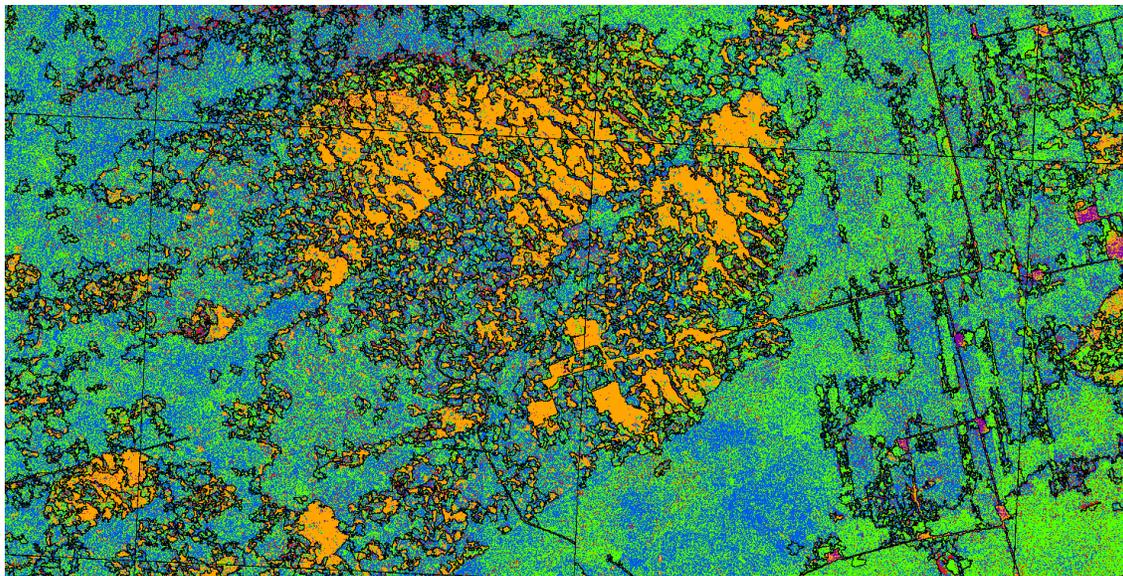


Alpha Texas Dunes Sagebrush Lizard (*Sceloporus arenicolus*) Habitat Model

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Abstract

This project created the Alpha version of the Texas Dunes Sagebrush Lizard (DSL) map depicting the spatial distribution of DSL (*Sceloporus arenicolus*) habitat within the Texas Conservation Plan (TCP) priority areas. Development of the map relied on an extension of the analytical approach taken in development of the New Mexico DSL map. This approach was specifically chosen to provide a compatible view of habitat delineations across the DSL range in New Mexico and Texas. We 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. This process was directly informed based on image segmentation using Object Based Image Analysis techniques. The resulting map provides four categories of DSL habitat (High, Intermediate I and II, and Low). These four classes are derived from high-spatial-resolution (1 meter) classified imagery. Preliminary accuracy assessments within the study area are being conducted based on a combination of high resolution drone imagery, ground-based land cover delineations and reference photography. Habitat categories target landscape level features such as shinnery oak (*Quercus havardii*) dune complexes, shinnery oak flats, dunes, etc derived from these defined habitat types in the New Mexico Model. DSL observation data within Texas were compared to the habitat map delineations with 96 percent of lizards contained in our highest suitable habitat category and the remaining 4 percent of DSL locations were contained within the Intermediate I category. Development of the Beta version of the map is incorporating additional ground truth data, refinement of habitat polygon classification and boundaries, and inclusion of additional quadrangles covering the expected range of DSL on the margins of the existing TCP permit areas throughout Texas.

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Introduction

Texas State University was tasked by the Comptroller of Public Accounts (CPA) to develop a habitat suitability model for the Dunes Sagebrush Lizard (DSL; *Sceloporus arenicolus*) in Texas. The modeling approach follows a process involving literature and data review, development of an Alpha version of the model with subsequent revision and validation to create a Beta model. The data review step examines relevant DSL survey data, corresponding survey techniques, and previously published literature on the life history and ecology of the DSL throughout its range (New Mexico and Texas). This review process sets the foundation for the identification of the conceptual model and the specific approach for the development of the Alpha version of the model. This is followed by a model validation process to guide necessary revisions to the Alpha model leading to development of the Beta model. The Beta model represents the revised DSL model and incorporates structural and conceptual modifications derived from the validation process and modifications reflecting the Adaptive Management Process.

