the Mescalero and Monahans Sandhills, New Mexico and Texas. Credit: Leavitt (2019, p. 8).

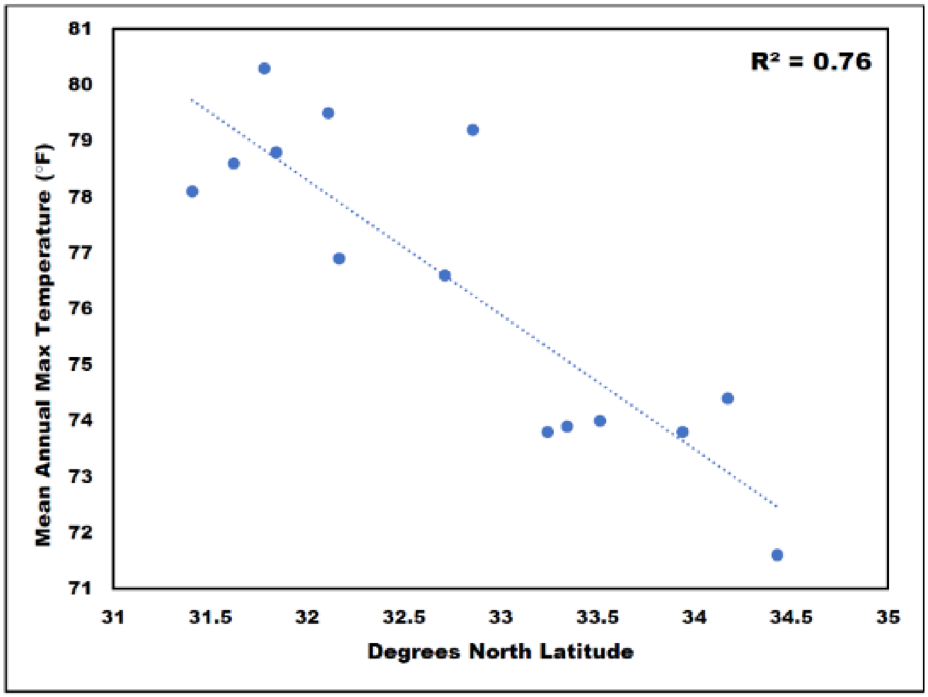

Figure 3-3 Mean annual maximum temperature in relation to latitude within the Mescalero and Monahans Sandhills, New Mexico and Texas. Credit: Leavitt (2019, p. 7).

3.1.3 Defining Representation Units

Given that the DSL occurs in two spatial disjunct sandhill regions (Mescalero and Monahans) that mostly fall in two separate states (New Mexico and Texas, respectively), these two regions have traditionally served as the primary subdivision to delineate the species. For example, as indicated in Chapter 2, any given survey or mapping effort is usually restricted to one of the states. Conservation agreements also typically fall at this level as well, especially given the landownership patterns in each state (Figure 3-4). In the Mescalero Sandhills, 21 percent (66,433.5 ha [164,160.9 ac]) of DSL habitat is under New Mexico State jurisdiction, 51 percent (162,291.4 ha [401,030.8 ac]) is owned by the BLM, and 28 percent (88,468.0 ha [218,609.2 ac]) is private property. Sixty-seven percent of the minerals within the range of the DSL in New Mexico is federally owned and falls under the BLM lease stipulations and Resource Management Plan (BLM 2008, entire). In contrast, virtually all DSL habitat in Texas occurs on private lands, except for habitat within Monahans Sandhills State Park, a 1,554 ha (3,840 ac) park in Winkler and Ward Counties which is managed by the Texas Parks and Wildlife Department (TPWD).

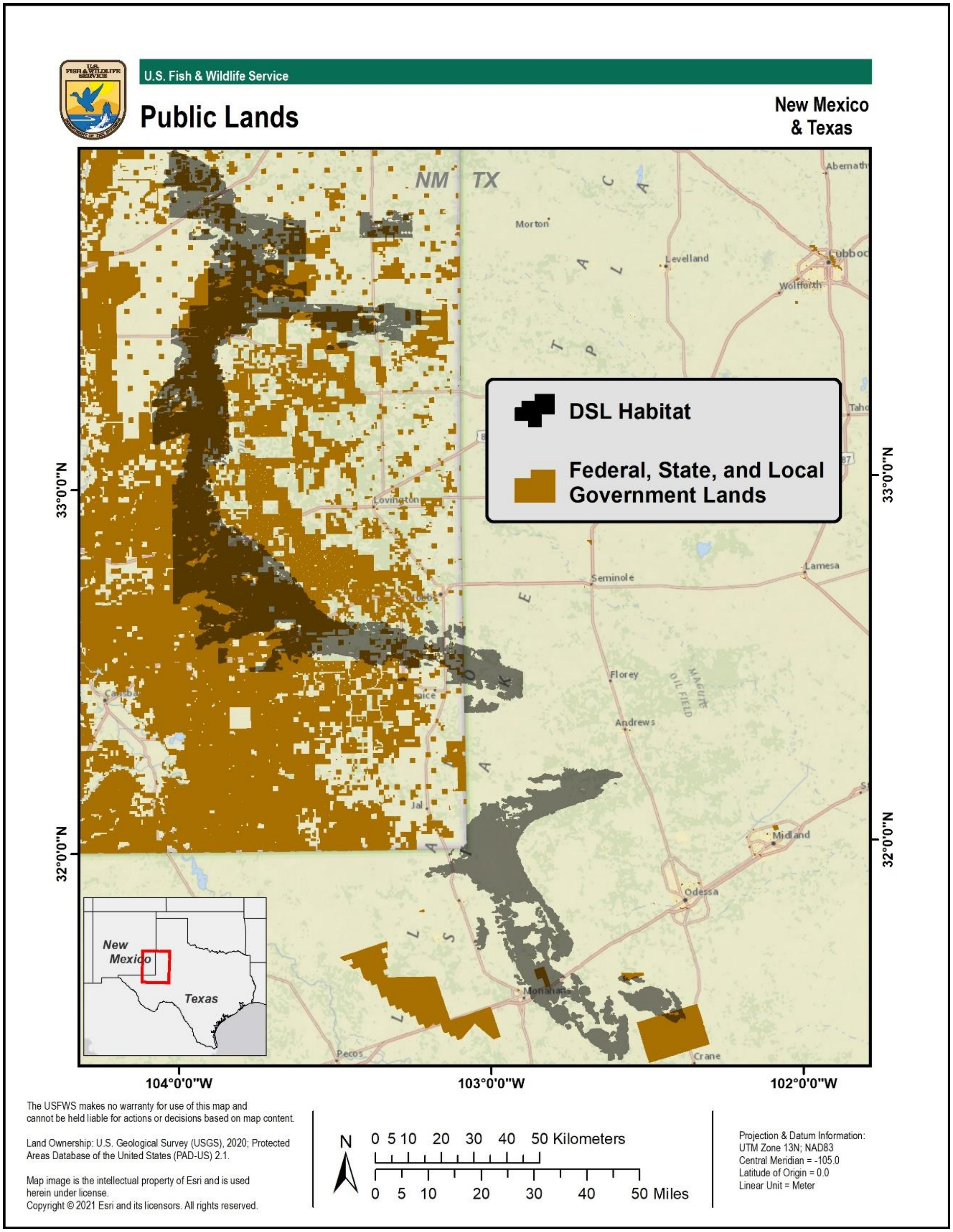

Figure 3-4 Distribution of publicly owned lands across the DSL range.

However, patterns of evolutionary relationships and adaptive capacity may not necessarily follow political boundaries. The phylogeographic history of a species can reflect the roles that habitat connectivity, gene flow, and population stability have played in a species' evolutionary persistence (Chan *et al.* 2020, p. 2). Habitat specialist species like the DSL are characterized by divergent lineages, with a history of limited dispersal and low connectivity among sites, especially in ecosystems with environmental gradients and discontinuous habitat, such as those found in the Mescalero and Monahans Sandhills (Chan *et al.* 2013, p. 316; Chan *et al.* 2020, pp. 2-3). The phylogeographic structure of the DSL reflects historical patterns of divergence and low connectivity overall (Chan *et al.* 2020, p. 3).

Based on genetic analysis, DSL in the Mescalero Sandhills are composed of at least two distinct phylogenetic lineages (Chan *et al.* 2009, p. 136; Chan *et al.* 2020, p. 6). These two lineages represent separate colonization events that are estimated based on genetic data to have 34,000 years ago (Northern Mescalero) and 16,000 years ago (Southern Mescalero) (Chan *et al.* 2020, p. 7). Thus, we divided the Mescalero Sandhills into the Northern Mescalero and the Southern Mescalero Representation Units, with a third lineage in the Monahans Sandhills, called the Monahans Representation Unit (Figure 3-5). Since these three lineages cover distinct portions of the species range, occur across a gradient of environmental conditions, and evolved in isolation, we believe they represent the appropriate units to represent adaptive capacity of the DSL. There appears to be no contemporary gene flow between these three units, except for a narrow contact zone between the North and South Mescalero lineages (Chan *et al.* 2020, p. 7).

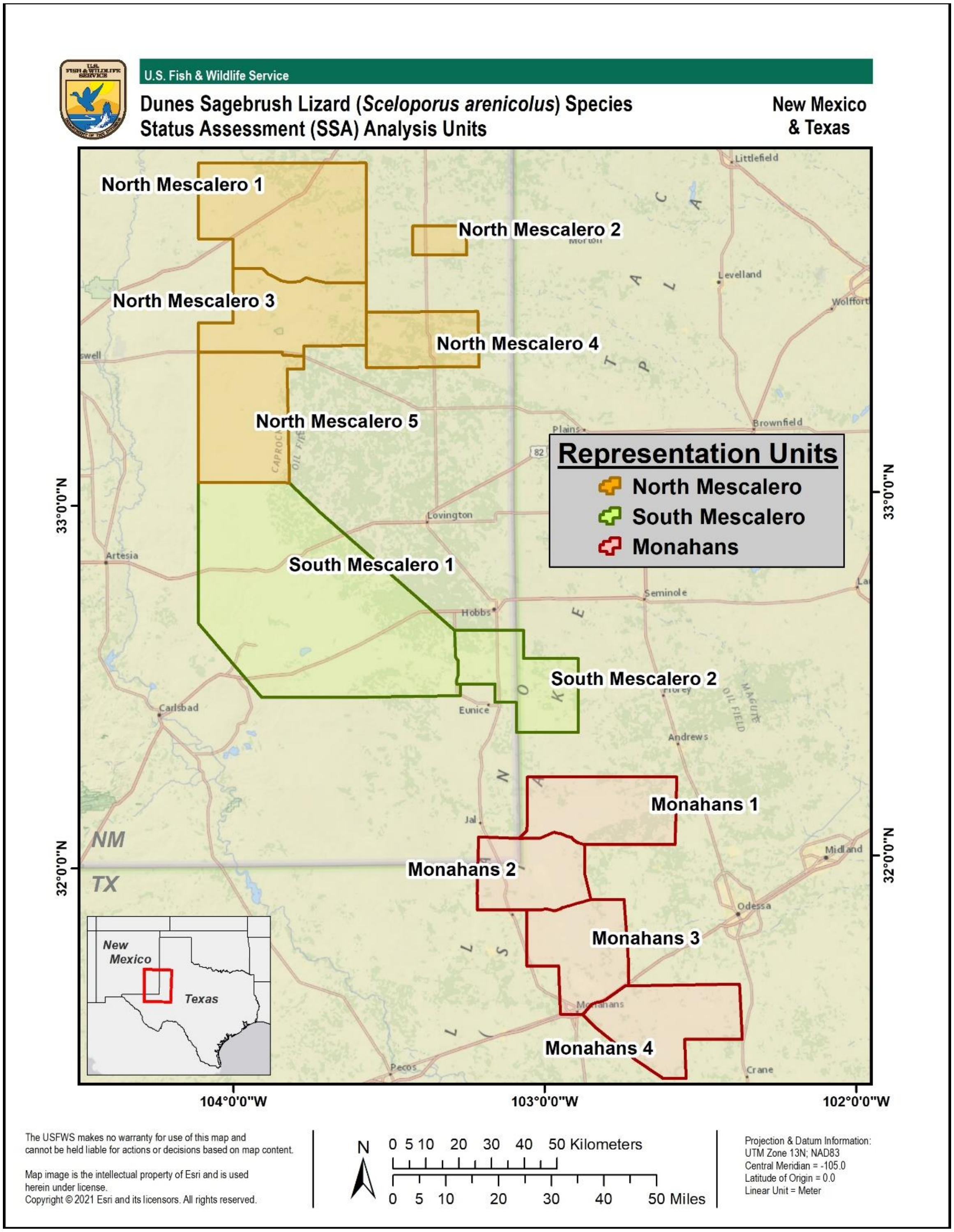

Figure 3-5 Representation Units and Analysis Units developed to characterize dunes sagebrush lizard representation and redundancy for this SSA.

3.2 Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely. Redundancy spreads risk and can be measured through the duplication and distribution of resilient populations that are connected across the range of the species. The larger the number of highly resilient populations distributed over a large area within each region, the better the chances the species can withstand catastrophic events. The most likely catastrophic events that may affect the DSL (see Chapter 4) are extreme drought (either in magnitude or temporal/spatial scale) or large pollution discharges.

At the species-level, redundancy in the DSL is expressed through the presence of multiple populations across the landscape. Genetic research has identified ten different distinct genetic groups across the DSL range, delineated primarily by mitochondrial DNA haplotypes and corroborated by nuclear microsatellite data (Chan *et al.* 2014, p. 9; Chan *et al.* 2020, entire). These groups reflect historical differentiation based on reduced connectivity between contiguous habitat patches (Chan *et al.* 2020, p. 2). Within these groups there appears to be varying levels connectivity and gene flow, with evidence of isolation by distance and resistance in several areas on New Mexico (Chan *et al.* 2014, pp. 33-41; Chan *et al.* 2017, pp. 9-22). Despite evidence of some gene flow between these groups based on nuclear microsatellite data (Chan *et al.* 2020, p. 7), they appear to function as independent units with intermixing restricted to narrow contact zones. Thus, there is limited potential for recolonization should these groups become extirpated. Thus, we consider the number and status of these groups represented an appropriate metric to base redundancy.

We were unable to obtain explicit location data for the genetic groups. To delineate the 11 Analysis Units, we combined existing habitat mapping and georeferenced locations of the genetic groups identified by Chan *et al.* (2020, entire). We then evaluated logical breakpoints based on the distribution of these groups and where habitat was mapped as discontinuous or where features such as highways may potentially explain the geographic division (e.g., Interstate-20). For the Northern Mescalero Representation Unit, there were 5 Analysis Units (North Mescalero 1-5), for the Southern Mescalero 2 Analysis Units (Southern Mescalero 1-2), and the Monahans 4 Analysis Units (Monahans 1-4). The distribution of these Analysis Units can be seen in Figure 3-5.

3.3 Resiliency

Resiliency describes the ability of a species to withstand stochastic disturbance. Stochastic events are those arising from random processes such as weather or fire or natural demographic variability. Resiliency is positively related to population sizes and growth rates and influenced by connectivity among populations. Generally, populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction despite disturbance. Even if stochastic events do lead to localized declines or extirpation, connectivity could facilitate the retention of these population.

Given the dynamic nature of the habitat and DSL occupancy, individual neighborhoods are likely to form and contract over time due to natural processes. Also, difficulties in detecting the DSL and estimating population sizes reduces our ability to define metrics to define resiliency. Therefore, we choose to define the resiliency of individual Analysis Units based upon the amount of suitable habitat, the distribution of that habitat among patches, and connectivity within them. The presence of large, interconnected habitat is more likely to promote the persistence of the DSL on the landscape. Conversely, Analysis Units with small, low quality, highly fragmented patches are less likely to facilitate natural population dynamics and less resilient. More details on our estimation of resiliency are available in Chapter 5.

Chapter 4: Factors influencing species viability

4.0 Summary

This chapter evaluates factors that may affect the long-term viability of DSL. Each factor is discussed below and explored further in the Cause and Effects Tables attached to this report (Appendix A**)**. The Cause and Effects Tables capture, in detail, the pathways through which each factor influences the species at both the individual and population level. Each factor is also examined temporally to determine the magnitude of potential impacts on the status of the species from a historical, current, and future perspective. These factors include: 1) habitat loss and modification, 2) pollution and contamination, 3) extreme weather, 4) groundwater depletion, and 5) direct mortality. We also summarize conservation management efforts that have influenced current status of the DSL and will affect future viability of the species. The factors we chose to examine are based on known stressors that either influence the DSL directly or influence the resources upon which lizards rely on for survival, growth, and reproduction. These factors as well as a discussion of the sources of these factors has been captured in Figure 4-1. Environmental stressors that are not known to affect DSL populations are not discussed in this SSA report.

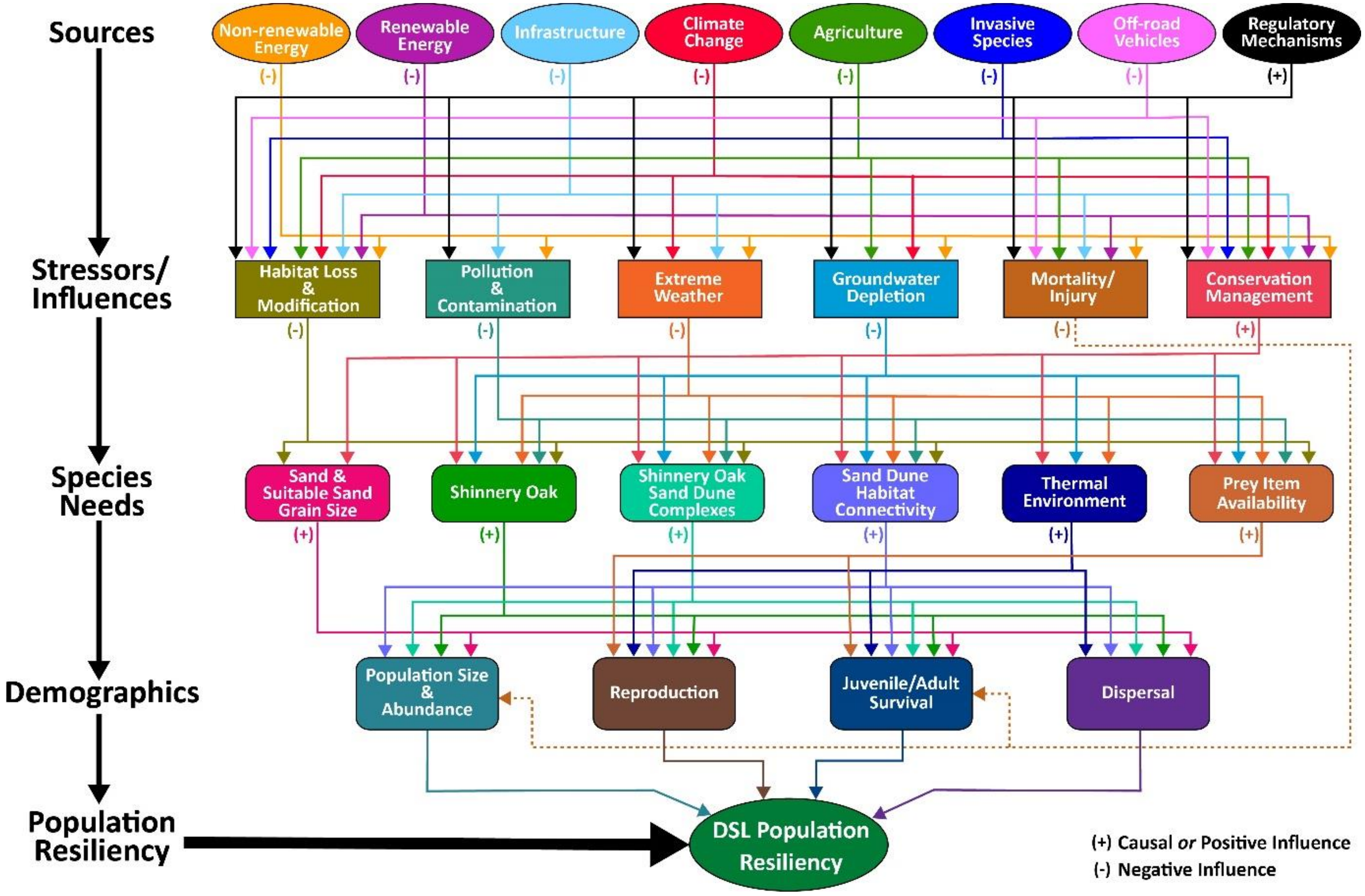

Figure 4-1 Conceptual diagram of the ecological needs of DSL and how those needs affect the species' viability and are stressed by anthropogenic sources. Arrows indicate causal relationships: a (+) indicates an interaction that is positive for DSL viability and a (-) an interaction that is negative for DSL viability.

4.1 Factor 1: Habitat Loss and Modification

4.1.1 Overview

Habitat specialists are more sensitive to habitat loss and fragmentation because of their dependence on a limited range of habitat (Henle *et al.* 2004, p. 239; Devictor *et al.* 2008, p. 511). Due to their reliance on shinnery oak duneland habitat within the Mescalero and Monahans Sandhills, the DSL is highly susceptible to habitat loss and fragmentation (Walkup *et al.* 2017, p. 2). At the individual-level, the removal of shinnery oak vegetation can impair DSL breeding (female nesting movements, juvenile dispersal, etc.), feeding, sheltering (thermoregulation, predator avoidance, etc.), dispersal, and survival (Machenberg 1984, pp. 16, 20-21; Degenhardt *et al.* 1996, p. 160; Snell *et al.* 1997, pp. 1-2, 6-11; Fitzgerald *et al.* 1997, p. 26; Peterson and Boyd 1998, p. 21; Painter *et al.* 1999, pp. 1, 27; Sartorius *et al.* 2002, pp. 1972-1975; Painter 2004, p. 3-4; Dhillion and Mills 2009, p. 264; Leavitt and Acre 2014, p. 700; Hibbitts and Hibbitts 2015, p. 157).

At the population-level, habitat destruction and fragmentation can affect DSL viability in multiple ways. Loss of habitat can lead to the reduction or even loss of populations. DSL are short lived and exhibit low reproductive potential (i.e., low population growth potential) and low to moderate adult dispersal ability (i.e., low population recovery potential). Species that exhibit these traits, or a combination thereof, tend to decline when confronted with fragmentation and are prone to extirpation (Henle 2004, p. 239; Devictor *et al.* 2008, p. 511; Hibbitts *et al.* 2013, p. 111; Leavitt and Fitzgerald 2013, p. 6; Walkup *et al.* 2017, p. 2). Smaller populations occupying smaller patches are more vulnerable to stochastic events. Fragmentation may also disrupt landscape-scale dynamics of the dune-blowout ecosystem, resulting in degradation of dune-blowout landforms beyond the immediate footprint of developed areas (Leavitt and Fitzgerald 2013, p. 9; Walkup *et al.* 2017, p. 11). Fragmented sites are often of lower quality, possessing fewer, more dispersed large dune blowouts as well as more large patches of flat open sand and barren ground (Leavitt and Fitzgerald 2013, pp. 9-10), which are less likely to support robust populations. Declines in population abundance due to reductions in habitat can result in a loss in genetic diversity and reduced dispersal due to fragmentation can lead to reduced gene flow. This in turn can lead to inbreeding depression and genetic drift, which can reduce population viability (Hokit and Branch 2003, p. 263; Chan *et al.* 2009, p. 140).

Across the broader landscape, habitat loss and fragmentation affect population dynamics. As populations and habitat patches disappear across the landscape, there are fewer “stepping-stones” to connect remaining populations through source-sink diffusion-dispersal dynamics (Young *et al.* 2018, p. 910). The DSL is not known to disperse across large expanses of unsuitable habitat. Thus, DSL populations may have little chance of receiving dispersers across areas where suitable habitat has been removed (Fitzgerald *et al.* 1997, p. 27). Movements of individual DSL between populations are hindered or precluded by fragmentation and do not occur at rates sufficient to sustain demographics necessary to prevent localized extirpations (Leavitt and Fitzgerald 2013, p. 11; Ryberg *et al.* 2013, p. 4; Walkup *et al.* 2017, p. 12; Young *et al.* 2018, p. 910). Over time, fragmentation isolates DSL populations and results in a progressive decline in population abundance until ultimately the species becomes extirpated (Leavitt and Fitzgerald 2013, p. 12).

Fragmentation of the shinnery oak ecosystem and DSL habitat may be non-reversible. Ryberg *et al.* (2015, p. 896) indicate that once shinnery oak dunelands are disturbed, these landforms shift to alternative stable states that are not prone to self-regeneration through ecological succession. Trials to restore and recreate shinnery oak dunelands have not been successful and additionally it is "far from certain that artificial dune blowouts could support populations of the species" (Ryberg *et al.* 2015, p. 896). The authors further argue that the successful restoration of shinnery oak dune forms is unlikely, due to the complexities of the natural processes that form and maintain these landforms, and the difficulty of replicating these processes. Johnson *et al.* (2016, p. 34) also notes that the restoration of shinnery oak vegetation and sand dune-blowout topography is not feasible. However, the authors suggest that the removal of caliche well pads and roads from the landscape may be able to recover the sand substrate component of DSL habitat at impacted sites and restore connectivity among habitat patches that were previously fragmented by oil and gas infrastructure.

4.1.2 Habitat Loss and Modification: Oil and Gas Development

4.1.2.1 Oil and gas development

Petroleum and natural gas production has occurred over much of the DSL range, which overlaps with the Permian Basin, a geologic province that hosts multiple basins each with multiple stratigraphic units from which hydrocarbons, water, and/or minerals are extracted. The Delaware and Midland Basins are the top oil producing subbasins of the overall Permian Basin (Figure 4-2). Oil exploration in the Permian Basin began in the early 1900s, but the first high producing wells in the region were not drilled until the 1920s (Dancy 2018, p. 1204).
By the 1940s, commercial oil and gas production had dramatically increased in the Permian Basin. As demand for energy has continued to increase so has oil and gas development in the Permian Basin (Figure 4-3). Several assessments of the Delaware and Midland Basins within the Permian Basin indicate significant technically recoverable oil and gas resources remain untapped within the region (USGS 2016, entire; USGS 2018, entire). Within the Permian Basin, DSL habitat directly overlies the northwest portion of the Delaware Basin and is near the western edge of the Midland Basin. Most of the DSL range, however, overlaps with the Central Basin, which has less recoverable oil reserves and correspondingly lower well densities (Figure 4-3).

Oil and gas development involves activities such as surface exploration, exploratory drilling, field development, and facility construction, including access roads, well pads, and operation and maintenance. Associated facilities can include compressor stations, pumping stations, and electrical generators. Activities such as well pad construction, seismic surveys, access road development, power line construction, and pipeline corridors can all result in direct habitat loss by disturbance and removal of shinnery oak duneland and associated vegetation. Indirect habitat loss also occurs from fragmentation of larger habitat into smaller parcels of suitable habitat by development.

Currently, 70 percent of land within the New Mexico range of the DSL has been leased by private entities, the BLM, or the New Mexico State Land Office (NMSLO) for oil and gas exploration and development. Seventy-one percent of the mineral rights within the range of the DSL in New Mexico are federally owned and fall under BLM lease stipulations and the Pecos District (New Mexico) Special Status Species Resource Management Plan Amendment (RMPA). In Texas, over 50 percent of oil production occurs in Districts 8 and 8A (Texas oil and gas districts); these districts overlap the known geographic range of the DSL (Tarver and Dasgupta 1997, p. 3670).

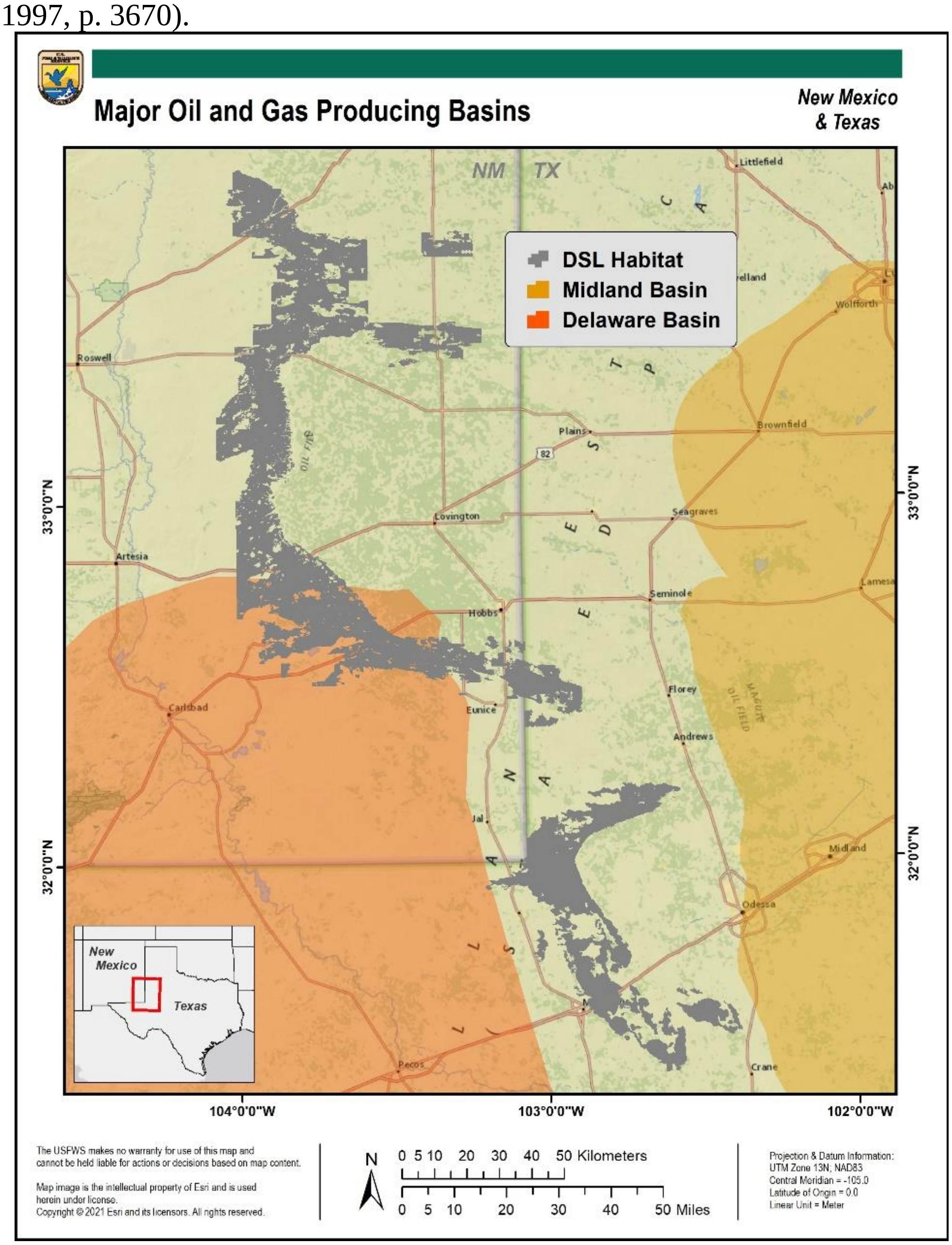

Figure 4-2 Map of major petroleum producing geological basins (Delaware and Midland Basins) and the range of the DSL.

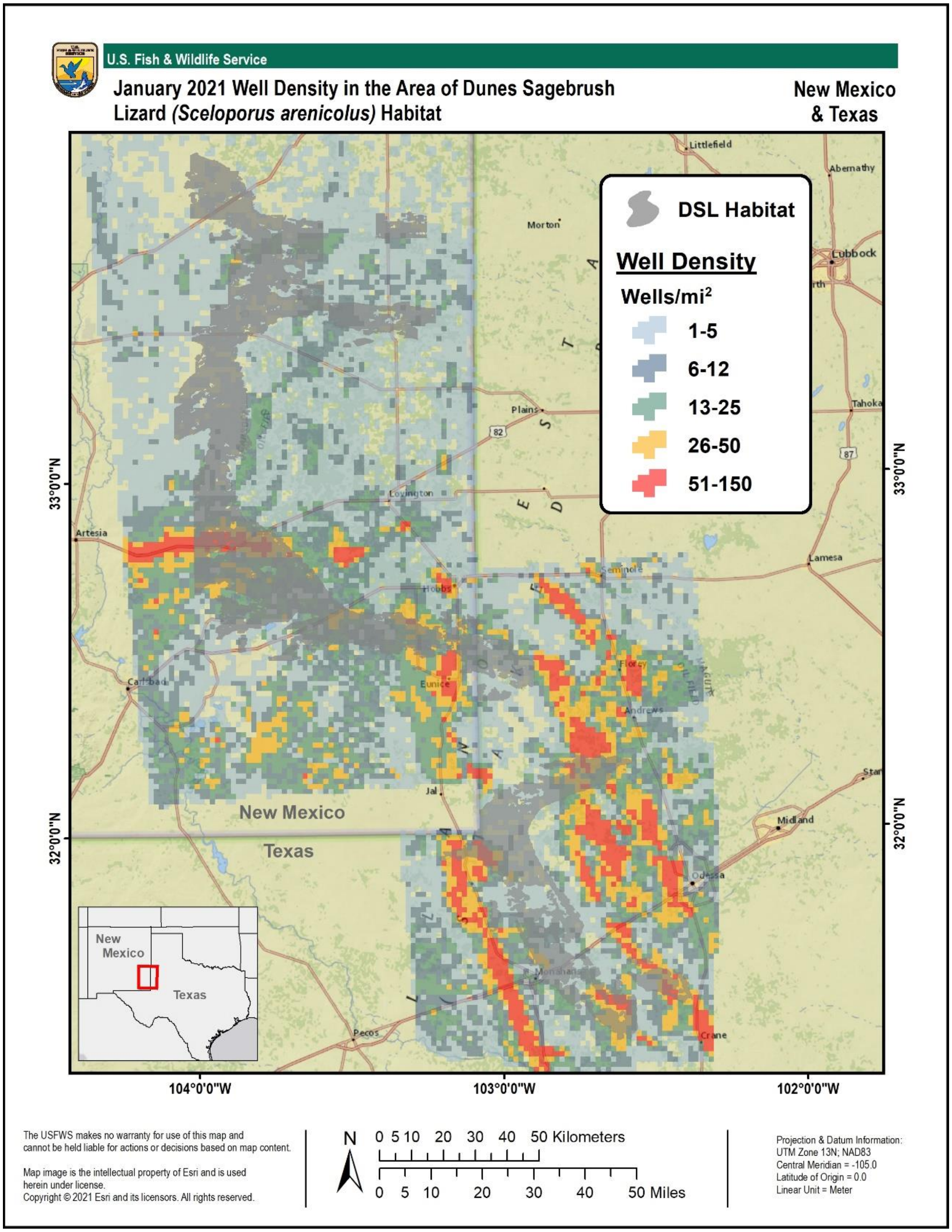

Figure 4-3 Map of oil well density in relation to the range of the DSL.

4.1.2.2 Well pad density

Fragmentation of DSL habitat and the consequential subdivision of populations into smaller, more vulnerable groups is often attributed to high densities of oil and gas well pads on the landscape. Several studies have demonstrated a negative relationship between well pad density and the number of DSL present at a site (Sias and Snell 1998, p. 1; Leavitt and Fitzgerald 2013, p. 9; Ryberg *et al.* 2015, p. 893; Johnson *et al.* 2016, p. 41; Walkup *et al.* 2017, p. 9). Sias and Snell (1998, p. 23) used a regression analysis to predict a 25 percent reduction in the abundance of DSL at densities of 13.64 wells pads/mi^2. At a density of 29.82 well pads/mi^2, reductions of 50 percent were predicted. Based on this study, Painter *et al.* (1999, p. 3) recommended that densities in New Mexico be limited to 13 well pads/mi^2. Leavitt and Fitzgerald (2013, p. 9) also found that areas with 13 well pads/mi^2 or greater had considerably lower abundance of DSL than non-fragmented sites. Further, they found that high well and road density at the landscape scale resulted in smaller, fewer, and more dispersed sand dune blowouts that are less suited to DSL persistence (Leavitt and Fitzgerald 2013, p. 9). Walkup *et al.* (2017, p. 10) further confirmed this pattern: they found that DSL populations had a relatively high susceptibility to local extinction in landscapes with 13 or more well pads/mi^2. They concluded that the network-like development of well pads and their connecting roads both isolate populations and disrupt the underlying geomorphologic processes that maintain the shinnery oak dune blowout formations. Johnson *et al.* (2016, p. 41) found a marked decline in DSL occurrence at well densities of 5 and 8 well pads/mi^2 with no lizards found at well densities above 23 well pads/mi^2. They suggested that 13 well pads/mi^2 should be considered “degraded” habitat as a standard in the scientific literature.

4.1.2.3 Roads

In many areas of oil and gas development, caliche roads are constructed in a grid-like network (Young *et al.* 2018, p. 6). Roads fragment habitat and impede DSL movement, reducing access to habitat, mates, and prey, decreasing population size and likelihood of population persistence. Roads may also create fugitive road dust that can blow and land on the surrounding dunelands, changing the composition of the top layer of sand. Hibbitts *et al.* (2017, p. 197) argued, based on road crossing experiments involving small caliche roads, that DSL avoid roads and they are a major source of fragmentation. In experimental trials, the authors found that approximately 20 percent of DSL crossed a road bisecting their enclosure (Hibbitts *et al.* 2017, p. 197). Young *et al.* (2018, p. 910) reported that among DSL equipped with radio transmitters,
only 1 of 799 documented movements involved the crossing of a road. Even the one instance of movement Young *et al.* (2018) document occurred where sand had blown over to cover the caliche road. There have been rare observations of DSL basking on caliche roads, but otherwise roads are recognized as a barrier to movement (Johnson *et al.* 2016, p. 11).

Roads may also adversely affect DSL by exposing lizards to vehicular traffic and by increasing mortality rates due to vehicle strikes as DSL move among habitat or disperse across landscapes that are fragmented by roads. In general, lizards as a group are susceptible to mortality due to collisions with vehicles (Delgado-Garcia *et al.* 2007, p. 2950; Goncalves *et al.* 2018, p. 1441).

4.1.2.4 Pipelines

Pipelines associated with oil and gas development also adversely affect DSL habitat. The most significant threat to the DSL is the construction process. Pipeline right of ways are typically 15 m (50 ft) wide. Construction of pipelines necessitates: (1) the staging and storage of equipment, materials, and vehicles; (2) clearing of right-of-ways; (3) trenching for the pipeline; and (4) constructing appurtenant facilities such as “pigging” stations, and compression and pumping stations. Such construction also requires access roads, parking lots, and fencing. Such activities remove vegetation and can destabilize the overall dune structure (Van Pelt *et al.* 2013, p. 37). Heavy equipment used to remove shinnery oak and bury the lines in the sand may cause direct mortality. The large open trenches can form linear pitfall traps from which DSL are unable to escape (Romano *et al.* 2014, p. 95).

Once pipelines are constructed, buried, and properly functioning, they are less of a threat to the DSL. Ongoing pipeline maintenance crews may travel by off-highway vehicles (OHV), directly and indirectly contributing to DSL habitat decline. DSL mortality may occur due to vehicular strikes. Extensive OHV use may result in soil compaction, reduced plant cover, and tire ruts that exacerbate erosional processes in the dune complexes (Van Pelt *et al.* 2013, p. 29), thus degrading DSL habitat. See the Off-Highway Vehicle Use section for more information.

4.1.3 Habitat Loss and Modification: Sand Mining

4.1.3.1 Sand Mining Overview

Frac sand is a naturally occurring sand used as a proppant during hydraulic fracturing of oil and gas wells to maximize production of unconventional reservoirs (Mossa and James 2013, pp. 76-79; Benson and Wilson 2015, pp. 1-50; Engel *et al.* 2018, pp. 1-13; Forstner *et al.* 2018, pp. 1-19; Mace 2019, entire). Sand mines consist of the following components: a processing plant, supporting infrastructure (roads, water pipelines, power transmission, well fields, etc.), and a mine site. Sand mining consists of the following activities: excavation, sediment processing, groundwater pumping, transport, and reclamation (Mossa and James 2013, pp. 76-79; Benson and Wilson 2015, pp. 1-50; Engel *et al.* 2018, pp. 1- 13; Forstner *et al.* 2018, pp. 1-20; Mace 2019, entire).

Sand mine facilities (i.e., processing plants and supporting infrastructure) are large and can range in size upwards of 350 ha (870 ac) (See Chapter 5). Size of the plant, permanent infrastructure, and spatial layout varies by the differences in the specific process being employed (Forstner *et al.* 2018, p. 1). The construction of industrial facilities, such as processing plants, generally involve the use of heavy equipment to clear vegetation, grade and pave the land surface, and construct buildings, roadways, and other infrastructure (Mossa and James 2013, pp. 76-79; Bio-West 2017, pp. 1-13; Forstner *et al.* 2018, pp. 1-19; Mace 2019, entire).

Construction of additional supporting infrastructure also involves the drilling of water wells at or near the facility and possible boring and trenching related activities associated with installation of flowlines, pipelines, and utilities. Trenches are dug to route power lines to the pump. Water may be routed to the facility by lay-flat hose or pipeline. Caliche may be placed at the site and on access roads. Where practical, equipment may be electrified, which involves the installation of in-field electrical distribution systems (poles, transformers and overhead wires) (Forstner *et al.* 2018, pp. 1-20; CPA 2019, pp. 24, 35, 37; Mace 2019, entire).

Sand mining involves the use of heavy equipment (e.g., sand excavators) and open-pit (open cut) methods to mechanically remove vegetation and sediment from near surface deposits of sand (e.g., sand dunes and sand sheets) (Breckle *et al.* 2008, pp. 453-454; Bensen and Wilson 2015, pp. 7-8, 49; Mossa and James 2013, pp. 76-80; Forstner *et al.* 2018, pp. 2-17; Mace 2019, pp. 42-61). Sand mine operators excavate sand from the land surface, often in a stair step paddock pattern (i.e., a pattern of steep vertical scarps), and can extract sand up to 24 m (80 ft) below ground (Bensen and Wilson 2015, pp. 7-8, 49; Mossa and James 2013, pp. 76-80; Bio-West 2017, pp. 1-13; Forstner *et al.* 2018, pp. 2-6). The actual depth of the excavation, however, is dependent on the depth of the sand formation and can vary spatially over a given mining parcel (Forstner *et al.* 2018, pp. 2-17).

4.1.3.2 Effects of Sand Mining on the DSL

Construction of sand mine facilities (e.g., processing plants and infrastructure) in DSL habitat removes shinnery oak; grades and compacts shinnery oak dunelands; and replaces these landforms with paved surfaces, buildings, and other structures (Boyd and Bidwell 2002, p. 332; Service 2012, p. 3688; Ryberg *et al.* 2014, pp. 888-890, 895-896; Forstner *et al.* 2018, pp. 1-5). Following construction, sand mining operations in DSL habitat remove entire shinnery oak duneland landforms, or portions thereof, alters dune topography, and produces deep, unnatural pits in the land surface (Breckle *et al.* 2008, pp. 453-454; Mossa and James 2013, pp 77-79, 85; Engel *et al.* 2018, pp. 1-13; Pye 2009, pp. 361-362; Forstner *et al.* 2018, pp. 2-21). Sand mine operators remove large volumes of sand (i.e., millions of tons of sand per mine) from sand dunes and return mostly non-commercial grade sediment (e.g., gravels, clays, silts, etc.) to mined areas after sediment processing (Bensen and Wilson 2015, p. 8; Forstner *et al.* 2018, pp. 2-3, 6; Mace 2019, pp. 2, 42-78), producing a landscape that lacks sand, shinnery oak vegetation, and dune topography (i.e., DSL habitat) (Mossa and James 2013, pp. 86, 91; Forstner *et al.* 2018, pp. 2-5, 18, 20).

The effects of sand mining can extend beyond the footprint of the actual mine itself. Removal of a portion of a sand dune promotes the loss and degradation of the entire landform (i.e., the remaining unmined segments) by undermining its stability and by promoting wind erosion and deflation (Carrick and Kruger 2007, pp. 771-772; Breckle *et al.* 2008, pp. 442, 453-454; Mossa and James 2013, pp 75, 88, 92; Engel *et al.* 2018, pp. 1-13; Forstner *et al.* 2018, pp. 3-21). For example, the removal of large volumes of sediment and the altered topography (e.g., steep scarps) of mined areas can make mined landforms more vulnerable to erosion, failure, shrinkage, and other morphological adjustments (Carrick and Kruger 2007, pp. 771-772; Mossa and James 2013, pp. 75, 88, 92). The removal of stabilizing vegetation, and the physical disturbance of sand during the mining process also promotes erosion and deflation of dune landforms via wind erosion (Machenberg 1983, pp. 6-31; Dhillion and Mills 2009, pp. 264, 270-271; Pye 2009, pp. 336, 355, 361-362; Engel *et al.* 2018, pp. 1, 3, 12). Dune sand that is set into motion by mining activities or entrained by wind can also cause physical damage to plants in adjoining areas of the dune and spread disease to unmined segments of the dune areas (Pye 2009, p. 358). Habitat edges adjacent to development and infrastructure tend to have limited resources relative to interior habitat and do not provide adequate resources for normal feeding, breeding, and sheltering behaviors, or for survival (Service 2012, pp. 36882- 36895). There is no evidence shinnery oak duneland landforms are self-regenerating in disturbed areas (Ryberg *et al.* 2015, p. 896). That is, DSL habitat can be permanently destroyed by construction and operation of sand mine facilities and infrastructure in DSL habitat (Forstner *et al.* 2018, pp. 1-2).

Sand mine construction and operations fragment habitat into smaller, more isolated remnants, separated by areas of uninhabitable terrain, while actively reducing connectivity among limited patches across the entire Texas range (Forstner *et al.* 2018, pp. 2-5, 18-20; Young *et al.* 2018, pp. 1-2). The physical setting of a sand mine facility and its infrastructure can also result in behavioral modifications associated with avoidance of the facility by DSL (Forstner *et al.* 2018, pp. 1-5) and can hinder movement and dispersal due to the propensity of DSL to avoid, or less readily disperse across roadways and developed areas (Hibbitts *et al.* 2017, pp. 194-198; Walkup *et al.* 2017, pp. 1-4, 8-11; Forstner *et al.* 2018, pp. 2- 21; Young *et al.* 2018, pp. 1-6).

Direct DSL mortalities are possible during facility construction and operation (Forstner *et al.* 2018, pp. 1-5). Construction activities and facility operations can crush, injure, and kill lizards and eggs buried below the surface as heavy equipment and vehicles clear, grade, and traverse DSL habitat (Sias and Snell 1998, pp. 22, 23; Painter 2004, p. 5; Forstner *et al.* 2018, pp. 3-17). Sand mine operations also create high volumes of vehicular traffic on local and regional roadways as trucks deliver sand to processing plants, and then from plants to regional well fields (Bensen and Wilson 2015, pp. 2-49; Engel *et al.* 2018, pp. 1-13; Forstner *et al.* 2018, pp. 1-20; Mace 2019, p. 6). Traffic density positively correlates with reptile strikes on roads (Goncalves *et al.* 2018, p. 1443; Hibbitts *et al.* 2017, pp. 195, 198; Forstner *et al.* 2018, pp. 4- 19) and increased vehicular traffic on roadways can contribute to direct DSL mortalities from vehicle strikes (Forstner *et al.* 2018, pp. 1-20).