DSL Life History, Data Availability and Implications to Inform DSL Habitat Suitability Modeling

The approach undertaken to develop the Alpha version of the DSL model for Texas was founded on a review of available data and their applicability to inform model development. Evaluation of available DSL data considered several aspects related to the ecology and biology of DSL including the implications of survey techniques, spatial extent of survey locations, and seasonal/diel timing of surveys. DSL average home range size is ~435 m² although can range as large of ~ 2800 m² and most often associated with shinnery oak dunelands with inclusions of blowouts. DSL are also known to traverse other landscape features such as shinnery oak shrublands (flats), pipeline scars with sand, open dunes and barren sandy areas when these are in contact with shinnery oak dunelands. Habitat heterogeneity in conjunction with specialized life history characteristics result in suitable habitat being unoccupied and impact detection probabilities especially in low observability habitat such as shinnery oak shrublands or when dune features have moderate grass and forb coverage.

We also note that restricted land access to private property has considerably constrained collection efforts in Texas versus New Mexico where public lands dominate the range of DSL. DSL habitat features have been characterized at spatial scales that range from 'microhabitat' to broader landscape level features. It is noted that some characteristics of DSL habitat potentially related to specialized life history requirements, such as sand grain size are infeasible for inclusion in the existing model. This is a pragmatic limitation given the spatial extent of the potential DSL range in Texas being evaluated and limitations of associated data availability. Although DSL can be active any time of year (Forstner, personal observation), the relationship between the probability of detecting a DSL, if it is present, and the time of year surveys are conducted has not been explicitly evaluated. An examination of all DSL detections based on museum records from New Mexico and Texas and pit fall trapping data from Texas A&M University from 2012 to 2016 indicate that ~80% of detections within the year occurred between April and July (Kiehne *et al.*, 2018). It is also known that detections within a day vary as function of ambient temperatures where detections are reduced due to thermoregulatory behaviors when substrate temperatures exceed ~37°C. DSL surveys methods in the published literature involving visual encounter surveys almost exclusively targeted observations between 0800 and 1400 to account for these known thermoregulatory behaviors. An exception is noted for some surveys (e.g., Laurencio *et al.*, 2007) continued surveys with substrate temperatures

exceeding 50°C) and radiotracking studies that included observations from later in the day as part of their methodology.

Implications of Sampling Techniques

Our review found that monitoring and research studies have used a variety of methods to sample DSL, including pit fall traps, transect-based distance sampling, area-constrained visual encounter surveys and limited application of radio tracking (Kiehne *et al.*, 2018). The review found that many of the DSL survey's in Texas were constrained by site access and in general focused on survey techniques and survey locations based on differing research objectives. The variability in survey techniques in combination with differential detection probabilities by habitat types, interannual variability of DSL detections at a given location and life history mediated differences in habitat use (i.e., home range versus dispersal) confounds use of available data for many types of "suitability modeling" (e.g., presence only, presence/absence, logistic regression, resource selection functions, occupancy, etc). DSL collection data in New Mexico is substantially more expansive in terms of spatial coverage of the assumed range of DSL as well as providing explicitly long-term collection efforts. These data have been leveraged by Johnson *et al.*, (2016) to develop a habitat suitability model for DSL over its range in New Mexico based on defined landscape features associated with use by DSL.

Pit Fall Trapping

Pit fall trapping can provide a number of quantitative assessments such as presence, absence, movement, and population density estimation when conducted over adequate spatial and temporal domains. Within Texas, pit fall trapping has almost exclusively targeted shinnery oak dune blowout habitats where variation in study sites generally considered degrees of habitat fragmentation due to well pad and road density or distance from these features. These studies focused on the implications of fragmentation on DSL microhabitat properties, population demographics and other life history components such as home range, movement patterns and dispersal (Sherwin, 2014; Leavitt and Fitzgerald 2013; Ryberg *et al.*, 2013; Ryberg *et al.*, 2015; Walkup *et al.*, 2017; Leavitt *et al.*, 2011). With the exception of Fitzgerald *et al.*, (2005), most studies do not provide sampling across a spectrum of different habitat types and/or landscape features.

Visual Encounter Surveys

Visual Encounter Surveys (VES) have been employed for distance sampling and time constrained search research. VES, specifically for DSL surveys, remain problematic due to differential observability across known habitat types (i.e., shinnery oak duneland blowouts versus shinnery oak shrublands) and known spatial and temporal heterogeneity of DSL. Smolensky and Fitzgeralds (2010) compared 238 distance line transects to densities of DSL measured in 20 total removal plots and concluded:

"It is clear that, even in the relatively open shinnery oak sand dune habitat, distance sampling methods were not reliable and underestimated the densities of lizards. The disparity in density estimates from distance sampling versus total removal plots was caused by violation of the assumption of perfect detection of individuals on the transect line. Individuals that were unavailable for detection greatly influenced the density estimates. Because of the difficulty in correcting for biases, we suggest that distance sampling is not an appropriate sampling method for estimating densities of lizards".