4.1.3.3 Extent of Sand Mining

Sand mine facilities began operating in the Mescalero and Monahans Sandhills (i.e., Monahans Analysis Units 1-4 and S. Mescalero Analysis Unit 2) in early 2017, and by the end of 2018, 17 facilities had registered with the Texas Commission on Environmental Quality for operations in the region (Mace 2019, pp. 1, 42-43, 78). Based on operator and press reported annual production amounts, these 17 facilities mined a total of 56.8 million tons of sand annually and an average of about 3.6 million tons per mine (Mace 2019, pp. 1, 42-43, 78).

Sand mine facilities (i.e., processing plants and supporting infrastructure) operating throughout the Monahans Sandhills are large and range in size from approximately 16.2 ha to greater than 350 ha (40-870 ac) (See Chapter 5; Bio-West, 2017; Forstner *et al.* 2018, p. 1). There are no statutory or regulatory restrictions on the amount of sand that can be excavated at mines in West Texas. Based on aerial imagery from 2018-2022, we estimated the median growth rate (i.e., surface excavation rates) of sand mines operating in the Monahans Sandhills region as 21.7

ha/year (53.64 ac/year) (See analyses in Chapters 5 and 6). The CPA (2019) reported an average growth rate of 34.8 ha/year (86 ac/year) for mines operating in the region from 2017-2018 (CPA 2019, p. 81). Cumulatively, sand mines disturbed 684.7 ha (1,692 ac) of DSL habitat (i.e., shinnery oak dunelands) in a little over a year of operations from 2017 to 2018, particularly in high suitability habitat (363.8 of 684.7 ha [899 of 1692 ac], or 53 percent) (CPA 2019, pp. 41, 77). Since 2018, impacts from sand mining to DSL habitat has surpassed 1,727 ha (4,267 ac) across DSL habitat in Texas (see Chapter 5).

Currently, most mines are in Winkler (11 of 17; 65 percent) and Ward (2 of 17; 12 percent) Counties (Monahans Analysis Units 1-3) (Mace 2019, p. 43-44, 56; see Chapter 5). Sand mining is expected to continue in these counties given the current location and density of mines in the counties, the average rates of surface mining, and the anticipated plans and growth of the industry in the area (Mace 2019, pp. 42-54; Bensen and Wilson 2015, pp. 1- 8, 54-57; Latham and Watkins 2020, pp. 12-13). Winkler and Ward Counties contain the largest acreages of DSL habitat in Texas (Hardy *et al.* 2018, p. 36; see Chapter 5). Laurencio *et al.* (2007, p. R002088) concluded that the stronghold for DSL in Texas seems to be the large band of sand dunes located in Winkler, Ward, and Andrews counties (i.e., Monahans Analysis Units 1-3). Fitzgerald *et al.* (2011, p. 14) also identified the contiguous habitat in this region as high suitability DSL habitat and as a priority for conservation to ensure connectivity among DSL populations in Texas and persistence of DSL populations into the future. The majority of the current mines occur adjacent, near, and/or in areas with some of the highest predicted probability of DSL occurrence in Texas (Walkup *et al.* 2022, p. 356, Figures 4 & 5; see map in Figure 5-4). Sand mining in Winkler and Ward Counties is expected to impact the large contiguous patches of DSL habitat where most populations may occur (See Chapter 6) and is likely to adversely affect the viability of the populations inhabiting habitat remnants within these areas (Forstner *et al.* 2018, pp. 18, 20-21).

The Permian Basin is estimated to contain 20 billion barrels of technically recoverable oil (Mace 2019, pp. 42, 47, 55-54). Thus, sand mining is expected to continue in Texas (Mace 2019, pp. 42, 47, 55-54), with the number of mines, and the intensity of mining in the region increasing or decreasing with the level of oil and gas production and amount of surplus frac sand in the market (Bensen and Wilson 2015, pp. 1, 5, 8, 54-57). Mace (2019, pp. 42, 47, 54-55) indicated that up to 30 sand mine facilities could be developed under positive market conditions in the Monahans Sandhills, a potential 75 percent increase. Under such conditions, more oil and gas companies would seek to self-source sand, and more sand mine facilities would seek to own storage and transportation assets to control costs. As a result, the share of locally produced sand could grow to 50 percent. In contrast, Latham and Watkins (2020, pp. 12-13) concluded that under negative market conditions, the number of sand mines operating in the region could decline to 12 mines.

4.1.4 Habitat Loss and Modification: Other Sources

4.1.4.1 Wind Energy

Nearly the entire DSL range occurs in areas determined to be suitable for wind development, assuming an average wind speed of 6 m (20 ft) per second 80 m (262 ft) above ground (U.S. Department of Energy Wind Exchange, accessed 07/2021; Figure 4-4). As of May 2021, Texas currently produced nearly double the amount of renewable energy (33,000 megawatts [MW]) of any other state, 20 percent of their electric grid mix (American Clean Power 2021, p. 7). New Mexico currently produces the 12th most renewable energy (2.7k MW), 21 percent of their electric grid mix (American Clean Power 2021, p. 7). In the first quarter of 2021, Texas installed the most wind energy capacity and New Mexico installed the 5th most new wind energy capacity out of all states (American Clean Power 2021, p. 8). In Texas, wind energy capacity additions could range from 35,000-44,800 MW by 2035, with 100-700 MW potential in Andrews and Ector Counties in the same timeframe (ERCOT 2020, entire). In 2019, New Mexico passed the clean energy bill requiring energy use to come from renewable sources by 50 percent by 2030, 80 percent by 2040, and 100 percent by 2050.

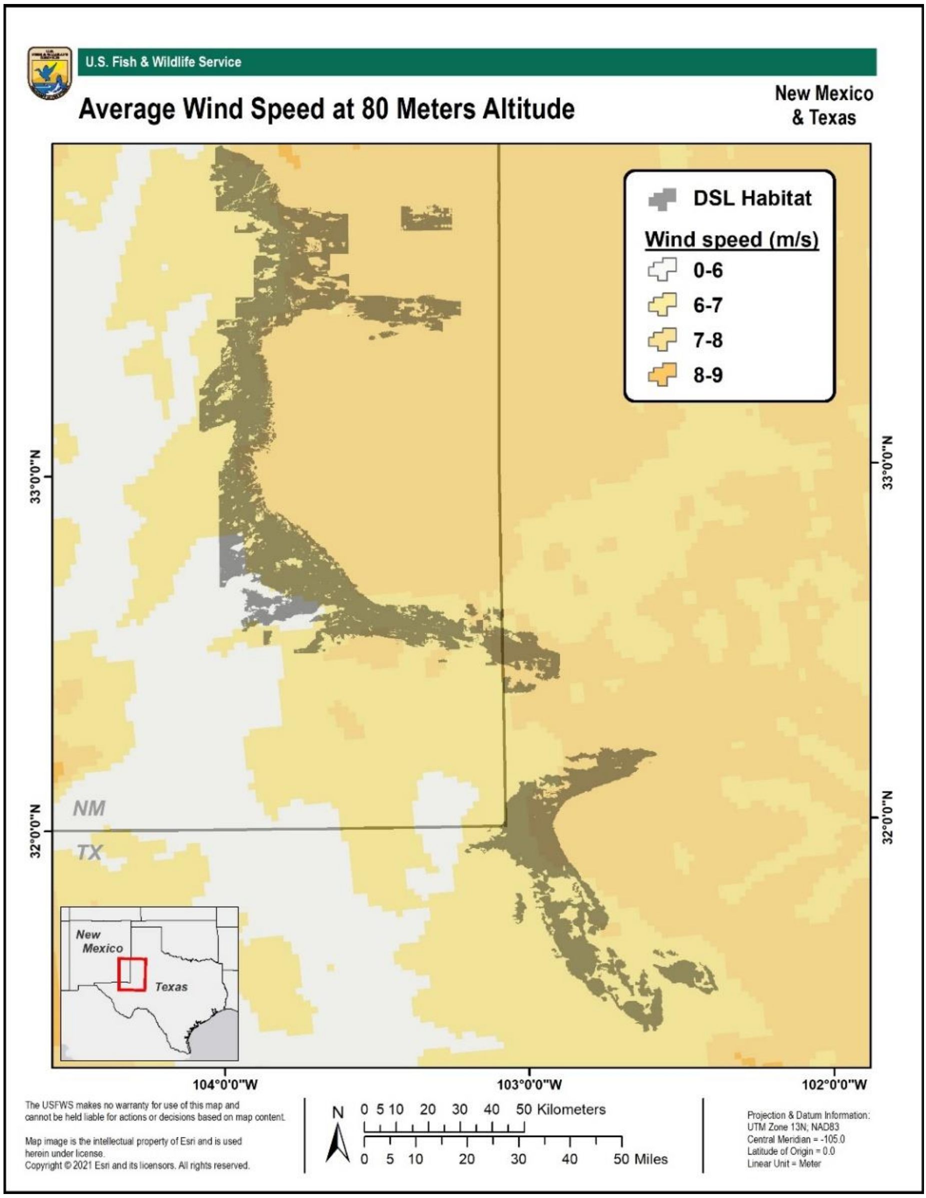

Figure 4-4 Map of average wind speed at 80 m (262 ft) above ground level across the range of the DSL. Average speeds above 6 m/s are suitable for wind energy development.

Impacts of wind farms on DSL have not been investigated. Demographic metrics for the side-blotched lizard, a desert lizard, near Palm Springs, California, were not significantly different between wind farms and reference sites (Keehn *et al.* 2019, p. 153). However, they found across all sites greater road density correlated with lower body condition, adult-skewed age structure, and reduced population growth. They found that wind farms are like other disturbed areas because the roads associated with the wind farms can fragment the habitat, despite the wind turbines having a smaller physical footprint than other energy sources (Keehn *et al.* 2019, p. 154). Wind farms would likely have a similar effect on DSL because they are sensitive to fragmentation.

As of July 2021, one wind farm occurred within the range of the DSL: the Jumbo Hill Project in Andrews County, Texas has 16 wind turbines that overlap with DSL habitat (Hoen *et al.* 2018, United States Wind Turbine Database). The current impact of wind energy development is low, but given the wind energy potential of the region and the rate of wind turbine placement in Texas and New Mexico, it could become a more prominent source of habitat disruption for DSL.

4.1.4.2 Solar Energy

There is a lack of research on the effects of utility-scale solar energy development on wildlife (Chock *et al.* 2021, p. 2). Lovich and Ennen (2011, pp. 984-986) discuss potential impacts to wildlife stemming from solar energy development and, like wind energy, the primary effects to DSL would be habitat destruction, fragmentation, and degradation from solar infrastructure and roads.

A 100-MW photovoltaic panel farm can have an average footprint of 120 ha (297 acres), while a concentrated solar power plant can have an average footprint of 190-240 ha (470-593 acres) (Jacobson 2008, p. 161). The footprints of concentrated solar power plant can expand to 380-470 ha (939-1161 acres) if storage is added to be used for additional solar collectors (Jacobson 2008, p. 161). Additional solar collectors would be used to transfer solar energy to the storage medium for use at night, increasing the turbine capacity (Jacobson 2008, p. 161).

As of 2021, there is only one major utility-scale solar energy project in the DSL range with 129 ha (318 ac) of an 814 ha (2013 ac) project within DSL habitat. However, there is a lot of potential for solar energy projects in New Mexico and Texas. In Texas, utility-scale solar capacity additions could range from 22,200-35,300 MW by 2035, with Andrews, Ector, Winkler, and Crane Counties having greater than 700 MW potential in each county in the same timeframe (ERCOT 2020, pp. 5 and 16). It is uncertain whether solar energy development will be a significant source of habitat loss for DSL in the future.

4.1.4.3 Shinnery Oak Treatment

Shinnery oak is often seen as an undesirable weed for agriculture and grazing because it competes with better livestock forage and during spring shinnery oak buds and leaves are toxic to cattle (Peterson and Boyd 1998, p. 26). Because it is viewed as detrimental to agriculture and livestock grazing, research on shinnery oak has focused on eradication (Peterson and Boyd 1998, p. 26). Shinnery oak eradication has been applied both mechanically and chemically.

Starting in 1974, tebuthiuron became popular as an effective herbicide to eradicate shinnery oak (Peterson and Boyd 1998, p. 27). Tebuthiuron defoliates shinnery oak, resulting in decreased vigor every year after use until it starts to die off in the second, third, or later years after treatment (Jones and Pettit 1984, pp. 489, 450; Peterson and Boyd 1998, p. 27). After the shinnery oak is removed from the landscape, wind erosion increases greatly and treated land becomes more susceptible to wildfire (Peterson and Boyd 1998, p. 29).

The removal of shinnery oak degrades the quality of DSL habitat, with abundance found to be between 70 and 94 percent lower in treated sites compared to untreated sites (Snell *et al.* 1994, pp. 10-11). Habitat changes from open blowouts and scattered areas of thick cover to a largely homogenous, evenly vegetated grassland likely causes the reduction in DSL abundance (Snell *et al.* 1994, p. 11). This change in habitat may increase competition exclusion from side-blotched lizards (*Uta spp.*) and increased predation because the DSL relies on shinnery oak for shelter from predators (Snell *et al.* 1994, p. 12).

Shinnery oak treatment was most prevalent in the 1980s and 1990s, primarily in New Mexico. By 1995, a total of 12,950 ha (32,000 ac) of shinnery oak had been treated in Texas and between 1981 and 1993 a total of 40,469 ha (100,000 ac) were sprayed with tebuthiuron in New Mexico (Peterson and Boyd 1998, p. 28). In 2014, Johnson *et al.* 2016 estimated that 53,709 ha (132,717 ac) of shinnery oak treatment had occurred in New Mexico. This disturbance included 38,295 ha (94,628 ac) treated with tebuthiuron by BLM. The remaining 15,414 ha (38,089 ac) of disturbance may have been either chemically or mechanically treated. In reviewing 2021 imagery for our GIS analyses, no additional shinnery oak treatments were observed beyond what was recorded in Johnson *et al.* 2016.

The length of time tebuthiuron may remain in the soil and environment varies between studies, likely having to do with the type of soil. In a study area in semiarid rangelands of Texas, tebuthiuron was still detectable in seasonal plant growth more than a decade after application (Johnsen and Morton 1991, p. 249). In semiarid savanna in South Africa, tebuthiuron is still affecting local plant growth more than a decade after it was initially treated (Bezuidenhout *et al.* 2015, entire). Tebuthiuron is described as a highly successful herbicide because of its long residual life (Bovey *et al.* 1982, p. 143). The long residual life of tebuthiuron adds another obstacle to the possibility of DSL habitat recovery, as vegetation removal destabilizes dune structures. As mentioned earlier, there is no evidence of shinnery oak duneland self-regenerating in disturbed areas (Ryberg *et al.* 2014, p. 896).

4.1.4.4 Mesquite Encroachment

Over the past 150 years, there has been a worldwide trend in the encroachment of grasslands by woody vegetation. Brushy and woody vegetation that may once have been present in riparian areas has moved into grasslands and other areas where it previously did not occur. In Southeast New Mexico and West Texas, honey mesquite (hereafter mesquite) comprises much of the woody encroachment. Mesquite can invade areas because it is not subject to the resource limitations that restrict the establishment and maintenance of plants it competes with (Wilson *et al.* 2001, p. 11; Branson 1985, p. 35). Mesquite produces abundant long-lived seeds that can germinate on a wide range of soil types, moisture, and light regimes (Archer *et al.* 1988, p. 123). It can fix nitrogen and seedlings quickly develop an extensive root system (Archer *et al.* 1988, p. 123). Mesquite can access groundwater with the deep root system (Wilson *et al.* 2001, p. 11). Limited research has been done in shinnery oak, but encroachment across the southwest shows an increase of 0.2-2.2 percent woody mesquite cover per year (Ansley *et al.* 2001, p. 173; Asner *et al.* 2003, p. 327; Barger *et al.* 2011, p. 4). At a site in New Mexico, mesquite density showed increases of 10-128 percent even in areas that had been treated with herbicides (Gibbens *et al.* 1992, p. 587). In southern New Mexico, one area that was 43 percent occupied by shrubs (i.e., mesquite) in 1915 had increased to 100 percent occupied by 1990 (Grover and Musick 1990, p. 307).

Considerable research has gone into identifying the drivers of this vegetation change (Van Auken 2000, entire). No individual driver can account for all woody encroachment. Instead, woody plant encroachment seems to be occurring due to complex interactions of multiple drivers, such as grazing by domesticated animals and reduction of fire in the landscape, as well as climate change through warming of the climate, increased droughts, and increased atmospheric carbon dioxide (Grover and Musick 1990, p. 305; Archer *et al.* 1995, p. 91; Wilson *et al.* 2001, p. 1). Livestock are an especially effective vector of mesquite seed dispersal that can transport large numbers of seeds and encourage growth (Archer *et al.* 1988, p. 124; Fredrickson *et al.* 2006, p. 290). Frequent fire across the landscape may have kept mesquite from encroaching historically. Although fire can kill mesquite seedlings and plants younger than 1.4 years old, larger mesquite plants are fire resistant (Gibbens *et al.* 1992, p. 585). The changing climate has also aided in the spread of mesquite. Changing climate patterns have promoted mesquite growth over the past century since it can handle the longer, more intense droughts, hotter temperatures (Fredrickson *et al.* 2006, p. 290), and may potentially even benefit from increased atmospheric carbon dioxide (Archer *et al.* 1995, entire; Van Auken 2000, p. 202).

Honey mesquite is encroaching into DSL habitat in the shinnery oak dunelands and shrublands. Little research has been done in this ecosystem, but observational data has shown encroachment by mesquite can cause loss of dune structure and degrade DSL habitat (Johnson *et al.* 2016, p. 20). Mesquite first establishes itself within blowouts; eventually blowouts become filled in by mesquite and short grasses (Johnson *et al.* 2016, pp. 25, 31; Fitzgerald *et al.* 2011, p. 13), altering and degrading DSL habitat. Shinnery oak dunelands invaded by mesquite are principally found at the margins of high quality habitat (Johnson *et al.* 2016, p. 82). Due to this degradation of the dunes, the DSL is less likely to be found in areas with mesquite encroachment (TAMU 2016, pp. 44, 59; Fitzgerald *et al.* 2011, p. 13; Hardy *et al.* 2018, p. 25; Johnson *et al.* 2016, p. 25; Texas Comptroller 2017, p. 52). Hardy *et al.* 2018 (p. 25) found that when mesquite exceeds 5 percent of the ground cover there are reduced detections of the DSL (Figure 4-5). The Texas Comptroller (2017, p. 52) reported a negative relationship between DSL presence and the proportion of mesquite. Additionally, they did not detect the DSL at any survey sites with more than 10 percent mesquite cover. Thus, where mesquite has become established, we expect that to represent a reduction in the quantity and quality of habitat available for the DSL.

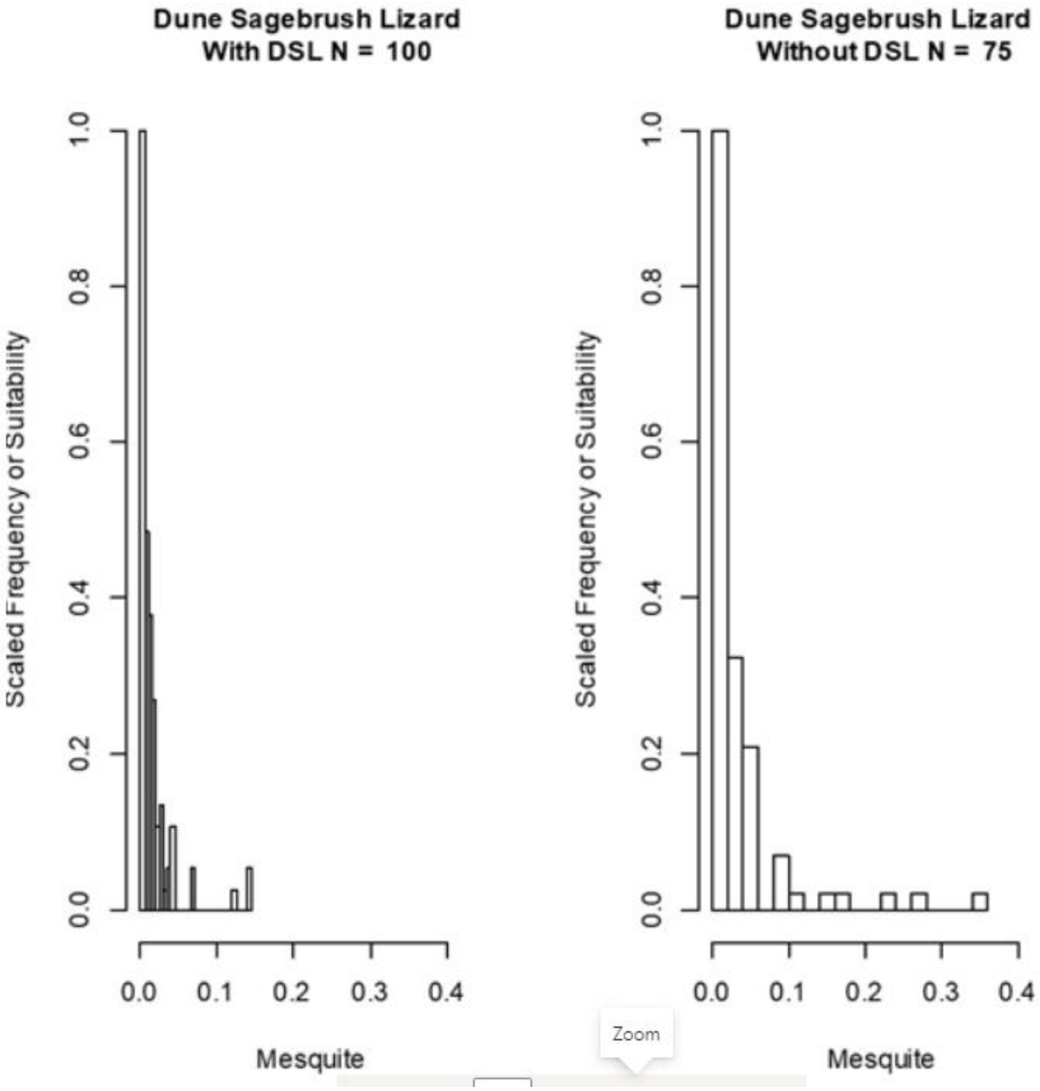

Figure 4-5 Proportion of aerial coverage composed by mesquite at study sites in which DSL were (left panel) and were not detected (right panel). Credit: Hardy *et al.* (2018, p. 25).

Considering the trends in mesquite expansion over the decades, we anticipate this will continue to impact the DSL into the future. In areas with mesquite encroachment that still have dune structure, mesquite removal may be a way to increase suitable habitat for the DSL. However, this must be done by looking at individual locations and the amount of mesquite encroachment along with the potential for dispersal by the DSL into these locations. Research has not yet shown successful reestablishment by the DSL in locations in which mesquite had been removed (Texas Comptroller 2017, p. 53).

4.1.4.5 Grazing

The primary issue with livestock grazing is that shinnery oak is not ideal forage for cattle, therefore shinnery oak is often removed to encourage growth of better forage (Peterson and Boyd 1998, p. 24). There is little research on the effects grazing has on the DSL, though it has been found in areas of moderate grazing (Painter *et al.* 1999, p. 32). Heavy grazing may result in extensive open sand dunes, which lack the shinnery oak the DSL uses for shelter (Painter *et al.* 1999 p. 32). Shinnery oak duneland provide for poor agriculture and are not suitable for long term heavy grazing because it can destabilize dunes (Dhillion and Mills 2009, p. 271). Grazing does occur across the range of the DSL. If grazing causes the destabilization of dunes, it is unlikely those sand dunes will self-regenerate, therefore posing a threat to the species (Ryberg *et al.* 2014, p. 896).

4.1.4.6 Off-Highway Vehicle Use

Off-highway vehicles (OHVs), or off-road vehicles, include any vehicle that is used to travel on or immediately over land and natural terrain. This can include motorcycles, motor bikes, all-terrain vehicles, dune buggies, snowmobiles, four-wheel drive vehicles, and any other vehicle designed for off-road travel (Ouren *et al.* 2007, p. 4). OHVs were identified as a threat to the DSL by Painter (2004, p. 6) due to impacts on habitat and the potential for direct mortality. In other dune systems, OHVs have been shown to cause loss of vegetation due to direct mortality and compacted soils (Ouren *et al.* 2007, p. 11; Brodhead and Godfrey 1977, p. 306; Luckenbach and Bury 1983 p. 280). Arthropod diversity and abundance significantly decline in areas with OHV use, likely due to the loss or decline in habitat quality (Van Dam and Van Dam 2008, p. 416; Luckenbach and Bury 1983, pp. 275-276).

Similarly, lizard diversity and abundance also decline in areas with OHV use, likely due to lower habitat quality and a reduction in the prey base (Bury *et al.* 1977, p. 16; Luckenbach and Bury 1983, p. 272). When compared to OHV impacted sites, undisturbed sites were found to support 1.8 times more lizard species, 3.5 times more individuals, and 5.9 times more biomass (Bury *et al.* 1977, p. 13). Tracks created by OHVs can fragment once continuous habitat, disrupting movement, dispersal, and genetic exchange of wildlife species (Ouren *et al.* 2007, p. 17). Direct mortality of lizards is frequently observed in areas of OHV use, along with much higher tail loss and a risk of crushing burrows (Luckenbach and Bury 1983, pp. 273, 277-278; Bury *et al.* 1977, p. 16).

There are few legally designated recreational OHV use areas in DSL habitat in either New Mexico or Texas. The Mescalero Sands North Dune Recreation Area encompasses about 243 ha (610 ac) of BLM lands in Chaves County, New Mexico and is used for recreational OHV use. Authorized OHV activities have degraded habitat by introducing weed species, exposing shinnery oak roots, and eroding the dunes (Hill 2008, p. 1). No DSL were detected in this recreational area in 2008 (Hill 2008, p. 1).

The Hackberry Lake OHV area includes about 40.5 ha (100 ac) of sand dunes. Hackberry Lake allows for intensive use of motorcycles, sand dune buggies, and other OHVs. About 486 ha (200 ac) of the Kermit Sand Dunes in west Texas was a popular destination for recreational OHV use until 2016 when it was bought by Hi-Crush Partners LP to produce frac sand. The extent of OHV use on private lands for recreation or personal use is unknown but could be a significant threat in areas occupied by the species.

4.2 Factor 2: Pollution and Contamination

As discussed earlier in this chapter, oil and gas activities occur across much of the DSL range. Oil and gas activities can result in pollutants released into the surrounding environment, which could be harmful to the DSL. We identified hydrogen sulfide, oil spills, and tebuthiuron as sources of pollution and contamination that could negatively affect the DSL.

4.2.1 Hydrogen Sulfide

Hydrogen sulfide is regulated under multiple federal statutes and considered a hazardous substance under the Comprehensive Environmental Response, Compensation, and Liability Act (USEPA 1993, p. iii). It is a naturally occurring gas and generated through industrial activities like oil and gas extraction and storage (Brenneman *et al.* 2000, p. 326). Humans suffer respiratory irritation at concentrations as low as 50 parts per million (ppm), while fatalities and respiratory paralysis have occurred at concentrations of 1,000 ppm and greater (Brenneman *et al.* 2000, p. 326). Rats have been observed to suffer olfactory toxicity at levels as low as 30 ppm, with long-term damage and death occurring in small mammals when gas levels exceed 50-100 ppm (Brenneman *et al.* 2000, p. 332; Lusk and Kraft 2010, p. 4). Avian species have been found to be at risk of irritated eyes and mucus membranes, dilated blood vessels, and stress reactions at concentrations greater than 25 ppm (Lusk and Kraft 2010, pp. 4, 14).

Since hydrogen sulfide is heavier than air, DSL have been hypothesized to be more prone to gas poisoning because of their association with the bottoms of dune valleys (Sias and Snell 1998, p. 23). Research since 1998 indicates that the risk hydrogen sulfide poses to the DSL is low, though additional long-term research is needed to conclusively rule out hydrogen sulfide as a threat to the species. Additionally, there is little research designed to assess the acute toxicity of a toxic gas to reptiles (Weir *et al.* 2015, p. 1281).

Weir *et al.* (2015, pp. 1279-1280) found no significant effects from 90 minutes of exposure at 30 ppm or 90 ppm of hydrogen sulfide gas to the congeneric western fence lizard (*Sceloporus occidentalis*), though they acknowledged that in the wild, low levels of gas will persist over a long-time frame with unknown effects. Lusk and Kraft (2010, p. 15) calculated DSL that are active could display adverse effects from hydrogen sulfide at concentrations greater than 14 ppm. The 14 ppm was calculated using the U.S. Environmental Protection Agency’s (1994) inhalation reference concentrations methodology, which the authors acknowledge has inherent uncertainty and imprecision because this methodology requires judgement, assumptions, and data extrapolations (Lusk and Kraft 2010, p. 10).

On the landscape, of 50 sites within 24 to 30 m (80 to 100 ft) of well pads, drilling rigs, oil storage tanks, pipelines, or oil pumps tested for hydrogen sulfide in southeastern New Mexico, only 4 sites had concentrations greater than 6 ppm (Lusk and Kraft 2010, pp. 7, 12, 33, 34, 36, 61). Similar results were found in DSL habitat near Andrews, Texas, where hydrogen sulfide concentrations were measured in habitat proximate to oil and gas production infrastructure (Salice and Anderson 2011, pp. C001766, C001769-C001770). No concentrations above one ppm were observed in this Texas study, except at the opening of an exhaust pipe from a nearby pump jack, although the authors acknowledged the study was restricted in scale and time (Salice and Anderson 2011, pp. C001766, C001770).

Overall, the evidence points to hydrogen sulfide gas being a relatively minor threat to the DSL. Research needs to address what the long-term effects of low concentrations of hydrogen sulfide can have on the species, especially because oil and gas activities occur throughout DSL habitat across the range.

4.2.2 Oil Spills

Due to the large amount of oil and gas activities throughout the DSL range, the possibility of an oil spill must be addressed. Studies of other lizard species have shown that carcinogenic polycyclic aromatic hydrocarbons, a group of chemicals formed during incomplete burning of oil and gas, can accumulate in lizards and the ants they consume (Al-Hashem *et al.* 2007, pp. 552, 554-555). The accumulation of pollutants in lizards can cause severe organ pathology, resulting in decreased fitness (Al-Hashem 2011, p. 1394-1395). Oil pollution can also cause behavioral effects. Oil can darken substrate and cause lizards to emerge earlier because the substrate warms faster due to its darker color (Al-Hashem *et al.* 2007, p. 592). Oil pollution can have long lasting, chronic effects on wildlife (Al-Hashem 2011, p. 1395; Esler *et al.* 2018, p. 41; Rosell-Mele *et al.* 2018, p. 1017). The DSL has a limited, heavily disturbed range; an oil spill could degrade more habitat and restrict the range further. However, the impacts are likely to be localized to the location of a spill. Given the stochastic nature of a spill, it would be difficult to predict the likelihood and scale of such an event. Most likely, the frequency of spills is correlated with the extent of oil production and transportation.

4.2.3 Tebuthiuron

The risk of tebuthiuron toxicity to wildlife is low, as studies have shown mice, rats, rabbits, dogs, and ducks were able to absorb and metabolize this herbicide (Emmerich 1985, p. 15). It is unknown what the effect may be on a reptile, like the DSL, however only high doses of tebuthiuron were found to produce negative effects in other animals (Emmerich 1985, p. 15). Negative effects included slower body growth and at very high levels, death (Emmerich 1985, p. 15). Large-scale active tebuthiuron spraying is no longer common in the DSL range and individuals are unlikely to encounter this chemical in concentrations that would pose a threat.

4.3 Factor 3: Extreme Weather

4.3.1 Overview

There are several weather and climate-related events that have the potential to impact the DSL, both at the individual and population-level. Because DSL are ectothermic, ambient temperatures affect their physiological performance and influence their daily activities (Sartorius *et al.* 2002, p. 1996). Daily DSL activity, for instance, declines as air and substrate temperatures increase due to thermoregulatory constraints (Sartorius *et al.* 2002, p. 1975; Fitzgerald *et al.* 2011, p. 4). To counter, the DSL possesses behavioral and physiological mechanisms to help them avoid extreme temperatures and may limit the direct effects of these events on the lizards themselves (Smolensky and Fitzgerald 2010, p. 374; Jacobson 2016, p. 3; Leavitt 2019a, p. 1). However, extreme events, particularly drought, could impact the shinnery oak habitat the DSL depends on. Climate change may alter the frequency and magnitude of these events, the effect of which can be further exacerbated by anthropogenic changes to the landscape.

4.3.2 Extreme cold and winter storms

As ectotherms that require a body temperature above 23°C (73°F) to be active (Johnson *et al.* 2016, p. 3), extreme cold weather snaps, sometimes accompanied by snow and hail, can reduce physiological activity and result in direct mortality. However, DSL are underground and inactive during the months when these events are most likely to occur. Ice storms could also result in destruction of shinnery oak, but they are likely to be sporadic and restricted spatially. Dispersal and source-sink dynamics likely allowed the DSL to persist in landscapes in which patches of habitat are disturbed due to extreme winter storms. It is unknown whether habitat fragmentation, by restricting patch size and dispersal ability, would create isolated populations vulnerable to sudden loss of habitat due to an extreme storm. Overall, this is little available information regarding the impact of extreme cold temperatures and severe winter storms on DSL individuals and populations.

4.3.3 Extreme heat and drought

The DSL is found in a semiarid climate with a history of extreme heat and droughts but also adapted to contend with such environmental variability. Over the last 20 years, southeastern New Mexico and west Texas have frequently been in drought conditions and periodically faced severe droughts (Figure 4-6, U.S. Drought Monitor, https://droughtmonitor.unl.edu/). As noted above, being an ectotherm, the DSL has behavioral adaptations that allow them to cope with elevated temperatures. They exhibit bimodal diel cycles of activity, avoiding the hottest portions of the day (Ferguson *et al.* 2014, p. 56; Leavitt 2019a, p. 1). Similarly, the DSL has evolved in an environment in which drought is a frequent occurrence. Droughts can vary from seasonal to multi-year events. Precipitation varies along a north-south gradient throughout the DSL range (Leavitt 2019a, p. 1). In the 1920s and 1930s, shinnery oak ecosystems on average encountered drought 1 to 2 years in northern portions and 2 to 3 years in southern portions out of every 10 years (Peterson and Boyd 1998, p. 14). In the past 20 years, moderate to exceptional drought has occurred every 1 to 2 years in the southern and northern shinnery oak ecosystems (Figure 4-6).

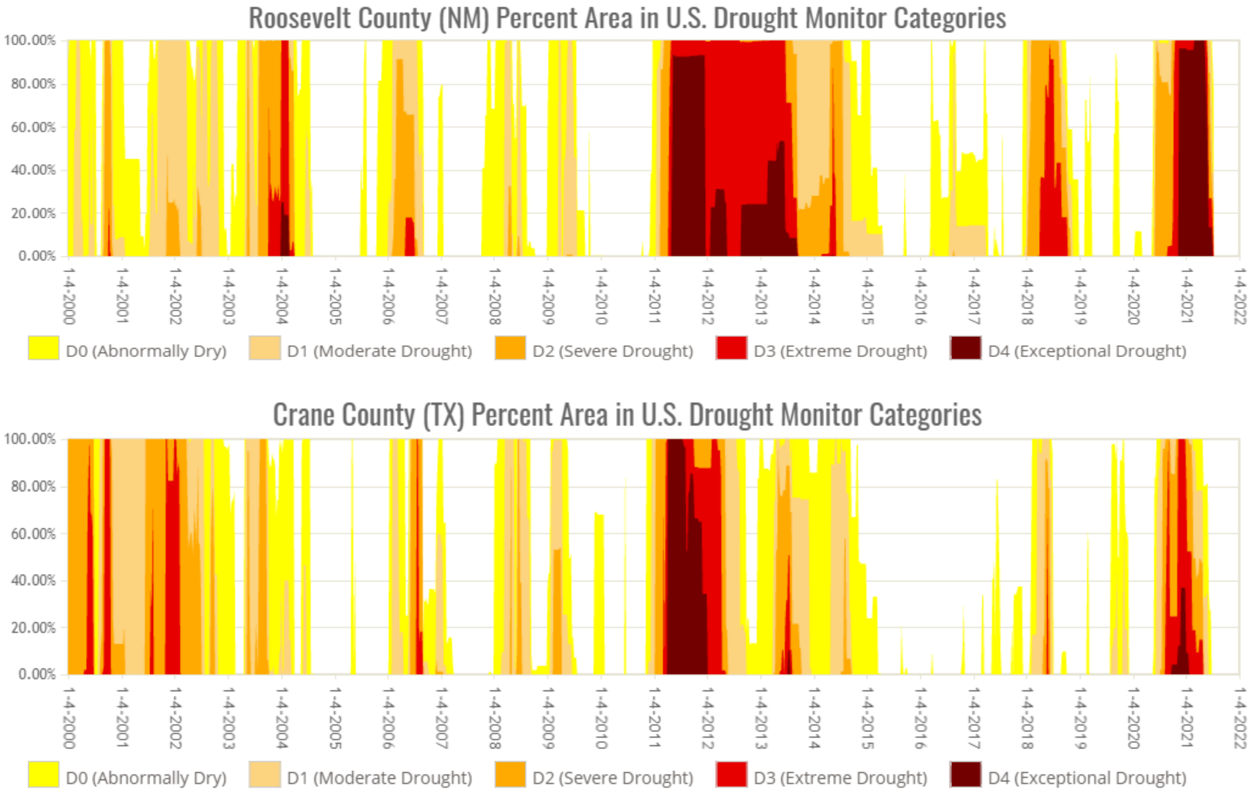

Figure 4-6 Drought intensity levels documented since 2000 in the northern-most county (Roosevelt County, NM) and the southern-most county (Crane County, TX) in the DSL range.

The impacts of extreme heat and drought on individual DSL is relatively unknown. Drought could impact food resources, which would then impact lizard productivity. The marbled whiptail (*Aspidoscelis marmoratus*), another lizard species found in the Monahans Sandhills, showed a decline in density during a period of drought (Fitzgerald *et al.* 2011, p. 30). If drought restricts available food resources, it could negatively affect DSL recruitment and survival.

The relationship between these weather events and DSL habitat (i.e., shinnery oak) has been better characterized. While shinnery oak is highly adapted for arid conditions, prolonged periods of drought may inhibit growth and reproduction. During drought, shinnery oak can lose its leaves or not even leaf-out (Peterson and Boyd 1998, p. 9). Recent droughts have resulted in a lack of the typical spring green-up for shinnery oak, instead occurring later with the seasonal summer monsoons (Johnson *et al.* 2016, p. 78). The timing of this green-up is important, as is provides shelter for adults as they become active in the spring and food for invertebrates that are consumed by the DSL.

Effects of drought on shinnery oak can also have broader consequences for duneland habitat. Shinnery oak clones may reach 15 m (50 ft) in diameter, making large areas of duneland habitat vulnerable in the event of drought-induced oak mortality (Gucker 2006, p. 7). Historically, natural groundwater discharge from the Cenozoic Alluvium aquifer characterized the Monahans dune system as “wet eolian”, where a shallow water table stabilized sand beneath the dune deposits (Garza and Wesselman 1959, p. 21). Any disruption to this system (e.g., drought) that lowers the water table may destabilize the dunes such that the system experiences a net loss in sand (Newton and Allen 2014, p. 4). Furthermore, periods of low rainfall are likely to inhibit shinnery oak colonization of disturbed areas, limiting potential for restoration and natural ecological dynamics. Ultimately, given the close association between the DSL and shinnery oak, decline or loss of this habitat would have ramifications for DSL viability.

Climate change is likely to increase the frequency and magnitude of drought in this region. On average, surface air temperatures across Texas are predicted to increase by 3ºC (5.4ºF) by 2099 (Jiang and Yang 2012, p. 238). In the southwest United States, temperature increases will be concentrated in the summer months. In Texas, the number of days exceeding 35ºC (95ºF) may double by 2050 (IPCC 2013; Kinniburgh *et al.* 2015, p. 8). According to climate change predictions, west Texas will experience greater variability in seasonal precipitation patterns with the greatest net loss experienced in winter (Jiang and Yang 2012, p. 238). An increase in drought frequency and intensity has been shown to be occurring throughout the range of the DSL (Kinniburgh *et al.* 2015, p. 62). Projections under future climate change indicate that groundwater resources will be further depleted with more extreme drought and increasing summer temperatures (Nielsen-Gammon et al. 2020, pp. 5-7; Yoon et al. 2018, entire).

Furthermore, alterations to the landscape are likely to exacerbate the impacts of climate change on the DSL. Habitat fragmentation can increase air temperatures and solar radiation, along with reducing the availability of microhabitats that can serve a thermal refugia (Jacobson 2016, pp. 3-4, 10). It would also restrict natural source-sink dynamics that could buffer against extreme weather impacts. For example, the impacts of drought may be variable over space and reductions in DSL productivity in each habitat patch could be augmented by dispersal. However, fragmentation and barriers may prevent dispersal to areas affected by drought, reducing resiliency.

4.4 Factor 4: Groundwater Depletion

4.4.1 Aquifers

The Pecos Valley Aquifer underlies the Pecos River Valley, an area of about 11,265 km^2 (7,000 mi^2) in west Texas and southeastern New Mexico (Figure 4-7). The aquifer occurs beneath the Monahans Sandhills and part of the Mescalero Sandhills. Aquifer sediments are exposed at the land surface and range in thickness from 0 to 427 m (0 to 1,500 ft) below ground (Jones 2008, p. 489; Anaya and Jones 2009, pp. 41-42; Meyer *et al.* 2012, pp. 25-25). The portion of the aquifer that underlies the Mescalero and Monahans Sandhills is saturated at a depth ranging from 1 m (3 ft) below the land surface to about 45 m (150 ft) below ground (Garza and Wesselman 1959, p. 1; Mace 2019, p. 12; Rainwater 2020, pp. 6-8).

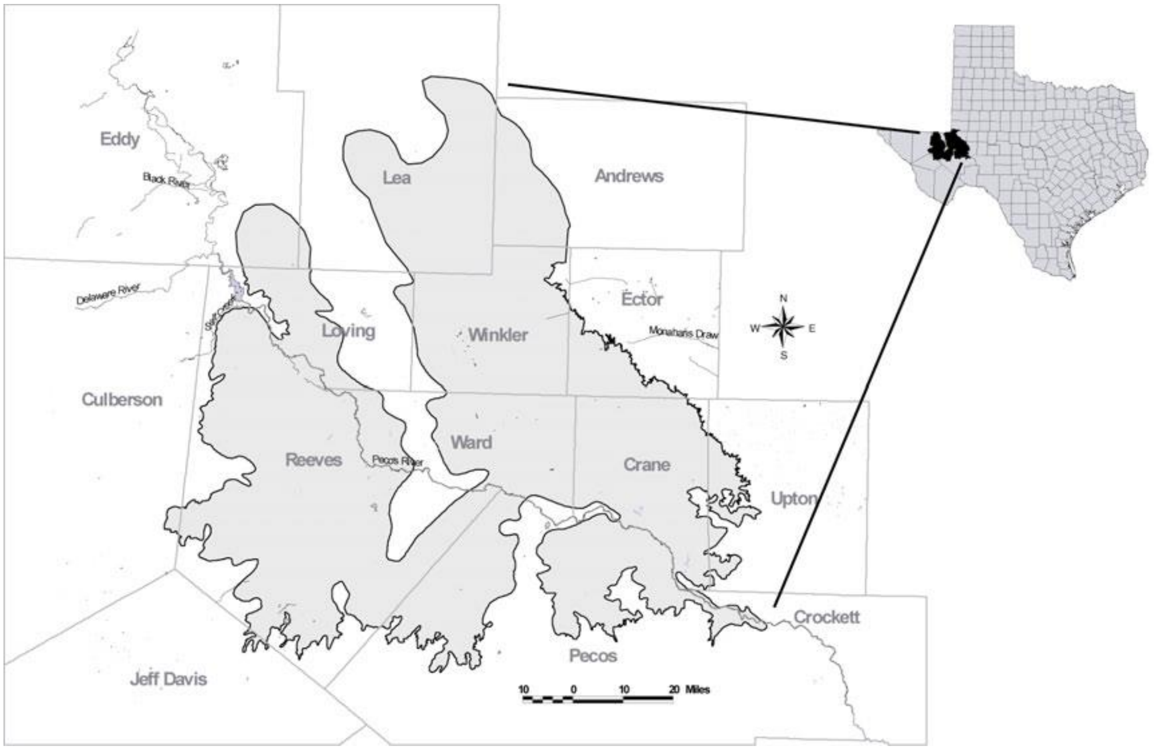

Figure 4-7 Map of Pecos Valley Aquifer in relation to Texas counties.

The Dockum aquifer extends over approximately 67,592 km^2 (42,000 mi^2) in portions of Colorado, Kansas, Oklahoma, New Mexico, and Texas (Figure 4-8). It occurs beneath both the Mescalero and Monahans Sandhills. The Dockum Aquifer is deeper than the Pecos Valley Aquifer, approximately 518 to 609 m (1,700 to 2,000 ft) deep; in southeastern New Mexico and west Texas, the Pecos Valley Aquifer overlays the Dockum Aquifer (Bradley and Kalaswad 2001, p. 167, 170).

Within the Mescalero and Monahans Sandhills, the water table is relatively shallow, with depths ranging from a meter below the surface to approximately 15 to 23 m (50-75 ft) below ground (Shafer 1956; Garza and Wesselman 1959, p. 13; White 1971, p. 17; Jones 2008, p. 489; Mace 2019, p. 12; Rainwater 2020, p. 18). The water table has been described as occurring at shallow depths beneath dune sands of the Monahans Sandhills of Texas and nearly intersecting the surface in deeper blowouts (White 1971, p. 17). Localized groundwater sources, known as perched aquifers, also occur throughout the Monahans Sandhills near the land surface, where precipitation infiltrates the ground and collects above less permeable soil layers perched above the water table (White 1971, p. 18; Machenberg 1984, pp. 25-26, 34; Weathers *et al.* 1994, pp. 51-52; Jones 2004b; p. 135; Mace 2019, pp. 1-2, 14, 78). Outside of sand dune areas, sandy soils are often underlain by finer materials (caliche and clay) that slow the downward percolation of water (White 1971, p. 18).

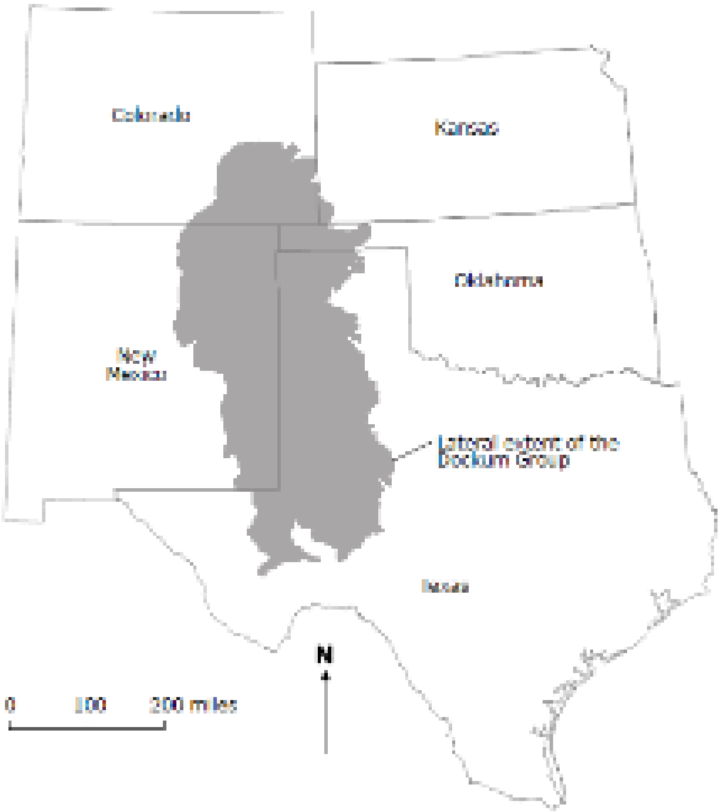

Figure 4-8 Map of Dockum Aquifer.

4.4.2 Groundwater Uses

Water needs throughout the Pecos River Valley are fulfilled primarily via extraction of water from the Pecos Valley and Dockum Aquifers. Agriculture (irrigated crop production and the raising of livestock) and production of oil and gas dominate the economy of the Pecos River Valley: both are heavily dependent on groundwater (Ashworth 1990, pp. v, 3; Scanlon *et al.* 2020, entire). Irrigation-related consumption accounts for a majority (i.e., 75 to 87 percent) of water withdrawals (Boghici 1998, p. 23; Jones 2004b; p. 133; Meyer *et al.* 2012, pp. 11-12), while consumption of groundwater by the oil and gas industry, ranchers, and municipalities accounts for the remaining 13 to 25 percent (Boghici 1998, p. 23; Jones 2004b, p. 133; Meyer *et al.* 2012, pp. 11-12). Sand mines have recently become established throughout the region and extract water from both the Pecos Valley and Dockum Aquifers (Mace 2019, pp. 46-48, 57-59; Rainwater 2020, p. 13, Table 2). In areas where sand mine operations are underway, mining-related consumption may meet, or exceed, the consumption of all other sectors combined (Mace 2019, pp. 2, 57-59). Perched aquifers may also be impacted by pumping from residential/recreational pools or for shallow quarries.

4.4.3 Groundwater Pumping and the Water Table

Groundwater pumping at a well creates a localized cone of depression (i.e., a zone where the water table is drawn down) around the well (Figure 4-9). Over time, the cone of depression become broader, affecting a wider area. Cones of depression formed around neighboring wells may interact, resulting in more drawdown at a location than if there was only one cone of depression (Freeze and Cherry 1979, pp. 304-335; Mace 2019, p. 57). Regionally, if the amount of water pumped from multiple wells exceeds the amount of water that effectively recharges the aquifer, then water-level declines may be seen across the aquifer year after year, as water is removed from storage (Mace 2019, p. 64). However, following cessation of groundwater pumping, water levels can recover and reduce the extent of the cone of depression.

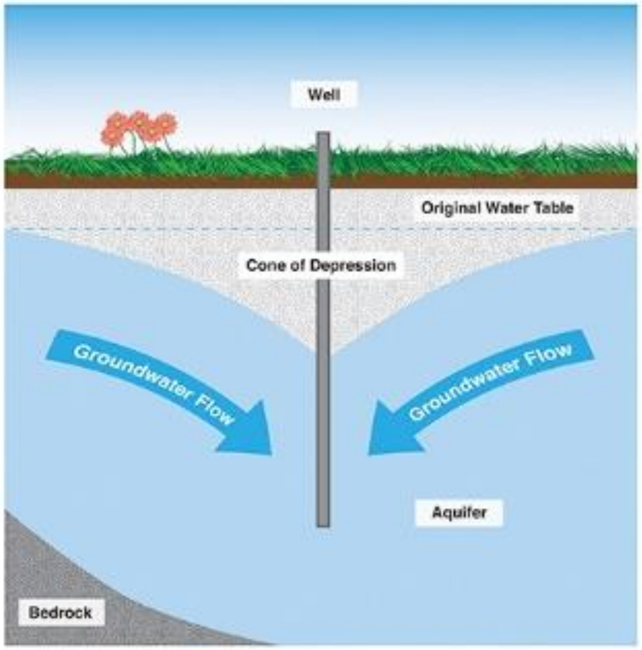

Figure 4-9 Schematic of how a cone of depression can affect surrounding groundwater levels.

The water table of the Pecos Valley Aquifer responds locally, and regionally, to groundwater pumping (Jones 2004a; pp. 128-129; Mace 2019, pp. 2-3, 60-63). Groundwater declines in parts of the aquifer are associated primarily with irrigated agriculture and levels fluctuate annually in response to seasonal irrigation cycles (Jones 2004a; pp. 128-129; Jones 2004b; pp. 139-141). Groundwater levels declined more than 61 m (200 ft) in the late 1940s and early 1950s in irrigation centers in the southwestern part of the aquifer (Reeves and Pecos Counties) in response to the development of large-scale irrigation farming (Oglibee and Wesselman 1962, entire). These declines began to moderate in the 1970s and groundwater levels subsequently rose in some areas due to decreased irrigation pumping (Jones 2004b; p. 141). Groundwater levels, however, remain below historical elevations in irrigation areas (Ashworth 1990, p. 23; Jones 2004; pp. 128-130), with major cones of depression still present in central Reeves and northern Pecos counties (Jones 2004b; pp. 140-141).

Groundwater level declines in parts of the aquifer are also attributable to groundwater pumping related to industrial use and public supply (Jones 2004a; pp. 128-130; Mace 2019, pp. 2-3, 60-64). Climate has a significant effect on the amount of groundwater pumped from the Pecos Valley Aquifer because of increased extraction rates during times of drought (Anaya and Jones 2009, pp. 48-49).

4.4.4 Effects of Groundwater Pumping on Sand Dunes and Shinnery Oak Vegetation

The effects of groundwater pumping on habitats associated with the DSL depends on the nature of the operation and the local water table. With the Pecos Valley Aquifer, the depth of the aquifer and its relationship to the water table varies spatially and, in some locales, may be disconnected. In other locales where the depth to the Pecos Valley Aquifer is within reach of shinnery oak taproots, which often go as deep as 30 ft (9.1m) (Figure 2-9; Gucker 2006, p. 6, Peterson and Boyd 1998, p. 5). Throughout the Monahans Sandhills region the water table is set by localized perched aquifers in some areas that can also interact with the shinnery oak vegetation (Mace 2019, pp. 14). Although the Pecos Valley Aquifer may be in reach of shinnery oak, pumping of the deeper Dockum aquifer may have little consequence for aboveground vegetation. If an aquifer is connected to the local water table, then pumping can lower the water table (and its capillary fringe), reducing its contribution to intradunal soil water. This can destabilize sand dunes by reducing sand grain cohesiveness, making dunes susceptible to wind erosion and deflation (Machenberg, 1984, pp. 6, 30-31, Kocurek and Havholm 1993, pp. 394, 398-400, 402-404, Pye 2009, p. 364; Newton and Allen 2014, pp. 1, 4, 28). Groundwater pumping can also reduce blowout stability and cohesion (Machenberg, 1984, pp. 6, 24, 30-31).

In certain situations, groundwater pumping, and subsequent declines in the water table adversely affects phreatophyte (i.e., shinnery oak) communities in arid climates (Cambell *et al.* 2017, p. 69). Groundwater depletion can stress phreatophytes through reduced photosynthesis and growth, which can lead to their deterioration (senescence) and death (Machenberg, 1984, pp. 6, 24, 30-31, Stromberg *et al.* 1992, pp. 45-46, 51, 53, 54-56; Stromberg *et al.* 1993, pp. 311-112; Laity 2003, pp. 196-197, 208-209, 212, 218). As water table depth increases, phreatophytes become scattered and less vigorous, and gradually diminish in size until they cease to exist altogether due to a reduction in the ability of plants to obtain water necessary for normal growth and survival (Robinson 1958, p. 22).

Death or deterioration of dune-anchoring phreatophytes, such as shinnery oak, can lead to the erosion and deflation of dune landforms by strong winds (Machenberg, 1984, pp. 6, 19-21, 24, 29-31, 33; Kocurek and Havholm 1993, pp. 394, 401-402; Muhs and Holliday 2001, pp. 75-76; Laity 2003, pp. 196-197, 216-217). Reduced growth rates can hinder plant growth, sand accumulation, and dune formation (Machenberg 1984, p. 16; Gucker 2006, entire; University of California Riverside 2018, Appendix IX). Groundwater depletion can also prevent young plants (e.g., seedlings and saplings), which have limited rooting depths, from becoming established (Laity 2003, pp. 196, 209-211; Cambell *et al.* 2017, p. 77) and can further preclude dune formation. Reduced recruitment of young plants into phreatophyte populations can lead to vegetation declines over time (Laity 2003, pp. 196, 209-211; Cambell *et al.* 2017, pp. 69, 76-77). The consequences of shinnery oak death and degradation from groundwater pumping effects are significant because shinnery oak cannot be readily replaced (Gucker 2006, entire; Peterson and Boyd 1998, pp. 1, 10).

Effects of lowering the water table can extend to the DSL as well. Female DSL prefer sandy soils with relatively high moisture content for nesting. The DSL digs burrows into the base of sand dunes or within dune blowouts; construct nest chambers at the soil moisture horizon; and pack eggs with moist sand from the surrounding substrate (Ryberg *et al.* 2012, pp. 583-584).

In summary, lowering of the water table underlying a dune field can deplete soil moisture; reduce the cohesiveness of sand grains; leave dune plants susceptible to water stress, desiccation, and death; and cause wind erosion and deflation of the dune landforms. However, this depends on the relationship between the aquifer and local water table. Given this uncertainty, localized nature of the impacts, and lack of data relating groundwater pumping to habitat loss, it is difficult to extrapolate how groundwater pumping has affected DSL habitat across its range. Over time, there will likely be further stress to aquifers and groundwater levels due to changes in precipitation patterns and increasing summer temperatures.

4.4.5 Sand mining and local aquifers

Sand mines use water to help process sand, filter it, and move it. They get the water from wells in local aquifers, mainly the Pecos Valley Aquifer and the Dockum Aquifer (Mace 2019, p. 1, 14; Rainwater 2020, p. 13, Mace and Jones 2023, p. 71, Table 4.). Lowering of groundwater in an aquifer can diminish groundwater contributions to intradunal and blowout soil moisture. Groundwater pumping by sand mines within the Monahans Sandhills could affect these local aquifers (Mace 2019, pp. 1, 14; Mace and Jones 2023, entire). The majority of sand mine wells get their water from the Pecos Valley Aquifer, although they may get their water from the Dockum Aquifer in areas in which the Pecos Valley Aquifer is too thin for productive wells (Rainwater 2020, p. 7). Although short-term data shows that water used by one sand mine was limited to an amount that was able to be recharged over a year (Rainwater 2020, p. 28), peer-reviewed research within the Monahans Sandhills region shows that water withdrawal by sand mines within the region could have larger affects to the water table in the Pecos Valley and Dockum Aquifers over time (Mace and Jones 2023, entire). Modeling done by Mace and Jones (2023, p. 72) shows that sand mines within the Monahans Sandhills region have potential to use 0.5-2 times the water that is currently used for other uses within the region.. Overuse of the Pecos Valley Aquifer, which provides water to the deep shinnery oak taproots, can cause a drawdown of the water table in surrounding areas. In these situations, loss of DSL habitat could occur beyond the footprint of the mining operation itself.

4.5 Factor 5: Direct Mortality

4.5.1 Overview

Direct mortality to individual DSL can occur from multiple sources. Specifically, there is potential for direct mortality caused vehicle strikes on roads, OHV strikes within DSL habitat, and heavy equipment use for construction of roads, pipelines, well pads, renewable energy infrastructure, and sand mining (refer to the Habitat Loss and Modification sections for more detail). Along with the direct mortality sources discussed earlier in this chapter, predation is another source of mortality for the DSL.

As noted in Chapter 2, there are several species that are predators of the DSL. In a nesting ecology study, 20 percent of radio-tracked DSL were eaten by snakes, with 4 of the 5 predators were confirmed to be coachwhips (Hill and Fitzgerald 2007, p. 5). Coachwhips are large, fast, diurnal snakes that primarily prey upon lizards. Loggerhead shrikes are birds that occur across many habitat types, ranging from deserts to suburban areas. These birds use fences, poles, trees, and utility wires as perches (Rappole 2000, p. 163; Hathcock and Hill 2018, pp. 222-223).

It has been hypothesized that areas with more artificial perches stemming from oil and gas infrastructure, utility wires and poles, and fencing can result in increased predation by bird species (Dinkins *et al.* 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796), especially in treeless, open areas (Slater and Smith 2010, p. 1080). Dinkins *et al.* (2014, p. 325) found breeding season survival of greater sage-grouse (*Centrocercus urophasianus*) hens to be negatively associated with power-line density, though this study looked at larger birds of prey, like corvids and raptors. In New Mexico, Hathcock and Hill (2018, entire) documented that over 50 percent of loggerhead shrike hunts were initiated from a power line. They did not find differences in loggerhead shrike consumption of DSL in fragmented versus unfragmented habitats, although they were limited by small sample size. Therefore, the relationship between artificial perches and levels of predation avian predators is unknown. The DSL has behavioral tactics (e.g., sand swimming) to avoid predation and shinnery oak provides shelter to limit exposure to aerial predators. In areas fragmented by infrastructure, the presence of perches coupled with removal of vegetation could increase DSL mortality due to predation.

4.6 Factor 6: Conservation Management

4.6.1 New Mexico Conservation Efforts

The DSL is listed as an endangered species within the state of New Mexico by the New Mexico Department of Game and Fish (NMDGF) and is considered a sensitive species by the BLM. A working group composed of local, state, and Federal officials, along with private and commercial stakeholders, published the Collaborative Conservation Strategies for the Lesser Prairie-Chicken and Sand Dune Lizard in New Mexico in August 2005 (New Mexico Lesser Prairie Chicken and Sand Dune Lizard Working Group 2005, entire). This document provided guidance in the development of the BLM's Special Status Species Resource Management Plan Amendment (RMPA)(BLM 2008) and the development of the Candidate Conservation Agreement (CCA) and Candidate Conservation Agreement with Assurances (CCAA) (CEHMM 2008) for the DSL and Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*, LEPC) in New Mexico.

The RMPA, which was approved in April 2008, provides guidance for the management of the lands with DSL habitat. The plan addressed concerns and threats of oil and gas development and shinnery oak removal due to herbicide spraying by outlining protective measures and basic guidelines for developing around DSL habitat. It provides for specific conservation requirements, lease stipulations, and the removal of 42,934 ha (106,091 ac) of DSL habitat from future oil and gas leasing (BLM 2008, entire). Since the RMPA was approved in 2008, BLM has closed approximately 120,000 ha (300,000 ac) to future oil and gas leasing and closed approximately 345,000 ha (850,000 ac) to wind and solar development (BLM 2008, p. 3). From 2008 to 2020, they have reclaimed 1,416 ha (3,500 ac) of abandoned well pads and associated roads. Additionally, BLM has implemented control efforts for mesquite on 335,740 ha (832,104 ac) and has plans to do so on an additional 12,141 ha (30,000 ac) annually (Carter 2020, pers. comm.).

Following approval of the RMPA, a CCA was drafted by a team including the Service, BLM, Center of Excellence (CEHMM), and participating cooperators to address the conservation needs of the LEPC and DSL on BLM lands in New Mexico by undertaking habitat restoration and enhancement activities and minimizing habitat degradation. A CCAA was also developed in association with the CCA to facilitate conservation actions for the LEPC and DSL on private and state lands in southeastern New Mexico. Through this CCA and CCAA, CEHMM works to: protect and enhance existing populations and habitats; restore degraded habitat; create new habitat; fund research studies; undertake other activities on private lands and Federal leases or allotments to improve the status of the LEPC; and minimize surface disturbances or relocate projects to avoid disturbance to the LEPC or DSL (CEHMM 2016, pp. 1–2).

The CCA and CCAA are “umbrella” agreements under which individual entities participate. In New Mexico, an estimated 35 percent of the occupied range of the DSL is on privately-owned and State-managed lands. There are no local or State regulatory mechanisms pertaining to the conservation of DSL habitat on private or State lands in New Mexico, nor is there NMSLO policy in place to protect sensitive species. Nearly all DSL habitat on New Mexico State Trust lands has been leased for oil and gas development with no stipulations on that development. The only mechanism for the preservation of DSL habitat on State Trust Lands currently is through enrollment of those lands in the CCAA.

These agreements allow private landowners and operators, such as ranchers and oil and gas companies, to participate in the conservation of the DSL. The agreements provide conservation measures that limit habitat modification and protect habitat corridors between shinnery oak dune complexes.

Since the CCA and CCAA were finalized in December 2008, 40 oil and gas companies and 37 ranchers have enrolled a total of 218,144 ha (539,046 ac) of the duneland habitat and 258,018 ha (637,577 ac) of the surrounding supportive matrix habitat (Table 4-1). The total acres of habitat enrolled by industry, ranches, NMDGF, and NMSLO currently covers around 85 percent of the range of the DSL within New Mexico.

Table 4-1. Total 2022 enrollment by industry and ranchers in the Candidate Conservation Agreement (CCA) and Candidate Conservation Agreement with Assurances (CCAA) (CEHMM 2008) for the DSL and LEPC in New Mexico within DSL habitat.

Enrollment	Shinnery oak Dunelands	Shinnery oak Supportive Habitat
CCA		
# Industry companies	40	40
# Ranchers	28	28
Industry	60,211 ha (148,784 ac)	53,539 ha (132,297 ac)
Ranchers	81,840 ha (202,230 ac)	71,117 ha (175,733 ac)
CCA Total	142,050 ha (351,014 ac)	124,655 ha (308,030 ac)
CCAA		
# Industry companies	34	34
# Ranchers	37	37
Industry	17,985 ha (44,443 ac)	37,921 ha (93,707 ac)
Ranchers	28,341 ha (70,031 ac)	47,397 ha (117,107 ac)
NMDGF	439 ha (1,084 ac)	1,451 ha (3,586 ac)
NMSLO	29,329 ha (72,474 ac)	46,598 ha (115,147 ac)
CCAA Total	76,094 ha (188,032 ac)	133,363 ha (329,547 ac)
OVERALL TOTAL	218,144 ha (539,046 ac)	258,018 ha (637,577 ac)

The Service received updated enrollment numbers for 2023, however, these updated numbers were not broken out by habitat type and ownership type. Updated enrollment numbers include a total of 104 ranches (33 new since 2022), 13 parcel-by-parcel (1 new since 2022), 50 all-activities, and 31 linear development enrollees. Areas enrolled as of 2023 includes 946,810 ha (2,339,619 ac) for ranching and 1,314,722 ha (3,314,722 ac) for industry, resulting in a total of 2,288,231 ha (5,654,341 ac). It is important to note that these enrollment numbers are for the joint LEPC-DSL programs, so enrollee numbers and acreage do not necessarily reflect DSL-specific coverage.

4.6.2 Texas Conservation Efforts

In Texas, the DSL is listed as a Species of Greatest Conservation Need (SGCN) by TPWD. This designation, however, does not afford the species any legal protection, but guides TPWD’s nongame conservation efforts, including regional efforts to conserve these species. Additionally, there are no local or other state mechanisms regulating impacts or pertaining to the conservation of DSL habitat on private lands. In Texas, nearly all DSL habitat is privately owned. Monahans State Park is the only public land on which the DSL is known to exist. The TPWD has a long-term lease on 1,408 ha (3,840 ac) of DSL habitat at Monahans State Park in Ward and Winkler counties. According to TPWD’s park history and ownership, Ward County owns 121 ha (300 ac) of the park, and the state leases about 1,214 ha (3,000 ac) from the Sealy-Smith Foundation and about 324 ha (800 ac) from the Williams family of Monahans.

4.6.2.1 Texas Conservation Plan

Since the first oil well was drilled in 1920 in the Permian Basin, this area has become a primary producer of oil and natural gas in the United States (Enverus 2020). Oil and gas development are long recognized threats to the DSL, prompting a proposal to list the DSL under the Act in 2010 (75 FR 77801). In response, in 2011 the Texas Comptroller of Public Accounts (CPA) led a group of stakeholders potentially affected by the proposed rule to list the DSL as endangered to develop the Texas Conservation Plan (TCP) for the DSL. The TCP provides the supporting framework for a CCAA and the associated Enhancement of Survival Permit under Section 10(a)1(a) of the ESA. The CPA's goal in developing the TCP was to balance conservation and protection of the DSL with oil and gas and agricultural development (CPA 2012, entire).

After six years of implementation, the CPA revised the TCP to address issues preventing the plan from achieving its conservation and protection goals (Gulley 2017a, entire; Gulley 2017b, entire; Koch 2018, entire; Hegar 2018a, entire; Hegar 2018b, entire; Gulley 2018a, entire; Gulley 2018b, entire; Hegar 2018d, entire; CPA 2019, entire). In 2018, the CPA submitted these revisions to the Service in the form of a new CCAA to replace the existing TCP, and subsequently surrendered its original permit for the TCP, pursuant to 50 Code of Federal Regulations (CFR) § 13.26 (Ashley 2018a, entire; Ashley 2018b, entire; Hegar 2018a, entire; Hegar 2018b, entire; Hegar 2018c, entire; CPA 2019, entire). The Service did not permit the new CCAA submitted by the CPA. In 2020, the Service revised and transferred the permit for the TCP to a new Permit Holder, the American Conservation Foundation (Falon 2019, entire; Fleming 2020a, entire; Fleming 2020b, entire).

The TCP authorizes impacts to DSL habitat (i.e., incidental take of the DSL) resulting from oil and gas development, agriculture, and ranching activities (i.e., covered activities) and establishes a conservation program focused on avoiding development of these activities in DSL habitat. If avoidance of DSL habitat cannot be accomplished, participants enrolled in the TCP must implement conservation measures that minimize and mitigate for habitat impacts via restoration or enhancement of DSL habitat (CPA 2012, entire; Service 2012, entire).

From 2012 to 2018, public or private entities conducting otherwise lawful oil and gas, agricultural, and ranching activities within the TCP's Permit Area were able to work with the CPA to voluntarily enroll in the TCP, to obtain authorization for impacts to DSL habitat resulting from covered activities (CPA 2012, entire). Until recently, the TCP serves only those Participants who were enrolled in the TCP at the time of its surrender in 2018 (Fleming 2020b, entire). An administrative change to the TCP in December 2023 allowed for new enrollment. Because incidental take for sand mining activities is not authorized under the TCP or its Permit (CPA 2012, pp. 16-18; Fleming 2020b, entire), the CPA determined that only those sand mining companies that completely avoid activities (and thus impacts) in DSL habitat could enroll in the TCP. Accordingly, the CPA enrolled eight sand mine companies in the plan in 2017 and 2018 (CPA 2018a, p. 5, 8, 17), based on purported agreement of these companies not to conduct sand mining activities in DSL habitat (Gulley 2017a, entire; Gulley 2018b, entire; Hegar 2018e, entire; CPA 2018a, pp. 5, 8, 17; Wellman 2018, entire; CPA 2019, pp. 41-42).

The Permit originally authorized 879 ha (2,173 ac) of incidental take for the TCP, with an additional authorization of up to 8,602 ha (21,257 ac) dependent on a positive biological response of the DSL to the TCP (CPA 2012a, pp. 58-61; Nicholopoulos 2012, entire). The revised 2020 Permit authorizes up to 708 ha (1,750 ac) of incidental take of DSL habitat, as classified by the Permit Area/Likelihood of Occurrence Map of the TCP (CPA 2012, Figure 1-2). This is the amount originally authorized (i.e., 879 ha [2,173 ac]), minus the total amount of impacts (171 ha [423 ac]) reported by Participants in 2019.

Under the TCP, DSL habitat consists of the shinnery oak dune complexes likely to be occupied by or particularly suitable for the species, as demarcated by the Permit Area/Likelihood of Occurrence Map of the TCP (CPA 2012, Figure 1-2). The Permit Area/Likelihood of Occurrence Map recognizes 79,968 ha (197,604 ac) of DSL habitat in shinnery oak duneland complexes in Andrews, Crane, Ector, Gains, Ward, and Winkler Counties (CPA 2012, p. 61, Appendix J). Enrollment of habitat by Participants in the TCP remained below industry commitments and Service expectations of greater than 71 percent, hovering in the 50 to 60 percent range from 2012 to 2018 (CPA 2012a, p. 25; Service 2012, pp. 36885-36886; Gulley 2017a, entire; CPA 2018, entire; Gulley 2018 a, entire; Gulley 2018b, entire). In 2017, the CPA reported 46,606 ha (115,167 ac) of enrolled habitat (58 percent of DSL habitat) in the TCP, with 24 participants, including 8 sand mining companies (CPA 2018, entire).

The CPA surrendered the permit in 2018 (Hegar 2018c, entire). Of the 29 Participants enrolled in the TCP on November 10, 2018, a total of 8 expressed interest in maintaining enrollment under the revised 2020 Permit. The Total Gross Acreage Enrolled in the TCP decreased significantly, from 120,193 ha (297,004 ac) in 2018, to 28,489 ha (70,397 ac) in 2020 (approximately 76 percent) (ACF 2021c, entire). The decrease in enrolled acres was due to the decline in the number of Participants originally enrolled in the TCP.

Approximately 1,847 ha (4,564 ac) of DSL habitat was impacted in the TCP Permit Area between 2012 and 2018. Of this total amount, Participant oil and gas companies disturbed 171 ha (423 ac) of habitat, whereas non-participant oil and gas and sand mining companies disturbed 1,676 ha (4,141 ac). Non-Participant sand mining companies disturbed at least 684 ha (1,692 ac) of habitat, whereas non-Participant oil and gas companies disturbed 991 ha (2,449 ac) (Gulley 2017a, entire; Gulley 2017b, entire; Gulley 2017c, pp. 7 - 10; Gulley 2018a, entire; Gulley 2018b, entire; Hegar 2018e, entire; CPA 2018a, pp. 5, 8, 14, 16-18; CPA 2018b, entire ; CPA 2019, pp. 41, 77-78).

The CPA mitigated Participant impacts to DSL habitat mostly via mesquite removal activities. From 2012 to 2018, the CPA implemented mesquite removal projects on 356 ha (880 ac) of DSL habitat and surrounding buffer area. By comparison, only 6 percent of the above-mentioned total of 171 ha (423 ac) of DSL habitat impacted by Participants was mitigated for via removal of oil and gas well pads and roads between 2012 and 2018 (Gulley 217a, entire; Gulley 2017c, entire; CPA 2018 a, pp. 16-18; Gulley 2018a, entire; Gulley 2018b, entire).

In 2016, the CPA suspended the use of mesquite removal as a mitigation activity after finding the activity was being inappropriately utilized under the TCP and that mesquite removal was providing little conservation benefit to the DSL (Gulley 2017c, entire; CPA 2018a, pp. 16-8; Gulley 2018a, entire; Gulley 2018b, entire). Further, under the TCP, oil and gas well pad and road removal activities are supposed to be prioritized as mitigation activities because they address the greater threats to the species of habitat loss and fragmentation from oil and gas development (CPA 2012, pp. 17, 25, 88-90, 92-93, 149-154; Service 2012, entire).

Surface disturbances made by TCP Participants to date have not been fully or effectively mitigated. That is, of the 210 ha (519 ac) of DSL habitat that has been disturbed by Participants to date, only 16 ha (39 ac) have been mitigated via abandoned well pad and road removal (CPA 2018a, pp. 5, 8, 14, 16-18). Per the TCP 2023 annual report, as of December 31, 2023, a total of seven participants are enrolled in the TCP. The total acreage enrolled by these seven participants is 135,296 ha (334,323 ac). Of this total acreage, 20,565 ha (50,816 ac) are located in DSL habitat, according to the map used by the TCP (Fitzgerald et al. 2011, p. 10). An additional 6,132 ha (15,153 ac) are located in the 200-meter buffer of DSL habitat.

4.6.2.2 2020 CCAA

Because the TCP does not cover sand mining as a Covered Activity, mining companies funded the drafting and submission of an application for a CCAA that covers oil and gas, sand mining, linear infrastructure (such as utilities and pipelines), wind, solar, local governments, and agriculture and ranching (referred herein as the 2020 CCAA).

Using habitat as a surrogate for quantifying the amount of incidental take, the total amount of take authorized during the permit term (23 years) is 14,140 ha (34,940 ac). Because it was not possible to determine how much DSL habitat would be disturbed or destroyed by Participants versus non-Participants, this estimate, which was formulated based on a variety of factors (see Section 18 of the 2020 CCAA), is the expected total impacts to DSL habitat in Texas over the permit term, including from the TCP.

Chapter 8.1 of the 2020 CCAA describes the goal and objectives of the CCAA conservation strategy. There is one overarching goal: contribute, directly or indirectly, to the conservation of the DSL by reducing or eliminating threats on enrolled properties. This goal is then followed by a list of objectives that emphasize conserving DSL habitat, restoring and reclaiming impacted areas, reducing habitat fragmentation, addressing stratification, and others. Each industry has various avoidance and minimization measures that they are encouraged to implement in addition to various fees based on DSL habitat type to be impacted. These fees are expected to support administration of the 2020 CCAA as well as conservation actions and research.

The permit was issued on January 20, 2021, and the Administrator is currently coordinating implementation with the Service and actively seeking participants to sign up under the 2020 CCAA. As of February 29, 2024, the Service has received seven Certificates of Inclusion (CI) for the 2020 CCAA from the Permit holder, which enrolled a total of 99,616 ha (403,232 ac). Of these 99,616 ha (403,232 ac), only 8,417 ha (34,061 ac) are reported to be in DSL habitat as mapped by Hardy et al (2018). While each CI has a requirement for implementing avoidance and conservation measures, no specific actions for each CI have been reported to the Service to date; thus, we remain unaware of the specific conservation measures being implemented by each participant per their CI.

Chapter 5: Current Condition

5.0 Summary

We assessed the current condition of the DSL through an analysis of existing habitat, featuring a geospatial analysis to estimate the current quantity and quality of available habitat. Our approach is rooted in the findings of numerous studies that the DSL experiences reductions in abundance and density as habitat is lost or becomes disturbed. Habitat loss has both direct (e.g., loss of duneland habitats) and indirect (e.g., habitat fragmentation) effects on the species, causing the remaining DSL populations to become smaller and more isolated.

The primary source of habitat loss in the last century has been surface disturbance associated with oil and gas production in the Permian Basin. In addition, past treatment of shinnery oak with herbicides for agricultural and ranching purposes has degraded habitat. In the last decade, additional habitat loss has occurred due to the development of sand mining, which produces products used by the oil and gas industry.

The results of our geospatial analysis indicate that across our analysis area, which is 529,161 ha (1,307,558 ac), there are 505,857 ha (1.25 million ac) defined as potential DSL habitat, with approximately 41 percent of that potential habitat composed of shinnery oak duneland. Our analysis found 47 percent of potential DSL habitat is considered minimally disturbed by human development, whereas 39 percent has been degraded to the point it is unable to support viable DSL populations. The remaining 14 percent has moderate levels of disturbance, where we anticipate there have been reductions in DSL viability. Levels of habitat degradation and disturbance were not equal across our 11 Analysis Units and we developed a system to rank the viability of DSL populations within these units based on habitat metrics. Our analysis provides the first range-wide assessment of DSL viability.

5.1 Current condition methodology

5.1.1 Framework

We assessed resiliency for our 11 Analysis Units using habitat metrics indicative of habitat quantity and quality. The use of population metrics or occurrence data to estimate current condition of the DSL range-wide is not feasible at present. Aside from localized estimates of neighborhood sizes (Ryberg *et al.* 2013, p. e56856), there have not been efforts to estimate absolute abundance of DSL range-wide. There has been an attempt to estimate DSL abundance in New Mexico based on density estimates and capture rates, but the assumptions implicit in these extrapolations create high uncertainty and large confidence intervals in these abundance estimates (Leavitt and Acre 2021, entire).

Additionally, a variety of survey methods have been used to derive different population metrics (e.g., densities and relative abundance metrics) across the species range (Leavitt 2019b, p. 4; Smolensky and Fitzgerald 2010, p. 379), limiting comparability of these metrics and our ability to assess changes in condition over time. Research has also revealed that methods commonly used to survey for the DSL have a low detection probability due to the cryptic nature of the species (Leavitt 2019b, p. 6; Smolensky and Fitzgerald 2010, p. 377). This survey research indicated that higher amounts of effort (e.g., number of surveys) are required to avoid false negative detections, which may reduce the utility of some historical surveys with insufficient effort to detect the species. Many DSL surveys in Texas may also have been constrained by site access to private lands and areas of potential habitat may have been incorrectly identified as unoccupied by the DSL based on insufficient survey effort (Hardy *et al.* 2018, p. 2; Walkup *et al.* 2021, p. 21; Walkup *et al.* 2022, pp. 351, 354, 357).

5.1.2 Habitat Classification

Because the DSL is a habitat specialist, estimating metrics associated with the status of its habitat provides a robust, spatially consistent method to assess its status. As indicated in Chapter 2, there have been several attempts to classify and quantify DSL habitat in New Mexico and Texas. Our approach builds upon these efforts to create a unified methodology applied across the species' range. We acknowledge that this provides an indirect measure of DSL resiliency since it equates the presence of habitat with the presence of the species (Walkup *et al.* 2021, pp. 20-21). Our assessment does not imply that the presence of habitat guarantees the presence of the DSL. However, given the dependence of DSL on specific habitat types and the challenges with developing range-wide population metrics, a habitat-based assessment provides the most feasible option to assess the current status of the species.

To assess habitat availability and quality in the 11 Analysis Units, we used existing classification schemes to classify habitat based upon its value to the DSL. Hardy *et al.* (2018, p. 21) identified four habitat types within the Mescalero and Monahans Sandhills with documented DSL occurrence data that serve as suitable habitat:

> "*Shinnery Oak Duneland – This landscape feature includes embedded dunes, blowouts, disturbed blowouts and barren sandy areas in association with shinnery oak. Dunes represent large active dune complexes where shinnery oak is in contact at the margins or as embedded vegetation within the larger open dune area. We recognize that Texas has some dune complexes that are much larger than dune complexes found in New Mexico. However, historic and current survey data have documented DSL in these open dune fields in the absence of vegetation as well as in contact with shinnery oak along the margins or as embedded vegetation within the dune interior. It is noted that these open dune fields are in fact dynamic in terms of interannual vegetation coverages especially when viewed over decadal time frames.*
>
> *Shinnery Oak-Honey Mesquite Duneland – This landscape feature includes dunes, blowouts, disturbed blowouts and barren sandy area in association with shinnery oak dominant versus honey mesquite. As noted in Johnson et al. (2016), it remains unclear at what percent honey mesquite inclusions represents degraded DSL habitat. We have assumed honey mesquite inclusions of < 25 percent to represent DSL habitats.*

> *Shinnery Oak Shrubland (flats) – This landscape feature represents flat-to-low rolling eolian plains in which blowouts, disturbed blowouts are somewhat deflated (i.e., reduced vertical dimensions) and limited to smaller scattered patches. These areas are considered dispersal corridors.*
>
> *Shinnery Oak-Honey Mesquite Shrubland – This landscape feature is dominated by mesquite and contains dunes, blowouts, and disturbed blowouts with some shinnery oak inclusions. When adjacent to shinnery oak dunelands these can be Intermediate II Suitability functioning as dispersal corridors. Grasslands when interspersed with blowouts and adjacent to shinnery oak dunelands can also function as dispersal corridors and therefore can be Intermediate II categories in these spatial contexts*."

Dunelands are known to host the majority of DSL breeding, rearing, and foraging habitats. However, the DSL has also been found to a lesser extent in surrounding shinnery oak flats and shrublands. These habitats may be used as dispersal and foraging habitat. Additionally, this supportive matrix habitat is critical to maintain the structure, integrity, and resilience of the dunelands, which shift around in the supportive matrix over time. We refined the habitat models developed by Hardy *et al.* (2018) and Johnson *et al.* (2016) to define two separate habitat categories: Shinnery Oak Duneland (hereafter Duneland) and Shinnery Oak Supportive (hereafter Supportive) Habitat.

> Shinnery Oak Duneland- The top-quality habitat with the most blowouts. It is used for DSL breeding, feeding, and sheltering. These habitats are associated with most existing DSL observational data from New Mexico and Texas. This habitat includes dune blowouts in which the few (<10) documented DSL nests have been found. Using available DSL locations in the Mescalero Sandhills, out of 877 observations, 93.8 percent of those observations were within the Shinnery Oak Duneland habitat. This category only includes areas with less than 10 percent mesquite cover in New Mexico and less than 5 percent mesquite cover in Texas (this difference is due to the differences in mapping between the two mapping efforts). This category includes Shin-Oak duneland from Johnson *et al.* (2016) and Shinnery Oak Duneland and Shinnery Oak-Honey Mesquite Duneland from Hardy *et al.* (2018).
>
> Shinnery Oak Supportive Habitat- These shinnery oak shrubland classes serve a connectivity role that links duneland habitat together. The surrounding shinnery-oak shrublands constitute a supportive habitat matrix that stabilizes and buffers the dune fields. In addition to potentially supporting dispersal and gene flow, this habitat stabilizes Duneland habitat against threats from future development, such as sand mining and groundwater use that may compromise dune structure and function. Although DSL have been observed in small numbers in this habitat type, how this habitat is used is unknown. This area is known to be used for dispersal, but this habitat may also potentially be used to a lesser degree for feeding and sheltering. No observations of breeding have been recorded within the shinnery oak shrublands. Using available DSL observations in the Mescalero Sandhills, 6.2 percent of the observations were located in the Shinnery Oak Supportive Habitat. Those observations within shinnery oak flats and shrublands were

> located within a mean distance of 130.0 (±20.85) m (426.50 ±68.41 ft) from dunelands. This category includes Shin-oak -honey mesquite duneland, Shin-oak Shrubland, and Shin-oak Honey Mesquite Shrubland from Johnson *et al.* (2016) and Shinnery Oak Shrubland/Flats and Shinnery Oak – Honey Mesquite Shrubland and Grasslands from Hardy *et al.* (2018). Shin-oak -honey mesquite dunelands may have similar rugosity to the sand dunes but will have higher than 5 percent mesquite cover. Hardy *et al.* (2018, p. 25) showed that shinnery oak habitat with greater than 5 precent coverage of mesquite had reduced detections of DSL.

We used this refined habitat model as our best available science to estimate potential habitat and habitat quality in each Analysis Unit.

5.1.3 Oil and Gas Well Pad Density

To assess habitat quality and connectivity, we determined oil and gas well pad density (well pads per square mile [wells/mi²]) in each Analysis Unit. As described in Chapter 4, there is a negative association between abundance of DSL and increasing well pad density. For instance, Sias and Snell (1998, pp. 9-10) found that the DSL, compared to locations with no oil wells, exhibited a 25 percent decline at densities of 13 well pads/mi²; a 50 percent decline at densities of 30 well pads/mi²; a 75 percent decline at densities of 50 well pads/mi²; and a 100 percent decline at densities of 76 well pads/mi². More recent studies have also demonstrated that DSL populations decline and exhibit a higher risk of extirpation at densities ≥13 well pads/mi² (Leavitt and Fitzgerald 2013, pp. 6-8; Walkup *et al.* 2017, pp. 6-9).

Johnson *et al.* (2016, p. 51) also demonstrated a negative relationship between DSL densities and well pad densities (Figure 5-1). Specifically, the authors identified incremental declines in DSL density at 5, 8, and 18 well pads/mi², with a sharp decline in density at ≥8 well pads/mi².

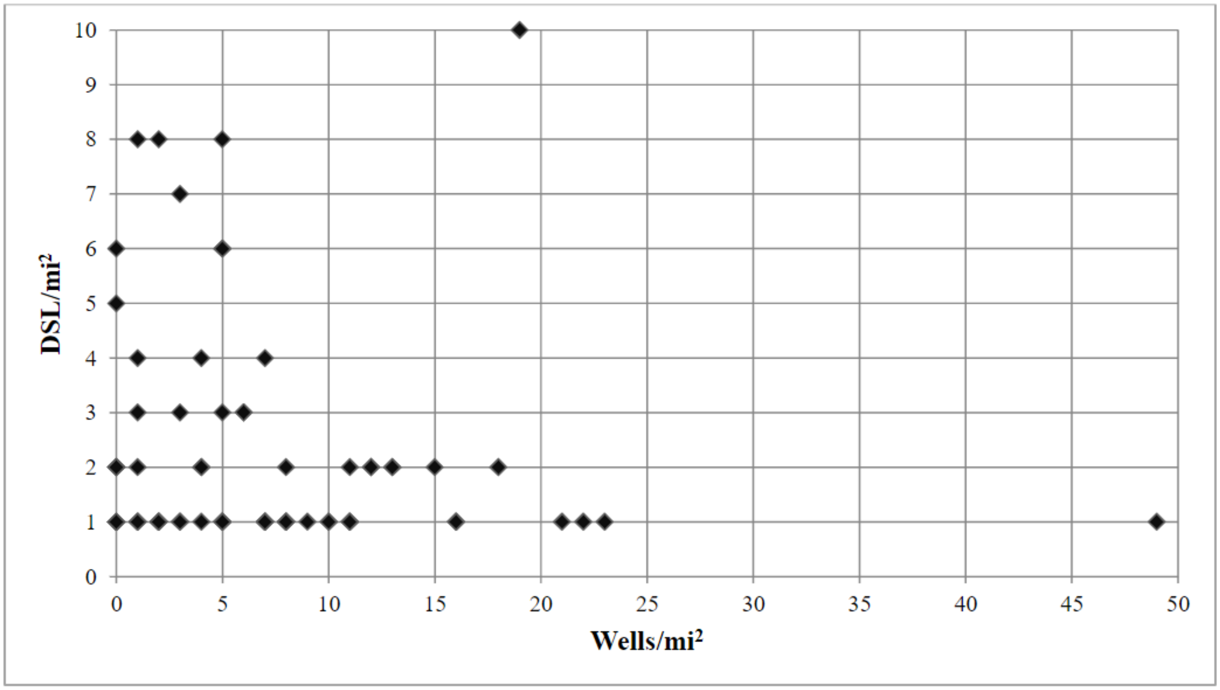

Figure 5-1 Plot of relationship between number of recent DSL detections to oil well pad density in Texas. From Johnson *et al.* (2016, p. 51).

Following these thresholds, we developed categories to represent the quality of habitat under different levels of oil and gas development (Table 5-1). Areas with ≥13 well pads/mi^2 were considered Degraded, as they are unlikely to support viable populations of the DSL. Areas between 5-12 well pads/mi^2 were considered Disturbed, meaning they may support populations of the DSL, but they are likely to be isolated and in reduced abundance. Areas with <5 well pads/mi^2 were considered Minimally Disturbed and have the potential to support the most robust and interconnected populations across the range.

5.1.4 Herbicide Treatment

As discussed in Chapter 4, areas in the DSL range have been treated with herbicides in the past, particularly tebuthiuron, to eradicate shinnery oak. Currently tebuthiuron is not used extensively, but past use occurred across large areas in New Mexico and Texas including within the DSL range. Eradication of shinnery oak via tebuthiuron results in a type conversion of the habitat to one dominated by grasses, and DSL abundance is substantially lower in areas that have been treated (Snell *et al.* 1994, pp. 10-11). Therefore, for our purpose of categorizing suitable DSL habitat, we considered any areas that have been treated with tebuthiuron in the past to be Degraded (Table 5-1).

5.1.5 Sand Mining in Texas

Sand mining in DSL habitat removes entire shinnery oak sand dune landforms, or portions thereof, alters dune topography, and produces deep, unnatural pits in the land surface (Breckle *et* *al.* 2008, pp. 453-454; Mossa and James 2013, pp 77-79, 85; Engel *et al.* 2018, pp. 1-2, 6, 12-13; Pye 2009, pp. 361-362; Forstner *et al.* 2018, pp. 2-3, 5, 16, 19-21). Sand mining extirpates DSL populations from mined areas (Forstner *et al.* 2018, pp. 18, 20-21). Since sand mines are a relatively new disturbance, with the first mines operational in 2017, there are no data quantifying the impact of sand mines on DSL populations beyond the footprint of the mine itself. We considered sand mines to be non-habitat for DSL within their footprint but did not elucidate broader impacts to neighboring habitat types. That is, we did not account for cascading effects that sand mining likely has on the DSL, such as habitat fragmentation, dune landform degradation, etc. Given the known sensitivity of DSL to such cascading effects, this approach is conservative and likely underestimates the effects of sand mining on the DSL and its habitat beyond the footprint of the mine.

5.1.6 Infrastructure

The DSL is a habitat specialist and sensitive to human development. Although human population densities are low in the Mescalero and Monahans Sandhills region, it is not devoid of human development, particularly infrastructure associated with the oil and sand mining industries. For our assessment, we considered the footprint of any human development (e.g., roads, towns, well pads, railroads) to be non-habitat for DSL. Aside from oil well pad density (see Section 5.1.3), we did not assume reduced habitat quality in the immediate proximity of human development, consistent with our approach to sand mines. Thus, as we note above, our approach is conservative and likely underestimates the cascading effects that infrastructure development has on the DSL and its habitat beyond the footprint of development.

Table 5-1 Summary of categories used to portray effects of human disturbance on DSL habitat.

Category	Description	Implications for individual DSL	Implications for DSL viability
Minimally Disturbed	Habitat with <5 well pads/mi^2 and no history of herbicide spraying	Adequate resources for breeding, sheltering, feeding, and dispersal	Robust and interconnected populations, natural source-sink dynamics that support high resiliency
Disturbed	Habitat with 5-12 well pads/mi^2 and no history of herbicide spraying	Reduced resources for breeding, sheltering, and feeding; dispersal potential reduced	Depressed abundance that reduces resiliency, reduced potential for colonization and/or rescue of existing populations
Degraded	Habitat with ≥13 well pads/mi^2 and/or history of herbicide spraying	Greatly reduced or non-existent resources for breeding, sheltering, feeding; dispersal greatly reduced to non-existent	Small, isolated populations with low resiliency and elevated risk of extirpation; colonization of suitable habitat patches unlikely
Non-habitat (Human Disturbance)	Human development devoid of habitat (e.g., well pads, roads, railroads, town, sand mines)	No resources present	No viable populations

5.2 Condition categories

As our assessment was based around habitat, our condition factors to assess condition of each Analysis Unit depended on the status of DSL habitat. The Analysis Units differ in terms of the quantity and quality of each habitat category, which subsequently affects the resiliency of the DSL within them. Populations are not uniformly distributed throughout available habitat and there is no information regarding the specific relationship of habitat area to DSL population abundance or demographics. For instance, studies have found that DSL neighborhood size is not strongly related to blowout size, but instead more tightly coupled to blowout shape and configuration (Ryberg *et al.* 2013, pp. 4-6; Ryberg *et al.* 2015, p. 893). Even still, the resolution of our mapping was not at the level to identify individual blowouts. Data are also lacking on the relationship between size of patch area and DSL abundance or resiliency. Again, we assume larger individual patches of Duneland habitat support more DSL, but this can also be influenced by quality of a given patch, proximity to other patches, and the surrounding habitat (Leavitt and Fitzgerald 2013, pp. 6-9; Ryberg *et al.* 2013, entire; Ryberg *et al.* 2015, entire; Ryberg and Fitzgerald 2015, pp. 118-119; Walkup *et al.* 2017, entire). We were also unable to find data examining the relationship between number and size of blowouts relative to the size of a sand dune landform. Thus, we were unable to make inferences of the potential number of DSL neighborhoods in each patch based upon habitat area.

Because of these uncertainties, we did not develop any condition categories based upon the size of Analysis Units or the amount of habitat. Although data regarding resiliency and habitat area are lacking, numerous studies have revealed that habitat quality affects DSL presence and abundance, especially when human disturbance is present. Therefore, we built our condition categories for the Analysis Units under the premise that regardless of the size of an Analysis Unit or the amount of habitat it contains, increasing disturbance will reduce the quality and connectivity of the habitat and DSL populations will become less resilient.

We selected three condition categories to reflect the quality of habitat in an Analysis Unit and its ability to support viable populations of DSL. Each category was divided into three conditions, High, Moderate, and Low (Table 5-2), based upon the DSL specialization and sensitivity to habitat loss and fragmentation, as described in this chapter and Chapter 4. The first category was the proportion of the total Analysis Unit classified as Minimally Disturbed. Under this metric, non-habitat was considered the same as Degraded to calculate the proportions. High condition meant more than 90 percent of the total Analysis Unit area was Minimally Disturbed, which would support abundant, interconnected populations at low risk of extirpation. Moderate condition was defined as between 50 to 90 percent of the total Analysis Unit area classified as Minimally Disturbed. We identified this range as capable of supporting enough habitat to maintain locally resilient populations, but connectivity was reduced, limiting the potential for natural source-sink dynamics. Low condition reflected Analysis Units with less than 50 percent of the total area as Minimally Disturbed. At this level of disturbance, we anticipated widespread local extirpations, reduced resiliency of remaining populations, and little to no connectivity.

We extended the same categories to a similar factor, proportion of Duneland habitat classified as Minimally Disturbed. We chose to use this as another condition factor due to the importance of Duneland habitat to the DSL. Even if ample Supportive habitat was available, a lack of Duneland habitat would limit an Analysis Unit’s ability to support DSL populations. As with total area, this category was divided into High, Medium, and Low categories using the same thresholds. We only calculated proportions based upon the three categories of Duneland habitat (Minimally Disturbed, Disturbed, Degraded). We could not for certain determine the original habitat type where non-habitat is now present, so we did not incorporate non-habitat in these estimates as it would inflate the total amount of potential Duneland habitat.

In our habitat classification, we distinguished between areas considered Degraded versus Disturbed. Although Minimally Disturbed habitat is most essential to DSL viability, we also acknowledge the potential for Disturbed areas to support DSL populations, although at reduced levels (Table 5-1). We therefore developed a third condition factor based upon the proportion of Duneland considered Degraded. This was the inverse of the other two categories. For High condition, an Analysis Unit had to have less than 10 percent of its Duneland habitat classified as Degraded. For Moderate, between 10 and 50 percent of the Duneland had to be classified as Degraded, and for Low greater than 50 percent.

We developed a formula to calculate an overall condition score for each Analysis Unit. Considering the sensitivity of the DSL to habitat disturbance, we wanted to weigh the proportion of Duneland classified as Degraded higher. Similarly, we wanted to weigh the importance of Minimally Disturbed Duneland higher than total area Minimally Disturbed. To develop a final condition score, we counted the proportion of Duneland Degraded (Z) score three times and the proportion of Duneland Minimally Disturbed (Y) score twice and the proportion of total area Minimally Disturbed (X) once and then took the average of the scores, as shown in Equation 1 below.

$$\text{Equation 1: } \frac{X+2Y+3Z}{6} = \textit{overall current condition}$$

For the calculations a High score was given a value of 3, a Moderate as 2, and Low as 1. If the average score fell between two values, we rounded to generate the final score.

Table 5-2 Current condition categories developed to assess the resiliency of DSL Analysis Units.

	Habitat Quality		
Analysis Unit Condition	Proportion of total area Minimally Disturbed	Proportion of Duneland Minimally Disturbed	Proportion of Duneland Degraded
High	>90%	>90%	<10%
Moderate	50-90%	50-90%	10-50%
Low	<50%	<50%	>50%

5.3 Geospatial Analysis Summary

A thorough discussion of our methodology to characterize the status of DSL habitat can be found in Appendix B. To summarize, we developed a scheme to identify equivalent habitat classes identified by Johnson *et al.* (2016, entire) and Hardy *et al.* (2018, entire). We then manually edited the original map of Johnson *et al.* (2016, entire) using aerial imagery from the National Agriculture Imagery Program (NAIP). For both New Mexico and Texas, we identified human disturbance features (e.g., roads, oil well pads, towns, sand mines) using photo interpretation of NAIP imagery from 2020.

To characterize habitat by level of disturbance, we obtained current well drilling data from the New Mexico Energy, Minerals and Natural Resources Department (NMEMNRD) and the Texas Railroad Commission (TRRC). Well data for New Mexico is dated as of August 2019 and January 2021 for Texas. In an initial pass, we then performed a raster-to-vector conversion, exported the features of $\geq$ 13 well pads/mi^2 to use as a recoding mask in ERDAS Imagine 2020 (Hexagon Geospatial). Similarly, we used the Treated/Fragmented layer created by Johnson *et al.* (2016) as a recode mask to capture the herbicide/mechanically treated areas. For Texas, we noted some areas that appeared to be disturbed in a similar fashion as those in New Mexico where herbicide treatment or mechanical grubbing had occurred. To investigate this, we contacted Thom Hardy and Jennifer Jensen at Texas State University. Along with the areas of ≥ 13 well pads/mi^2 being further defined with the Degraded qualifier, we proposed a series of additions to account for the treated areas noted above and adjacent areas we perceived as suitable or supportive habitat. These edits to the Hardy *et al.* (2018) habitat model were submitted to the Texas State University team for review and concurrence. Upon their review, agreed upon edits were made to the Alpha model and used in subsequent analysis.

To further account for lower levels of oil well pad density, we created a kernel density surface with a 1 mi^2 cell size and a geodesic method in ArcMap 10.8.1 (Esri 2020) and rounded the result up to the nearest integer. We then performed a raster-to-vector conversion and exported the intervals of 0-5, 6-12, and ≥13 well pads/mi^2 to use as a recoding mask in ERDAS Imagine 2020 (Hexagon Geospatial).

5.4 Current habitat condition

5.4.1 Range-wide

Our geospatial analysis covered an analysis area of 529,161 ha (1,307,558 ac) in the Mescalero and Monahans Sandhills region (Figures 5-2, 5-3, 5-4). After removing non-habitat (e.g., infrastructure), there are 507,789 ha (1,254,747 ac) of potential DSL habitat. Of this, 210,506 ha (520,161 ac) are classified as Duneland, which amounted to 42 percent of the potential habitat. The remainder are classified as Supportive Habitat (297,283 ha [734,586 ac]).

DSL habitat is not overly concentrated in any of the three Representation Units. Northern Mescalero covers about 39 percent of the species range, followed by Southern Mescalero at 35 percent and Monahans at 26 percent. They are almost even in terms Duneland area: 37 percent of all Duneland across the DSL range is in Northern Mescalero, with 33 percent in Monahans and 30 percent in Southern Mescalero.

Across the DSL range, our analysis indicates that 47 percent of the habitat (including both Duneland and Supportive Habitat) is Minimally Disturbed (Figure 5-5). Another 35 percent is Degraded, another 14 percent is Disturbed, and the remaining 4 percent is direct human disturbance, or non-habitat. Focusing on Duneland, range-wide 50 percent is Minimally Disturbed, with 35 percent Degraded and 15 percent Disturbed.

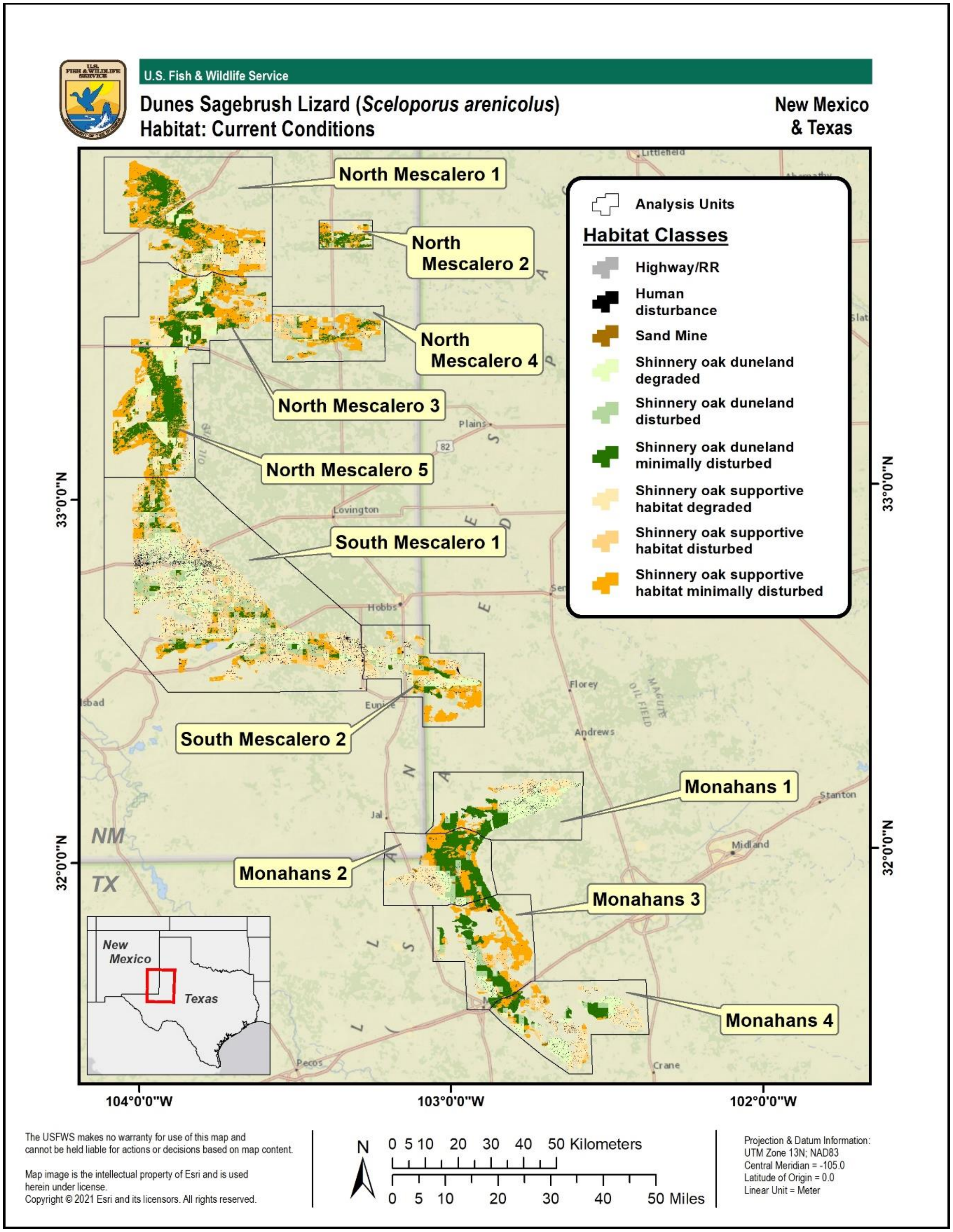

Figure 5-2 Map of habitat categories across the DSL range. The outlines delineate the 11 Analysis Units used to describe the condition of DSL.

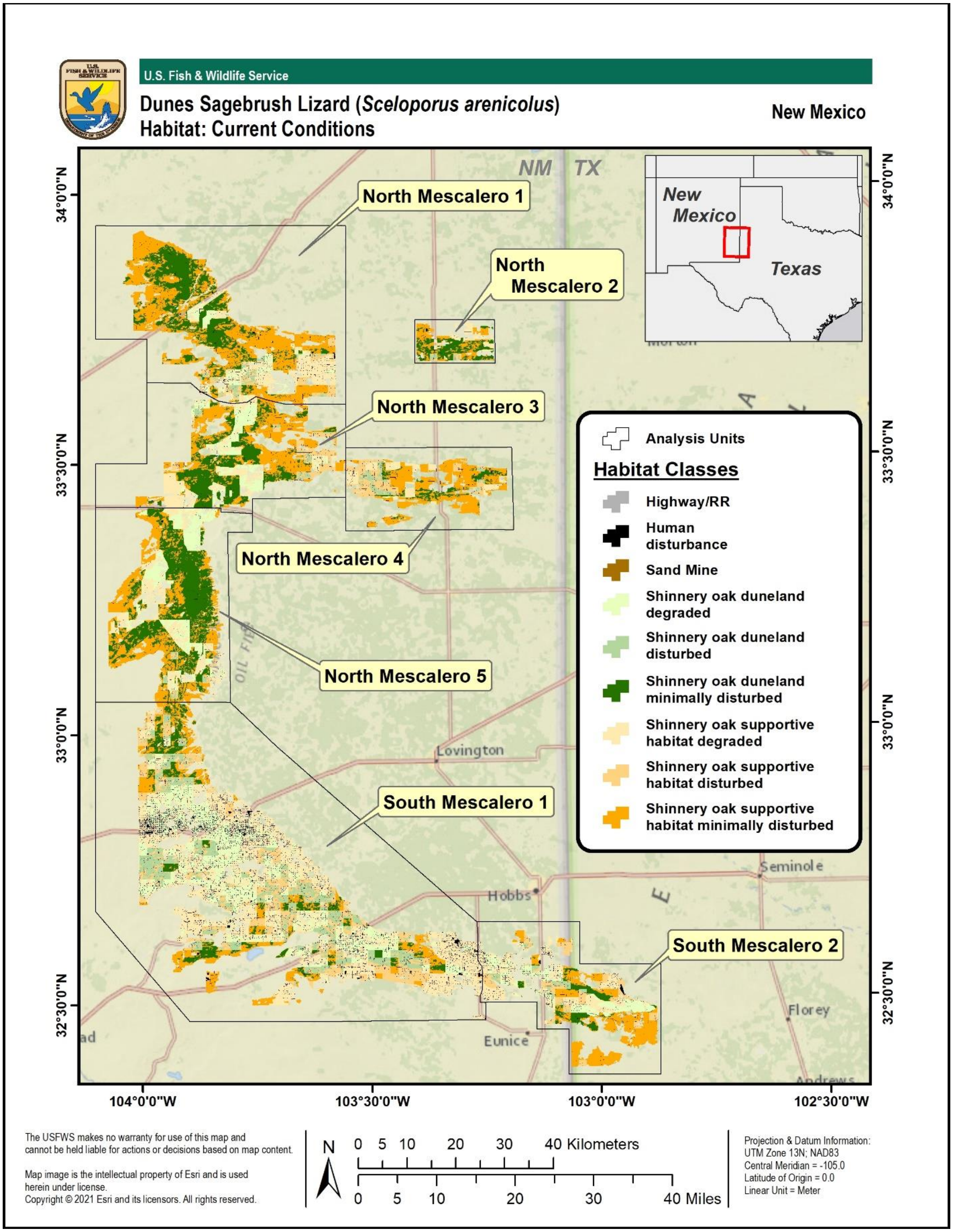

Figure 5-3 Map of DSL habitat in the Mescalero Sandhills. The outlines delineate the 7 Analysis Units used to describe the condition of the DSL in this region.

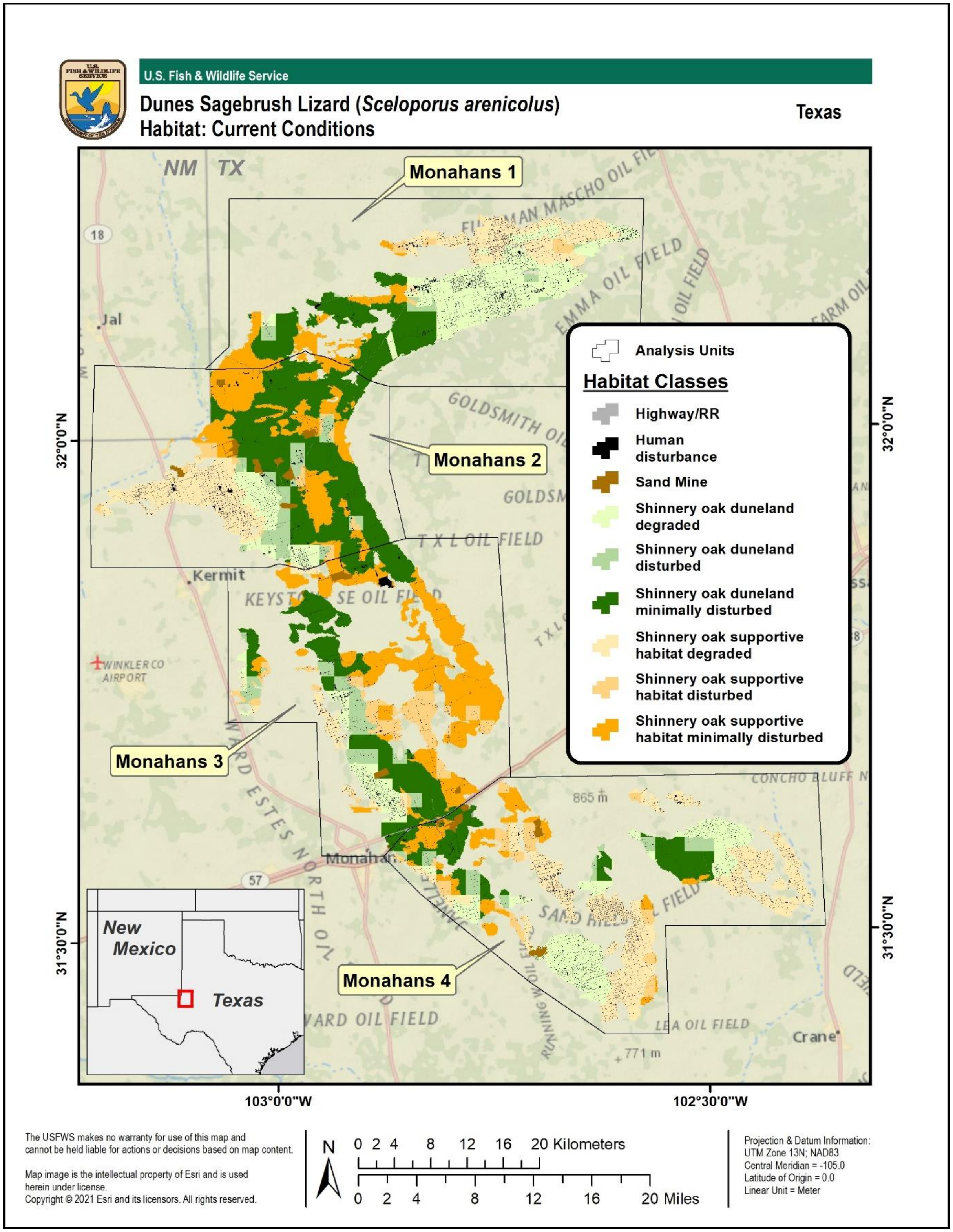

Figure 5-4 Map of DSL habitat in the Monahans Sandhills. The outlines delineate the 4 Analysis Units used to describe the condition of the DSL in this region.

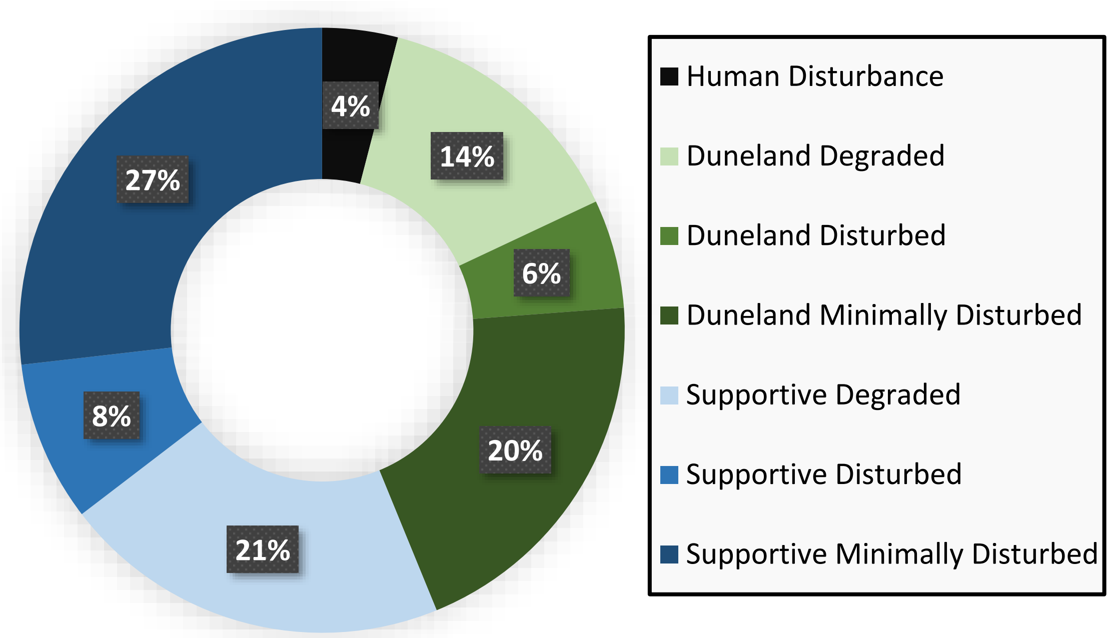

Figure 5-5 Proportion of the DSL range classified into the habitat categories developed for this assessment. Human disturbance reflects non-habitat for the DSL.

5.4.2 Analysis Units

Both the quantity and quality of habitat is variable across the DSL range (Table 5-3). For example, the largest Analysis Unit, S. Mescalero 1 (150,808 ha [372,648 ac]), is nearly 17 times larger than the smallest, N. Mescalero 2 (8,890 ha [21,966 ac]). In fact, S. Mescalero 1 is over twice the size of the next largest Analysis Unit, N. Mescalero 1 (64,849 ha [160,241 ac]). Across the Analysis Units, total unit area is highly correlated with the amount of Duneland habitat (R^2=0.88, p<0.001) (Figure 5-6). A similar relationship is observed between total Analysis Unit area and amount of Supportive habitat (R^2=0.96, p<0.001). These correlations indicate a consistent relationship between the ratio of Duneland to Supportive habitat across the DSL range, meaning that none of the Analysis Units have disproportionately high and low density of Duneland habitat. S. Mescalero 2 contains over 25 percent of the total Duneland area across the DSL range, whereas 3 Analysis Units each contain less than 5 percent of the total Duneland (N. Mescalero 2, N. Mescalero 4, and S. Mescalero 2).

Table 5-3 Total size of each Analysis Unit and amount of area classified as Duneland and Supportive habitat. The amount of each habitat type classified as Minimally Disturbed is also included. Areas are presented in hectares.

Representation Unit	Analysis Unit	Total area	Total Duneland area	Minimally Disturbed Duneland area	Total Supportive area	Minimally Disturbed Supportive area
N Mescalero	N Mescalero 1	64,849	20,657	16,428	42,846	31,548
	N Mescalero 2	8,890	3,719	3,459	5,012	3,269
	N Mescalero 3	48,475	19,373	12,505	28,376	17,567
	N Mescalero 4	23,388	3,806	2,225	19,094	12,014
	N Mescalero 5	59,222	29,938	21,125	28,810	20,259
S Mescalero	S Mescalero 1	150,809	53,904	9,304	86,700	16,628
	S Mescalero 2	35,481	9,459	2,641	24,505	11,681
Monahans	Monahans 1	29,673	18,898	7,537	9,419	3,272
	Monahans 2	38,396	21,209	15,507	15,436	8,376
	Monahans 3	35,487	15,193	9,852	19,024	13,633
	Monahans 4	34,493	14,350	5,321	18,061	3,666

The Analysis Units have also been subjected to uneven levels of disturbance and reduction in the quality of habitat (Figures 5-2, 5-3, 5-4, and Table 5-3). For instance, when comparing total size of Analysis Units to the amount of Minimally Disturbed Duneland, there is no correlation ($R^2<0.01$, $p=0.33$) (Figure 5-7). However, this is primarily driven by one Analysis Unit, S. Mescalero 1, which has the lowest proportion of Duneland in the Minimally Disturbed category. Even still, when this Analysis Unit was removed, there is only a moderate correlation between total area and the amount of Minimally Disturbed Duneland $R^2=0.63$, $p<0.001$), as compared to that with total area to Duneland area.

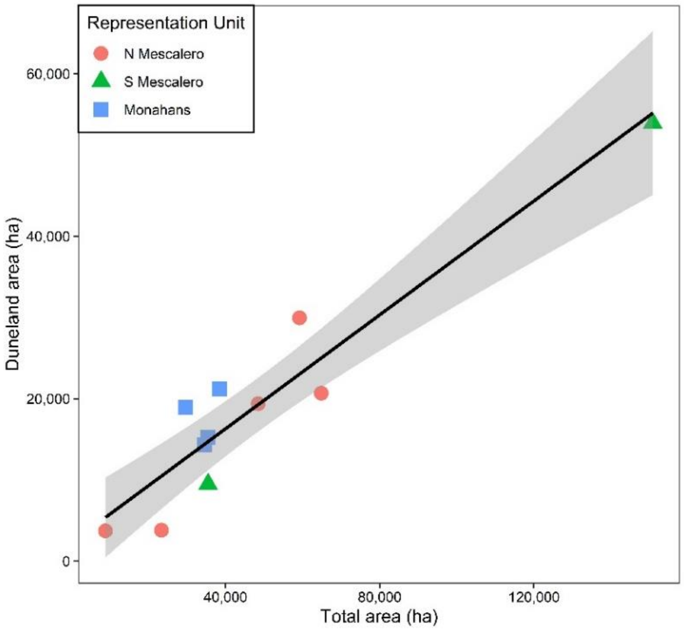

Figure 5-6 Scatter plot of total size of an Analysis Unit to the total amount of Duneland habitat within it. Symbology reflects three DSL Representation Units identified for this assessment. The line is a fitted linear model, and 95 percent confidence interval is the shaded area.

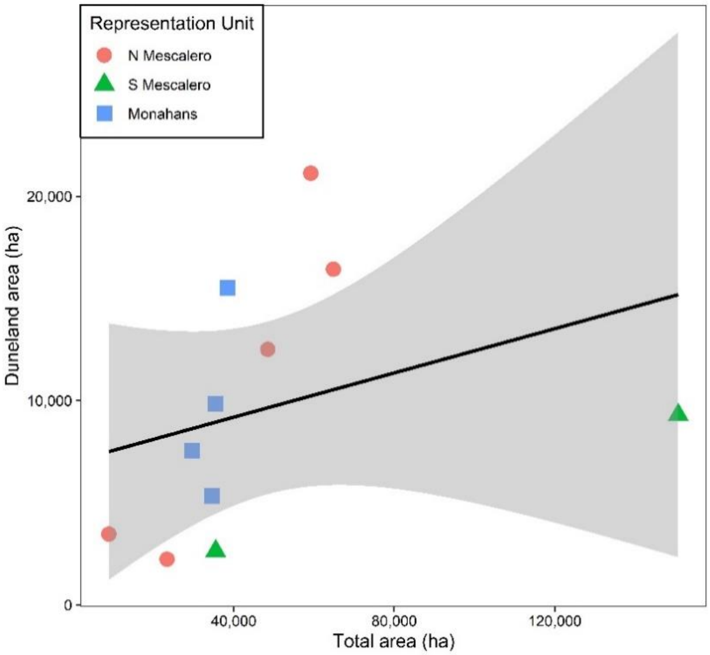

Figure 5-7 Scatter plot of total size of an Analysis Unit to the amount of Minimally Disturbed Duneland habitat within it. Symbology reflects three DSL Representation Units identified for this assessment. The solid line is a fitted linear model, and 95 percent confidence interval is the shaded area.

This disparity among Analysis Units is further revealed when estimating the proportion of Minimally Disturbed Duneland relative to the other categories. The proportion of Duneland classified as Minimally Disturbed varied from a high of 93 percent (N. Mescalero 2) to a low of 17 percent (S. Mescalero 1) (Figure 5-8).

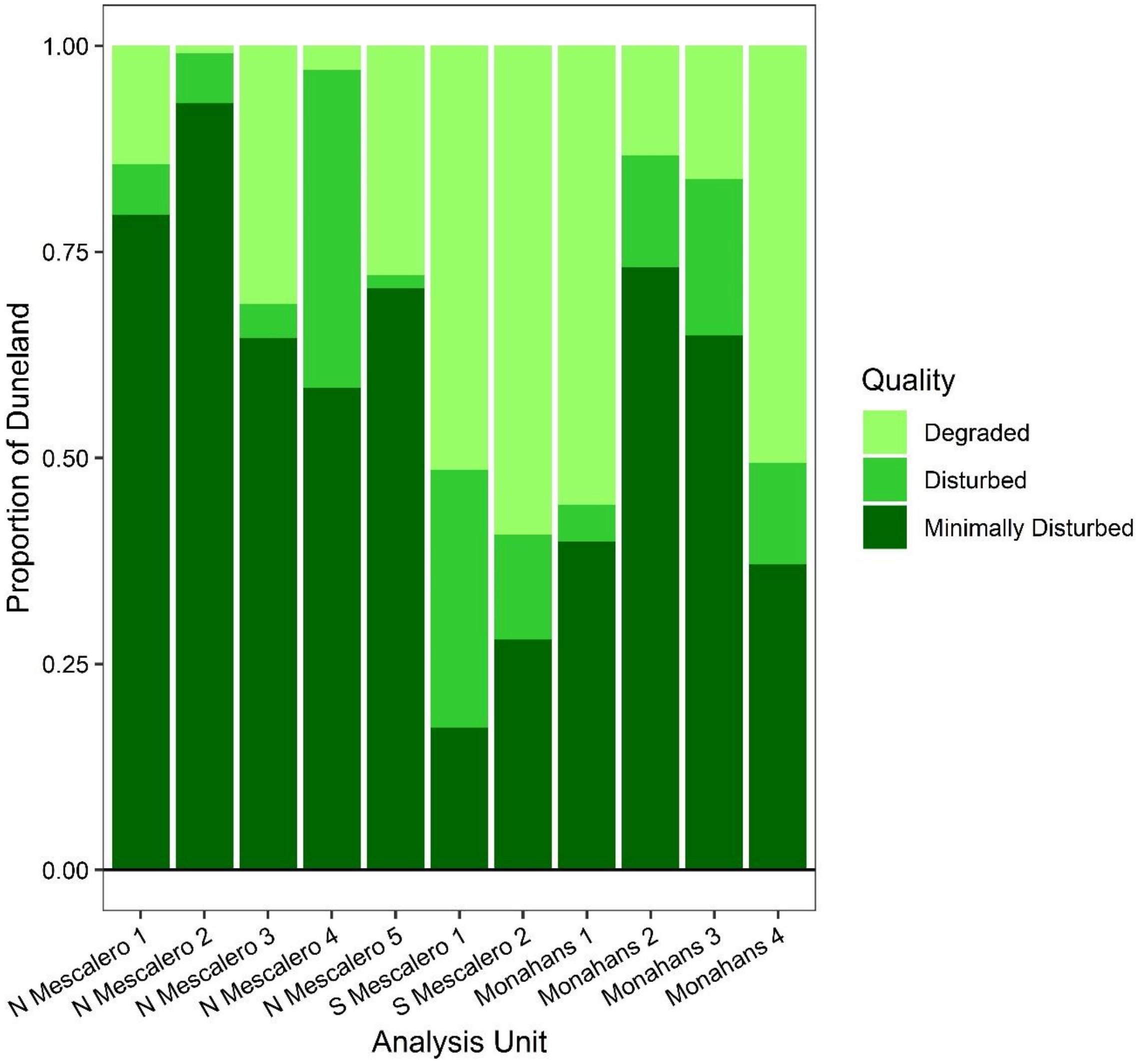

Figure 5-8 Proportion of Shinnery Oak Duneland habitat under the three categories of human disturbance by Analysis Unit.

A similar pattern exists for Supportive habitat: across Analysis Units, the proportion of Minimally Disturbed Duneland is correlated with the proportion of Minimally Disturbed Supportive habitat (R^2=0.75, p<0.001). However, there are some Analysis Units where the disturbance level differed between Duneland and Supportive Habitat (Figure 5-9). There are three Analysis Units (N. Mescalero 2, Monahans 2, Monahans 4) in which the proportion of Duneland classified as Minimally Disturbed is over 10 percent higher compared to the amount of Supportive Habitat classified as Minimally Disturbed. In contrast, there is only one Analysis Unit (S. Mescalero 2) in which the amount of Duneland classified as Minimally Disturbed is over 10 percent lower compared to the amount of Supportive Habitat classified as Minimally Disturbed.

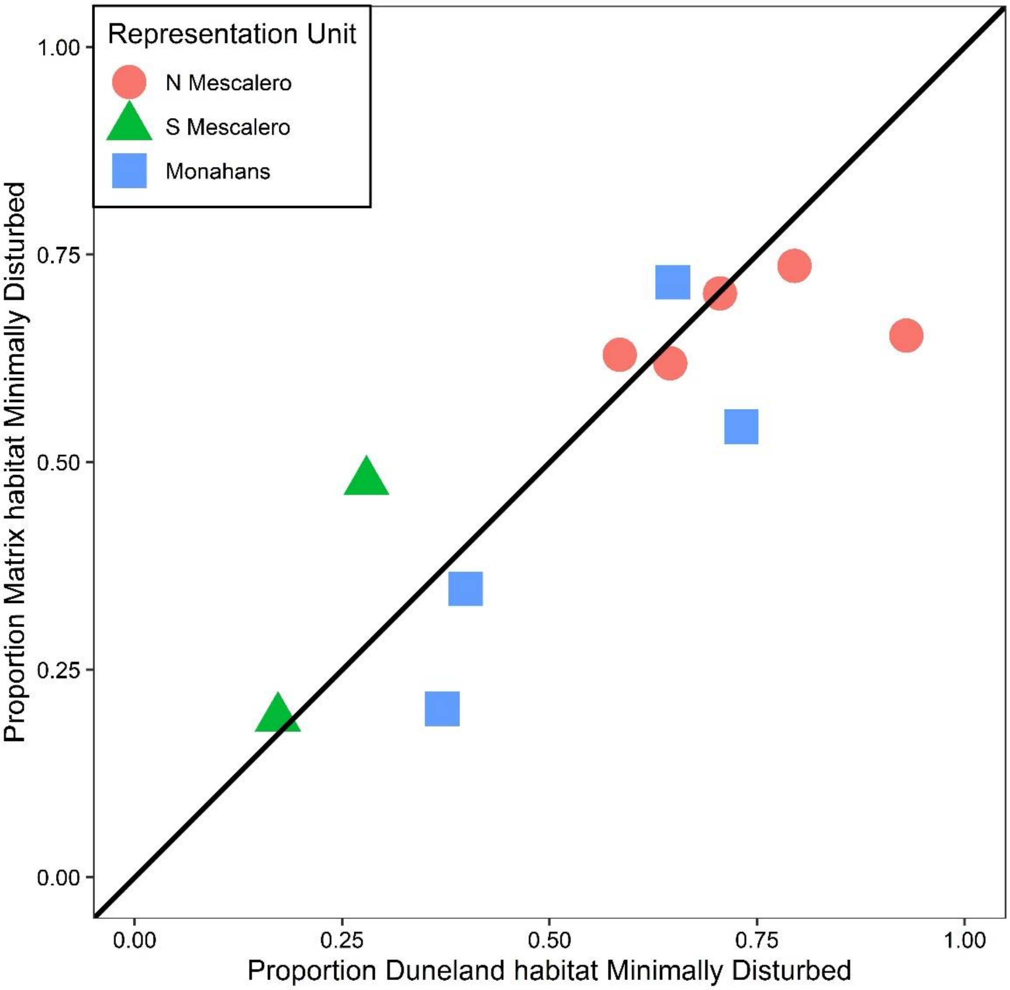

Figure 5-9 Comparison of the proportion of Duneland habitat and Supportive Habitat classified as Minimally Disturbed per Analysis Unit. The solid line indicates a one-to-one correspondence between the proportion of each habitat type. Analysis Units below the line have a higher proportion of Duneland habitat in the Minimally Disturbed category, Analysis Units above the line have a higher proportion of Supportive Habitat in the Minimally Disturbed category.

5.4.3 Condition Category Scores

Using the condition categories to assess the condition of Analysis Units, we found two Analysis Units have an overall resiliency score of High, five are Moderate, and four are Low (Table 5-4). Our weighting scheme had little effect on the final scores: only two Analysis Units (N. Mescalero 2 and N. Mescalero 4) have any condition scores that differed across the three conditions factors. If we took the straight average of scores and did not apply any weighting, the only change would have been that N. Mescalero 4 would have been scored as having Moderate overall resiliency instead of High.

The distribution of these conditions is not even across the species range: all Analysis Units in the Northern Mescalero Representation Unit are in either High or Moderate condition. In contrast, both Analysis Units in the Southern Mescalero Representation Unit are in Low condition. Two of the Analysis Units in the Monahans Representation Unit are in Low condition and the other two in Moderate.

As noted earlier, these Analysis Units are not equal in size (Figures 5-2, 5-3, 5-4, Table 5-5). Using the total size of the Analysis Units, we estimated the proportion of the total DSL range that fell into these different condition categories. Only 6 percent of the species range is estimated to have High resiliency, whereas 47 percent is considered to have Low resiliency. The remaining 47 percent is considered Moderate resiliency.

Table 5-4 Results from the condition category scores and the overall resiliency condition for each Analysis Unit.

Representation Unit	Analysis Unit	Proportion of total area Minimally Disturbed	Proportion of Duneland Minimally Disturbed	Proportion of Duneland Degraded	Overall condition
N Mescalero	N Mescalero 1	0.74	0.80	0.14	Moderate
	N Mescalero 2	0.76	0.93	0.01	High
	N Mescalero 3	0.62	0.65	0.31	Moderate
	N Mescalero 4	0.61	0.58	0.03	High
	N Mescalero 5	0.70	0.71	0.28	Moderate
S Mescalero	S Mescalero 1	0.17	0.17	0.51	Low
	S Mescalero 2	0.40	0.28	0.59	Low
Monahans	Monahans 1	0.36	0.40	0.56	Low
	Monahans 2	0.62	0.73	0.13	Moderate
	Monahans 3	0.66	0.65	0.16	Moderate
	Monahans 4	0.26	0.37	0.51	Low

Table 5-5 Total size and current amount of Minimally Disturbed Duneland in each Analysis Unit and their overall resiliency condition.

Representation Unit	Analysis Unit	Total area (ha)	Proportion of total DSL range	Minimally Disturbed Duneland area (ha)	Proportion of remaining Minimally Disturbed Duneland	Overall condition
N Mescalero	N Mescalero 1	64,849	0.12	16,428	0.16	Moderate
	N Mescalero 2	8,890	0.02	3,459	0.03	High
	N Mescalero 3	48,475	0.09	12,505	0.12	Moderate
	N Mescalero 4	23,388	0.04	2,225	0.02	High
	N Mescalero 5	59,222	0.11	21,125	0.20	Moderate
S Mescalero	S Mescalero 1	150,809	0.28	9,304	0.09	Low
	S Mescalero 2	35,481	0.07	2,641	0.02	Low
Monahans	Monahans 1	29,673	0.06	7,537	0.07	Low
	Monahans 2	38,396	0.07	15,507	0.15	Moderate
	Monahans 3	35,487	0.07	9,852	0.09	Moderate
	Monahans 4	34,493	0.07	5,321	0.05	Low

5.5 Assessment of Current Viability

5.5.1 Resiliency

Our assessment suggests that a small portion (6 percent) of the overall DSL range is in high enough condition to support robust, highly viable populations. This is not surprising as our geospatial analysis revealed that less than half of the DSL range is considered Minimally Disturbed by human development. There are large portions of the range and even an entire Representation Unit (Southern Mescalero) that we assessed as unlikely to support viable populations of the DSL. Since our assessment is based on habitat, we acknowledge that even these Low condition areas likely support DSL populations. However, we expect that those populations are likely reduced, have limited recruitment and higher mortality, and are disconnected from each other. As indicated by estimates of genetic effective size (Table 2-2), several of these highly modified Analysis Units have effective sizes below thresholds recommended to maintain long-term genetic health (Chan pers. comm. 2023; Hoban *et al.* 2023, entire). The long-term viability of the DSL depends on having interconnected habitat patches in which populations shift around the landscape. Highly disturbed, highly fragmented areas are unable to support this requirement.

Areas considered to be in Moderate condition are likely to support viable populations of DSL, but we anticipate local extirpations are more common and interconnectedness reduced. However, given that nearly half (47 percent) of the DSL range is in Moderate condition, these areas are important for maintaining viability of the species. Since a minor portion of the DSL range is in High condition (6 percent), long-term viability of the species will depend on further persistence of those populations still existing in Moderate condition Analysis Units.

To further emphasize this point, the largest contiguous patch of Minimally Disturbed Duneland habitat we identified in the entire DSL range is in N. Mescalero 5. At 10,667 ha (26,358 ac), it is larger than the combined amount of Duneland habitat in the two Analysis Units in High condition (N. Mescalero 2 and 4; combined 7,525 ha [18,595 ac] of total Duneland). Also, Leavitt and Acre (2021, p. 20) found that N. Mescalero 3 and 5 had areas with the highest predicted densities of DSL in New Mexico (Figure 2-11). In fact, adjusting for total Duneland area, the number of DSL estimated per ha by Leavitt and Acre was highest in the three Analysis Units classified as Moderate condition in our assessment (Table 5-6). The two High condition Analysis Units, on the other hand, have similar estimated DSL densities to the two Low condition Analysis Units. This highlights a drawback of a habitat-based assessment because areas less disturbed by human activity may have naturally lower DSL densities due to environmental or habitat conditions. Therefore, the High condition we estimated for N. Mescalero 2 and 4, which are the smallest and most isolated Analysis Units and have the least amount of Duneland, may be an over-estimate of their potential resiliency. They also have low genetic effective sizes (Table 2-2), indicating that DSL populations may not be viable due to the limited size of those areas. Continued degradation of the Moderate condition Analysis Units could reduce the viability of remaining strongholds for DSL and cause them to pass a tipping point at which they may no longer be able to support viable populations. Even some of these Analysis Units classified as being in Moderate condition may be more at-risk than predicted, as all populations in Texas were estimated to have low effectives sizes.

Table 5-6 Estimates of total DSL population size from Leavitt and Acre (2021, p. 21) for each Analysis Unit in New Mexico. Densities were calculated by taking the total population estimate and dividing by the amount of total Duneland area as identified by this assessment.

Representation Unit	Analysis Unit	Total population estimate	Total Duneland area (ha)	Density (DSL/ha)
N Mescalero	N Mescalero 1	236,687	20,657	11.46
	N Mescalero 2	6,851	3,719	1.84
	N Mescalero 3	117,158	19,373	6.05
	N Mescalero 4	20,887	3,806	5.49
	N Mescalero 5	284,084	29,938	9.49
S Mescalero	S Mescalero 1	317,513	53,904	5.89
	S Mescalero 2	32,765	9,459	3.46

An important uncertainty in this assessment is the condition of Monahans 4. The northern portion of this Analysis Unit covers Ward County and is part of the same dune field as Monahans 3 (Figure 5-4). Interstate-20, which we assumed was a complete barrier to DSL movement, cuts through this dune field. The DSL has been documented in this dune field both north and south of I-20 (Laurencio *et al.* 2007, p. 3; Walkup *et al.* 2021, p. 4). The southern portion of Monahans 4 covers Crane County and contains several dune fields disjunct from the larger Monahans Sandhills system (Figure 5-4; Hardy *et al.* 2018, p. 36). Contemporary surveys in Crane County have yielded no positive detections of DSL (Walkup *et al.* 2021, p. 4), suggesting the species does not occupy this area, despite the presence of suitable Duneland habitat and extensive gaps in geographical sampling (Hardy *et al.* 2018, p. 36; Walkup *et al.* 2021, p. 16; Walkup *et al.* 2021, pp. 351, 354, 357; this assessment). Voucher specimens, however, have been collected from this area, suggesting it is part of the historical DSL range (Laurencio *et al.* 2007, p. 3). The status of DSL in Crane County has ramifications for our assessment. If DSL are indeed not present in this Analysis Unit, the most plausible explanation is that the species has been extirpated. Should this be the case, then the amount of habitat occupied by DSL in Monahans 4 would be greatly reduced and restricted to a narrow area adjacent to a major interstate. Since this Analysis Unit is one of the more heavily disturbed, it could serve as a bell-weather for the ability of the DSL to persist in a such a landscape.

5.5.2 Redundancy

All 11 Analysis Units have some DSL habitat classified as Minimally Disturbed, meaning they support some level of DSL populations. Given the size of the range, it is unlikely that a single catastrophe would eliminate the entire species. The resiliency scores of some Analysis Units, however, suggests that they are potentially vulnerable to extirpation. Loss of the Low condition Analysis Units would reduce the total number to 7, with those remaining concentrated in North Mescalero. It is a vulnerability that the Analysis Units in the strongest condition are clustered geographically: North Mescalero also includes some of the smallest units. An extreme event centered in that area could reduce abundance in the last strongholds for the species, leaving its viability tied to Low condition areas in Southern Mescalero and Monahans.

5.5.3 Representation

All Analysis Units and Representation Units are extant, and we are unaware of any significant range reductions, meaning that the phylogenetic lineages identified by Chan *et al.* (2020, entire) are still represented. The mere existence of these lineages on the landscape suggests there is still raw genetic variation present within the species that can support adaptive capacity. However, some Representation Units are composed of populations with low resiliency. Both Analysis Units in the Southern Mescalero are in Low condition. The low viability of these units suggests that an entire phylogenetic lineage is currently at high risk for extirpation. Two of the four Analysis Units in Monahans are also in Low condition. Importantly, these two units cover the northern and southern extremes of the DSL range in the Monahans Sandhills. Loss of these Analysis Units could result in the loss of genetic variation associated with extremes in the environmental variation experienced by the species in Monahans, reducing adaptive capacity. In fact, a general pattern is that Analysis Units are in better condition in the northern part of the species range (N. Mescalero). Southern populations experience higher temperatures and drier conditions (See Chapter 3) and may have higher capacity to withstanding climate change. However, their poor current condition limits their potential to contribute to long-term adaptation of the species.

5.5.4 Sand mining

During this assessment, one of most noticeable trends was the pace of industrial activity and landscape alteration. Even over the course of a few years, the expansion of human development can change the quantity and quality of habitat. This trend is epitomized by the expansion of the sand mining industry in Texas. In developing our habitat map, most of the spatial imagery we used was taken in September or October 2020. Since then, more recent spatial imagery has become available, which allowed us to use a longer time series to estimate sand mine growth rates for our future scenarios (see Chapter 6). Over 15 months from the fall of 2020 to January 2022, 9 sand mines in our analysis area grew an average of 53 ha (131 ac) each, with one expanding a total of 237 ha (585 ac) (Table 5-7).

This rapid growth has several implications for our assessment. First, it obstructs our ability to truly assess the "current" state of the DSL, because habitat conditions can change over a short period of time. If we only used spatial imagery up to the fall of 2020, we would have estimated the footprint of the 18 sand mines in our analysis area to cover 2,391 ha (5,907 ac). With the January 2022 data, we now know these 18 mines cover 2,895 ha (7,154 ac). That is a change of 504 ha (1,247 ac) over 15 months. This does not cover all active sand mines as imagery from 2022 was not available for all of them.

Second, we likely underestimated the effects of sand mines by only accounting for their footprint. As discussed in Chapter 4, sand mines may have a broader effect on DSL beyond their footprint, such as edge effects, groundwater alteration, dune destabilization, and mortality from increased vehicular traffic. This means the rapid growth of sand mines may have cascading effects on the DSL over more of the remaining habitat in Texas, particularly in Monahans 2 and 3 where sand mines are concentrated. Thus, the viability of the DSL in the Monahans Representation Unit may be reduced compared to the outlook provided by our current condition assessment.

Table 5-7 Size of 18 sand mines (ha) identified in our analysis area using aerial imagery. Each column represents the size of mines at different times based on the date of the imagery. Blank cells mean that imagery was not available for the location of that particular mine at that date.

Sand mine	Sept/Oct 2018	Sept/Oct 2020	Feb/Mar 2021	Jan 2022
1	62	75		93
2	73	191		265
3	78	124		149
4	60	111		127
5	14	57		76
6	82	102		119
7	57	91		119
8	137	190		234
9	109	161	177	
10	102	140	140	
11	54	116		
12	86	129	129	
13	84	112	115	
14	186	241	250	
15	25	34	34	
16	131	207	207	
17	74	194		
18	44	116		352

Chapter 6: Future Scenarios

6.0 Summary

To assess the viability of the DSL into the future, we developed several scenarios to forecast the condition of the species under different projections of threats. Although there are several factors that may influence the condition of the DSL in the future, we focused on oil and gas development and sand mining as the threats most likely to impact DSL habitat. We discuss qualitatively how other factors may impact the DSL under different scenarios.

6.1 Approach

6.1.1 Future threats

As with Current Conditions (Chapter 5), we centered our assessment of DSL future conditions using a habitat-based approach. Since we had a contemporary evaluation of DSL habitat, we used those data to serve as the starting conditions for all our scenarios. We then incorporated projections of factors likely to impact DSL viability into the future. Our assessment followed the same approach as Current Conditions in terms of classifying habitat type and quality. To account for lost habitat due to oil and gas and sand mine projections, an additional metric was added to focus on the loss of Minimally Disturbed Duneland habitat within each Analysis Unit (see Section 6.1.4).

In Cause and Effects (Chapter 4) we discussed several factors that influence DSL viability. Of these, we identified oil and gas development and sand mining as the primary factors influencing the future quantity and quality of DSL habitat. We expect that these factors will continue to affect DSL into the future. Existing infrastructure and on-going activity associated with these industries is unlikely to dissipate or be removed from the landscape on a meaningful spatial or temporal scale. That means the existing extent of oil well pads, sand mines, roads, and associated infrastructure will continue to impact the DSL into the future. Furthermore, there is no expectation that either industry will stop expanding its footprint: the uncertainty is the scale, pace, and location of these future impacts. We also expected that areas previously treated with herbicides will continue to be low quality habitat; however, as use of these herbicides to treat shinnery oak has declined, we do not anticipate additional areas will become degraded by this activity.

There are other factors, such as pollution, direct mortality, groundwater pumping, and extreme weather that will likely affect the DSL into the future. We did not incorporate these factors quantitatively into our projections for several reasons. First, several of these factors, such as pollution and direct mortality, are primarily associated with industrial development; capturing the growth of the oil and sand mining industries will account their potential scope. Second, for many of these factors we do not have empirical data about their historical scale, spatial distribution, frequency, or effects on DSL, let alone future projections. Thus, we did not have sufficient information to incorporate threats such as groundwater pumping and extreme weather explicitly into our future habitat projections. Instead, we qualitatively discuss how these factors may manifest themselves under our different future scenarios, including under projections of climate change.

Both mesquite expansion and renewable energy development are factors for which we have historical data and possible forecasts of future growth. The effects of mesquite on DSL habitat have been documented (TAMU 2016, p. 44, p. 59, Fitzgerald *et al.* 2011, p. 13, Hardy *et al.* 2016, p. 25, Johnson *et al.* 2016, p. 25, Texas Comptroller 2017, p. 52). Although the effects of renewable energy development, specifically wind energy, are less known for the DSL, we assume at the very least that any areas within the footprint of infrastructure will be transformed into non-habitat. We decided not to incorporate these two factors explicitly into our future habitat projections. Although both have potential to affect DSL viability, the magnitude of their scale and scope is dwarfed by those of oil and gas development and sand mining. Also, there are no existing data or future projections about the expansion of mesquite, inhibiting our ability to incorporate it into our spatially explicit model. As with other factors, we qualitatively discuss the potential impacts of mesquite expansion and wind energy development under our different scenarios.

6.1.2 Projections of oil and gas development

Given the history and importance of the oil and gas industry in the Permian Basin, there are extensive datasets of past trends and predictions of future growth. Because our model was spatially explicit, we wanted to use projections that could be integrated into our framework. There are general estimates of the total amount of potential altered habitat due to future oil and gas development in the DSL range (e.g., ACF 2021a, entire), but these are not spatially explicit. In other words, although they extrapolate past trends in habitat loss to make future projections, they are not explicit as to the location of the development in the future. Where the habitat is impacted is equally important as how much. Also, expressing future projections solely in terms of area of habitat converted due to infrastructure does not account for cascading effects on the DSL, such as habitat fragmentation and direct mortality. Since DSL density and abundance have a negative relationship with oil well pad density, spatially projecting the number and placement of future wells on the landscape is important for capturing these effects.

Pierre *et al.* (2020, entire) created a spatially explicit model to project future landscape alteration associated with oil and gas development in the Permian Basin. There are several reasons their model was ideal for our future condition assessment. First, it incorporated existing locations of well pads to spatially project future locations of new well pads under a set of assumptions. For example, they assumed well pads are more likely to be installed near existing infrastructure but may also reach a critical density at which more pads cannot be added to a given area. Expansion then progresses into new areas following expectations that the trends observed in oil and gas production since the advent of hydraulic fracturing technology will continue. Projections followed three scenarios, which they labelled as “Low”, “Medium”, and “High”, that differed based upon assumed numbers of wells developed on each pad. Their assumptions are based on past, current, and anticipated future production practices that consider evolving new technology that enables multiple wells to be developed on a single pad, ultimately requiring a smaller footprint per well. All three scenarios were projected to 2050. Second, in their model Pierre *et al.*

specifically prevented oil well pads from being established in certain locations, including areas set aside for conservation, such as state parks and BLM Areas of Critical Environmental Concern (ACEC) lands closed to oil drilling. Considering these attributes, Pierre *et al.* (2020, entire) represents a scientifically rigorous projection of future oil and gas development throughout the range of the DSL suitable for this SSA.

We were provided the data layers produced by the three scenarios developed by Pierre *et al.* (2020, entire). Given the relationship between the DSL and oil well pad density, we focused on using the spatial projections of future well pad locations. We acknowledge that many considerations are factored into the exact location where a well pad may be placed. As with our Current Condition assessment, we projected the effects of oil and gas development in terms of density per mi^2 using the same thresholds to define an area as Degraded, Disturbed, or Minimally Disturbed. Relying on density on a per unit basis captures the inherent uncertainty as to the exact location of future well pads while still be being spatially explicit enough to assess changes in habitat. For our projections, we took the existing well pad densities we used for our Current Conditions assessment and then added the number of well pads projected under the three scenarios to the mi^2 grids. We then added up the new total, adjusting habitat quality if the addition of new wells crossed thresholds of critical densities (i.e., 5 well pads/ mi^2 and 13 well pads/ mi^2).

Although we had projections of the number of future well pads, we did not extrapolate the amount of habitat area turned into non-habitat by those well pads. The spatial extent of oil well pads is variable, driven primarily by the number of wells drilled at an individual pad (Pierre *et al.* 2020, p. 351). The three scenarios of Pierre *et al.* (2020, entire) had different assumptions of the number of wells per pad to estimate the absolute area disturbed by oil development. However, since the biological response of DSL has been related to several factors associated with habitat loss (e.g., fragmentation, disturbance, and other cascading effects), and not just the area of habitat loss, we did not further estimate the amount of habitat projected to be converted under these scenarios. The amount of area already converted to non-habitat by oil well pads is small relative to the overall size of the DSL range and does not account for the threat of fragmentation (see Chapter 5), so only projecting future area converted was less likely to represent future impacts to DSL than well pad density. More details on the methods used to generate these scenarios and overlay them with our DSL habitat map can be found in Appendix B.

6.1.3 Projections of sand mining

The sand mining industry is relatively young in west Texas, with the first mines appearing in 2017. Thus, there are not ample published data on past industry trends that could be used to project future growth. This raises uncertainty about projecting the growth of existing sand mines and the potential for new mines to be developed. There have been several attempts to estimate past sand mine growth rates over the last five years using aerial imagery and industry data (Appendix C). In the petition to list the DSL, the petitioners applied a change detection algorithm to aerial images to estimate an average annual growth rate of 59 ha (146 ac), with a maximum growth of 178 ha (440 ac) in a single year (CBD and DOW 2018, p. 18). Using data up to January 2019 on registered frac sand facilities reported by Mace (2019, p. 43), we estimated average and median annual growth rate of those facilities to be 56 and 45 ha (138 and 110 ac), respectively. From 2017 to 2018, a survey of five sand mines in DSL habitat reported disturbing an average of 35 ha (86 ac) per year (Texas CPA 2019, p. 81). However, these estimates are from the early years when the local frac sand industry was still getting established. Lack of data from subsequent years means ebbs and flows in the market are not accounted for in those estimates. A more recent analysis that incorporated data from 2017 to March 2020 suggested an average growth rate of 42 ha (105 ac) per year across 19 sand mines in the Permian Basin; mines in DSL habitat averaged a growth rate of 27 to 28 ha (67 to 70 ac) per year (ACF 2021b, pp. 4-8).

Projections of future sand mine growth rates are often based on general estimates using trends rather than quantitative projections. One projection suggested sand mines would not grow more than 40 ha (100 ac) annually (Texas CPA 2017, entire). Other industry estimates suggested growth rates would be between 16 to 24 ha (40 to 60 ac) annually (Atlas Sand 2018, entire; Forstner *et al.* 2018, pp. 1-2; Texas CPA 2019, pp. 79, 81). The most quantitative estimate available correlated sand mine growth rates to oil prices to project future DSL habitat loss due to these mines under different oil price projections (ACF 2021b, pp. 8-9). The projections were applied to different DSL habitat models (Hibbitts vs. Hardy) in Texas. Under their high oil price scenario, sand mine expansion was projected to be 38 ha (93 ac) per year; under the baseline and low oil prices scenarios, estimates dropped to 22 and 13 ha (54 and 31 ac) per year, respectively.

For our future scenarios, we chose to model future sand mine expansion using our own empirical estimates of sand mine growth rates. Using the latest aerial imagery, we were able to estimate growth of individual sand mines within the DSL range from 2017 to 2022, depending on the availability of imagery (see Chapter 5). We incorporate an additional two years of data on sand mine expansion compared to other estimates (e.g., ACF 2021b, p. 6), providing the most recent empirical estimate of sand mine growth available. Also, with the time coverage of the aerial imagery (five years), we believe our estimates capture sufficient variation in oil markets.

Along with growth rates, another source of uncertainty is whether new sand mines would appear on the landscape or if existing mines would shut down and cease to expand. This is tied to market trends and whether existing mines can meet demand of the frac sand industry. Data from Mace (2019, pp. 42, 47) suggested the industry could support 30 to 38 sand mines in the future in west Texas. In their projections of future sand mine growth, ACF (2021b, p. 9) assumed no new sand mines would be developed in DSL habitat.

We identified 18 sand mines within our analysis area. For our future scenarios, we only projected expansion for those existing 18 sand mines. We did not add any new sand mines, nor did we assume were to shut down and cease growing. Also, we restricted our projections of future sand mine growth to only those mines for which we have spatial data. Given the uncertainty in industry trends and the unique factors driving expansion of each mine, we believe it would be speculative to extrapolate past trends to infer the placement and expansion of mines that currently do not exist.

To capture the ebbs and flows of the market, we selected three estimates of sand mine growth rates and integrated them into the future scenarios developed by Pierre *et al.* (2020, entire). For the Medium scenario, we selected the median growth rate calculated using the aerial imagery, which was 22 ha (51 ac) per mine per year. With the High scenario we selected the 75th percentile of sand mines growth rates, which was 30 ha (74 ac) per mine per year, and with the Low scenario the 25th percentile, which was 16 ha (39 ac) per mine per year. We then used geospatial analyses to project sand mine growth to 2050, which matches the time frame of the Pierre *et al.* (2020, entire) scenarios. More details on our geospatial analysis can be found in Appendix B. Like our analysis of current conditions, we anticipate that this approach is conservative and likely underestimates the effects of sand mining on the DSL and its habitat beyond the footprint of the mine.

We paired these projections of oil well pad density and sand mine expansion to capture the extent of potential future impacts to the DSL, not to generate a holistic, integrated economic scenario. In other words, we did not assume that the economic forces that would result in an outcome for one industry would necessarily result in a similar trend for another. Instead, our scenarios were meant to capture the plausible range of landscape impacts caused by both industries under the upper and lower plausible limit. The likely future lies somewhere between these boundary scenarios and it is important to interpret our scenarios as bounds of plausible future outcomes for the DSL.

6.1.4 Accounting for Duneland loss in the future

To assess the future condition of the Analysis Units, we added another metric to reflect the impacts of projected changes to the highest quality Duneland habitat. We wanted to fully account for the future loss of this valuable habitat type. Although our current condition analysis includes the proportion of Duneland considered Minimally Disturbed, this metric has some limitations in expressing future habitat loss. This metric is based on the proportion of Duneland considered Minimally Disturbed relative to all Duneland on the landscape. With the oil and gas projections, as more well pads were added in the future scenarios, it results in a shift in the proportions of habitat considered Minimally Disturbed versus Degraded and Disturbed. In other words, the amount of Duneland habitat within an Analysis Units did not change, only its quality. However, this was not the situation with sand mines. Sand mines were considered non-habitat for the DSL, so as they expanded in our future scenarios, they converted existing habitat to non-habitat. This would include not only Minimally Disturbed habitat, but also those currently assessed as Disturbed or Degraded. Thus, sand mine growth resulted in an overall decrease in the amount of area considered suitable habitat. Our concern was that the existing proportion of Duneland classified as Minimally Disturbed metric, although still valuable, did not account for the conversion of high-quality Duneland to non-habitat.

To specifically highlight the loss of Minimally Disturbed Duneland, the highest quality habitat with the potential for the greatest and most productive DSL populations, we added one additional future condition metric looking at the proportion of the loss of minimally disturbed duneland within each analysis unit. This metric was simply the proportion of currently existing Minimally Disturbed Duneland projected to be lost by 2050. This loss could be due to either degradation or conversion. Our formula to calculate an overall future condition score for each Analysis Unit was identical to that used for current condition except for this additional metric. To develop a future condition score, we counted the proportion of Duneland Degraded (Z) score three times and the proportion of Duneland Minimally Disturbed (Y) score twice and the proportion of total area Minimally Disturbed (X) once and then took the average of the scores, as was done in current condition. From there, we incorporated the proportion of Minimally Disturbed Duneland lost (A) into the formula, as in Equation 2 below.

$$\text{Equation 2: } \frac{X+2Y+3Z}{6} - A = \text{overall future condition}$$

For our future condition score, we used this metric to reduce the overall condition of an Analysis Unit (Table 6-1). If 10-50 percent of the Minimally Disturbed Duneland area in an Analysis Unit was lost, a value of 0.5 was subtracted in the formula. If more than 50 percent of the Minimally Disturbed Duneland was projected to be lost, a value of 1 was subtracted, which in effect would drop the condition scores by category. As in current conditions, we rounded the final score produce an overall condition rating.

Table 6-1 Future condition categories developed to assess the resiliency of DSL Analysis Units.

	Habitat Quality			
Analysis Unit Condition	Proportion of total area Minimally Disturbed (X)	Proportion of Duneland Minimally Disturbed (Y)	Proportion of Duneland Degraded (Z)	Proportion of Minimally Disturbed Duneland Lost (A)
High	>90% (3)	>90% (3)	<10% (3)	<10 (0)
Moderate	50-90% (2)	50-90% (2)	10-50% (2)	10-50 (0.5)
Low	<50% (1)	<50% (1)	>50% (1)	>50% (1)

6.1.5 Conservation agreements

As discussed in Chapter 4, there are several conservation agreements that have been put in place to minimize the impact of industrial activity on the DSL and its habitat. For projecting future conditions, we considered the nature of the agreements and accounted for them in our projections of future habitat. The protection of public lands in New Mexico were accounted for in the oil projections: Pierre *et al.* (2020, p. 349, Table S3) excluded certain areas from future oil well pad placement, including protected areas, conservation easements in New Mexico, and BLM lands closed to future oil drilling. Thus, areas protected under the auspices of the conservation agreements, mainly the CCA in New Mexico, would not be developed in our future scenarios. Private lands enrolled in the voluntary CCAA and non-protected federal lands enrolled in the CCA in New Mexico are still included under the Pierre *et al.* analyses.

In Texas, since most landownership is private and there are fewer protected areas officially closed to future development, there were fewer restrictions on future oil development in the

Pierre *et al.*'s model. Furthermore, unlike the CCA and CCAA in New Mexico, which require avoidance of DSL habitat, the TCP and CCAA in Texas authorize impacts to habitat. For instance, the Texas CCAA authorizes sand mine growth rates of up to 24 ha/year, which fall between the Medium (22 ac) and High (30 ac) growth scenarios projected above. The TCP and CCAAs are also voluntary agreements and areas set aside to preserve DSL habitat by Participants are not under permanent or long-term protection. Further, the TCP and CCAA do not provide any property-specific commitments to avoid DSL habitat areas for the duration of these agreements, only commitments to mitigate for DSL habitat impacts that result from covered activities. Also, since these are private lands, we would not know the location of the habitat being avoided. As discussed in Chapter 4, enrollment in the TCP has declined significantly over the past several years and the plan has not performed as expected due to several factors, including implementation errors, low enrollment, activities of non-Participants, stratification of enrolled and non-enrolled properties, etc. The 2020 CCAA also currently has similar issues, such as low enrollment, stratification of properties, lack of clarity to date on conservation measures and other activities. While conservation measures are a requirement of participation in the CIs, we are unsure of the extent of conservation measure implementation in Texas, as well as the locations of areas where conservation is occurring. Thus, while we continue to coordinate with the plan administrators, based on performance reporting to date, it has not yet been demonstrated that these agreements will be adequate or effective at protecting the DSL or its habitat in Texas into the future. Therefore, we did not include potential future conservation efforts resulting from these plans in our scenarios projecting the species' future status. We did not adjust our future projections of oil well pad density or sand mining to account for these agreements.

6.2 Future condition projections

6.2.1 Future projections of habitat

In our Current Conditions assessment, we found 47 percent of DSL habitat range-wide was Minimally Disturbed (see Chapter 5.4.1). Another 39 percent was Degraded or non-habitat and the remaining 14 percent Disturbed. In the Low future scenario, by 2050 we project 44 percent to remain Minimally Disturbed, whereas the proportion considered Degraded increased to 40 percent and Disturbed to 16 percent. In the Medium scenario, 36 percent was considered Minimally Disturbed, 45 percent as Degraded, and 19 percent as Disturbed. With the High scenario, 25 percent was Minimally Disturbed, 53 percent Degraded, and 22 percent Disturbed. A similar trend was observed with the proportion of Duneland habitat under the three scenarios (Figure 6-1), except in general Duneland was slightly less disturbed than the overall area.

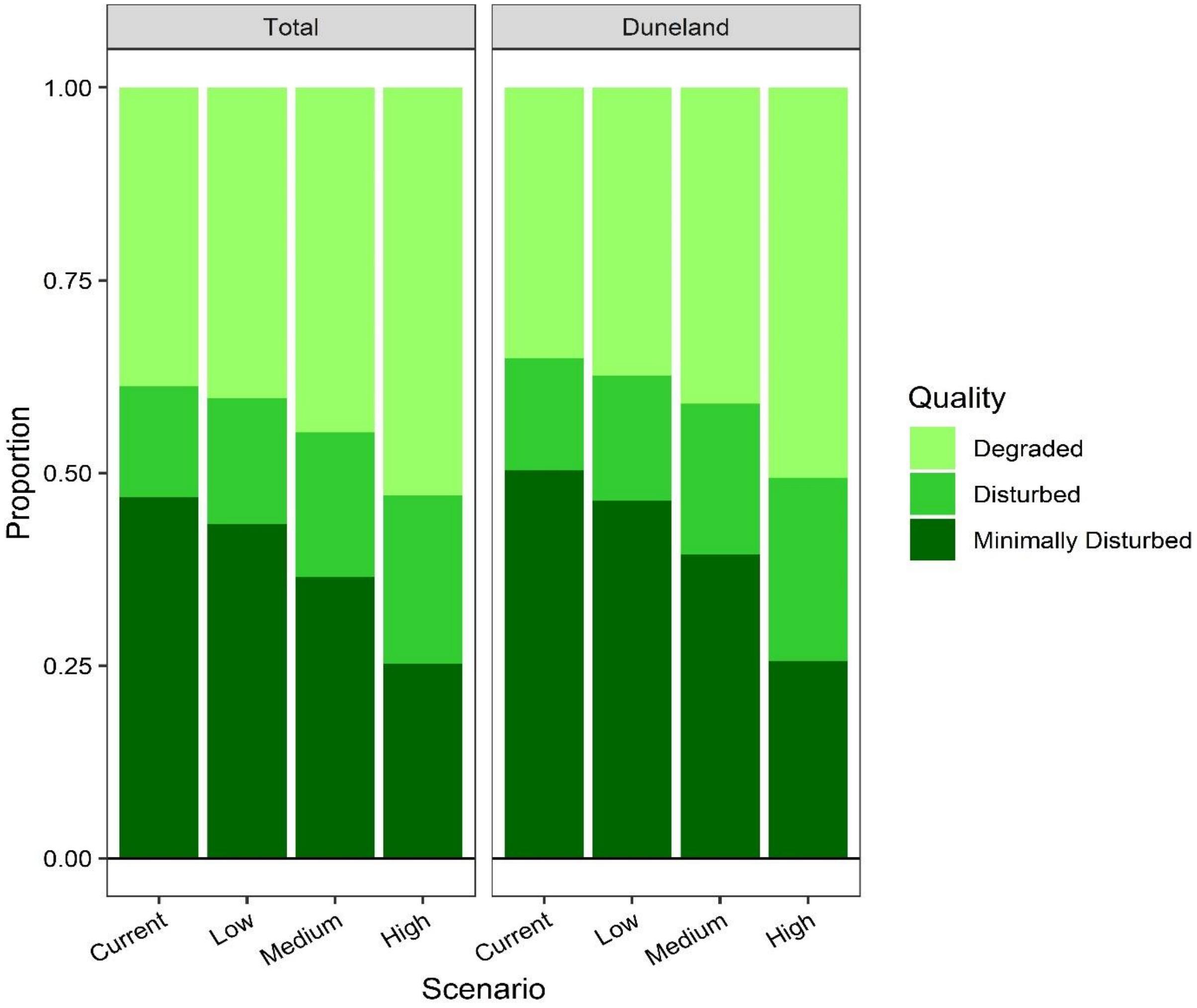

Figure 6-1 Comparison of the proportion of total DSL habitat (left panel) and Duneland habitat (right panel) currently and projected by 2050 under the three future scenarios. Quality refers to the categories of human disturbance defined for this assessment.

Future projections of habitat disturbance varied spatially across the DSL range (Figures 6-2, 6-3, 6-4; Appendix D). In general, the increasing severity of the future conditions scenarios, from Low to High, resulted in incremental increases in the amount of Duneland habitat classified as Disturbed or Degraded (Figure 6-5). There were several instances in which the scenario caused a notable shift in the quality of habitat (Figure 6-6). For example, in N. Mescalero 5 under current condition and the Low scenario the amount of Duneland classified as Minimally Disturbed was 71 and 67 percent, respectively. However, it dropped to 42 percent under the Medium scenario and 13 percent under the High. Likewise, Monahans 2 and 3 saw large decreases in the proportion of Duneland classified as Minimally Disturbed under the High scenario (23 and 21 percent, respectively) compared to current (73 and 65 percent), Low (72 and 55 percent), and Medium (70 and 47 percent).

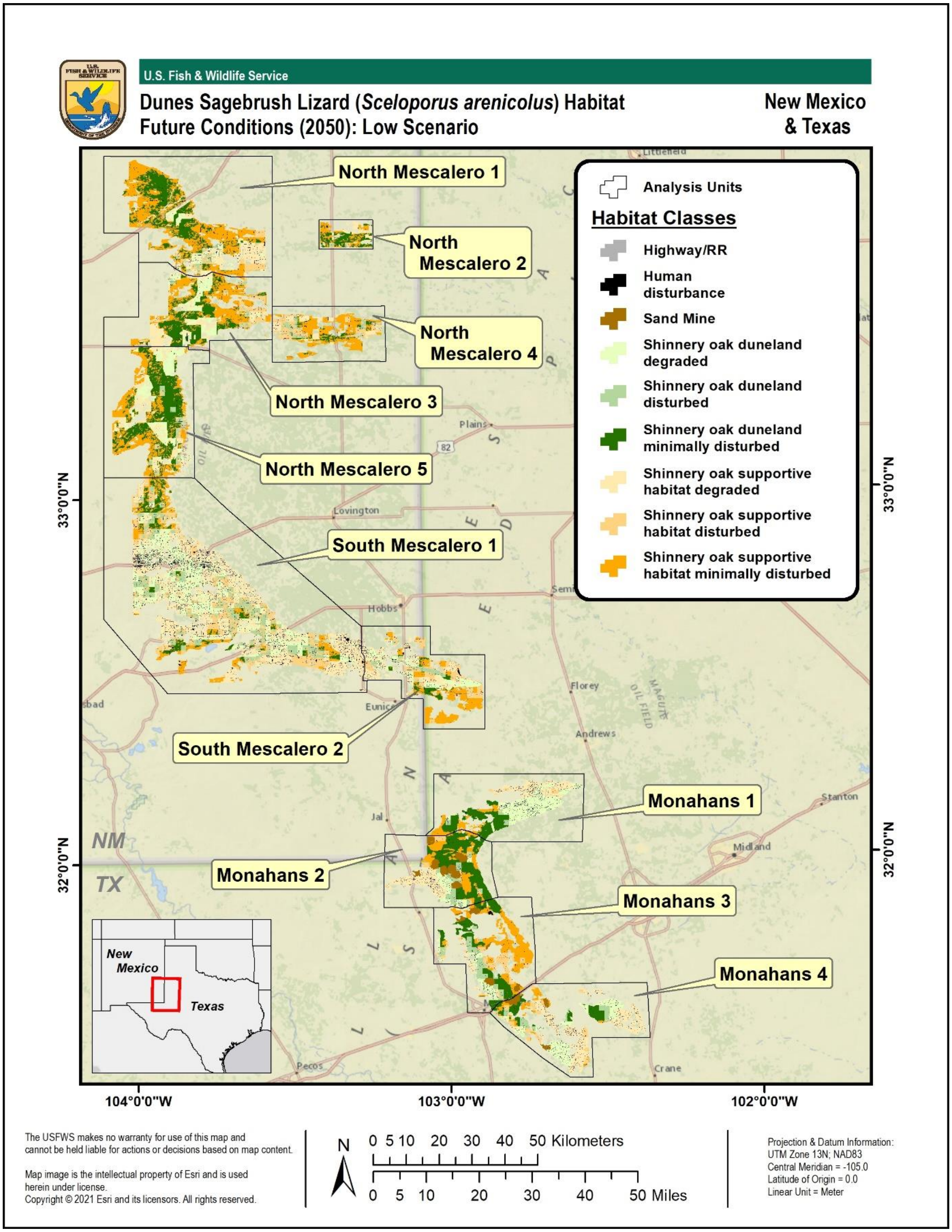

Figure 6-2 Future projection of DSL habitat in 2050 under the Low scenario. The outlines are for the 11 Analysis Units.

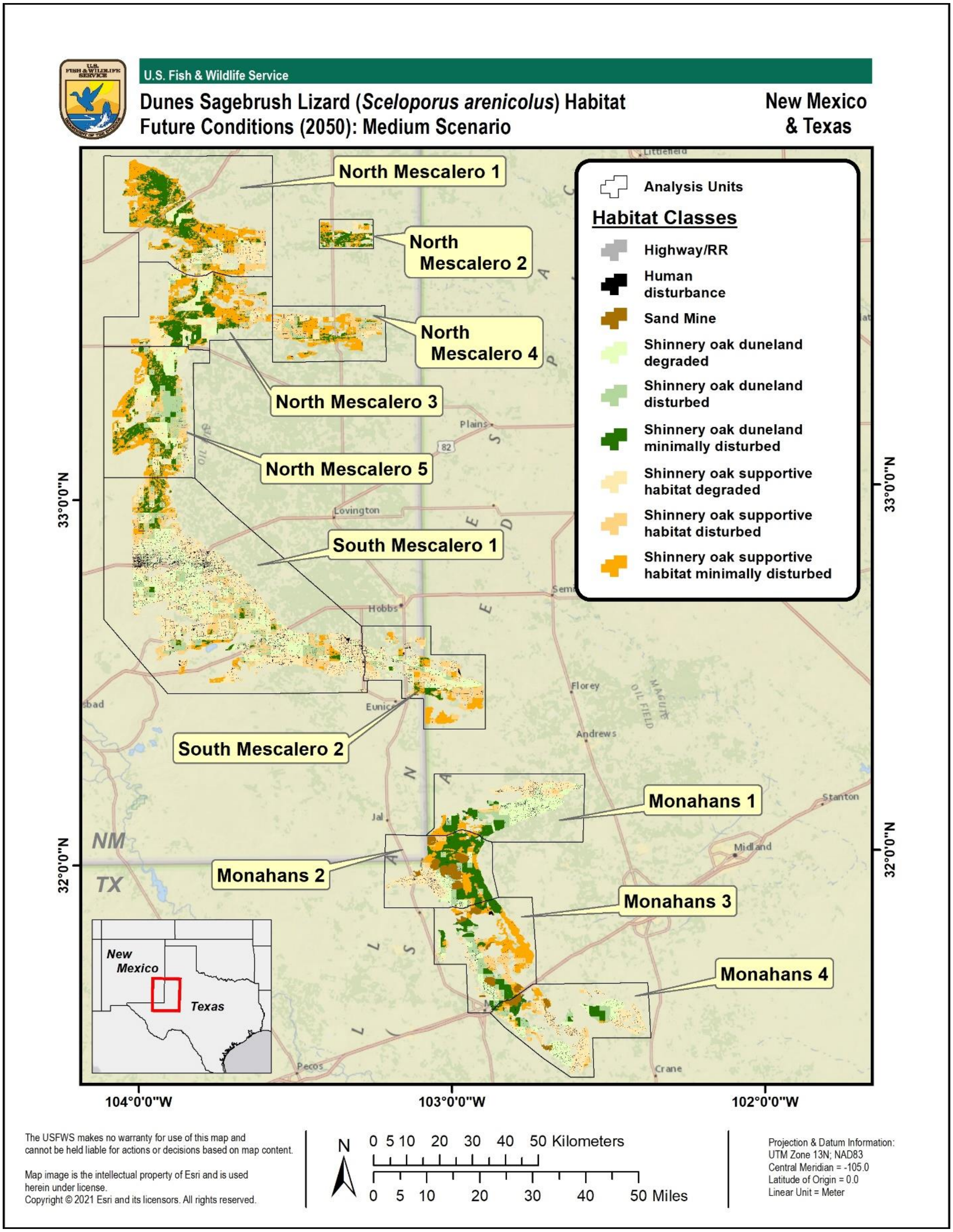

Figure 6-3 Future projection of DSL habitat in 2050 under the Medium scenario. The outlines are for the 11 Analysis Units.

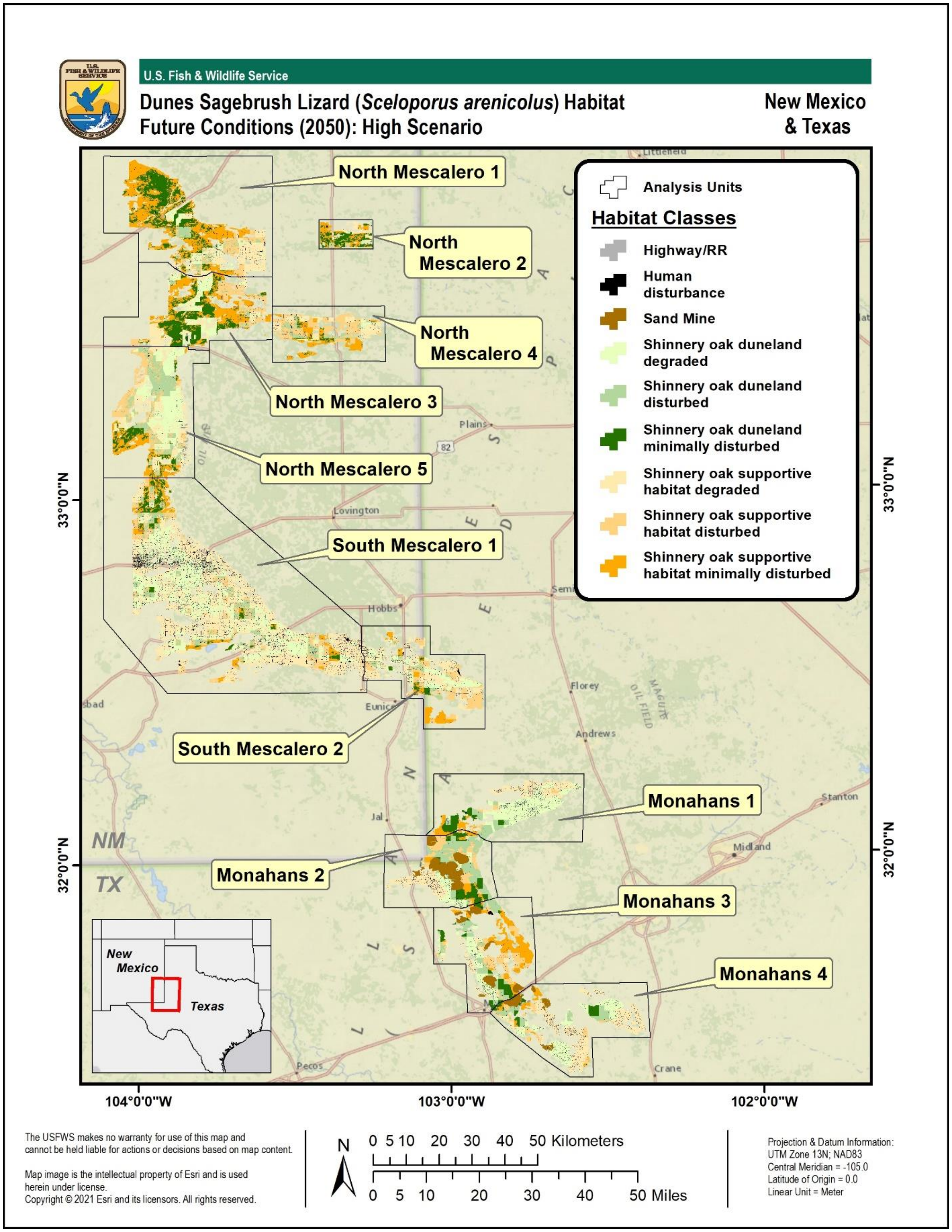

Figure 6-4 Future projection of DSL habitat in 2050 under the High scenario. The outlines are for the 11 Analysis Units.

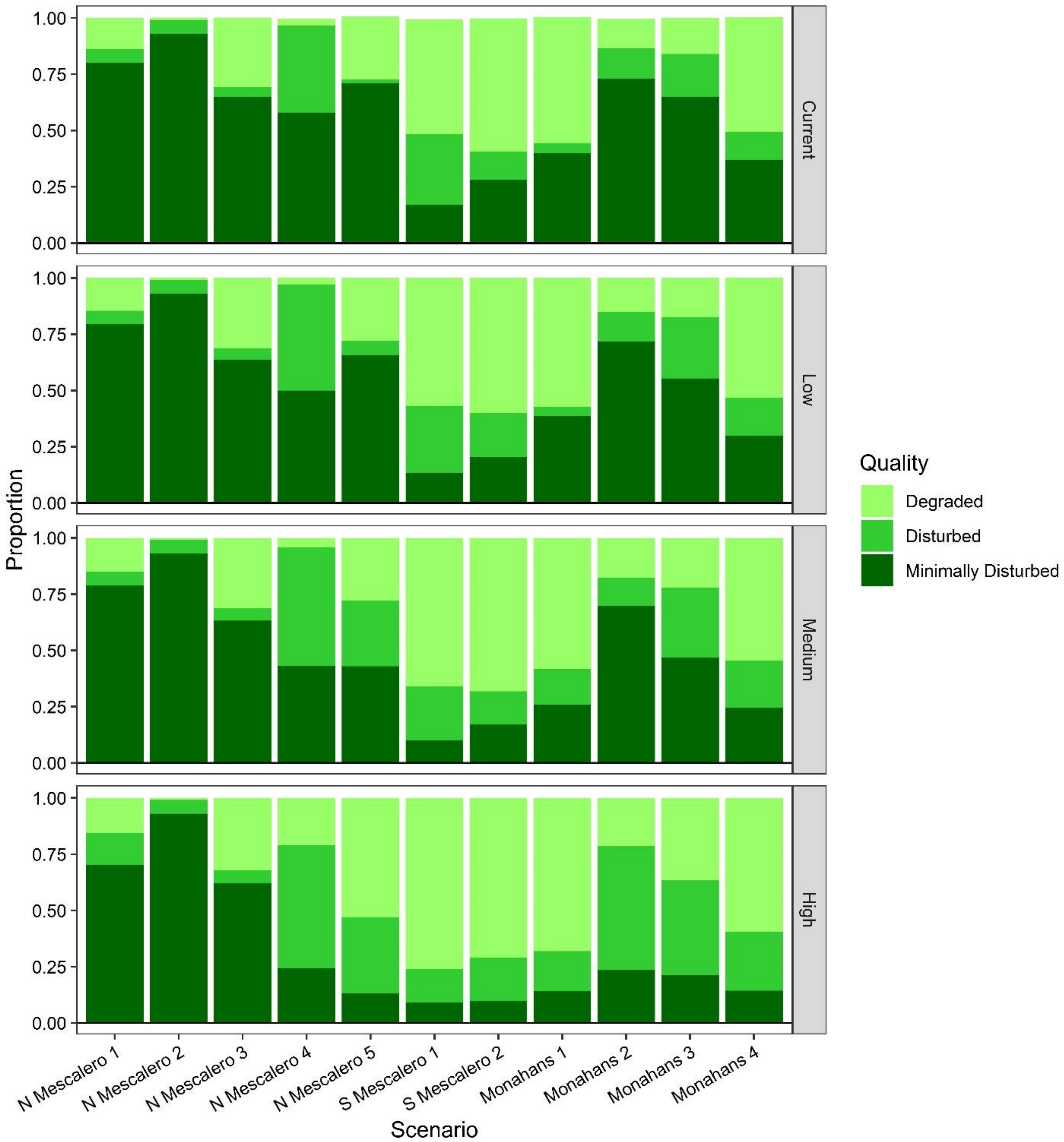

Figure 6-5 Current status of Duneland habitat in each Analysis Unit and projections under the three future scenarios.

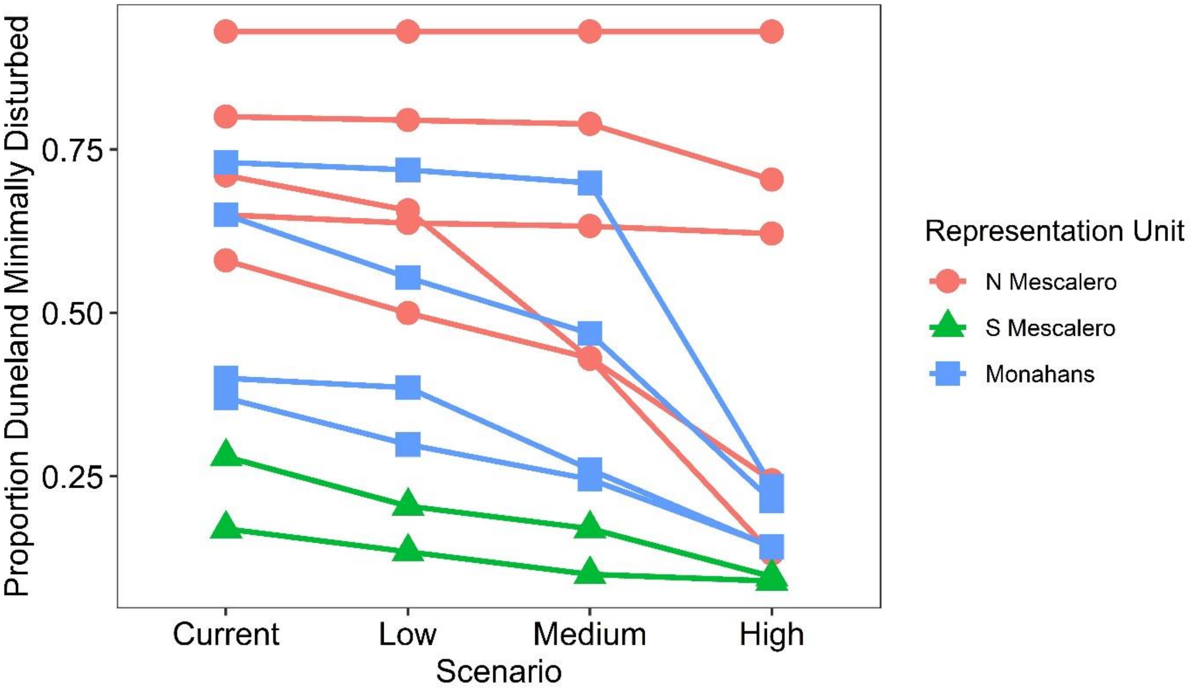

Figure 6-6 Trend in the proportion of Duneland habitat classified as Minimally Disturbed currently and across the three future scenarios. Each line represents an individual Analysis Unit.

Some of these projections resulted in shifts in the condition category scores for the Analysis Units. Compared to current conditions, all Analysis Units maintained the same score in the Low scenario except for N. Mescalero 4, which dropped from High to Moderate condition (Table 6-2). Moving from the Low to Medium scenario, Monahans 2 and 3 shifted to Low condition (Table 6-3). Under the High scenario, N. Mescalero 5 also changed from Moderate to Low condition (Table 6-4). Under all scenarios, only 2 percent of the DSL range was projected to be in High condition. In contrast, under the Medium scenario 72 percent of the DSL range is projected to be in Low condition. This increases to 77 percent under the High scenario. With the Low scenario, 51 percent of the DSL range is projected to be in Moderate condition: this drops to 26 and 21 percent for the Medium and High scenarios, respectively.

Table 6-2 Results for the condition category scores and the overall resiliency condition for each Analysis Unit under the Low future scenario.

Representation Unit	Analysis Unit	Proportion of total area Minimally Disturbed	Proportion of Duneland Minimally Disturbed	Proportion of Duneland Degraded	Proportion Minimally Disturbed Duneland lost	Overall condition
N Mescalero	N Mescalero 1	0.72	0.79	0.15	0.00	Moderate
	N Mescalero 2	0.76	0.93	0.01	0.00	High
	N Mescalero 3	0.61	0.64	0.31	0.01	Moderate
	N Mescalero 4	0.56	0.50	0.03	0.15	Moderate
	N Mescalero 5	0.66	0.66	0.28	0.07	Moderate
S Mescalero	S Mescalero 1	0.13	0.13	0.57	0.22	Low
	S Mescalero 2	0.33	0.20	0.60	0.27	Low
Monahans	Monahans 1	0.35	0.39	0.57	0.03	Low
	Monahans 2	0.53	0.72	0.14	0.12	Moderate
	Monahans 3	0.57	0.55	0.18	0.19	Moderate
	Monahans 4	0.19	0.30	0.52	0.22	Low

Table 6-3 Results for the condition category scores and the overall resiliency condition for each Analysis Unit under the Medium future scenario.

Representation Unit	Analysis Unit	Proportion of total area Minimally Disturbed	Proportion of Duneland Minimally Disturbed	Proportion of Duneland Degraded	Proportion Minimally Disturbed Duneland lost	Overall condition
N Mescalero	N Mescalero 1	0.71	0.79	0.15	0.01	Moderate
	N Mescalero 2	0.76	0.93	0.01	0.00	High
	N Mescalero 3	0.59	0.63	0.31	0.02	Moderate
	N Mescalero 4	0.49	0.43	0.04	0.26	Moderate
	N Mescalero 5	0.48	0.43	0.28	0.39	Low
S Mescalero	S Mescalero 1	0.10	0.10	0.66	0.42	Low
	S Mescalero 2	0.24	0.17	0.68	0.39	Low
Monahans	Monahans 1	0.25	0.26	0.58	0.35	Low
	Monahans 2	0.50	0.70	0.18	0.18	Low
	Monahans 3	0.48	0.47	0.22	0.32	Low
	Monahans 4	0.16	0.25	0.54	0.37	Low

Table 6-4 Results for the condition category scores and the overall resiliency condition for each Analysis Unit under the High future scenario.

Representation Unit	Analysis Unit	Proportion of total area Minimally Disturbed	Proportion of Duneland Minimally Disturbed	Proportion of Duneland Degraded	Proportion Minimally Disturbed Duneland lost	Overall condition
N Mescalero	N Mescalero 1	0.63	0.70	0.15	0.12	Moderate
	N Mescalero 2	0.76	0.93	0.01	0.00	High
	N Mescalero 3	0.54	0.62	0.32	0.04	Moderate
	N Mescalero 4	0.26	0.24	0.21	0.58	Low
	N Mescalero 5	0.19	0.13	0.53	0.81	Low
S Mescalero	S Mescalero 1	0.08	0.09	0.76	0.48	Low
	S Mescalero 2	0.13	0.10	0.71	0.65	Low
Monahans	Monahans 1	0.16	0.14	0.68	0.65	Low
	Monahans 2	0.16	0.23	0.21	0.74	Low
	Monahans 3	0.31	0.21	0.37	0.70	Low
	Monahans 4	0.11	0.14	0.60	0.64	Low

6.2.2 Future projections of sand mining

As with our assessment of current conditions, future impacts of sand mining were restricted to the projected footprints of the existing mines under our three scenarios. However, these footprints are projected to be substantially larger in the future (Appendix D). Currently, the 18 mines that were identified cover an area of 2,895 ha (7,154 ac). By 2050, their combined size is expected to increase to 11,135 ha (27,515 ac) under the Low scenario, 14,304 ha (35,345 ac) under the Medium scenario, and 18,529 ha (45,785 ac) under the High scenario. Thus, the overall extent of sand mines in the DSL range is projected to increase between 3.8 and 6.4 times their current area in less than 30 years.

6.2.3 Other threats

Although more limited in scale compared to oil exploration and sand mining, other factors may further contribute to the future viability of the DSL. Climate change will likely only have negative effects on the DSL. Given that the DSL is a habitat specialist with a restricted range, it cannot simply shift its distribution northward or higher in elevation to follow changing climatic patterns. The Mescalero and Monahans Sandhills lie at the intersection of the southern Great Plains and Chihuahuan Desert (Muhs and Holliday 2001, p. 77; Breckle *et al.* 2008, p. 441): climatic shifts could push the entire region from a semiarid to arid environment (Seager *et al.* 2007, entire). Increased air temperatures (Jiang and Yang 2012, p. 238), less precipitation (Spencer and Altman 2010, entire), and more frequent drought (Cook *et al.* 2015, entire; Kinniburgh *et al.* 2015, p. 62; Spencer and Altman 2010, entire) projected under climate change will likely impact shinnery oak itself, particularly in the southern portion of the DSL range. Even in the northern portion of the range, multiple years in the past decade have already experienced drought that has prevented shinnery oak from leafing out until late in the season; or as in 2011, from leafing out at all. Weakening or mortality of shinnery oak reduces the stability of the entire sand dune system (Gucker 2006, p. 7; Newton and Allen 2014, p. 4). As shinnery oak duneland habitat becomes more fragmented into the future, remaining patches may no longer be suitable for the DSL due to shinnery oak die-off and sand dune instability. We anticipate areas in the northern portion of the species range (i.e., North Mescalero) will be more resilient to climate change, especially since they are projected to be less disturbed and degraded. Populations in the south, especially Monahans, are more vulnerable to the impacts of climate change.

Future impacts of groundwater pumping likely mirror those of climate change: as temperatures increase and drought becomes more frequent, agriculture may become more dependent on pumping water from the region's aquifers. Indeed, climate models for the area encompassing the range of the DSL in New Mexico and Texas predict limitations on water availability in the region as groundwater withdrawal exceeds recharge by 2050 (Spencer and Altman 2010, entire). Given our uncertainty in the nature of the water table in the DSL range, it is difficult to predict the impacts of groundwater pumping on DSL habitat. However, expansion of sand mining is likely to have consequences for ground water levels regardless. The actual impact of sand mining will extend beyond their footprint if they disrupt perched aquifers and cause a drawdown of the water table. More research is needed to determine the magnitude and scope of sand mining impacts to surrounding shinnery oak ecosystems due to changes in water supply.

Mesquite encroachment has been on-going in the Southwest for decades and we have no reason to believe it will cease, especially since it is resilient to temperature increases (Fredrickson *et al.* 2006, p. 290). As discussed in 4.1.4.4, mesquite encroachment is most likely to occur in areas in which mesquite is already present in the landscape in areas primarily outside and at the margins of high quality shinnery oak duneland habitats. Although we have limited research on encroachment rates within the shinnery oak ecosystem, mesquite has been increasing between 0.2-2.2 percent cover annually at locations across the southwest (Ansley *et al.* 2001, p. 173; Asner *et al.* 2003, p. 327; Barger *et al.* 2011, p. 4). As shinnery oak dunelands continue to become fragmented and climate change continues to impact the landscape, mesquite will gain more of a competitive edge, increasing degradation of the shinnery oak dunelands.

The U.S. Census Bureau (2010, 2020) has documented steady population growth in counties overlapping the DSL range. In New Mexico, both Lea and Eddy County grew at a rate of over 15 percent between 2010 and 2020, largely due to the influx in development of the oil and gas industry in the area. Additionally, the Texas Demographic Center has identified counties in the Permian Basin as areas of the highest projected growth in terms of the number of households added. The increase in population is likely to necessitate changes to infrastructure such as the expansion of roads and highways and increased housing development that may further exacerbate threats of habitat loss and fragmentation to DSL. Furthermore, additional people available in the workforce of these areas can increase the pace and scale of industry development within DSL habitat.

6.3 Assessment of Future Viability

6.3.1 Resiliency

We are projecting an overall decrease in resiliency for the DSL, with no plausible expectations of improvement in the species condition in the future. Even under the best-case scenario, we project that only a small portion of the DSL range (2 percent) will be in High condition, whereas in the worst-case scenario 77 percent will be in Low condition. Decreases in habitat quality from current condition to the Low and Medium scenarios are mostly linear across Analysis Units (Figure 6-6). However, considering the High scenario results in substantial reductions in the quality of habitat, this underscores the relationship between DSL viability and the petroleum industry in the Permian Basin. Increases in the price of oil will facilitate more extensive drilling and expansion of sand mines. Currently oil prices are within the range projected under scenarios that would encourage industry development and high habitat loss (ACF 2021a, p. 7; Figure 6-7). Should these trends continue, DSL resiliency will continue to decline, especially in the Southern Mescalero and Monahans Representation Units where industrial development is projected to be highest.

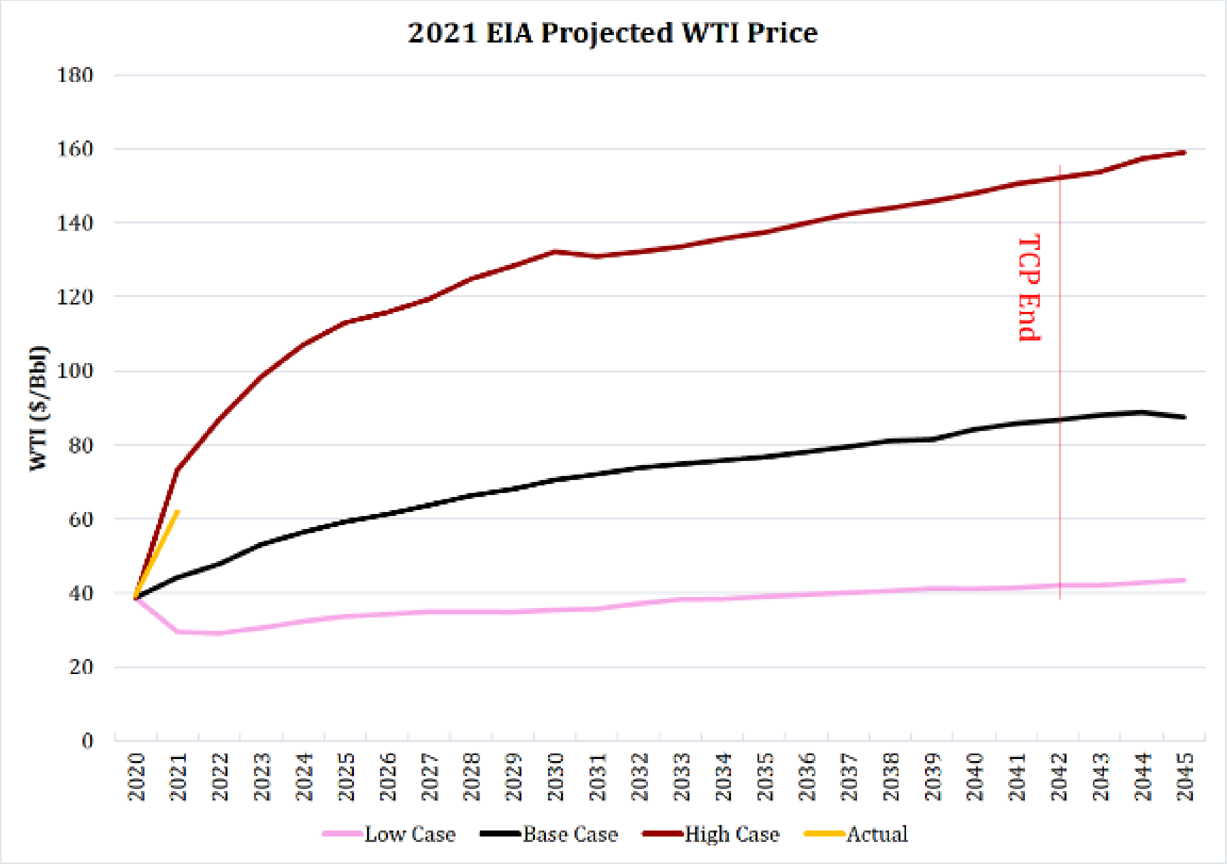

Figure 6-7 Projections of future oil prices to 2045 under different economic and technological scenarios. Base Case represents the U.S. Energy Information Agency's projection of oil prices of how energy markets will operate through 2050 and is meant to serve as a baseline scenario. High

Case is a projection of oil prices under increased demand, whereas Low Case is projection under reduced demand. The line denoting Actual shows real oil prices in 2020 and 2021.As of February 22, 2022, the price of oil had surpassed $91.00 a barrel. Credit: ACF (2021, p. 7). TCP End refers to expiration date of the latest Texas Conservation Plan.

Based on our future scenarios, we are projecting incursions of industrial activity in some of the largest, highest quality habitat patches currently remaining. For example, the largest patch of Duneland we identified in the entire DSL range is projected to be become completed Disturbed under the High scenario. This 10,667 ha (26,358 ac) patch in N. Mescalero 5 is projected to decrease to 4,800 ha (11,862 ac) under the Medium scenario. Under the High scenario, it will no longer be the largest Minimally Disturbed patch even within N. Mescalero 5, falling to less than 1,295 ha (3,200 ac). Similarly, the second largest patch of Minimally Disturbed Duneland currently in the DSL range is in Monahans 2 at 5,825 ha (14,393 ac). Under the Medium scenario, it is projected to be 5,172 ha (12,779 ac). However, under the High scenario, it is projected to reduce in size to 868 ha (2,145 ac). In both these situations, large Minimally Disturbed patches of Duneland that are current strongholds for the DSL are expected to experience substantial reductions in habitat quality. Reductions in the viability of these strongholds could have cascading effects in the surrounding landscape.

This underscores an important uncertainty for this assessment: the relationship between landscape-scale habitat alteration and extinction risk. Although we know increasing well pad density and habitat degradation elevate extirpation risk at a local scale, we lack information of how this would translate across a broader scale. Even in highly degraded landscapes, pockets of suitable habitat may maintain populations of DSL. However, persistence of these populations in such areas does not mean they are not at elevated risk of extirpation. Small, isolated populations are at elevated risk of stochastic events that may eventually result in extinction. Thus, the condition scores of our Analysis Units should not be interpreted as a prediction of DSL presence in 2050, but rather the relative risk of extirpation faced by those populations over that period.

Trends in sand mining also have consequences for future DSL resiliency in Texas. Our modeling approach allowed sand mines to grow in all directions, but placed limits on expanding into areas already converted to development (e.g., well pads, major roads). It is unlikely that sand mines will grow into areas already dedicated to certain industries and infrastructure. This is important, for we project that sand mining will likely be expanded into areas that have not yet been developed. Undeveloped areas may consist of prime Duneland in Texas. Areas we considered Minimally Disturbed may present the least encumbrances for sand mines to contend with, for they would have lower road and well pad densities that would minimize conflicts. Continued growth of the sand mining industry may impact the Minimally Disturbed DSL habitat remaining in Texas.

The amount of habitat directly lost due to sand mining is not the only effect of these mines: the orientation of these mines matters as well. For example, especially in Monahans 2, the projected growth patterns of sand mines will stretch across entire dune fields containing Duneland habitat (Appendix D). That will block any potential dispersal of the DSL, isolating populations that are currently connected. This may further reduce the viability of the DSL in those Analysis Units, eliminating connectivity and gene flow between remaining habitat patches that are expected to persist.

6.3.2 Redundancy

Our future projections suggest Analysis Units currently in Low condition will continue to remain so and experience further reductions in the quality of habitat. That indicates these portions of the DSL range will continue to have reduced viability and elevated risk of extinction. Loss of any of these Analysis Units would reduce the overall redundancy of species. Furthermore, under the Medium scenario, Monahans 2 and 3 are projected to be in Low condition. The High scenario adds another Analysis Unit (N. Mescalero 5) to that level. That would place most of the species' range (77 percent) at low levels of viability.

Elevated risk is concentrated in the southern portion of the DSL range, meaning that should DSL become extirpated in those Analysis Units, the species would only have strongholds in the north. This creates a potential vulnerability, for a catastrophic event restricted to just the geography of the Northern Mescalero Representation Unit could cause extirpations of the populations likely to be the most viable into the future.

6.3.3 Representation

By 2050 we project that all three of the main DSL phylogenetic lineages, corresponding to our Representation Units, will still have extant populations. However, these lineages will be subjected to varying levels of threat. As indicated in Chapter 5, the Southern Mescalero Representation Unit currently is in Low condition and is expected to worsen in the future. Under the Medium and High scenarios, all Analysis Units in the Monahans Representation Unit would also be in Low condition. Degradation of two Representation Units, which includes two unique evolutionary lineages that cover a range of environmental conditions, would greatly reduce the adaptive capacity of the DSL.

Although we do not project all the Analysis Units in Northern Mescalero to be in Low condition by 2050, they are expected to experience continual degradation of DSL habitat. Some of the largest patches, which likely support the most robust populations, are expected to become more highly disturbed in the Medium and High scenarios. Large, continuous patches of habitat tend to support largest population sizes and act as reservoirs for genetic diversity. Fragmenting this habitat can cause population declines and reduce dispersal to the point that it facilitates genetic drift. Degradation of current DSL strongholds can have consequences for long-term viability of the species.

Also, even though we are not projecting extirpation of any Analysis Units or Representation Units, the current and projected alteration of this landscape would inhibit the ability of the DSL to respond to long-term environmental change. The species has naturally low dispersal capabilities: there is no evidence of on-going gene flow between Representation Units or many of the Analysis Units (Chan *et al.* 2020, entire). Anthropogenic development has created significant barriers that would further reduce or eliminate movement. Thus, even if the DSL currently retains much of its adaptive capacity, it would be virtually impossible for it to spread around the landscape. This is especially pertinent in the context of climate change: DSL currently occupies a gradient of environmental conditions across its range and could possess the adaptive capacity to respond to changes in temperature and precipitation patterns.

Aside from a few exceptions, we did not project that there would be large, continuous patches of Minimally Disturbed habitat that would span multiple Analysis Units. Under the Low and Medium scenarios, we anticipate there will be continuous patches of Minimally Disturbed habitat connecting Monahans 1, 2, and 3 (Figures 6-2, 6-3, Appendix D), but these linkages would disappear under the High scenario (Figure 6-4). These three Analysis Units are genetically distinct with limited evidence of gene flow between them (Chan *et al.* 2020, p. 7). Loss of connections between them would increase isolation and eliminate the potential for gene flow or population shifts. Across all scenarios we project linkages at the boundary between N. Mescalero 5 and S. Mescalero 1, which is currently a contact zone for the two lineages (Chan *et al.* 2020, p. 7). Although this is a contact zone with some evidence of admixture, there is no evidence of on-going or historical gene flow between the Northern and Southern Mescalero lineages. This implies some mechanism, such as low dispersal capabilities, limits gene flow across this zone. Given that movement within this zone is already restricted, the level of alteration anticipated in the Medium and High scenarios would further limit the potential for gene flow or population shifts into either the Northern or Southern Mescalero Representation Units. Even in the North Mescalero Representation Unit, which is projected to retain the highest proportion of quality habitat for the DSL into the future, there are notable breaks in habitat and anthropogenic barriers that would restrict the potential for future movement. Habitat degradation and fragmentation will limit the ability of the DSL to move across the broader landscape, restricting the ability of the species to adapt as environments change into the future.

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Appendix A: Cause and Effect Tables

This table of Confidence Terminology explains our rationale in characterizing confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	**Explanation**
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

THEME: Habitat Loss & Modification from Oil & Gas			
[ESA Factor(s): A, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	**Construction** **Drilling** **Seismic Exploration** **Operation & Maintenance**	Highly Confident	
- Activity(ies)	**Construction**: Well construction. Building pipelines, powerlines, roads. Covering wellpads and roads with caliche. Installation of tank batteries, pump jacks. **Drilling**: Drilling of well. Installation of associated infrastructure. **Seismic**: Shakes the ground to allow for recording subsurface layers, installing seismic equipment in grid pattern (often large scale), can involve large amounts of disturbance to landscape due to human and motor traffic **Operation and Maintenance**: Monitoring and maintenance of oil and gas infrastructure, roads, pipelines, electrical lines.	Highly Confident	
STRESSOR(S)	**Construction**: Removal/disturbance of vegetation, ground disturbance, fragmentation from increased well density, increased density of roads, sand scrapes, road cuts, pipeline cuts, removal of dunes and connectivity habitats, increased human traffic (motor and foot), degradation of the geomorphological processes that maintain shinnery oak dune blowout formations. **Drilling**: piercing of ground, physical surface and ground disturbance, vegetation removal, vegetation trampling, increased human traffic (motor and foot) **Seismic**: Shaking of ground, piercing of ground with probe, physical disturbance of surface and ground, vegetation removal **Operation and Maintenance**: Increased human traffic (motor and foot).	Highly Confident	Johnson *et al.* 2016, p. 41; Leavitt and Fitzgerald 2013, p. 9; Ryberg *et al.* 2015, p. 895, Sias and Snell 1998, p. 1; Walkup *et al.* 2017, p. 9

- Affected Resource(s)	Direct removal of breeding, feeding, sheltering, and dispersal habitat. Decreased quality of habitat (loss of larger, steeper sand dunes) due to degradation of the shinnery oak dune blowouts by fragmentation. Isolation and loss of connectivity between populations. Direct effects in terms of crushing or destruction of individuals/eggs.	Highly Confident	Hibbitts et al 2013, p. 108; Johnson *et al.*, 2016, p. 41; Leavitt and Fitzgerald, 2013, p. 9; Painter et al 1999, p. 3; Ryberg et al 2015, p. 895; Sias and Snell, 1998, p. 1; Walkup *et al.*, 2017, pp. 9, 10
- Exposure of Stressor(s)	All life stages. Potentially all habitat, but higher density in southern Mescalero and Monahans analysis units where oil and gas resources are higher.	Highly Confident	Pierre *et al.* 2020, p. 6; Johnson *et al.* 2016, p. 26; Hibbitts *et al.* 2013, p. 105; USGS 2018, entire.
- Immediacy of Stressor(s)	Past present and future.	Highly Confident	USGS 2018, entire.
Changes in Resource(s)	Loss and Fragmentation of habitat.	Highly Confident	
Response to Stressors: - INDIVIDUALS	Behavioral avoidance of DSL results due DSLs tendency to avoid well pads, roadways and other developed areas and areas of lower quality habitat. Direct mortality of individuals or eggs can occur due to physical harm during construction, drilling, seismic activity, or due to increased human traffic. Lizards on the surface and/or lizards and eggs buried below the surface could be crushed, injured, or killed due to heavy equipment and vehicles clearing and traversing DSL habitat. Drilling or probing the surface during drilling or seismic activity could crush, injure, or kill DSL, including DSL nests and eggs). High levels of vehicular traffic during construction, seismic activity, or operation and maintenance could contribute to direct DSL mortalities from vehicle strikes.	Moderately Confident	Hibbitts *et al.* 2013, p. 108; Hibbitts *et al.* 2017, p. 197; Sias and Snell 1998, pp. 1, 2
POPULATION & SPECIES RESPONSES			
Effects of Stressors: -POPULATIONS	Oil and gas development is expected to result in declines of DSL in developed areas where habitat is removed, destroyed, and fragmented. Where DSL dispersal is constrained due to fragmented and unsuitable habitat, DSL populations are isolated and can lead to lack of gene flow between populations and loss of genetic diversity. Isolation of populations in smaller and lower quality habitat remnants may prevent diffusion-dispersal from occurring at rates sufficient to sustain population size and demographics necessary to prevent localized extirpations. Fragmentation and habitat loss may result in a progressive decline in abundance until localized extirpations of populations may occur. Isolated populations lost through stochastic events may not be naturally recolonized.	Highly Confident	Johnson et al 2016, p. 41; Leavitt and Fitzgerald 2013, p. 9; Ryberg *et al.* 2013, p. 6; Ryberg *et al.* 2015, p. 896; Sias and Snell 1998, p. 10; Walkup *et al.* 2017, p. 10; Walkup 2018, p. 34

- GEOGRAPHIC SCOPE	The entire range has been fragmented due to oil and gas. In the Southern Mescalero and Monahans analysis units, there are larger oil and gas resources which has led to larger loss and fragmentation of habitat in Monahans and southern Mescalero regions.	Highly Confident	Pierre et al 2020, p. 6; Johnson *et al.* 2016, p. 26; Hibbitts *et al.* 2013, p. 105; USGS 2018, entire.
- MAGNITUDE	Oil and gas development is distributed throughout the entirety of the DSL Range. DSL habitat has undergone extensive destruction and fragmentation in this region due to oil and gas development in the last century. Oil and gas development continues to occur across this region and projections estimate this development will continue and expand.	Highly Confident	
SUMMARY	Oil & gas development is affecting DSL on a large scale. The primary effects come from the loss of habitat and fragmentation of the remaining habitat. These effects are well studied, and we are certain that they are occurring across the range.		

THEME: Habitat Loss & Modification from Sand Mining			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Sand mining, sand processing (which includes groundwater pumping), and sand transport. Frac sand is a naturally occurring sand used as a proppant during hydraulic fracturing of oil and gas wells to maximize production of unconventional reservoirs.	Highly Confident	Mossa and James 2013, pp. 76-79; Benson and Wilson 2015, pp. 1-2, 8, 33, 45, 49-50; Engel *et al.* 2018, pp. 1, , 6, 12, 13; Forstner *et al.* 2018, pp. 1, 5-6, 18-19; Mace 2019, pp. 1-4, 14, 34, 42, 45-56, 58, 63, 78-79
- Activity(ies)	**Sand mines consist of the following components**: a processing plant, supporting infrastructure (roads, water and power pipelines, well fields, etc.), and a mine site. Sand mining consists of the following activities: excavation, sediment processing, groundwater pumping, transport, and reclamation.	Highly Confident	Mossa and James 2013, pp. 76-79; Benson and Wilson 2015, pp. 1-2, 7-8, 33, 45, 49-50; Engel *et al.* 2018, pp. 1, , 6, 12, 13; Forstner 2018, pp. 1-5, 16-17, 19-20; Mace 2019, pp. 1-4, 6, 14, 34, 42, 45-46, 48-56, 63, 78-79

STRESSOR(S)	**Sand Mine Facilities**: Sand mine facilities (i.e., processing plants and supporting infrastructure) are large and can range in size upwards of 100 acres. The construction of industrial facilities, such as processing plants, generally involves the use of heavy equipment to clear vegetation, grade and pave the land surface, and construct buildings, roadways, and infrastructure. Construction of additional supporting infrastructure also involves the drilling of water wells at, or near the facility, and possible boring and trenching related activities associated with installation of flowlines, pipelines, and utilities. Caliche may be placed at the site and on access roads. Sand Mining Operations: Sand mining involves the use of heavy equipment (e.g., sand excavators) and open-pit methods to mechanically remove vegetation and sediment from sand dunes and sand sheets. Sand mine operators excavate sand from the land surface, often in a stair step paddock pattern and can extract sand up to 80 feet below ground. Excavated sand is transported by truck to mine facilities for processing and storage, and ultimately transported to regional oil and gas fields. Non-commercial grade sediments (e.g., gravels, fines, organic material) removed during excavation are often returned to the mined area after sorting and processing. Sand mining operations create high volumes of vehicular traffic (over 350 trucks each day, 365 days per year) on local and regional roadways as trucks deliver sand to processing plants, and then from plants to regional well fields. Groundwater Pumping: Sand mine facilities utilize water for mining and transport, sand processing, dust control, and on-site potable needs. Mining operations self-source water from underlying aquifers at on-site well fields and pump large volumes from groundwater to meet processing and operational needs. Generally, groundwater pumping at a well creates a localized cone of depression (i.e., a zone where the water table is drawn down) around the well. Over time, the cone of depression becomes broader, affecting a wider area. Reclamation: Where surface mining extracts large volumes of sediment from an area, recreating the original form and function of the landscape is not possible. Reclamation generally does not reestablish the original topography and produces a landscape that has very different soil and climate character than before mining. The state of Texas requires few permits for sand mines - primarily an air permit for dust and emissions related to sand drying and a multi-sector general permit for industrial activities. The state does not regulate sand mining activities and has no requirements pertaining to the reclamation of mining sites. Forstner *et al.* (2018) report a general lack of demonstrable reclamation strategies at sand mines operating in the Monahans Sandhills.	Highly Confident	Mossa and James 2013, pp. 75-80, 86, 89, 91; Bio-West 2017, pp. 1-13; Forstner *et al.* 2018, pp. 1-6, 16-20; Mace 2019, pp. 1-6, 12-14, 34, 42-43, 45-64, 78-79, 87, 113; CPA 2019, pp. 24, 35, 37; Breckle *et al.* 2008, pp. 453-454; Benson and Wilson 2015, pp. 1-2, 7-8, 33, 45, 47-50, 53-57; Engel *et al.* 2018, pp. 1, 6, 12, 13; Carrick and Kruger 2007, pp. 769-770, 773; Mossa and James 2013, pp. 75, 77, 80, 89; Forstner *et al.* 2018, pp. +D1. 2-3, 6; Mace 2019, pp. 2, 42-43, 47, 58, 60-61, 78; Lewis 1980, p. 155

- Affected Resource(s)	**Sand Mine Facilities**: Dunes sagebrush lizard habitat is permanently destroyed by sand mining activities. Construction of sand mine facilities in DSL habitat removes shinnery oak; grades and compacts shinnery oak-sand dunes; and replaces these landforms with paved surfaces, buildings, and other structures. Construction also fragments habitat into smaller, more isolated remnants, separated by areas of uninhabitable terrain. There is no evidence shinnery oak-sand dune landforms are self-regenerating in disturbed areas. Facility development and operation can also degrade habitat located proximate to the facility. General construction activities create stressors such as turbulence, noise, lights, and emissions from gas/diesel-driven equipment that can disturb the normal behaviors of DSL and displace lizards from habitat. Direct DSL mortalities are also possible during facility construction and operation. Construction activities and facility operations can crush, injure, and kill lizards and eggs buried below the surface as heavy equipment and vehicles clear, grade, and traverse DSL habitat. The physical setting of a sand mine facility and its infrastructure can also result in behavioral modifications associated with avoidance of the facility by DSL and can hinder movement and dispersal of lizards across the landscape. Sand Mining Operations: Sand mining in DSL habitat removes entire shinnery oak-sand dune landforms, or portions thereof, alters dune topography, and produces deep, unnatural pits in the land surface. Sand mine operators remove large volumes of sand (i.e., millions of tons of sand per mine) from sand dunes and return mostly non-commercial grade sediment (e.g., gravels, clays, silts, etc.) to mined areas after sediment processing, producing a landscape that lacks sand, shinnery oak vegetation, and dune topography – i.e., DSL habitat. Mining also fragments habitat and contiguous landscapes. The removal of a portion (or portions) of a sand dune promotes the loss and degradation of the entire landform (by undermining its stability and by promoting wind erosion and deflation. The removal of a large volume of sand from a dune landform can also create a long-term sediment deficit, causing the dune to transition from a stable state, with a neutral (or positive) sediment budget, to a state of erosion and deflation. The excavation, transport, and processing of sand may also entrain, crush, injure, and kill DSL (including DSL nests and eggs) as mechanized equipment clears, grades, excavates, processes, and traverses DSL habit. Sand mine operations also create high volumes of vehicular traffic on local and regional roadways as trucks deliver sand to processing plants, and then from plants to regional well fields. Traffic density positively correlates with reptile strikes on roads and increased vehicular traffic on roadways that traverse DSL habitat can contribute to direct DSL mortalities from vehicle strikes. The physical setting of a sand mine can also result in behavioral modifications associated with avoidance of the mine and mining activities by DSL.	Highly Confident	Boyd and Bidwell 2002, p. 332; Ryberg *et al.* 2014, pp. 888-890, 895-896; Forstner *et al.* 2018, pp. 1-7, 16-21; Young *et al.* 2018, pp. 1-2, 5-6; Ryberg *et al.* 2014, 896; Hibbitts *et al.* 2013, pp. 104, 106, 108-109; Service 2012, pp. 36882, 36887-36889, 36893, 36894, 36895; Sias and Snell 1998, pp. 1, 2, 14, 19, 22-23; Hibbitts *et al.* 2017, pp. 194-195, 197-198; Walkup *et al.* 2017, pp. 1-4, 8-11; Sias and Snell 1998, pp. 22, 23; Painter 2004, pp. 5; Breckle *et al.* 2008, pp. 442, 453-454; Mossa and James 2013, pp. 75, 77-79, 81, 85-86, 88, 91-92; Engel *et al.* 2018, pp. 1-3, 6, 12-13; Pye 2009, pp. 361-362; Bensen and Wilson 2015, pp. 8, 47-50, 53-56; Mace 2019, pp. 2, 6, 42-43, 47, 58, 60-61, 78; Carrick and Kruger 2007, pp. 767-772; Machenberg 1984, pp. 6, 16, 20-21, 28-31; Dhillion and Mills 2009, pp. 264, 270-271; Pye 2009, pp. 336, 355, 358, 361-362; Kocurek and Havholm 1993, pp. 393, 395, 402-403, Kocurek and Lancaster 1999, pp. 505, 509; Borges *et al.* 2002, pp. 89-90, 92-94; Laity 2003, p. 218; Muhs and Holliday 2001, pp. 75, 84; Bensen and Wilson 2015, pp. 2, 8, 33, 45, 49

Affected Resource(s) Cont.	Groundwater Pumping: Groundwater pumping at sand mine can lower the underlying water table, affecting the water table in areas proximate to the mine. Mace (2019) modeled the impact of groundwater pumping for industrial sand mine facilities in the Monahans Sandhills. Groundwater pumping can lower the water table, reducing its contribution to intradunal soil water. This can destabilize sand dunes, or preclude dune formation altogether, by reducing sand grain cohesiveness, making dunes susceptible to wind erosion and deflation. Water availability is a limiting factor for the establishment and growth of shinnery oak, a critical dune-anchoring phreatophyte of the Mescalero and Monahans Sandhills. Groundwater pumping can also reduce blowout stability and cohesion. Groundwater pumping can also adversely affect phreatophyte communities in arid climates. Groundwater depletion can stresses (e.g., reduce photosynthesis and growth) phreatophytes, which can lead to their deterioration (senescence) and death. Reclamation and Habitat Restoration: Strong and persistent winds, low rainfall, and extreme soil conditions in arid desert environments often prevent self-regeneration of sand dune landforms in mined areas. Ryberg *et al.* (2014) found that shinnery oak-sand dunes are not self-regenerating in disturbed areas. The large scale of excavation in mined areas reduces the probability of natural recovery. Large disturbed areas are less likely to recover because they have a relatively small contact zone with the surrounding vegetation, and wind speeds are greater due to lack of resistance from vegetation. Additionally, shinnery oak grows slowly (e.g., ring growth averages 1 mm/year); regenerates primarily via lateral rhizomatous extension; and is slow to recolonize disturbed areas. External sources of sand from surrounding dune fields are also unlikely to replenish mined areas because the Mescalero and Monahans Sandhills is currently sediment availability limited. Human assisted restoration of shinnery oak vegetation and shinnery oak-sand dunes is also not feasible at present. Sand mining creates a landscape that lacks sand, shinnery oak vegetation, and dune topography. Ryberg *et al.* (2014) indicate that successful restoration of shinnery-oak sand dunes is unlikely, due to the complexities of these landforms and the difficulty of replicating the natural processes responsible their formation. Sand mine operators remove large volumes of sand (i.e., millions of tons of sand per mine) from sand dunes and return mostly non-sandy, commercial grade sediment (e.g., gravels, clays, silts, etc.) to mined areas after sediment processing. The DSL however, is a psammophilic (sand-dwelling); shinnery oak - a critical vegetative component of DSL habitat - requires sandy soils in order to establish and grow; and sand is the essential substrate of shinnery oak-sand dunes. The restoration of shinnery oak in degraded areas is further hindered by a general lack of information on shinnery oak biology and ecology, such as germination and seeding. Lastly, in order to restore habitat in mined areas, the original topography of the landscape that existed prior to mining must be restored. However, reclamation generally does not reestablish the original topography and produces a landscape that has very different soil and climate character than before mining. Forstner *et al.* (2018) indicates that reclamation of mined areas within the Monahans Sandhills is only expected to restore a fraction (approximately 25 percent) of the original grade due to the removal of large volumes of sand during the mining process. Additionally, based on interviews with sand mine companies operating in the region, Forstner *et al.* (2018) also notes that sand mining companies had no long-term plans nor cohesive structure for eventual restoration or recovery of mined sites.	Highly Confident	Mace 2019, pp. 2-3, 42-43, 47,57-58, 60-64; Forstner *et al.* 2018, pp. 1,-6, 17-18, 20-21; Garza and Wesselman 1959, pp. 23-24; White 1971, p. 17; Kocurek and Havholm 1993, pp. 394, 398-400, 301-404, 407; pp. 4; Newton and Allen 2014, pp. 1, 4, 28; Pye 2009, pp. 333-334, 363-364; Robinson 1958, pp. 22; Machenberg, 1984, pp. 6, 19-21, 24,29-31, 33; Stromberg *et al.* 1992, pp. 45-46, 51, 53, 54-56; Stromberg *et al.* 1993, pp. 311-112; Peterson and Boyd 1998, pp. 8, 11; Muhs and Holliday 2001, pp. 75-76, 84; Laity 2003, pp. 196-197, 208-212,216- 218; Gucker 2006, Entire; Cambell *et al.* 2017, pp. 69, 76-77; University of California Riverside 2018, p. Appendix IX; Laity 2003, pp. 196, 209-211; Carrick and Kruger 2006, pp. 767, 769, 771-773, 776-777; Breckle *et al.* 2008, p. 454; Ryberg *et al.* 2014, pp. 888-890, 893, 895-897; Johnson *et al.* 2016, p. 41; Gucker 2006; Carroll *et al.* 2019, pp. 632, 634; Mossa and James 2013, pp. 86, 91; Bensen and Wilson 2015, pp. 8, 47-50, 53-56; Ryberg and Fitzgerald 2015, pp. 1-2; Hardy *et al.* 2018, pp. 18-20; Peterson and Boyd 1998, pp. 1-4, 6-7; Dhillion and Mills 2009, pp. 263-265

- Exposure of Stressor(s)	Sand mining has the potential to destroy and degrade shinnery oak vegetation and shinnery oak-sand dune habitats utilized by all life stages of the DSL wherever sand mine facilities and sand mining operations occur within, or proximate to these landforms. Sand mine facilities and operations also fragment habitat and contiguous landscapes into smaller, more isolated remnants, separated by areas of uninhabitable terrain. Currently, seventeen sand mines occur throughout the Mescalero and Monahans Sandhills of West Texas (i.e., Monahans Analysis Units 1-4). The majority of mines are located in Winkler (11 of 17; 65%) and Ward (2 of 17) Counties (Monahans Analysis Units 1-3); with the remaining mines located in Crane (2 of 17) (i.e., Monahans Analysis Unit 4); and Ector (1 of 17) Counties. One sand mine occurs in the Mescalero Sands (Analysis Unit 7) in Gains County but is reportedly idle. Winkler and Ward Counties contain the largest acreages of DSL Habitat (and High Suitability Habitat) in TX. Laurencio *et al.* (2007) concluded that the stronghold for DSL in Texas seems to be the large band of sand dunes located in Winkler, Ward, and Andrews counties (i.e., Monahans Analysis Units 1-3). The authors indicate that this band of sand dunes may contain most of the remaining populations of DSL in Texas. Fitzgerald *et al.* (2011) also identified the contiguous habitat in this region as high suitability DSL habitat and as a priority for conservation to ensure connectivity among DSL populations in Texas and persistence of DSL populations into the future.	Highly Confident	See report; Forstner *et al.* 2018, pp. 2-5, 18-20; Young *et al.* 2018, pp. 1-2; Mace 2019, pp. 43-44, 56; Hardy *et al.* 2018 , pp. 36; Laurencio *et al.* 2007, p. R002088; Fitzgerald *et al.* 2011, p. 14
- Immediacy of Stressor(s)	**Sand Mine Facilities and Operations:** Sand mine facilities (i.e., processing plants and supporting infrastructure) operating throughout the Monahans Sandhills are large and range in size from approximately 40 to greater than 100 acres. There are no statutory or regulatory restrictions on the amount of sand that can be excavated at mines in West Texas. Tons of sand. The estimated median growth rate (i.e., surface excavation rates) of sand mines operating in the Monahans Sandhills region is currently 69.5 acres/year. The CPA (2019) reported an average growth rate of 86 acres/year for mines operating in the region from 2017- 2018. **Groundwater Pumping:** Sand mining extracts large volumes of water from the aquifers underling the Monahans Sandhills (i.e., Pecos Valley and Dockum Aquifers). Due to the dry climate and lack of surface-water resources of the Pecos River Valley, mines almost exclusively use groundwater from local aquifers for mining and sand processing. In areas where sand mine operations are underway, mining-related consumption may meet, or exceed, the consumption of other sectors combined. Mace (2019) estimates sand mining operations extract an average of 3.6 million tons of sand per year per mine. Given that a typical sand mine consumes 60 to 250 gallons of water per ton of sand processed, Mace (2019) estimates that the 16 sand mines operating in the Pecos River Valley in 2019 consumed anywhere from 3.4 billion to 14.2 billion gallons of water (10,459 to 43,578 acre-feet) per year, collectively.	Highly Confident	See report; Bio-West, 2017; Forstner *et al.* 2018 , p. 1; CPA 2019, p. 81; Mace 2019, pp. 1-2, 42-43, 46-48, 57-64, 78

Changes in Resource(s)	**Sand Mine Facilities and Operations:** Sand mine facilities began operating in the Mescalero and Monahans Sandhills (i.e., Monahans Sandhills Analysis Units 1-4 and Mescalero Sands Analysis Unit 7) in early 2017, and by the end of 2018, 17 facilities had registered with the Texas Commission on Environmental Quality for operations in the region. Based on operator and press reported annual production amounts, these 17 facilities mined a total of 56.8 million tons of sand annually and an average of about 3.6 million tons per mine. The CPA (2019) reported an average surface excavation rate (i.e., growth rate) of 86 acres/year or mines operating in the region from 2017- 2018. Based on annual projections of surface excavation reported by sand mine companies operating in the region in 2017 and 2018, the projected average annual surface excavation rate —the projected acreage of excavation for the coming year in addition to the previous acres excavated—was approximately 160 acres/year. Cumulatively, sand mines disturbed 1,692 acres of DSL Habitat in a little over a year of operations from 2017 to 2018, particularly in high suitability habitat (899 of 1692 acres; 53%). Since 2018, impacts to DSL habitat has surpassed 3,000 acres across the Monahans Sandhills (Analysis Units 1-4). Much of this disturbance has occurred in Winkler and Ward Counties (i.e., Monahans Analysis Units 1-3) due to the large concentration of mines in this region. Sand mines have fragmented the high priority and contiguous habitat areas described above by Laurencio *et al.* (2007) and Fitzgerald *et al.* (2011) in these Counties (i.e., habitat in Monahans Analysis Units 1-3). Modeled growth rates indicate mines will disturb 17,993 acres of DSL habitat in Monahans Units 2-3 by 2035 (i.e., in 15 years) (Service unpublished data; Figure/Table X). This estimate does not include sand mines operating in Andrews, Crane, or Gaines Counties. The Permian Basin consists of up to 10 stacked reservoirs holding an estimated 20 billion barrels of technically recoverable oil. Thus, sand mining is expected to continue for the foreseeable future in the Mescalero and Monahans Sandhills, with the number of mines, and the intensity mining in the region increasing or decreasing with the level of oil and gas production. **Groundwater Pumping:** Mace (2019) modeled the impact of groundwater pumping for industrial sand mine facilities in the Monahans Sandhills, utilizing two aquifer and sand mine facility type cases that were representative of the hydrogeology of the area. For a sand mine facility pumping groundwater form the Pecos Valley Aquifer, there was a modeled water-level decline of 25 feet (8 meters) after one year and 47 feet (14 meters) after ten years. For a sand mine facility pumping from the Dockum Aquifer, there was a water level decline of 272 feet (83 meters) after one year and 360 feet (110 meters) after ten years. Over time, cones of depression generally become broader, affecting a wider area. For the type case sand mine facility pumping within the Pecos Valley Aquifer, the lateral extent of the cone of depression from the well to the point of five-foot water table decline was about 0.10 mile (550 feet) after pumping for one year and 0.75 mile (4,400 feet) after pumping for 10 years. For a sand mine facility pumping within the Dockum Aquifer, the lateral extent of the cone of depression, from the well to the point of five-foot water table decline was 7.5 miles (40,000 feet) after pumping for one year and over 24 miles (130,000 feet) after pumping for 10 years.	Highly Confident	See report; Mace 2019, pp. 1, 42-44, 47, 54-57, 60-64, 78; CPA 2019, p. 81; Fitzgerald *et al.* 2011, p. 14; Bensen and Wilson 2015, pp. 1, 5, 8, 54-57; Latham and Watkins 2020, pp. 12-13; Forstner *et al.* 2018, pp. 5, 19-20; Forstner *et al.* 2018, pp. 5, 19-20

Response to Stressors: - INDIVIDUALS	The DSL is a habitat specialist and relies on shinnery oak-sand dune habitats of the Mescalero and Monahans Sandhills for survival. Dunes sagebrush lizard habitat is destroyed by the construction of sand mine facilities and by sand mining operations. Construction of sand mine facilities (e.g., processing plants and infrastructure) in DSL habitat removes shinnery oak; grades and compacts shinnery oak-sand dunes; and replaces these landforms with paved surfaces, buildings, and other structures. Sand mining in DSL habitat removes entire shinnery oak-sand dune landforms, or portions thereof, alters dune topography, and produces deep, unnatural pits in the land surface. Facility development and mining operations can also degrade habitat located proximate to the facility and mine. Construction of sand mine facilities and mining operations also fragments habitat into smaller, more isolated remnants, separated by areas of uninhabitable terrain, reducing habitat connectivity across the landscape. The removal of shinnery oak vegetation is associated with significant reductions in DSL abundance. The removal of shinnery oak vegetation impairs DSL breeding (female nesting movements, juvenile dispersal, etc.), feeding, sheltering (e.g., thermoregulation, predator avoidance, etc.), dispersal, and survival. The loss of shinnery oak-sand dunes is also associated with significant reductions in DSL abundance. The DSL is a psammophilic (sand-dwelling) species and fine-grained sediments (e.g., clay and silt) are not suitable DSL habitat features. The removal of sand and shinnery oak-sand dunes also destroys DSL habitat and impair DSL breeding (e.g., nesting habitat), feeding, sheltering (e.g., thermoregulation, predator avoidance, etc.), dispersal, and survival. Removal of shinnery-oak sand dunes can also displace DSL from habitat, which can harm lizards through the loss of feeding, breeding, and sheltering opportunities necessary for survival. The physical setting of a sand mine facility and its infrastructure, and the fragmentation of habitat, can also result in behavioral modifications associated with avoidance of the facility by DSL and can hinder movement and dispersal of lizards across the landscape due to the propensity of DSLs to avoid, or less readily disperse across roadways and developed areas, and other unhospitable terrain. Direct DSL mortalities are also possible during facility construction and operation. Construction activities and facility operations can crush, injure, and kill lizards and eggs buried below the surface as heavy equipment and vehicles clear, grade, and traverse DSL habitat. The excavation, transport, and processing of sand may also entrain, crush, injure, and kill DSL (including DSL nests and eggs) as mechanized equipment clears, grades, excavates, processes, and traverses DSL habitat. Sand mine operations also create high volumes of vehicular traffic on local and regional roadways as trucks deliver sand to processing plants, and then from plants to regional well fields. Traffic density positively correlates with reptile strikes on roads and increased vehicular traffic on roadways that traverse DSL habitat can contribute to direct DSL mortalities from vehicle strikes.		Sias and Snell 1998, pp. 22, 23; Painter 2004, pp. 3-5; Forstner *et al.* 2018, pp. 1-8, 15-22; 25 Bensen and Wilson 2015, pp. 2, 8, 33, 45, 47-50, 53-56; Engel *et al.* 2018, pp. 1-3, 6, 12-13; Hibbitts *et al.* 2017, pp. 195, 198; Painter *et al.* 1999, pp. 1, 27; Fitzgerald and Painter 2009, pp. 199-200; Hibbitts *et al.* 2013, pp., 104-106, 108-111; Leavitt and Fitzgerald, 2013, pp. 1, 6, 8, 10-12; Ryberg *et al.*, 2014, pp. 888-890, 895-896; Hardy *et al.* 2018, pp. i, 2,4 10, 21-27; Boyd and Bidwell 2002, p. 332; Service 2012, p. 3688; Breckle *et al.* 2008, pp. 442, 453-454; Mossa and James 2013, pp. 75, 77-79, 85-86, 88, 91-92; Pye 2009, pp. 361-362; Mace 2019, pp. 2, 6, 42-43, 47, 58, 60-61, 78; Carrick and Kruger 2007, pp. 771-772; Machenberg, 1984, pp. 6, 16, 19-21, 24, 29-31; Stromberg *et al.* 1992, pp. 45-46, 51, 53, 54-56; Kocurek and Havholm 1993, pp. 394, 401-402; Stromberg *et al.* 1993, pp. 311-112; Muhs and Holliday 2001, pp. 75-76; Laity 2003, pp. 196-197, 208-209, 212, 216-218; Snell *et al.* 1997, pp. 1-2, 6-11, 10-11; Degenhardt *et al.* 1996, p. 160; Fitzgerald *et al.* 1997, p. 26; Peterson and Boyd 1998, p. 21; Sartorius *et al.* 2002, pp. 1972-1975; Dhillion and Mills 2009, p. 264; Leavitt and Acre 2014, p. 700; Hibbitts and Hibbitts 2015, p. 157; Sias and Snell 1998, pp. 1-2, 8-10, 12, 18-20, 22, 25; Johnson *et al.* 2016, pp. 3, 31, 38, 41, 51; Walkup *et al.*, 2017, pp. 1-4, 7-11; Sias and Snell 1998, pp. 1-2, 8-10, 12, 18-20, 22, 25; Hibbitts

			et al. 2013, pp. 104-105, 110-111; Hibbitts *et al*. 2017, pp. 194-195, 197-198; Walkup *et al*. 2017, pp. 1-4, 8-11; Young *et al*. 2018, pp. 1-2, 5-6
POPULATION & SPECIES RESPONSES			

Effects of Stressors: **- POPULATIONS**	Sand mining is likely to result in localized extirpations of the DSL in mined areas. Dunes sagebrush lizard populations can be reduced or eliminated in areas where shinnery oak habitat is removed/destroyed by sand mine facility construction and sand mining operations. Reductions in shinnery oak habitat reduce the viability of DSL populations. Dunes sagebrush lizard populations decline with increasing intensity of habitat loss and fragmentation. Only minor levels of disturbance to shinnery oak landforms are necessary to initiate population decline. Sand mine facilities and operations also fragment habitat into smaller, more isolated remnants, separated by areas of uninhabitable terrain. Dunes sagebrush lizard dispersal is constrained across large expanses of unsuitable habitat. Fragmentation isolates DSL populations in smaller and lower quality habitat remnants and disrupts diffusion-dispersal dynamics that maintain populations. Diffusion-dispersal of individual DSL between populations is hindered or precluded by fragmentation of the landscape and does not occur at rates sufficient to sustain population size (i.e., growth rates) and demographics necessary to prevent localized extirpations. Small habitat patches constrain population size and increase population extirpation risk due to stochastic environmental events and chance fluctuations in demographics and genetics. Overtime, habitat loss and fragmentation isolates DSL populations and results in a progressive decline in abundance until local populations become extirpated. Reduced diffusion dispersal rates in fragmented areas can also lead to reduced gene flow and loss of genetic diversity in these populations. This in turn can lead to inbreeding depression and genetic drift, which can reduce population viability.	Highly Confident	Forstner *et al.* 2018, pp. 2-5, 18, 20-21; Snell *et al.* 1997, pp. 1-2, 6-8, 10-11; Sias and Snell 1998, pp. 1-2, 8-10, 12, 17-20, 22, 25, Figure 3, Figure 7; Hibbitts *et al.* 2013, pp. 104-105, 110-111; Leavitt and Fitzgerald, 2013, pp. 1, 4, 6, 10-12; Ryberg *et al.*, 2014, pp. 888, 890, 895-896; Johnson *et al.* 2016, pp. 3, 38, 41, 51; Walkup *et al.*, 2017, pp. 1, 3-4, 7-12; Young *et al.* 2018, pp. 1-2, 6; Hokit and Branch 2003, pp. 257, 262-263; Henle *et al.* 2004, pp. 210, 211-212, 216, 221, 228-230, 232-233; Chan *et al.* 2014, p. 39; Chan *et al.* 2009, p. 140
- GEOGRAPHIC SCOPE	All populations within the Mescalero and Monahans Sandhills of West Texas (i.e., all populations within Monahans Analysis Units 1-4; and Mescalero Analysis Unit 7) are likely to be affected by the impacts of sand mining operations and fragmentation of the landscape that results from such practices.	Highly Confident	See report; Service 2012, pp. 36875, 36888-36889, 36891, 36891 ; Borges *et al.* 2002, pp. 89-90, 92-94; Carrick and Kruger 2007, pp. 767-771; Breckle *et al.* 2008, pp. 442, 453-454; Mossa and James 2013, pp. 75, 78, 81, 92; Engel *et al.* 2018, pp. 1-3, 6, 12-13; Forstner *et al.* 2018, pp. 5, 13, 18-21; Mace 2019, pp. 42-44, 47, 55-54; Bensen and Wilson 2015, pp. 1, 5, 8, 54-57; Latham and Watkins 2020, pp. 12-13; Hardy *et al.* 2018 , p. 36; Laurencio *et al.* 2007, p. R002088; Fitzgerald *et al.* 2011, p. 14
- MAGNITUDE	Sand mines are distributed throughout the entirety of the Mescalero and Monahans Sandhills region of West Texas (i.e., throughout Monahans Analysis Units 1-4 and Mescalero Analysis Unit 7. Dunes sagebrush lizard habitat has already undergone extensive destruction and fragmentation in this region due to past and present land uses, including oil and gas development, sand mining, habitat conversion for ranching and agriculture, and off-highway vehicle (OHV) use. Continued sand mining operations are expected to result in significant habitat destruction and fragmentation throughout this region due to the cumulative impact of mining and expanded infrastructure associated with mines.	Highly Confident	

SUMMARY	Sand mining is affecting primary DSL habitat in the Monahans Sands and has potential to become an issue in the Mescalero Sands. Current development is occurring in both Shinnery oak Dunelands and the surrounding Shinnery oak Supportive habitat. The main effects come from habitat loss and fragmentation of existing habitat. This is a fairly new business in the Permian Basin and has potential to quickly disrupt and destroy large areas of DSL habitat. Due to the short length of time sand mining has been occurring in DSL habitat, little research has occurred looking in to effects on habitat surrounding the sand mines, so effects to habitat surrounding sand mines is still unknown.		

THEME: Habitat Loss & Modification from Renewable Energy Sources, Infrastructure, Agriculture, Invasives, ORVs			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Renewable Energy (Solar and Wind), Shinnery Oak Treatment, Grazing, Off-Highway Vehicle Use		
- Activity(ies)	Wind Energy: Construction of roads and windmills using heavy equipment. Maintenance of windmills and resulting traffic on maintenance roads. Solar Energy: Construction of roads and the installation of solar panels. Solar panels will take up large amounts of land, causing changes in microclimate and loss of habitat. Shinnery Oak Treatment: Removes shinnery oak from the landscape, usually using Tebuthiuron. Increased susceptibility to fire and erosion. Grazing: Livestock are grazing vegetation OHV: OHVs can directly crush individuals and prey items; ORVs cause compaction of surface, loss of vegetation, and subsequently more erosion from wind.	Highly Confident	Renewable Energy: Keehn *et al.* 2019, pp. 153-154; Lovich and Ennen 2011, pp. 984-986; Jacobson 2008, p. 161 Shinnery Oak Treatment: Peterson and Boyd 1998, pp. 27-30; Jones and Pettit 1984, Entire; Snell *et al.* 1994, Entire Grazing: Peterson and Boyd 1998, pp. 23-25; Painter *et al.* 1999, p. 32, 35; Dhillion and Mills 2009, Entire OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007, Entire; Cheung 2018, Entire; Ouren *et al.* 2007, pp. 4-41; Luckenbach and Bury 1983, Entire; Brodhead and Godfrey 1977, Entire; Bury *et al.* 1977, Entire; Hill 2008 [Beetles and OHV use] Van Dam and Van Dam 2008, Entire; [Fringed-toed lizard] Painter 2004, p. 8; Chen *et al.* 2006, p. 32

STRESSOR(S)	Renewable Energy: Disruption and removal of Habitat; Soil Compaction. Shinnery Oak Treatment: Removal of shinnery oak. Grazing: Reduction in vegetation; soil compaction and increased nutrient load. OHV: Direct mortality; loss of vegetation/habitat; increased erosion; soil compaction; reduced prey abundance	Highly Confident	Renewable Energy: Sanchez-Zapata *et al.* 2016, p. 104; Keehn *et al.* 2019, pp. 153-154; Lovich and Ennen 2011, pp. 984-986 Shinnery Oak Treatment: Peterson and Boyd 1998, pp. 27-30; Jones and Pettit 1984, Entire; Snell *et al.* 1994, Entire Grazing: Peterson and Boyd 1998, pp. 23-25; Painter *et al.* 1999, p. 32, 35; Dhillion and Mills 2009, Entire OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007, Entire; Cheung 2018, Entire; Ouren *et al.* 2007, pp. 4-41; Luckenbach and Bury 1983, Entire; Brodhead and Godfrey 1977, Entire; Bury *et al.* 1977, Entire; Hill 2008 [Beetles and OHV use] Van Dam and Van Dam 2008, Entire
- Affected Resource(s)	Renewable Energy: Habitat Shinnery Oak Treatment: Shinnery oak Grazing: Shinnery oak OHV: Direct effect on individuals; suitable habitat could be fragmented and destroyed; indirectly decreases insect abundance by removing and disturbing habitat.	Highly Confident	Renewable Energy: Sanchez-Zapata *et al.* 2016, p. 104; Keehn *et al.* 2019, pp. 153-154; Lovich and Ennen 2011, pp. 984-986 Shinnery Oak Treatment: Peterson and Boyd 1998, pp. 27-30; Jones and Pettit 1984, Entire; Snell *et al.* 1994, Entire Grazing: Peterson and Boyd

			1998, pp. 23-25; Painter *et al.* 1999, p. 32, 35; Dhillion and Mills 2009, Entire OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007, Entire; Cheung 2018, Entire; Ouren *et al.* 2007, pp. 4-41; Luckenbach and Bury 1983, Entire; Brodhead and Godfrey 1977, Entire; Bury *et al.* 1977, Entire; Hill 2008 [Beetles and OHV use] Van Dam and Van Dam 2008, Entire
- Exposure of Stressor(s)	Renewable Energy: Affects the Species across all life stages Shinnery Oak Treatment: Affects the species across all life stages. Grazing: Affects the species across all life stages. OHV: Popular in dunelands for recreation and also minor use by ranchers, oil and gas, sand mining to get around.	Highly Confident	
- Immediacy of Stressor(s)	Renewable Energy: DSL habitat occurs in potential wind and solar energy areas. However, as of 2021, the amount of renewable energy development in DSL habitat is limited. One solar project has been developed within DSL habitat along the edges. Multiple wind projects have been built up to the edge of DSL habitat but, as of 2021, only one wind project has been built with 16 wind turbines overlapping DSL habitat. Shinnery Oak Treatment: Tebuthiuron was primarily used in the 1980's and 1990's. 100,000 acres in New Mexico were treated with herbicide between 1983 and 1998 (Peterson and Boyd 1998, p. 2). Grazing: Grazing has occurred historically and currently. OHV: Has decreased, as Kermit dunes were closed due to fracking. Historically only occurred for recreation in small parts of the range. Ranchers, oil and gas, sand mining, etc. may use it to get around.	Highly Confident	Renewable Energy: ERCOT 2020, p. 5, 16; Hoen *et al.* 2018, entire; U.S. Dept of Energy Wind Exchange, entire Shinnery Oak Treatment: Peterson and Boyd 1998, p. 2 Grazing: Peterson and Boyd 1998, pp. 23-25; Painter *et al.* 1999, p. 32, 35; Dhillion and Mills 2009, Entire

Changes in Resource(s)	Renewable Energy: Direct removal of breeding, feeding, sheltering, and dispersal habitat. Decreased quality of habitat (loss of larger, steeper sand dunes) due to degradation of the shinnery oak dune blowouts by fragmentation. Isolation and loss of connectivity between populations. Direct effects in terms of crushing or destruction of individuals/eggs. Shinnery Oak Treatment: Tebuthiuron defoliates shinnery oak, resulting in decreased vigor every year after use until it starts to die off in the second third or later years after treatment. Our analysis indicates roughly 153,150 acres of shinnery oak DSL habitat were lost to herbicide treatment. Grazing: Shinnery oak can be trampled and degraded by cattle. Shinnery oak is often removed to encourage growth of better forage. OHV: Dunes are eroded and fragmented by trails.	Highly Confident	Renewable Energy: Keehn *et al.* 2019, pp. 153-154; Lovich and Ennen 2011, pp. 984-986 Shinnery Oak Treatment: Jones and Pettit 1984, pp. 489-490; Peterson and Boyd 1998, p. 27 Grazing: Peterson and Boyd 1998, p. 24 OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007; Cheung 2018; Ouren *et al.* 2007; Luckenbach and Bury 1983; Brodhead and Godfrey 1977; Bury *et al.* 1977; Hill 2008 [Beetles and OHV use] Van Dam and Van Dam 2008
Response to Stressors: - INDIVIDUALS	Renewable Energy: Removal of habitat will cause local extirpation. Shinnery Oak Treatment: Removal of habitat will cause local extirpation. Grazing: Removal of habitat will cause local extirpation. OHV: Direct mortality and less available habitat and prey base.	Highly Confident	OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007; Cheung 2018; Ouren *et al.* 2007; Luckenbach and Bury 1983; Brodhead and Godfrey 1977; Bury *et al.* 1977; Hill 2008
POPULATION & SPECIES RESPONSES			

Effects of Stressors: - POPULATIONS	Renewable Energy: Lower connectivity, lower abundance because of lower habitat quality or removal of habitat. Shinnery Oak Treatment: Lower connectivity, lower abundances with reductions of 69-94% observed at treated sites (Snell et al 1997, pp. 2 and 7). Grazing: Lower connectivity, lower abundance because of lower habitat quality or removal of habitat. OHV: Reduced abundance.	Highly Confident	Renewable Energy: Keehn *et al.* 2019, pp. 153-154; Lovich and Ennen 2011, pp. 984-986 Shinnery Oak Treatment: Snell et al 1997, pp. 2 and 7 OHV: [General OHV] Lovich and Bainbridge 1999, pp. 315-317; Groom et. al. 2007; Cheung 2018; Ouren *et al.* 2007; Luckenbach and Bury 1983; Brodhead and Godfrey 1977; Bury *et al.* 1977; Hill 2008 [Beetles and OHV use] Van Dam and Van Dam 2008
- GEOGRAPHIC SCOPE	Renewable Energy: Potential to occur across the range of the species. Shinnery Oak Treatment: This primarily impacts the New Mexico portion of the range. Grazing: Grazing occurs across the range of the species. OHV: Affects a small portion of the range. 610 acres of BLM lands on the Mescalaro sand dunes east of Roswell. There used to be OHV use on the Kermit sand dunes until fracking began.	Highly Confident	
- MAGNITUDE	Renewable Energy: Small magnitude currently because it is limited to small areas. Shinnery Oak Treatment: Moderate effect. This has had a large effect in the past but is not as common currently. Livestock Grazing/Agriculture: Small effect, dune habitats are poor agricultural landscapes and inadequate for long-term heavy grazing. OHV: Small magnitude currently, because it is limited to small areas.	Highly Confident	Shinnery Oak Treatment: Dhillion and Mills 2009, entire Grazing: Dhillion and Mills 2009, p. 271

SUMMARY	Renewable Energy has the potential to effect DSL habitat on a large scale; however, because it is currently only on the outskirts of DSL habitat, the effects are not large. It is uncertain whether renewable energy development will be a significant source of habitat loss for DSL in the future. Shinnery Oak Treatment has had large effects in the past in New Mexico where at least 132,717 acres of shinnery oak were treated and disturbed. While small numbers of DSL may still be found on some areas in which the shinnery oak was treated, these treatments have lasting effects on DSL use long into the future. However, these treatments are no longer popular and in the past 5-10 years, very little shinnery oak has been treated within DSL habitat. Livestock grazing can have a detrimental effect to DSL habitat; however, that only occurs from long-term heavy grazing and Shinnery oak dunelands Recreation and OHV likely exacerbate larger stressors on a local scale. OHVs could be a larger issue if more areas are opened up for recreational use. OHVs have been found to be a threat to the fringed-toed lizard, so if OHVs can be a threat to DSL if use becomes more frequent and widespread. Roads likely have a major effect on the dispersal ability of the species and a moderate effect on abundance due to mortality from construction and traffic. The effect of roads will differ based on the type of road it is (asphalt vs. dirt) and the amount of traffic, with asphalt roads inhibiting dispersal more than dirt roads.		

THEME: Pollution & Contamination			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Oil and Gas	Highly Confident	
- Activity(ies)	Oil and gas exploration, development, extraction, treatment, storage, transportation, and refining of petroleum products.	Highly Confident	Hydrogen Sulfide: U.S. EPA 1993, p. ii; Weir *et al.* 2015; Lusk and Kraft 2010; Brenneman *et al.* 2000; Sias and Snell 1998; Salic and Anderson 2011; TAMU 2016
STRESSOR(S)	Hydrogen Sulfide/herbicide treatment (Krovar and Quest): Decreased air quality Oil Spills: decreased habitat quality or loss of habitat; Increased substrate temperature	Moderately Confident	
- Affected Resource(s)	Hydrogen Sulfide/herbicide treatment: Direct effect on individual; prey abundance Oil Spills: Direct effect on individual; Habitat; Burrows and basking sites	Moderately Confident	Hydrogen Sulfide: Lusk and Kraft 2010, pp. 5, 50; Weir et. al. 2015, p. 1280
- Exposure of Stressor(s)	Overlaps with all stages of life history and all types of habitat.	Highly Confident	
- Immediacy of Stressor(s)	Becoming increasingly more frequent with increased oil and gas development.	Highly Confident	
Changes in Resource(s)	Hydrogen Sulfide/herbicide treatment: Direct physiological effects; Decreased prey abundance/biomass from increase in well pads (could simply be from fragmented and less habitat) Oil Spills: Direct physiological effects; habitat can become non-habitat or low-quality habitat; burrows and basking sites become hotter because of darker substrate from the oil	Somewhat Confident	

Response to Stressors: - INDIVIDUALS	Hydrogen Sulfide/herbicide treatment: Lusk and Kraft 2010 calculated active lizards could suffer nasal lesions of the olfactory mucosa and a "startle" effect (constricted blood vessels, increased heart rate and blood pressure) at a LOAEL of 6.1ppm and FEL at 14.5ppm. Weir et. al. 2015 tested 30 and 60ppm on a congeneric and found no effects on behavior. However, the authors noted that their study may have been too short and longer term effects are unknown. The length of the study is important to note because individuals in the wild will be exposed to H2S in the long-term. Individuals could have a slower growth rate and survival rate if there is a decreased abundance of prey items. Oil Spills: Lizards in areas heavily polluted by oil were found to have severe liver damage - prolonged exposure to oil pollution may result in severe liver pathology. Lizards in areas heavily polluted by oil were found to emerge from burrows earlier because they warmed earlier, resulting in an energetic advantage from starting to eat earlier. Basking times were decreased because of hotter substrate.	Somewhat Confident	Hydrogen Sulfide: Lusk and Kraft 2010, pp. 6, 50; Brenneman et. al. 2000; Weir et. al. 2015, pp. 1279, 1281 Oil Spills: AlHashem 2011, p. 1395; AlHashem 2008, p. 591
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS	Decrease in fitness from oil spills and lower prey biomass could increase the mortality rate, decreasing abundance.	Moderately Confident	
- GEOGRAPHIC SCOPE	Entire range of the species.	Highly Confident	
- MAGNITUDE	Hydrogen Sulfide/herbicide treatment: small to moderate Oil Spills: Could have a major effect if it happens	Somewhat Confident	
SUMMARY	There is a lot of uncertainty surrounding the direct and indirect effects of H2S in the long term. The two herbicides tested in Weir et. al. 2015 had no short term effects, but have unknown long term effects. More research is needed to assess the long-term effects of H2S and herbicide treatments stemming from oil and gas operations. Oil spills will have a significant effect on the entire ecosystem of the DSL, however the likelihood of a spill may be low. Even if there is a low likelihood of an oil spill, it should still be considered as a significant stressor because of the large, long-lasting effect it could have.	Moderately Confident	

THEME: Extreme Weather			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Natural weather events (e.g. droughts, extreme heat, extreme cold, winter storms) Weather patterns (e.g. El Nino; La Nina; polar vortex) Climate Change	Highly Confident	
- Activity(ies)	There are two categories of extreme weather events that correspond to seasonal climate patterns. The first are winter events, such as deep cold consisting of sub-freezing temperatures and ice storms. The second are summer events, such as extreme heat and drought.	Highly Confident	
STRESSOR(S)	**Winter**: decreased ambient air and soil temperatures, freezing, destruction of shinnery-oak during ice storms **Summer**: Increased ambient air and soil temperatures, decreased soil moisture, delayed green-up and mortality for shinnery-oak	Highly Confident	Peterson and Boyd 1998, p. 9; Johnson *et al.* 2016, p. 78; Gucker 2006, p. 7; Jacobson 2016, pp. 3-4, 10
- Affected Resource(s)	**Winter**: direct effect, since DSL have reduced activity and possible death if temperatures are below their physiological range. Intense winter storms could destroy shinnery-oak habitat. **Summer**: direct effect, as high temperatures could result in reduced activity, even death. Reduces availability of food resources. Also impacts on shinnery-oak, as heat and drought can alter spring green up, stressing plants, and reduce sand dune stability, causing a net loss of sand.	Winter: Somewhat Confident Summer: Highly Confident	Johnson *et al.* 2016, p. 3; Peterson and Boyd 1998, p. 9; Johnson *et al.* 2016, p. 78; Gucker 2006, p. 7; Jacobson 2016, pp. 3-4, 10; Fitzgerald *et al.* 2011, p. 30

- Exposure of Stressor(s)	**Winter**: only adults and older juveniles are present, but both are inactive during winter months and buried belowground. This limits exposure to the direct effects of cold and winter storms. Late and early season winter events could occur when DSL are still active, but these are difficult to predict. Cold and winter storms could occur range-wide, but the effects of winter storms on shinnery-oak is likely to be localized. **Summer**: High temperatures are most likely during summer months and droughts tend to occur from April-July. These correspond with the breeding, rearing, and foraging periods for DSL. Temperatures can vary daily, but DSL exhibit bimodal diel cycles of activity, avoiding the hottest periods of the day. Drought will reduce moisture in the soil, which is most direct exposure to DSL. Impacts of heat and drought on shinnery-oak affects the foundation of DSL habitat. Droughts can vary from seasonal to multi-year events.	Winter: Somewhat Confident Summer: Highly Confident	Ferguson *et al.* 2014, p. 56; Leavitt 2019a, p. 1; Peterson and Boyd 1998, p. 14; Smolensky and Fitzgerald 2010, p. 374; Jacobson 2016, p. 3
- Immediacy of Stressor(s)	**Extreme cold**: natural interval of unknown frequency in DSL range, influenced by global climate cycles. During La Nina events, which occur several times per decade, winter months are drier and warmer than average. Likely to decrease due to climate change. **Winter storms**: Sporadic, unknown frequency in DSL range, but disruptive extreme winter events have documented multiple times over past 40 years. Unknown future frequency due to climate change. **Natural interval of drought**: within any 10-year period it is common for the region to experience 2 or 3 years with less than 75% of the average annual precipitation; we expect that frequency to increase due to climate change. Drought and associated declines in soil moisture most likely from April-July until the summer monsoons arrive. **Extreme heat**: Summer temperatures regularly exceed DSL thermal maxima but only for discrete portions of the day. Air temperatures across Texas expected to increase by 3º Celsius by 2099 and number of days exceeding 95ºF expected to double by 2050.	Winter: Somewhat Confident Summer: Highly Confident	Peterson and Boyd 1998, p. 14; Jiang and Yang 2012, p. 238; IPCC 2013; Kinniburgh *et al.* 2015, p. 8; Kinniburgh *et al.* 2015, p. 62; Ferguson *et al.* 2014, p. 56; Leavitt 2019a, p. 1
Changes in Resource(s)	Changes vary seasonal and do not necessarily reflect a permanent condition. This is relevant for direct effects of environmental conditions on DSL. Loss of shinnery-oak or dune instability would be a more permanent change. Drought has become more frequent in DSL range.	Highly Confident	Newton and Allen 2014, p. 4; Kinniburgh *et al.* 2015, p. 62

Response to Stressors: - INDIVIDUALS	**Winter**: reduced survival. Only relevant for adults and older juveniles. **Summer**: decreased reproduction; reduced survival; decreased fitness (reduced breeding/reproduction, feeding, sheltering); reduced prey availability affects feeding. Could affect all life stages.	Winter: Less Confident Summer: Moderately Confident	Johnson *et al.* 2016, p. 3; Fitzgerald *et al.* 2011, p. 30; Jacobson 2016, pp. 3-4, 10
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS	**Winter**: Elevated mortality that would reduce starting population size for the following year. Possible change in occupied sites if population is extirpated or habitat patch is lost. **Summer**: lower reproductive rates, reduced population growth rate, decline in population size. Loss of shinnery-oak habitat patches could alter distribution.	Winter: Less Confident Summer: Moderately Confident	Fitzgerald *et al.* 2011, p. 30; Gucker 2006, p. 7; Newton and Allen 2014, p. 4; Jacobson 2016, pp. 3-4, 10
- GEOGRAPHIC SCOPE	Depends on the scale of the weather event. Impacts of extreme storms are likely to be localized, but extreme temperatures and seasonal variation in precipitation can be regional in scale. There is a precipitation gradient along a north-south axis. Shinnery-oak ecosystems on average encounter drought 1-2 years in northern portions and 2-3 years in southern portions every decade. Climate cycles, such as La Nina, can have large geographic footprints.	Moderately Confident	Leavitt 2019a, p. 1; Peterson and Boyd 1998, p. 14
- MAGNITUDE	Extreme weather can have a very large impact.	Highly Confident	
SUMMARY	**Extreme winter events**: Cold and winter storms could affect DSL, but they are primarily inactive and below ground, limiting direct effects. Destruction of shinnery-oak could impact habitat availability, but this sporadic, localized, and difficult to predict. It will not be considered in predicting the future conditions of DSL. **Extreme heat and drought**: DSL are adapted to cope with extreme heat through behavioral and physiological mechanisms. However, declines in prey availability could impact survival and reproduction. The larger impact is on shinnery-oak and DSL habitat. Extensive heat and drought weaken shinnery-oak, decreasing viability of individual plants. Reduced soil moisture makes dunes unstable, resulting in sand loss. Given the potential impacts of heat and drought on the resources DSL needs to survive and the likelihood of these event increasing in frequency and magnitude, they will be considered in predicting future conditions.	Highly Confident	Sartorius *et al.* 2002, p. 1996; Smolensky and Fitzgerald 2010, p. 374; Jacobson 2016, p. 3; Leavitt 2019a, p. 1; Johnson *et al.* 2016, p. 3; Ferguson *et al.* 2014, p. 56; Fitzgerald *et al.* 2011, p. 30

THEME: Groundwater Depletion			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	**Water table lowering:** Groundwater pumping for oil and gas production, sand mining and processing, agricultural-related consumption (irrigation and livestock), and municipal uses. Disturbance of the water table by sand mining.	Highly Confident	Garza and Wesselman 1959, p. 22-23; White 1971, p. 17-18; Machenberg 1984, p. 3; Ashworth 1990, p. v, 3; Boghici 1998, p. i, 1, 23, Table 4; Peterson and Boyd 1998, p. 14; Jones 2004a, Jones 2004b; p. 133; Meyer *et al.* 2012, p. 11-12; Mace 2019, p. 2, 46-48, 57-59
- Activity(ies)	Drilling of water wells and groundwater pumping. Sand mining.	Highly Confident	Boghici 1998, p. 5, 20, 23, Table 4; Jones 2004a, p. 128-129; Figure 9-9; Jones 2004b; p. 133, 139-141; Meyer *et al.* 2012, p. 11-12; Mace 2019, p. 2-3, 15, 46-48, 57-59, 60-63
STRESSOR(S)	**Groundwater pumping**: Pumping at a water well creates a localized cone of depression (i.e., zones where the water table is drawn down) around the well. Over time, the cone of depression become broader, affecting a wider area. Regionally, if the amount of water pumped from multiple water wells exceeds the amount of water that effectively recharges the aquifer, then water-level declines may be seen across the aquifer year after year, as water is removed from storage. The water table of the Pecos Valley Aquifer responds locally, and regionally, to groundwater pumping. Water-level declines in parts of the aquifer are associated with irrigation pumping and water levels fluctuate annually in response to seasonal irrigation cycles. Water level declines in parts of the aquifer are also attributable to groundwater pumping related to public supply and industrial use. **Sand mining**: Improperly constructed groundwater wells for mines, if the surface seal is not properly emplaced, could potentially create a cross-formational flow potential, with downward flow of groundwater perched on caliche down into unsaturated portion of PVA. A similar process can occur if caliche layer were penetrated by excavation by mine operators.	Highly Confident	Weathers *et al.* 1994, pp. 50-56; Jones 2004a; p. 128-129, Figure 9-9; Jones 2004a; p. 128-129; Figure 9-9; Jones 2004b; p. 139-141; Mace 2019, p. 2-3, 57, 64, 60-64

- Affected Resource(s)	Shinnery oak and other vegetation, shinnery oak-sand dunes, blowout formations. Groundwater pumping and sand mining may lower the water table, reducing its contribution to intradunal soil water. This can destabilize sand dunes, or preclude dune formation altogether, by reducing sand grain cohesiveness, making dunes susceptible to wind erosion and deflation. Groundwater pumping can also reduce blowout stability and cohesion. Groundwater depletion can stress phreatophytes, which can lead to their deterioration and death. Loss of dune-anchoring phreatophytes, such as shinnery oak, can lead to the erosion and deflation of dune landforms by winds. Reduced growth rates can hinder plant growth, sand accumulation, and dune formation. Groundwater depletion can also prevent young plants, which have limited rooting depths, from becoming established and can further preclude dune formation.	Moderately Confident	Robinson 1958; Machenberg, 1984, p. 6, 19-21, 24,29-31, 33; Stromberg *et al.* 1992, 45-46, 51, 53, 54-56; Kocurek and Havholm 1993, p. 394, 398-400, 401-404; Stromberg *et al.* 1993, p. 311-112; Peterson and Boyd 1998, p. 8, 11; Muhs and Holliday 2001, p. 75-76; Laity 2003, p. 196-197, 208-212,216- 218; Gucker 2006; Pye 2009, p. 364; Newton and Allen 2014, p. 1, 4, 28; Cambell *et al.* 2017, p. 69, 76-77; University of California Riverside 2018, p., Appendix IX; Laity 2003, p. 196, 209-211

- Exposure of Stressor(s)	**Groundwater pumping**: There is uncertainty regarding the relationship between underground aquifers and the sand dune fields. The depth of the Pecos Valley Alluvium varies spatially and may be substantially deep enough below ground to be disconnected from the land surface. Instead, shinnery-oak dunelands may be maintained by shallower perched aquifers. These shallower aquifers are not targeted by groundwater pumping, but could be impacted by disturbances caused by sand mining. Where the deeper aquifer does connect to the sand dunes field, groundwater pumping has the potential to affect shinnery oak vegetation and shinnery oak-sand dune habitats utilized by all life stages of the DSL for feeding, breeding, and sheltering, wherever the water table is drawn down under these landforms. Water-level declines attributable to industrial use and public supply have occurred in eastern Ward, Reeves, and Pecos Counties. Major cones of depression also exist in irrigation centers in the southwestern part of the aquifer close to the Pecos River, in central Reeves and northern Pecos counties as a result of groundwater extraction. The production of oil and gas and agriculture (livestock and irrigated crop production) dominate the economy of the Pecos River Valley, and are heavily dependent on groundwater (Ashworth 1990, p. v, 3). Within the area of the Pecos River Valley, large concentrations of oil and gas development occur in Andrews and Crane Counties (i.e., Monahans Analysis Units 1 and 4), with smaller, localized concentrations spread throughout Ward and Winkler Counties (Monahans Analysis Units 2 and 3). Sand mines are distributed throughout the entirety of the Monahans Sandhills. Mace (2019) modeled the impact of groundwater pumping for industrial sand facilities and projected water-level declines of 25 feet after one year, and 47 feet after ten years at a sand mine facility extracting water from the Pecos Valley Aquifer, and water level declines of 272 feet after one year, and 360 feet after ten years at facility extracting groundwater from the Dockum Aquifer. **Sand mining**: Penetration of the caliche layer may draw down shallow aquifers, causing disruption of shinnery-oak dunelands required by DSL.	Somewhat Confident	Ashworth 1990, p. v, 3; Garza and Wesselman 1959, p. 1, 13, 70, Plate 1; White 1971, p. 17, 69-70; Machenberg 1984, p. 25-26, 34; Ashworth 1990, p. v, 3; Jones 2004a; p.128-130; Figure 9-9; Jones 2004b; p. 135, 139-141; Figure 9-8; Jones 2008, p. 489; Anaya and Jones 2009, p. 3-4, 41-42, Figure 3-3; Jiang and Yang, 2012; Meyer *et al.* 2012, p. 25-25; Kinniburgh *et al.*, 2015; Mace 2019, p. 1-3, 12,14, 57, 60-64, 78

- Immediacy of Stressor(s)	**Groundwater pumping**: The Pecos Valley Aquifer experiences a great deal of groundwater pumping by existing (farmers, ranchers, oil and gas industry, and local municipalities) and new users (sand mines). Groundwater extraction in the northeastern portions of the aquifer, which underlies Monahans Analysis Units 1-4, is mostly attributable to industrial use and public supply. Mace (2019) estimates total water use ranges from 1,400 to 5,500 acre-feet per year for conventional oil and gas drilling practices and 8,000 acre-feet of water per year for unconventional drilling practices (e.g., fracking). He reports municipalities pump approximately 8,000 acre-feet of water and farmers and ranchers pump approximately 1,800 acre-feet of water in this region. Sand mining extracts large volumes of water in the portion of the aquifer which underlies Monahans Analysis Units 1-4. In areas where sand mine operations are underway, mining-related consumption may meet, or exceed, the consumption of other sectors combined. Mace (2019), estimates sand mining operations extract an average of 3.6 million tons of sand per year per mine. Given that a typical sand mine facility may consume 60 to 250 gallons of water per ton of sand processed, the 16 sand mines operating in the Pecos River Valley in 2019 consumed anywhere from 3.4 billion to 14.2 billion gallons of water (10,459 to 43,578 acre-feet) per year. In irrigated areas, water levels exhibit seasonal fluctuations related to annual irrigation cycles. Water levels decline during summer months when irrigation demand is greatest, and recover during winter when little or no irrigation is taking place. The average annual recharge rate for the Pecos Valley Aquifer has been estimated at approximately 67,800 acre-feet per year and 89,900 acre-feet per year. Current water demands are in excess of estimated annual recharge rates and water levels are predicted to decline over time. Changes in groundwater levels are likely to have a gradual impact on shinnery-oak and sand dune formations, depending on how rapidly the water table is drawn down. Precipitation and recharge can counteract the impacts of groundwater depletion. **Sand mining**: Penetration of the caliche layer can result in the immediate draw-down of shallow perched aquifers, having impacts on dunes and shinnery-oak.	Highly Confident	Ashworth 1990, p. v; Boghici 1998, p. 20-23, 25-27, Table 4; Jones 2004b; p. , 133, 141; Anaya and Jones 2009, p. 67, 75, Table 7-2; Meyer *et al.* 2012, p.11-12; Mace 2019, p. 3, 15, 42-43, 47-48, 57-61, 64, 78
Changes in Resource(s)	Loss of shinnery-oak and associated duneland complexes in localized areas. There has not been rigorous evaluation of the extent to which DSL habitat has been affected by groundwater pumping.	Somewhat confident	Ashworth 1990, p. v, 1, 23; Garza and Wesselman 1959, p. 1, 21, 24-28, 32; White 1971, p. 17, Table 4; Boghici 1998, p. v, 23, 26-27; Jones 2004a; p.120, 128-131, Figure 9-9; Jones 2004b; p. 140-142, Figure 9-8; Anaya and Jones 2009, p. 67, Table 7-2; Meyer *et al.* 2012, p. 12; Mace 2019, p. 3, 12, 15, 60-64

Response to Stressors: - INDIVIDUALS	Water table lowering: The removal of shinnery oak vegetation is associated with reductions in DSL abundance. Death or deterioration of shinnery oak vegetation can impair DSL breeding (e.g., female nesting movements) feeding, sheltering (e.g., thermoregulation, predator avoidance, etc.), dispersal, and survival. The loss of shinnery oak-sand dune habitat is also associated with reductions in DSL abundance. Erosion of sand dunes can destroy DSL habitat and impair DSL breeding (e.g., nesting habitat), feeding, sheltering, dispersal, and survival. Lowering of the water table can diminish groundwater contributions to intradunal and blowout soil moisture, which can impair DSL nesting and breeding behaviors. Female DSL prefer sandy soils with relatively high moisture content for nesting. Dune sagebrush lizards dig burrows into the base of sand dunes or within dune blowouts; construct nest chambers at the soil moisture horizon; and pack eggs with moist sand from the surrounding substrate.	Moderately Confident	Machenberg, 1984, p. 6, 19-21, 24, 29-31; Stromberg *et al.* 1992, 45-46, 51, 53, 54-56; Kocurek and Havholm 1993, p. 394, 401-402; Stromberg *et al.* 1993, p. 311-112; Degenhardt *et al.* 1996 p. 160; Fitzgerald *et al.* 1997, p. 26; Snell *et al.* 1997, p. 1-2, 6-11; Peterson and Boyd 1998, p. 21; Sias and Snell 1998, p. 1-2, 8-10, 12, 18-20, 22, 25; Painter *et al.* 1999, 1, 27; Muhs and Holliday 2001, p. 75-76; Sartorius *et al.* 2002, 1972-1975; Laity 2003, p. 196-197, 208-209, 212, 216-218; Painter 2004, p. 3-4; Dhillion and Mills 2009, p. 264; Fitzgerald and Painter 2009, p. 199-200; Ryberg *et al.* 2012, p. 583-584; Hibbitts *et al.* 2013, p., 104-105, 110-111; Leavitt and Fitzgerald, 2013, p. 1, 6, 8, 10, 11-12; Leavitt and Acre 2014, p. 700; Ryberg *et al.*, 2014, p. 888, 890, 895-896; Hibbitts and Hibbitts 2015, p. 157; Walkup *et al.* 2017, p. 1-4, 7, 9, 11-12; Johnson *et al.* 2016, p.3, 38, 31, 41, 51; Forstner *et al.* 2018, p. 4-5, 15-16, 18; Hardy *et al.* 2018, p. i, 2,4 10, 21-27
POPULATION & SPECIES RESPONSES			

Effects of Stressors: **- POPULATIONS**	Water table lowering: Dunes sagebrush lizard populations can be reduced or eliminated in areas where shinnery oak habitat is lost or degraded due groundwater extraction and subsequent lowering of the water table. Reduction in shinnery oak habitat reduces the viability of DSL populations. Dunes sagebrush lizard populations decline with increasing intensity of habitat loss and fragmentation. Only minor levels of disturbance to shinnery oak landforms are necessary to initiate population decline. Habitat can also be fragmented in areas where shinnery oak vegetation dies or is degraded, or where shinnery-oak sand dunes are eroded due to groundwater pumping and lowering of the water table. Fragmentation isolates DSL populations in smaller and lower quality habitat remnants and disrupts diffusion-dispersal dynamics that maintain populations, which results in a progressive decline in abundance until local populations become extirpated. Reduced diffusion dispersal rates in fragmented areas can also lead to reduced gene flow and loss of genetic diversity in DSL populations. This in turn can lead to inbreeding depression and genetic drift, which can further reduce population viability.	Moderately Confident	Snell *et al.* 1997, p. 1-2, 6-12, 17-20, 22, 25; Sias and Snell 1998, p. 1-2, 8-10, 12, 17-20, 22, 25, Figure 3, Figure 7; Hokit and Branch 2003, p. 262-263; Chan *et al.* 2009, p. 140; Hibbitts *et al.* 2013, p. 104-105, 110-111; Leavitt and Fitzgerald, 2013, p. 1, 4, 6, 10-12; Chan *et al.* 2014, p. 39; Ryberg *et al.*, 2014, p. 895-896; Johnson *et al.* 2016, p. 3, 9, 38, 41, 51; Walkup *et al.*, 2017,p. 1, 3, 7, 9-12; Young *et al.* 2018, p. 1-2, 6
- GEOGRAPHIC SCOPE	Pecos River Valley: All populations within the Pecos River Valley (Monahans Analysis Units 1-4) are vulnerable to water table declines due to high levels of groundwater pumping by existing and new users. These population are also likely to be affected by groundwater pumping and lowering of the water table in the future due to projected increases in pumping rates. The climate of the Pecos River Valley is semiarid and the region is characterized by low precipitation rates, high evaporation rates (often in excess of annual rainfall rates), and recurring drought. The frequency and severity of droughts are expected to exacerbate to increase due to climate change. Current and projected water demands are in excess of the estimated annual recharge rate and water levels are predicted to decline over time. Climate change may further increase water demand due to reduced recharge rates, diminishing groundwater supplies, and increased competition for groundwater. However, it unknown where water table lowering will appear in the landscape. Impacts are most immediate to the location of a well or sand mine, so effects to shinnery-oak are likely to manifest in localized hotspots spread across a potentially large geographic area.	Moderately Confident	Garza and Wesselman 1959, p. 22-23; White 1971, p. 17-18; Machenberg 1984, p. 3; Ashworth 1990, p. v; Boghici 1998, p. i, 1, 20-23, 26-27; Peterson and Boyd 1998, p. 14; Jones 2004a, p.120; Anaya and Jones 2009, p. 67, Table 7-2; Meyer *et al.* 2012, p. 12; Kinniburgh *et al.*, 2015; Mace 2019, p. 3, 15, 59, 64

- MAGNITUDE	Groundwater pumping is likely to have a large effect on populations in the Monahans Sandhills in West Texas (Monahans Analysis Units 1-4) and parts of the Mescalero Sandhills in Southeastern New Mexico. Should water table lowering result in degradation of shinnery-oak vegetation and/or sand dunes, the effects on DSL could be severe. The loss or degradation of habitat due to groundwater pumping, and the subsequent lowering of the water table, can reduce population abundances and increase the risk of extirpation in affected areas. Lowering of the water table, and any subsequent loss or degradation of habitat exacerbates the effects of habitat destruction resulting from oil and gas development, sand mining, and agricultural activities.	Moderately Confident	
SUMMARY	Groundwater pumping and disruption of the water table could have severe consequences for DSL should it negatively affect shinnery-oak vegetation and sand dunes. Impacts are likely to be restricted to the immediate location of a well and/or sand mine, but given the vast area over which these activities occur and magnitude of operations it could result substantial impacts to DSL habitat. However, there is still uncertainty as to whether the aquifers targeted by groundwater pumping are connected to the water table in the sandhills region. Thus, pumping of these aquifers may have little to no impact on the water table that maintains shinnery-oak habitats. There is also limited data showing a relationship between groundwater pumping, loss of shinnery-oak, and DSL resiliency. Furthermore, many of the industries that exploit groundwater (e.g. oil production, sand mining) already have more immediate affects on DSL through habitat loss and fragmentation. Thus, groundwater will not be incorporated in assessment of current conditions and will not be explictly modeled in our projection under future conditions.	Somewhat Confident	

THEME: Mortality & Injury			
[ESA Factor(s): A, C, E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Predation Crushed/Run over Entrainment		
- Activity(ies)	Predation: Direct mortality of individuals from snakes and birds (coachwhips and loggerhead shrikes); potential increase in predation from birds using artificial perches - fences, power lines Roads: Building roads through habitat and subsequent traffic on those roads. Different types of roads can be built, such as asphalt or dirt.	Highly Confident	Predation: [artificial perches] Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080; [predators] Hill and Fitzgerald 2007, p. 5; Rappole 2000, p. 163 Roads: Ballesteros-Barrera *et al.* 2007; Delgado-Garcia *et al.* 2007; Brehme *et al.* 2013; Hibbitts *et al.* 2017; Ingelfinger and Anderson 2004; Jaeger *et al.* 2005; Smolensky and Fitzgerald 2011
STRESSOR(S)	Predation: Predation Roads: Building roads can remove suitable habitat. Roads can increase ambient temperature.	Highly Confident	Predation: Hill and Fitzgerald 2007, p. 5; Rappole 2000, p. 163
- Affected Resource(s)	Predation: Direct mortality of individuals Roads: Suitable habitat, direct effect on individuals	Highly Confident	Predation: Hill and Fitzgerald 2007, p. 5; Rappole 2000, p. 163
- Exposure of Stressor(s)	Predation: All life stages, increased predation anywhere there are human made structures and edges. Roads: Roads disrupt dispersal needs of the species and reduces suitable habitat. Occurs throughout all types of habitat.	Highly Confident	Predation: [artificial perches] Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080; [predators] Hill

			and Fitzgerald 2007, p. 5; Rappole 2000, p. 163
- Immediacy of Stressor(s)	Predation: across time Roads: Increasing number of roads as time progresses.	Highly Confident	
Changes in Resource(s)	Predation: Increased human development has increased artificial perches and edges. Roads: Dispersal is disrupted, especially on asphalt roads and highways. Suitable habitat is lost.	Moderately Confident	Predation: Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080
Response to Stressors: - INDIVIDUALS	Predation: Direct mortality Roads: Direct mortality; less available habitat for sheltering, breeding, and feeding.	Highly Confident	Predation: Hill and Fitzgerald 2007, p. 5; Rappole 2000, p. 163
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS	Predation: Could exacerbate other stressors that lower survivorship and abundance. Could decrease dispersal if artificial perches are near dispersal corridors. Could exacerbate the disruption of the metapopulation structure. Roads: Reduced resiliency of populations due to less dispersal and suitable habitat. More isolated populations. Reduced abundance.	Highly Confident on exacerbation; Somewhat Confident on decreased dispersal.	Predation: Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080
- GEOGRAPHIC SCOPE	Predation: Rangewide, but higher effects in areas of development. Roads: Rangewide	Highly Confident	Predation: Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080
- MAGNITUDE	Predation: Could be increased from historical levels due to increased number of perches. Roads: Large magnitude. Fragments the habitat across the range.	Somewhat Confident	Predation: Dinkins et. al. 2014, p. 320; Lammers and Collopy 2007, p. 2752; Prather and Messmer 2010, p. 796; Slater and Smith 2010, p. 1080

SUMMARY	Predation and OHV likely exacerbate larger stressors on a local scale. OHVs could be a larger issue if more areas are opened up for recreational use. OHVs have been found to be a threat to the fringed-toed lizard, so if OHVs can be a threat to DSL if use becomes more frequent and widespread. Roads likely have a major effect on the dispersal ability of the species and a moderate effect on abundance due to mortality from construction and traffic. The effect of roads will differ based on the type of road it is (asphalt vs. dirt) and the amount of traffic, with asphalt roads inhibiting dispersal more than dirt roads.		

Appendix B: Dunes Sagebrush Lizard SSA Geospatial Methods

The following describes the methods employed in the acquisition, creation, and processing of all geospatial data used in the DSL SSA.

B.1 Current Conditions

Two independently derived habitat models were used to compile a contemporary, range-wide account of DSL habitat. The first was completed by Natural Heritage New Mexico (NHNM; Johnson *et al.* 2016, entire) and characterized DSL habitat in southeastern New Mexico. The second was subsequently completed by Texas State University (TSU; Hardy *et al.* 2018, entire) and described habitat in west Texas. Each model is briefly summarized below. For more detailed information, please see the individual references.

> ***New Mexico*** – Johnson *et al.* (2016, entire) produced a 585,635.7 ha (1,447,137.3 ac) map that included all existing DSL occurrences held in NHNM's NMBiotics database and both the surrounding suitable and non-suitable habitat landcover classes. The NHNM model utilized field data and remote sensing techniques to produce a high resolution, spatially explicit habitat model within New Mexico. The initial intent was to combine the spectral and temporal advantages of Landsat Thematic Mapper (TM) with the spatial resolution of the 4-band National Agricultural Imagery Program (NAIP) 2011 imagery in a pixel-based image classification approach. Unfortunately, a prolonged drought affected the spring leaf-out of the shinnery thus compromising the analytical use of the Landsat TM imagery. It was further concluded that use of the Landsat TM imagery would actually confound the analysis and a simpler but more labor-intensive approach was adopted (see Johnson *et al.* 2016, p. 77).
>
> The final set of mapping products included 15 map units and series of habitat models that are a subset of the regional mapping. A heuristic habitat connectivity model was also completed that identified areas, in general, where connectivity tends to be constrained by development or existing landcover (e.g., caprock). A formal accuracy assessment showed an overall accuracy of 84 percent and an accuracy of 87 percent for the suitable habitat classes (Johnson *et al.* 2016, p. 21).
>
> ***Texas*** – Hardy *et al.* (2018, entire), a team from Texas State University, produced an "Alpha" habitat model intended to broadly parallel the Johnson *et al.* (2016) effort in order to foster a generally consistent, range-wide account of DSL habitat. The result of the Hardy *et al.* (2018) model provided a 116,277.2 ha (287,327.3 ac) account of DSL habitat in Texas but with some notable differences to the New Mexico mapping. The image analysis used in Texas expanded on that used in New Mexico by also employing an object-based, or image segmentation, approach. Image segmentation has the advantage of producing objects (grouped image pixels with similar spectral characteristics) that represent edifying features with clearly defined boundaries at various scales. Objects can then be assigned to various landcover classes (map units). Ultimately, and again purposefully patterned after the New Mexico model, Hardy *et al.* (2018) defined the

> Texas Alpha model through four principal classes meaningful to DSL ecology (see Hardy *et al.* 2018, p. 21). These class names differ from those used in New Mexico only with respect to the name itself; the definitions are largely congruent across both states. In short, the first two classes (High and Intermediate I) are duneland landforms that represent feeding, breeding, and sheltering while the last two (Intermediate II and Low) are shrubland landforms that tend to lack the overall rugosity of dunelands and open sandy areas. Intermediate II and Low represent dispersal areas when adjacent and interspersed with dunelands. We also believe that the shrubland classes serve as a buffer and provide a degree of stability to duneland classes.
>
> The U.S. Fish and Wildlife Service (Service) funded the Texas State team to conduct a formal accuracy assessment for the Alpha model (Jensen and Hardy 2021, entire). The accuracy assessment in Texas was confounded by a lack of land access permission and was therefore carried out through a non-standard approach using a combination of high-resolution drone/satellite imagery and independent photo interpretation. Given these difficulties, and others detailed in Jensen and Hardy (2021, p. 7), the overall accuracy assessment results were not as high as New Mexico but averaged 57.8 percent between the two analysts.

There is no functional overlap between the two models except for a very narrow strip that spans the New Mexico/Texas state line (N Mescalero 2 Analysis Unit). Since this area lies within Texas, and in order to create a seamless, non-overlapping edge match, we used the Hardy *et al.* (2018) mapping to clip out the New Mexico portion of overlapping area. In addition, roads (paved and unpaved), well pads, and other human disturbance features were also updated to the summer/fall of 2020 through photo interpretation of NAIP imagery.

B.1.1 Habitat classes

The Service SSA Team expanded the classes (or map units) that define DSL habitat (see Section 5.1.2 for further discussion). The broader habitat characterization includes the following classes as defined by Johnson *et al.* (2016, Appendix B) and extended to Texas by Hardy *et al.* (2018, p. 21): Shin oak duneland, Shin oak-mesquite duneland, Shin oak shrubland, and Shin oak-mesquite shrubland. While these classes were considered habitat by Hardy *et al.* (2018), the suitable habitat model for New Mexico only included Shin oak duneland, Blowout disturbed, and Shin oak shrubland.

The addition of Shin oak-mesquite duneland and Shin oak-mesquite shrubland resulted in the need for significant clean-up editing of the raster layer in New Mexico as the pixel-based classification approach left a highly mottled and discontinuous product when the additional classes selected by the SSA Team were included. This was necessary to make the New Mexico mapping commensurate with Texas in terms of its degree of class-level generalization and also to make connectivity modeling, if used in future analysis, consistent across the range. In addition, the manual editing, as opposed to an algorithmic method, of the raster in ERDAS Imagine (Hexagon Geospatial) was necessary to maintain the positional consistency of the individual class boundaries throughout the Johnson *et al.* (2016) habitat map. An algorithmic approach will tend to shift boundaries and thus not preserve the original intent and mapping of Johnson *et al.* (2016). No such editing of the Hardy *et al.* (2018) Alpha model was necessary; however, some minor edits were necessary (see below).

B.1.2 Map unit equivalency and disturbed qualifier

The map unit definitions in New Mexico and Texas are largely equivalent; however, Hardy *et al.* (2018) opted to relate the class names to DSL suitability whereas Johnson *et al.* (2016) retained the vegetation cover-type as a class name.

The SSA Team also chose to append a *disturbed* qualifier on the map unit to better describe areas of 1) ≥13 well pads/mi^2; and 2) areas treated with herbicide or mechanical grubbing of vegetation. Johnson *et al.* (2016, p. 34) originally created a layer (Treated/Fragmented) comprised of documented areas of herbicide/mechanical vegetation treatments that was provided by the Bureau of Land Management, additional areas determined through photo interpretation of similar types of disturbance, and areas identified as having ≥13 well pads/mi^2. There was no corresponding layer created by Hardy *et al.* (2018) for Texas.

In order to both update the New Mexico Treated/Fragmented layer and create a similar coverage for Texas, we attempted to obtain all current well drilling data for New Mexico from the NMEMNRD and the TRRC. Well data for New Mexico is dated as of August 2019 and January 2021 for Texas. There are wells included in both datasets that do not necessarily correspond to well pads on the ground; however, we used all wells provided in both of these datasets.

To update the areas defined as *disturbed,* we created a kernel density surface from the well drilling data with a 1 mi^2 cell size and a geodesic method in ArcMap 10.8.1 (Esri 2020) and rounded the result up to the nearest integer. We then performed a raster-to-vector conversion, exported the features of ≥ 13 well pads/mi^2 to use as a recoding mask in ERDAS Imagine 2020 (Hexagon Geospatial). Similarly, we used the Treated/Fragmented layer created for New Mexico as a recode mask to capture the herbicide/mechanically treated areas.

In addition to the areas of ≥13 well pads/mi^2, we noted some areas in Texas that appeared to be *disturbed* in a similar fashion as those in New Mexico where herbicide treatment or mechanical grubbing had occurred. To investigate this further, we contacted the Texas State University team (Thom Hardy and Jennifer Jensen). Along with the areas of ≥13 well pads/mi^2 being defined with the *disturbed* qualifier, we proposed a series of additions to account for the treated areas noted above and a number of adjacent areas we perceived as potential habitat. These edits to the Hardy *et al.* (2018) Alpha habitat model were submitted to the Texas State University team for review and concurrence. Upon their review, agreed upon edits were made to the Texas Alpha model and used in subsequent analysis.

Given this situation and process, we needed to slightly revise the map unit schema so equivalency in class definitions could be achieved over the entire range. We therefore established the following to correlate the classes between New Mexico and Texas (note, no sand mines in New Mexico):

Johnson *et al.* 2016 (New Mexico)
1. Shin oak duneland
2. Shin oak-mesquite duneland
3. Shin oak duneland, disturbed
4. Shin oak-mesquite duneland, disturbed
5. Shin oak shrubland
6. Shin oak-mesquite shrubland
7. Shin oak shrubland, disturbed
8. Shin oak-mesquite shrubland, disturbed
9. Human Disturbance (Roads/Well pads)
10. Highways/RR

Hardy *et al.* 2018 (Texas)
1. High
2. Intermediate I
3. High, disturbed
4. Intermediate I, disturbed
5. Intermediate II
6. Low
7. Intermediate II, disturbed
8. Low, disturbed
9. Human Disturbance (Roads/Well pads)
10. Highways/RR
11. Sand Mines

where,

- *Disturbed* qualifier denotes ≥13 well pads/mi^2 + herbicide/mechanically treated areas; and
- *RR = Railroad*

B.1.3 Mesquite composition

An inconsistency exists between the percentage of the mesquite component in the duneland map units for New Mexico vs. Texas. In New Mexico (Johnson *et al.* 2016, Appendix B), the Shin oak duneland map unit contains <10 percent mesquite whereas in Texas, High (Shin oak duneland equivalency) has a minimal amount of mesquite (Hardy *et al.* 2018, p. 22; pers comm, T. Hardy August 8, 2021). Therefore, these two classes are not equivalent in terms of their mesquite components but remain the highest quality habitat in both models. In addition, the Texas class of Intermediate II (Shin oak-mesquite duneland) contains a <5 percent mesquite component whereas in New Mexico it contains >10 percent mesquite and is thus not equivalent to Texas. To solve this discrepancy, we chose to combine the Shin oak duneland and Shin oak-mesquite duneland map units to create a Shin oak duneland, not to exceed 10 percent mesquite class. This combination then equates the Shin oak duneland classes between New Mexico and

Texas but leaves Shin oak-mesquite duneland (having a >10 percent mesquite component) as a class unique to New Mexico. This has no analog in Hardy *et al.* 2018 except that it is combined with the Shin oak-mesquite shrubland or Low (pers comm T. Hardy, Aug 8, 2021). To resolve this final issue, we combined the following into a “supportive” class where:

- New Mexico = 1) Shin oak-mesquite duneland (having a >10 percent component) + 2) Shin oak shrubland + 3) Shin oak-mesquite shrubland and;
- Texas = 1) Shin oak shrubland (Intermediate II) + Shin oak-mesquite shrubland (Low)

The disturbed qualifier would simply follow the parent. The revised schema would then be as follows:

Revised Map Unit	**Combined Map Units**	
	New Mexico	**Texas**
Shinery-oak duneland	Shin oak duneland	Shin oak duneland (High) Shin oak-mesquite duneland (Intermediate I)
Shinery-oak duneland disturbed	Shin oak duneland disturbed	Shin oak duneland disturbed (High disturbed) Shin oak-mesquite duneland disturbed (Intermediate I disturbed)
Shinnery-oak supportive Habitat	Shin oak-mesquite duneland Shin oak shrubland Shin oak-mesquite shrubland	Shin oak shrubland (Intermediate II) Shin oak-mesquite shrubland (Low)
Shinnery-oak Supportive Habitat Disturbed	Shin oak-mesquite duneland disturbed Shin oak shrubland disturbed Shin oak-mesquite shrubland disturbed	Shin oak shrubland disturbed (Intermediate II disturbed) Shin oak-mesquite shrubland disturbed (Low disturbed)

B.1.4 Oil well pad densities

The SSA Team wanted to account for areas of < 13 well pads/mi^2. While these areas represent a lesser degree of disturbance it nonetheless manifests in reduced habitat quality and DSL abundance. To define these areas, we used the same kernel density approach as discussed previously to produce a series of recoding masks to derive the following bins and therefore the adaptations to the revised map unit schema from the table above:

0-5 well pads/mi^2 = minimally disturbed
6-12 well pads/mi^2 = disturbed
≥13 well pads/mi^2 = degraded

Note: the qualifier of “disturbed” from the previous table above was replaced with “degraded” and also includes herbicide and mechanically treated areas. “Degraded” therefore defines areas with ≥ 13 well pads/mi^2 + treated areas. The “disturbed” qualifier was then used as indicated above to define 0-5 well pads/mi^2 (minimally disturbed) and 6-12 well pads/mi^2 (disturbed).

Map Unit revisions are therefore:

Texas (including the Hardy *et al.* 2018 portion of the Mescalero 7 Analysis Unit)

1a. Shin oak duneland minimally disturbed
2a. Shin oak duneland disturbed

3a. Shin oak duneland degraded

and

1b. Shin oak-mesquite duneland minimally disturbed
2b. Shin oak-mesquite duneland disturbed
3b. Shin oak-mesquite duneland degraded

Concatenation of map units for the above revised schema (to equate mesquite levels in New Mexico and Texas) + well pad density integration for ***duneland*** classes. These revisions were performed on the exported vector layer through the simple addition of an attribute field (RevisedClassName):

1. *Shinnery oak duneland minimally disturbed (1a + 1b)*
2. *Shinnery oak duneland disturbed (2a + 2b)*
3. *Shinnery oak duneland degraded (3a + 3b)*

In addition,

1c. Shin oak shrubland minimally disturbed
2c. Shin oak shrubland disturbed
3c. Shin oak shrubland degraded

and

1d. Shin oak-mesquite shrubland minimally disturbed
2d. Shin oak-mesquite shrubland disturbed
3d. Shin oak-mesquite shrubland degraded

Concatenation of map units for the above revised schema (to equate mesquite levels in New Mexico and Texas) + well pad density integration for ***supportive*** habitat classes. These revisions were also performed on the exported vector layer through the simple addition of an attribute field (RevisedClassName):

1. *Shinnery oak supportive habitat minimally disturbed (1c + 1d)*
2. *Shinnery oak supportive habitat disturbed (2c + 2d)*
3. *Shinnery oak supportive habitat degraded (3c + 3d)*

New Mexico (including the Johnson *et al.* 2016 portion of the Mescalero 7 Analysis Unit)

1. Shin oak duneland minimally disturbed
2. Shin oak duneland disturbed
3. Shin oak duneland degraded

Concatenation of map units for the above revised schema (to equate mesquite levels in New Mexico and Texas) + well pad density integration for ***duneland*** classes. These revisions were performed on the exported vector layer through the simple addition of an attribute field (RevisedClassName):

1. *Shinnery oak duneland minimally disturbed*
2. *Shinnery oak duneland disturbed*
3. *Shinnery oak duneland degraded*

In addition,

1a. Shin oak-mesquite duneland minimally disturbed
2a. Shin oak-mesquite duneland disturbed
3a. Shin oak-mesquite duneland degraded

1b. Shin oak shrubland minimally disturbed
2b. Shin oak shrubland disturbed
3b. Shin oak shrubland degraded

1c. Shin oak-mesquite shrubland minimally disturbed
2c. Shin oak-mesquite shrubland disturbed
3c. Shin oak-mesquite shrubland degraded

Concatenation of map units for the above revised schema (to equate mesquite levels in New Mexico and Texas) + well pad density integration for ***supportive*** habitat classes. These revisions were also performed on the exported vector layer through the simple addition of an attribute field (RevisedClassName):

1. *Shinnery oak supportive habitat minimally disturbed (1a + 1b + 1c)*
2. *Shinnery oak supportive habitat disturbed (2a + 2b + 3c)*
3. *Shinnery oak supportive habitat degraded (3a + 3b + 3c)*

The final range-wide classes are therefore defined as follows:

Shinnery oak duneland minimally disturbed – Duneland habitat dominated by shinnery oak, does not exceed a 10% mesquite component; 0-5 well pads/mi^2.

Shinnery oak duneland disturbed – Duneland habitat dominated by shinnery oak, does not exceed a 10% mesquite component; 6-12 well pads/mi^2.

Shinnery oak duneland degraded – Duneland habitat dominated by shinnery oak, does not exceed a 10% mesquite component; ≥13 well pads/mi^2, includes areas of herbicide/mechanical treatment.

Shinnery oak supportive habitat minimally disturbed – Duneland habitat >10% mesquite, shinnery oak shrubland, shinnery oak-mesquite shrubland; 0-5 well pads/mi^2.

Shinnery oak supportive habitat disturbed – Duneland habitat >10% mesquite, shinnery oak shrubland, shinnery oak-mesquite shrubland; 6-12 well pads/mi^2.

Shinnery oak supportive habitat degraded – Duneland habitat >10% mesquite, shinnery oak shrubland, shinnery oak-mesquite shrubland; ≥13 well pads/mi^2, includes areas of herbicide/mechanical treatment.

Human disturbance – well pads, roads, production water ponds, solar farms, etc.

Highway/RR – paved roads and railroad.

Sand mine – sand mine excavation, processing/loading/parking/office facilities.

After all revisions were completed and reviewed, results were the summarized (including for each analysis unit) for the SSA Team to evaluate.

B.2 Future Conditions

B.2.1 Oil and gas development

The SSA Team utilized the comprehensive analysis by Pierre *et al.* (2020, entire) to evaluate the impact of future oil and gas development of the Permian Basin in New Mexico and Texas to 2050. Three scenarios were modeled ranging from ***Low*** which describes conditions such as lower number of wells drilled, transition to renewable energy, or more wells drilled per well pad to ***Medium*** where current trends continue to ***High*** that forecasts development under assumptions that a higher number of wells are drilled or lower number of wells drilled per pad. See Pierre *et al.* (2020, entire) for further details.

The revised class schema described above, which captures current well pad density, will be used as a starting point to apply the three future scenarios of Pierre *et al.* (2020). We derived a point layer from Pierre *et al.* (2020, Supplemental Data) which forecasts the number of additional well pads for each scenario to 2050. As before, we created a kernel density surface with a 1 mi^2 cell size with a geodesic method in ArcMap 10.8.1 (Esri 2020) and rounded the result up to the nearest integer. We then performed a raster-to-vector conversion and exported the intervals of 0-5, 6-12, and ≥13 well pads/mi^2 to use as a recoding mask in ERDAS Imagine 2020 (Hexagon Geospatial). The recode operation reflected the various transitions from minimally disturbed to disturbed to degraded with respect to the forecasted well density bins of each future scenario of Pierre *et al.* (2020). After recoding the raster, we exported the results to vector files where we recalculated the area values and summarized the results (including for each analysis unit) for the SSA Team to evaluate.

B.2.2 Sand mines

We also needed to evaluate the impacts sand mining would have on DSL habitat into the future. A total of 18 existing sand mines (all located in Texas) were used to determine the mean rate of growth over a known period of time which was then applied to model future growth out to 2050.

It is estimated that current frac sand capacity is about 40 percent of total demand. It is thus expected to grow by 50 percent by 2023 and that more than 30 potential facilities could currently be identified (Mace 2019, p. 42). Given these estimates, our depiction of 18 mines modeled into the future, with no additional mines included, is a conservative approach even if few or no future sand mines impact DSL habitat.

The determination of a growth rate was evaluated through photo interpretation over the course of time from 2018-2021/22. Source imagery was as follows:

- 2018 and 2020 National Agricultural Imagery Program (NAIP)
- 2021 and 2022. MAXAR Technologies (©2022 MAXAR\Nextview License)

Of the 18 sand mines included, 9 had January 2022 imagery available; 8 had March 2021 imagery, and 1 had only NAIP September 2020 imagery available.

The footprint of each mine was digitized from the available imagery and the incremental growth was calculated for each time step (i.e., 2018-2020; 2020-2021/22 and the entire period of record from 2018-2021/22). There were 4 mines with 0-growth from Sep/Oct 2020-Mar 2021. For these 0-growth mines and the single mine with only NAIP 2018 and 2020 imagery available, we used the values obtained from the previous incremental time step (2018-2020) for our evaluation.

We then normalized the incremental observed growth rates for each mine to an annual (365 days) value and derived the 25th, 50th, and 75th percentiles to partially account for the effects of outliers. The time step chosen by the SSA Team for the final growth rate was the entire 2018-2021/22 period, which included the zero-growth mines to 2020 only. The percentile approach allowed us to apply different growth rates that represent a range of market conditions in the future. In addition, the percentile approach allowed us to combine the sand mine growth model with the Low, Medium, and High scenarios of Pierre *et al.* (2020) in Texas and derive a set of future condition habitat models that incorporated both oil and gas and sand mine growth to the year 2050; again, there are no sand mines located in New Mexico and none were added to any of the future condition analyses.

The sand mine growth rate scenarios and percentiles are as follows (rounded to the nearest acre):
- Low scenario (25th percentile) = 39 acres/yr.
- Medium scenario (50th percentile/median) = 54 acres/yr.
- High scenario (75th percentile) = 74 acres/yr.

To model the growth of each sand mine to the year 2050, we applied the above annualized growth rates to the total area observed in the most recent imagery (2021/22 or 2020). We did not limit the growth to a maximum value. Several sand mines (OBJECTID 12, 16, and 17) are multipart facilities with spatially distinct portions. For 12 and 16, growth was split equally (50/50) between two portions of the mine. For 17, growth was split 75/25 as the two components as this is generally representative of the past growth patterns.

Tabular results are shown below:

Low Scenario

OBJECTID	Current Condition (acres)	Current Condition (hectares)	Low Growth Rate as of 12/31/2050 (acres)	Low Growth Rate as of 12/31/2050 (hectares)	Percent Change Current Conditions to 2050
1	208.5	84.4	1,339.5	542.1	542.4
2	654.6	264.9	1,785.6	722.6	172.8
3	368.1	149.0	1,499.1	606.7	307.3
4	314.8	127.4	1,445.8	585.1	359.2
5	187.5	75.9	1,318.5	533.6	603.2
6	295.0	119.4	1,426.0	577.1	383.4
7	293.2	118.7	1,424.2	576.4	385.7
8	579.3	234.4	1,710.3	692.1	195.2
9	436.7	176.7	1,567.7	634.4	259.0
10	345.4	139.8	1,476.4	597.5	327.4
11	308.9	125.0	1,439.9	582.7	366.1
12	318.7	129.0	1,449.7	586.7	354.8
13	285.2	115.4	1,416.2	573.1	396.5
14	616.8	249.6	1,747.8	707.3	183.4
15	83.8	33.9	1,214.8	491.6	1,349.7
16	510.8	206.7	1,641.8	664.4	221.4
17	479.3	194.0	1,610.3	651.7	235.9
18	870.3	352.2	2,001.3	809.9	130.0
Total	7,157.1	2,896.4	27,515.1	11,135.0	284.4

Medium Scenario

OBJECTID	Current Condition (acres)	Current Condition (hectares)	Medium Growth Rate as of 12/31/2050 (acres)	Medium Growth Rate as of 12/31/2050 (hectares)	Percent Change Current Conditions to 2050
1	208.5	84.4	1,774.5	718.1	751.0
2	654.6	264.9	2,220.6	898.6	239.2
3	368.1	149.0	1,934.1	782.7	425.4
4	314.8	127.4	1,880.8	761.1	497.4
5	187.5	75.9	1,753.5	709.6	835.1
6	295.0	119.4	1,861.0	753.1	530.9
7	293.2	118.7	1,859.2	752.4	534.1
8	579.3	234.4	2,145.3	868.2	270.3
9	436.7	176.7	2,002.7	810.5	358.6
10	345.4	139.8	1,911.4	773.5	453.4
11	308.9	125.0	1,874.9	758.8	506.9
12	318.7	129.0	1,884.7	762.7	491.3
13	285.2	115.4	1,851.2	749.2	549.0
14	616.8	249.6	2,182.8	883.3	253.9
15	83.8	33.9	1,649.8	667.6	1,868.8
16	510.8	206.7	2,076.8	840.5	306.6
17	479.3	194.0	2,045.3	827.7	326.7
18	870.3	352.2	2,436.3	985.9	179.9
Total	7,157.1	2,896.4	35,345.1	14,303.7	393.8

High Scenario

OBJECTID	Current Condition (acres)	Current Condition (hectares)	High Growth Rate as of 12/31/2050 (acres)	High Growth Rate as of 12/31/2050 (hectares)	Percent Change Current Conditions to 2050
1	208.5	84.4	2,354.5	952.8	1,029.1
2	654.6	264.9	2,800.6	1,133.3	327.9
3	368.1	149.0	2,514.1	1,017.4	583.0
4	314.8	127.4	2,460.8	995.9	681.6
5	187.5	75.9	2,333.5	944.3	1,144.4
6	295.0	119.4	2,441.0	987.8	727.6
7	293.2	118.7	2,439.2	987.1	731.9
8	579.3	234.4	2,725.3	1,102.9	370.4
9	436.7	176.7	2,582.7	1,045.2	491.4
10	345.4	139.8	2,491.4	1,008.2	621.3
11	308.9	125.0	2,454.9	993.5	694.6
12	318.7	129.0	2,464.7	997.4	673.3
13	285.2	115.4	2,431.2	983.9	752.4
14	616.8	249.6	2,762.8	1,118.1	347.9
15	83.8	33.9	2,229.8	902.4	2,561.0
16	510.8	206.7	2,656.8	1,075.2	420.1
17	479.3	194.0	2,625.3	1,062.4	447.7
18	870.3	352.2	3,016.3	1,220.7	246.6
Total	7,157.1	2,896.4	45,785.1	18,528.6	539.7

All geoprocessing was carried out in ArcMap 10.8.1 (Esri 2020).

In order to build a spatially explicit representation of the Low, Medium, and High sand mine growth models we first established boundaries (*Barrier Features* – see also input parameters below) where we assumed any given sand mine could not intrude upon or ultimately occupy.

These include the following:

1. Existing oil well fields – These areas were identified from the current condition mapping and photo interpretation where substantial networks of well pads and their associated infrastructure occur.
2. Certain growth pattern limits – These are zones where adjacent sand mines could potentially occupy the same area in the future. We therefore divided these zones, by imposing a barrier, such that each mine has the opportunity to fill the zone equally. This was most consequential in the Kermit Sands area where several sand mines are in close proximity to each other and have shown substantial growth since 2018.
3. Other features – These include areas where inadequate sand resources appear to be located (e.g., hardpan and drainages) other areas of development (e.g., municipal areas, Monahans Sands State Park, solar farm) and major highways.

In the case of minor paved roadways (e.g., 2-lane opposing) sand mines were allowed to grow over these features but were then clipped out of the final model. This assumes that a given mine could span both sides of the roadway but could not include the road's right-of-way.

To then create the geospatial data/representation of the sand mine growth models, we used the ***Increase Polygon Area*** in the Production Mapping Toolbox.

Inputs parameters to the algorithm are:

Input Polygon Features = Sand mines as of the most recent imagery (2021/22 or 2020).

Minimum Size = This is the target area in which to grow a given sand mine. The values used are shown in the results tables above for each individual sand mine (OBJECTID). The end result of the algorithm is within 5 acres (2.02 ha) of the minimum size value. We also created incremental output for 2030 and 2040.

Buffer increase = Is the value by which the area is increased for the input feature. A buffer to the previous iteration is applied until the feature reaches the *Minimum Size* described above. The smaller the value is the closer the end result is to the *Minimum Size* (target area). We used a value of two (2) meters.

Intersect Features = Optional parameter; the features that intersect the input polygons. Input polygons that intersect are enlarged. We did not invoke this parameter.

Barrier Features = See the three (3) boundary layers described above.

We then incorporated the 2050 Low, Medium, and High sand mine growth models into the corresponding oil and gas future conditions model built from Pierre *et al.* (2020) study in Texas only; again, no sand mines are located in New Mexico and none were added to the future scenarios. The process is as follows:

1. Clipped the 2050 future condition sand mine polygon feature classes with the 2050 oil and gas feature class derived previously from Pierre *et al.* (2020). This removed areas from the sand mine growth models that are not located within a mapped habitat class in Texas (Hardy *et al.* 2018).
2. Performed an Erase (ArcToolbox>Analysis Tools>Overlay>Erase) of the highways and railroads from the clipped version of the sand mine models from above.
3. Used the clipped version of the 2050 sand mine polygon feature class to perform an Erase in of each polygon feature class created from the Low, Medium, and High oil and gas future conditions (Pierre *et al.* 2020).
4. Merged the clipped 2050 sand mine feature class into the feature class created in #2 above. Completed attribution of the newly created features as a “Sand mine” class name (Map Unit).
5. Recalculated area geometry and created summaries for the SSA Team to evaluate.

Appendix C: Estimates of Sand Mine Growth Rates

Table C-1 Collection of estimated past annual sand mine growth rates in Texas. Listed are the estimated growth rates, the statistic estimated, source of the information, and the methods used to generate them.

Hectares per year	Statistic	Reference	Methods
40	NA	TX CPA (2017, p. 2)	NA
17	Minimum	Atlas Sand (2018, unpaginated)	NA
26	Maximum		
59	Average	CBD and DOW (2018, p. 18)	Automated change detection algorithm and manual verification with satellite imagery
178	Maximum		
16-24	NA	Forstner *et al.* (2018, p. 2)	Interviews with several company operations personnel and engineers and a synthesis from related published literature
56	Average	Mace (2019, p. 43)	Analysis of registered frac sand facilities as of Jan. 21, 2019
24	25th Percentile		
45	Median		
94	75th Percentile		
20-35	Average	TX CPA (2019, p. 79, 81)	Derived from change detection analysis of satellite imagery.
24	NA	Canyon Environmental (2020, pp. 59, 89)	Derived from change detection analysis of satellite imagery.

15-25	Average	ACFb (2021, p. 12)	RapidEye imagery to monitor surface changes from sand mining activity from May 2016 to June 2019, with four separate annual images captured during the growing season (May-June). Additional SPOT imagery was acquired for March 2020.
28	Average	ACFb (2021, pp. 10-11)	Derived from analysis of satellite imagery.
22	25th Percentile		
28	Median		
37	75th Percentile		

Appendix D: Maps of DSL Habitat Under Future Scenarios

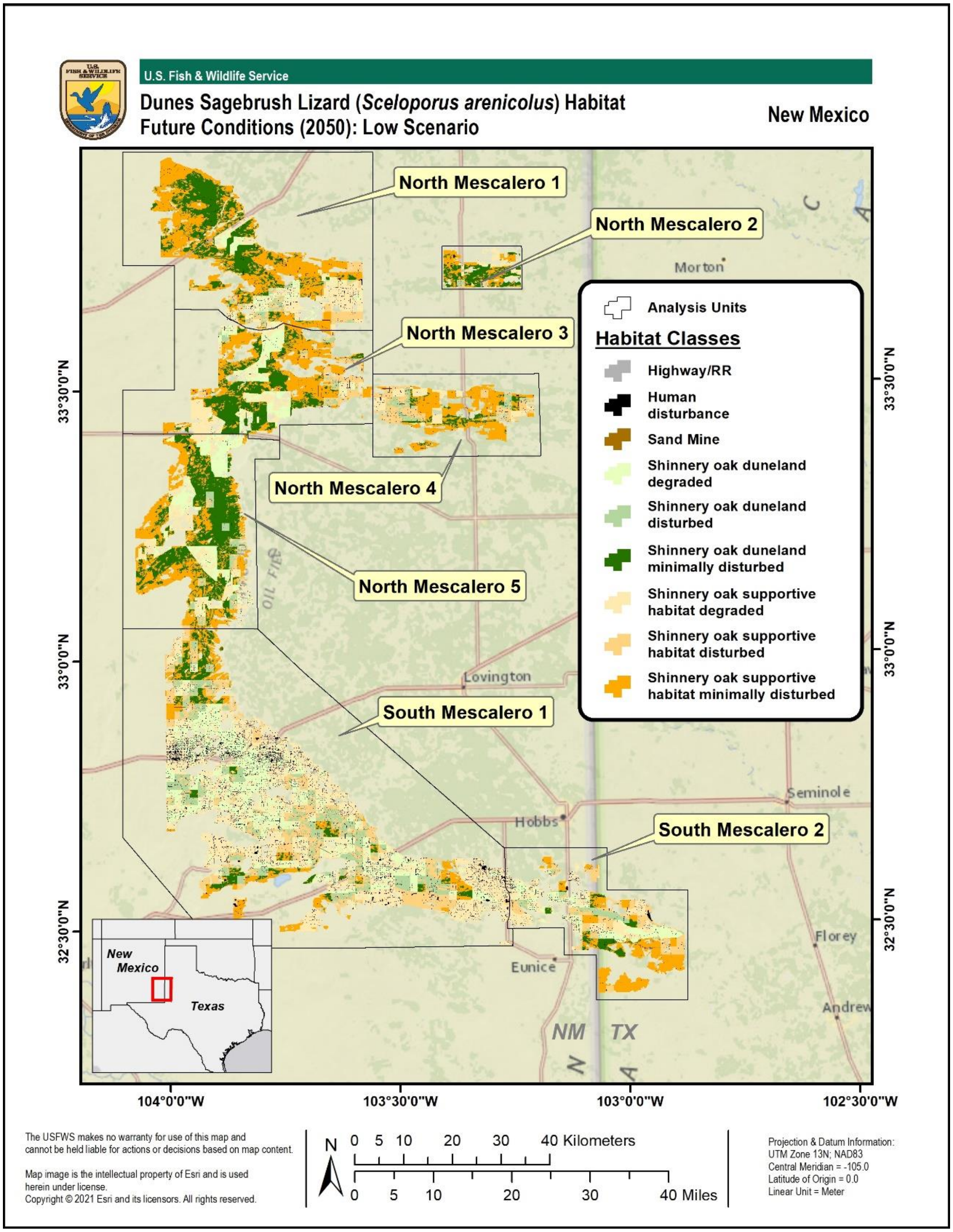

Figure D-1 Future projection of DSL habitat in 2050 under the Low scenario. The outlines are for the 7 Analysis Units in the Northern and Southern Mescalero Representation Units.

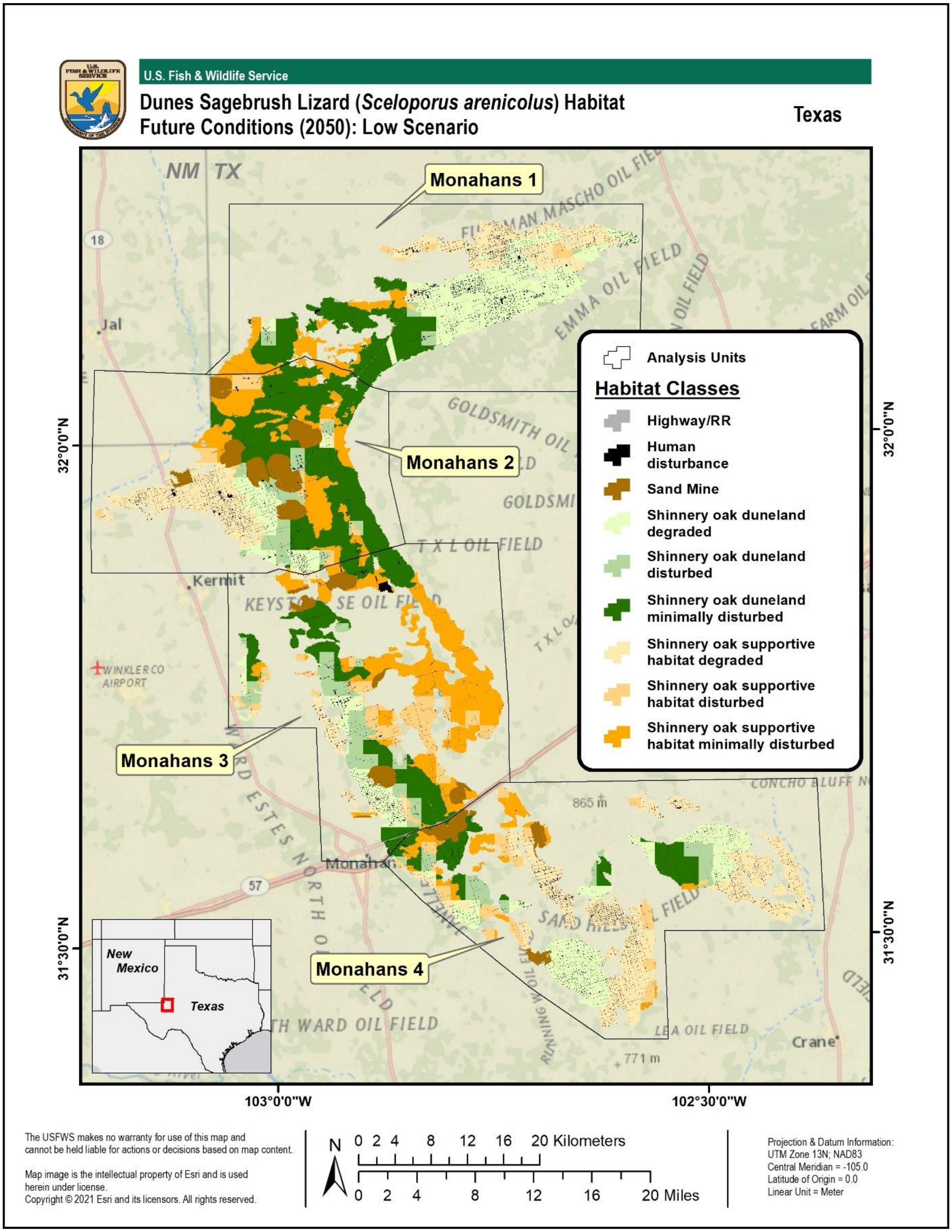

Figure D-2 Future projection of DSL habitat in 2050 under the Low scenario. The outlines are for the 4 Analysis Units in the Monahans Representation Units.

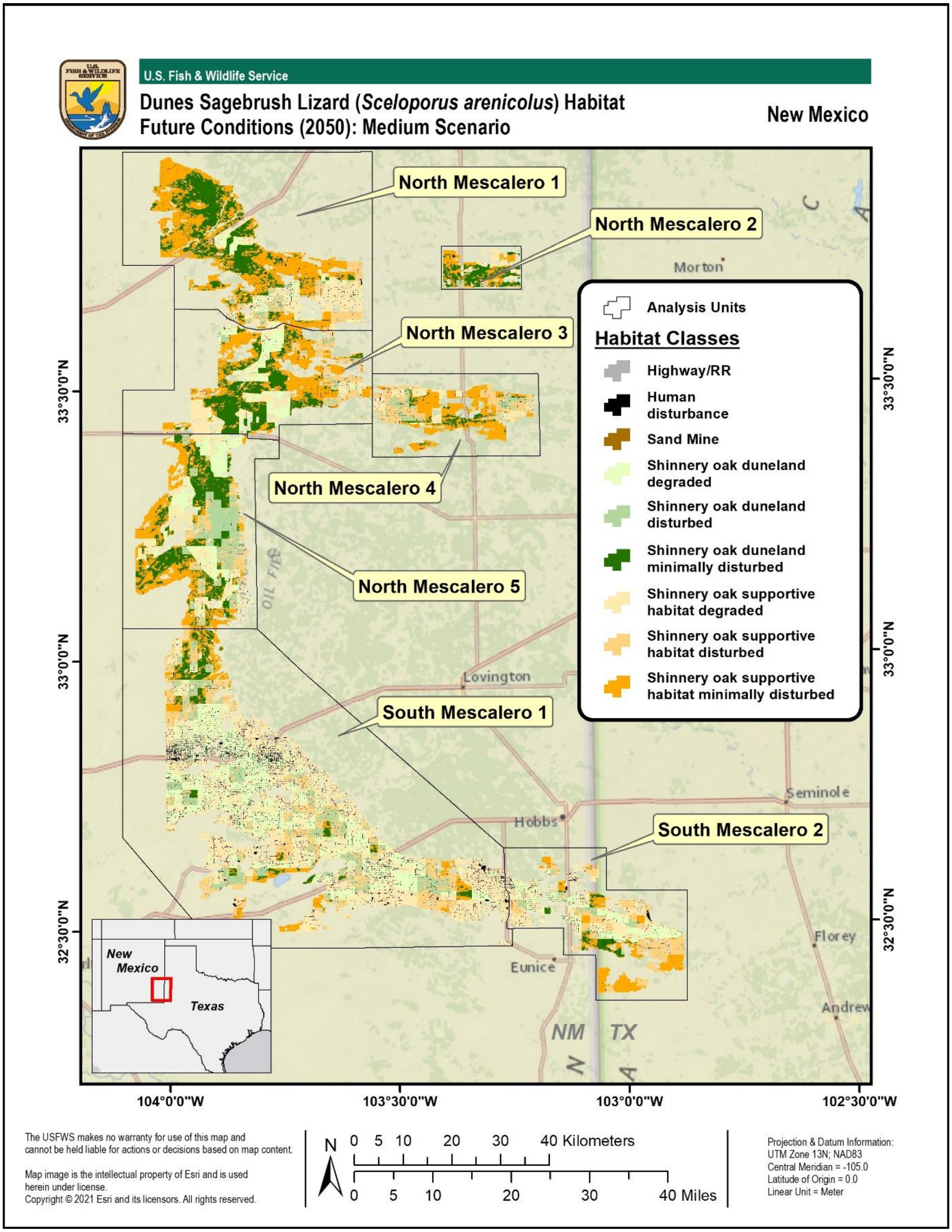

Figure D-3 Future projection of DSL habitat in 2050 under the Medium scenario. The outlines are for the 7 Analysis Units in the Northern and Southern Mescalero Representation Units.

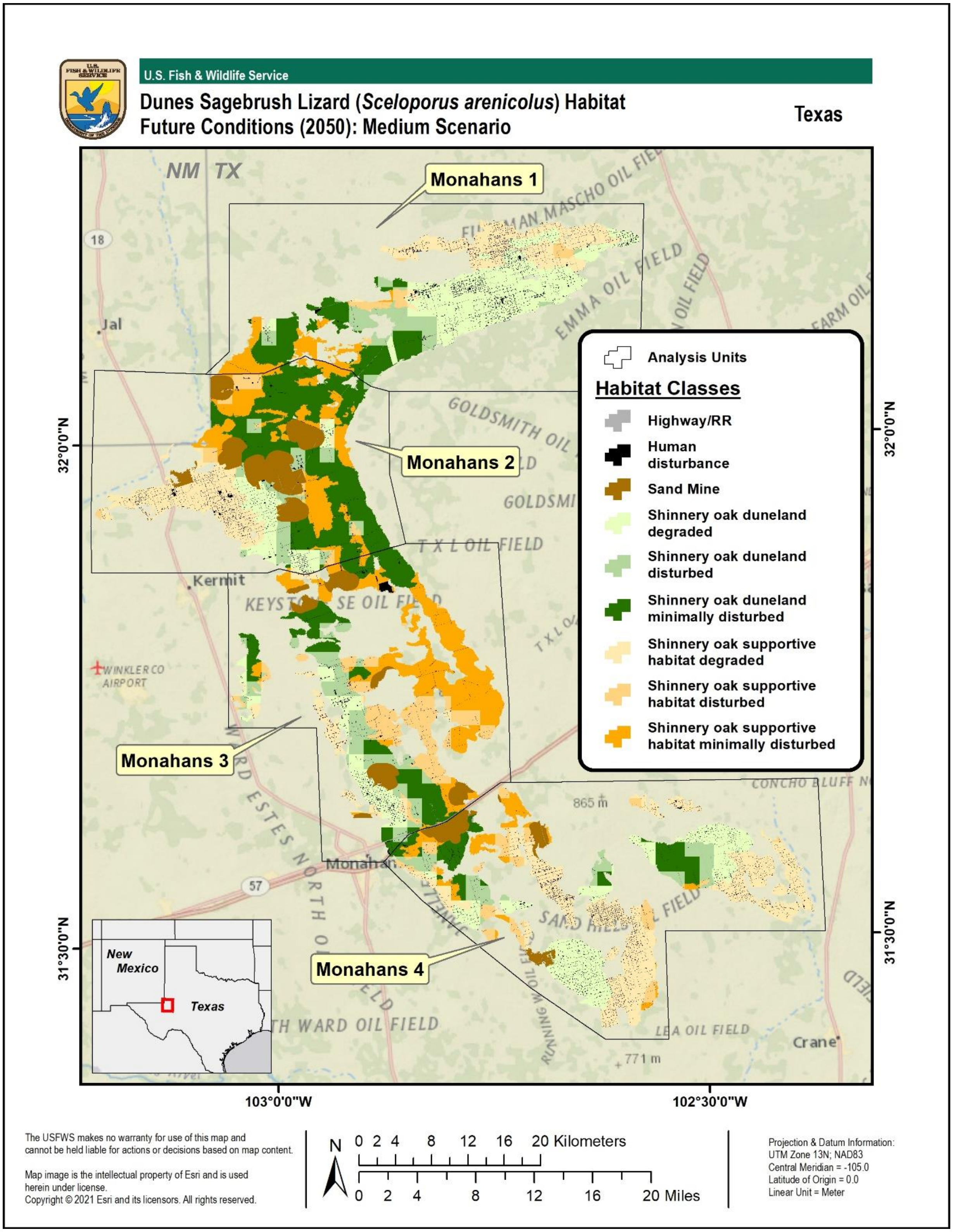

Figure D-4 Future projection of DSL habitat in 2050 under the Medium scenario. The outlines are for the 4 Analysis Units in the Monahans Representation Units.

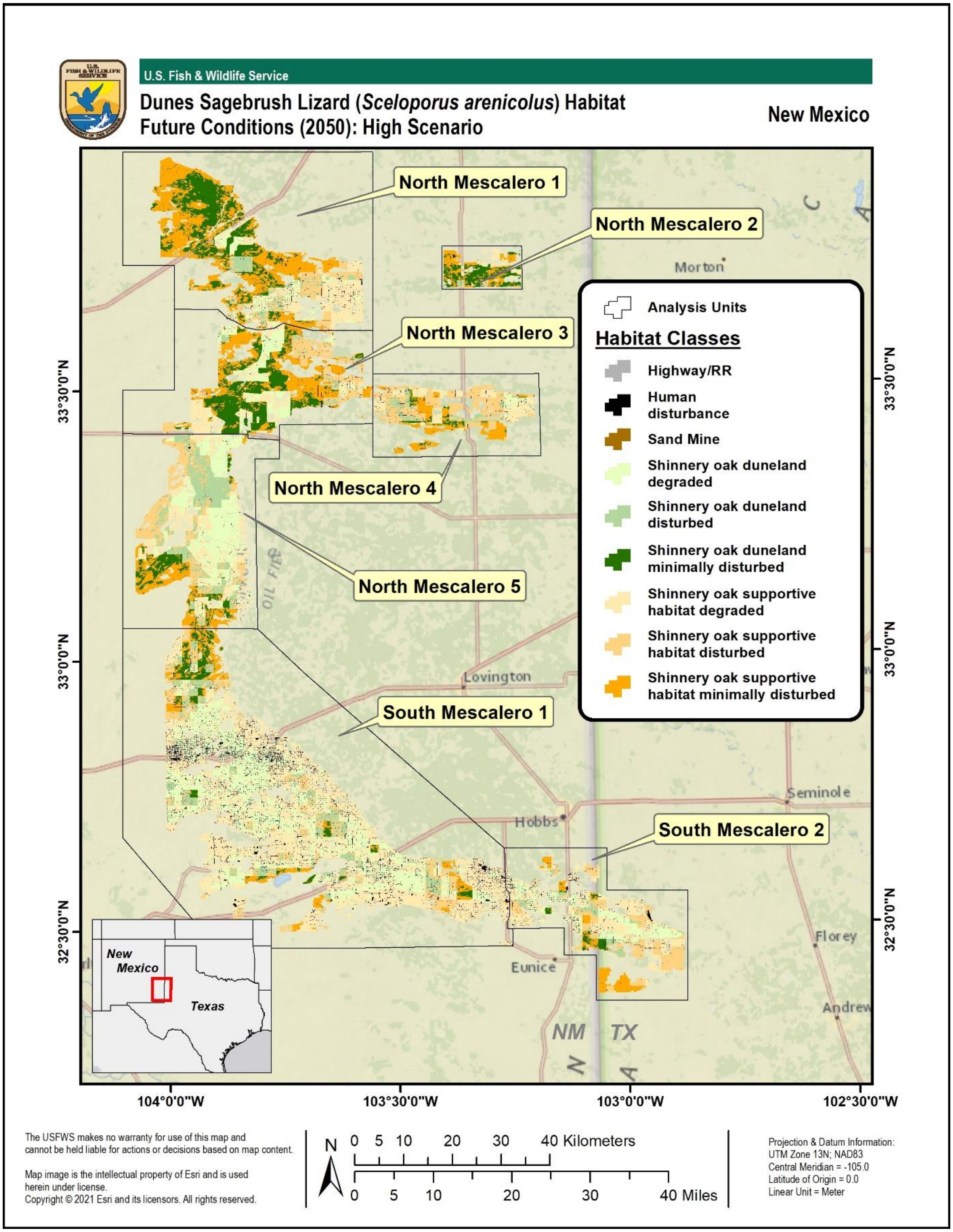

Figure D-5 Future projection of DSL habitat in 2050 under the High scenario. The outlines are for the 7 Analysis Units in the Northern and Southern Mescalero Representation Units.

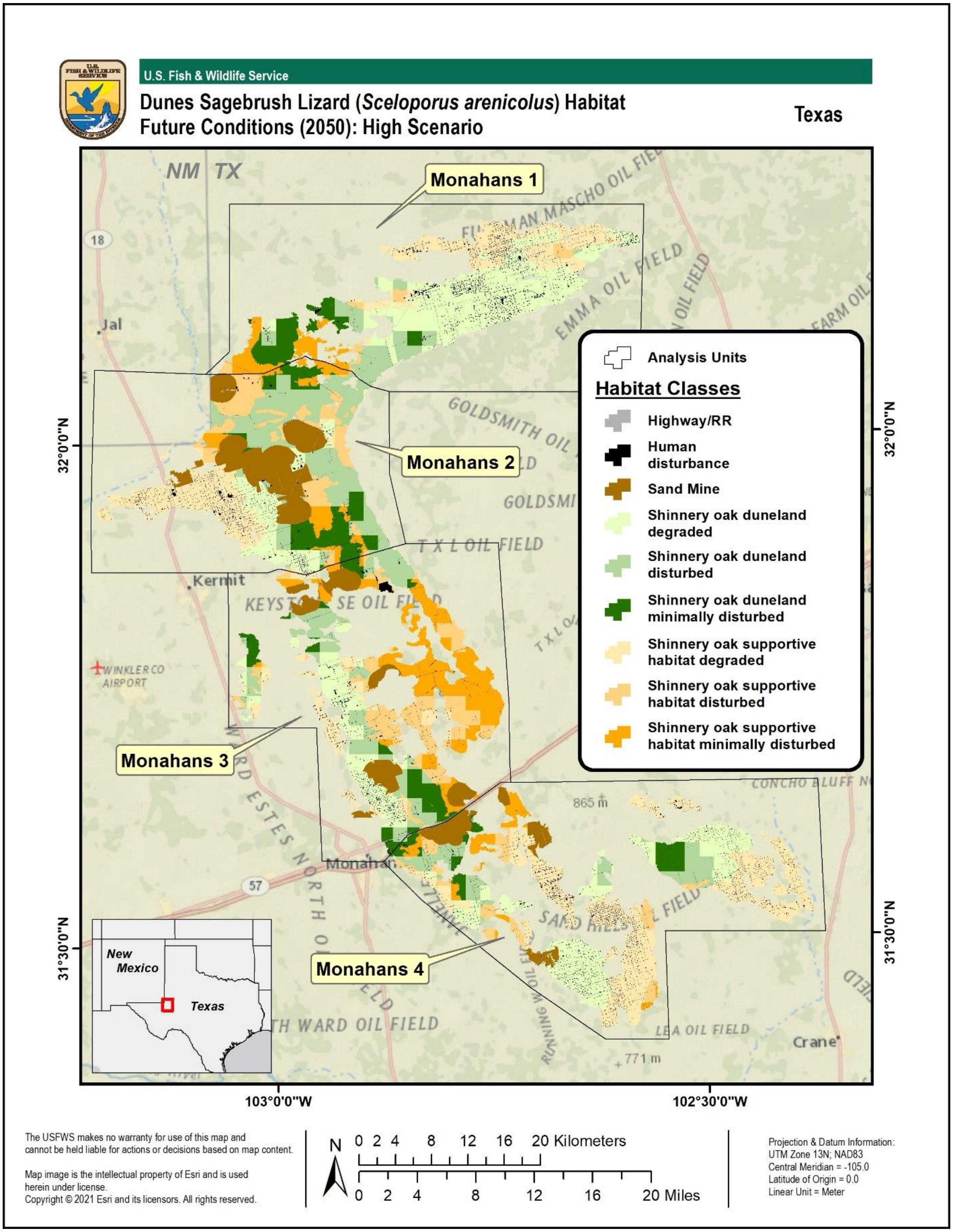

Figure D-6 Future projection of DSL habitat in 2050 under the High scenario. The outlines are for the 4 Analysis Units in the Monahans Representation Units.