Although the study focused on a comparison of density estimates, a fundamental conclusion can be inferred that visual detectability is difficult for DSL even in open dune habitats and further degraded in other DSL occupied habitats such as shinnery oak flats. Kiehne *et al.*, (2018) also note a number of related issues that contribute to potential VES bias:

The primary assumption is that all individuals of all species are equally likely to be detected, including equal detection rates among observers (Guyer & Donnelly, 2012), however neither assumption is likely true, particularly in the case of rare species. One confounding factor that could lead to inaccurate sampling is availability bias. This is bias caused by a study subject being undetectable, or unavailable, during the survey. This is typically due to the animal being inactive by taking shelter under cover. Additionally, obstacles such as vegetation or topographical features can obstruct surveyors' field of view (Guyer & Donnelly, 2012). In the case of the Dunes Sagebrush Lizard, dense shinnery oak could obscure lizards from observers and prevent detection (Figure 6). In addition to vegetation limiting visibility of lizards, the rugose topography in the form of sand dunes limit the sight distance, and therefore the detection distance of lizards. Ultimately these issues are much less important when the goals of the surveys are the development of occupancy models, which account for detectability issues, but these issues are absolutely critical where the goal of the survey is to make a determination of absence to defend disturbance of otherwise suitable habitat.

Sampling bias is also confounded by DSL life history traits which include patchy distribution across apparently suitable habitat. Published studies clearly identified temporal variability in DSL detections at a given spatial location even in the highest observability habitats such as shinnery oak duneland blowouts (Laurencio *et al.*, 2007; Fitzgerald *et al.*, 2011; Mike Hill, personal communication). Fitzgerald *et al.*, (2011) note:

*“An important outcome of the present study [Fitzgerald *et al.*, 2011] is that we documented the presence of *S. arenicolus* at or near many sites where they were not found or were difficult to find in the past (e.g., Laurencio *et al.* 2007). In the Laurencio *et al.* (2007) study, for example, *S. arenicolus* was not found in Monahans Sandhills State Park even though the species was known there since the 1960s. *Sceloporus arenicolus* was not detected there again until summer 2010, despite multiple searches over several years (Fitzgerald 2010). Letter and photographs to Texas Parks and Wildlife). Since 2010, *Sceloporus arenicolus* has been found in the park with regularity. We suspect the species was always present in the park in low numbers, making it difficult to find during 2006-2009. However we can not reject the alternative explanation that the species could have been temporarily absent, and individuals had dispersed and recolonized areas of Monahans Sandhills State Park.”*

Radio Tracking

Radio tracking can provide access to data reflecting DSL life history information not readily obtainable by pit fall trapping or VES. Although limited in its application to DSL research to date, it has provided important insights to habitat use not reflected by pit fall trapping of VES. This includes long distance movements beyond home range areas that implied crossing a caliche road and traversing shinnery oak flats (Fitzgerald *et al.*, 2005). The implications of alternative interpretation of published results is exemplified by Young *et al.*, (2018) who utilized radio tracking to examine DSL home range sizes and movements between fragmented and unfragmented sites. The authors state that

a single DSL crossed a caliche road out of 14 lizards monitored with 799 relocations. Alternatively, if one assumes that the computed minimum convex polygon areas encapsulates the total movement area of a DSL, then there were only two DSL home ranges that in fact were in contact with a caliche road and of these two, one crossed the road representing a 50 percent crossing rate.

Implications on Modeling

The temporal aspect of DSL observations for a given site over extended periods has important implications when interpreting previous DSL observation data. Failure to detect DSL at a specific time does not necessarily imply poor habitat conditions at that location. It is evident that sampling for DSL to determine presence or absence requires multi-year and seasonal sampling and that the most definitive approach would be to use pit fall trapping versus VES techniques when sampling low observability habitats such as shinnery oak flats. Differential sampling techniques have also demonstrated differential results related to DSL habitat use. For example, pit fall trapping and radio tracking results confirmed caliche road crossings as well as DSL traversing of shinnery oak shrubland not substantiated by VES.

Historical DSL Habitat Maps and Modeling

We reviewed the basis for the Hibbitts map (likelihood of occurrence), recent DSL suitability modeling efforts in Texas (Ryberg *et al.*, 2016) and the New Mexico DSL habitat modeling approach (Johnson *et al.*, 2016). The reviews provide a basis for framing the modeling approach taken in this current study. A brief synopsis of these efforts is provided below within the context of their applicability to inform the development of the DSL Texas habitat model.

Hibbitts Map

An initial delineation of the geographic distribution of DSL in Texas was undertaken by Laurencio *et al.*, (2007). Field surveys were conducted at 27 sites based on historic DSL survey records and mapped locations of shinnery oak habitats (Figure 1). DSL were found at 3 localities using VES methods. DSL surveys in Cochran county were negative during 2006 and 2007 while Yoakum county was excluded from survey efforts:

“Reconnaissance in field vehicles determined that the areas in Lynn, Terry, Yoakum, Dawson, Howard, most of Gaines and extreme southwest Cochran counties were not suitable for S. arenicolus.”

The resulting atlas of DSL habitat for Texas (Figure 2) excludes the Cochran and Yoakum county shinnery oak areas.

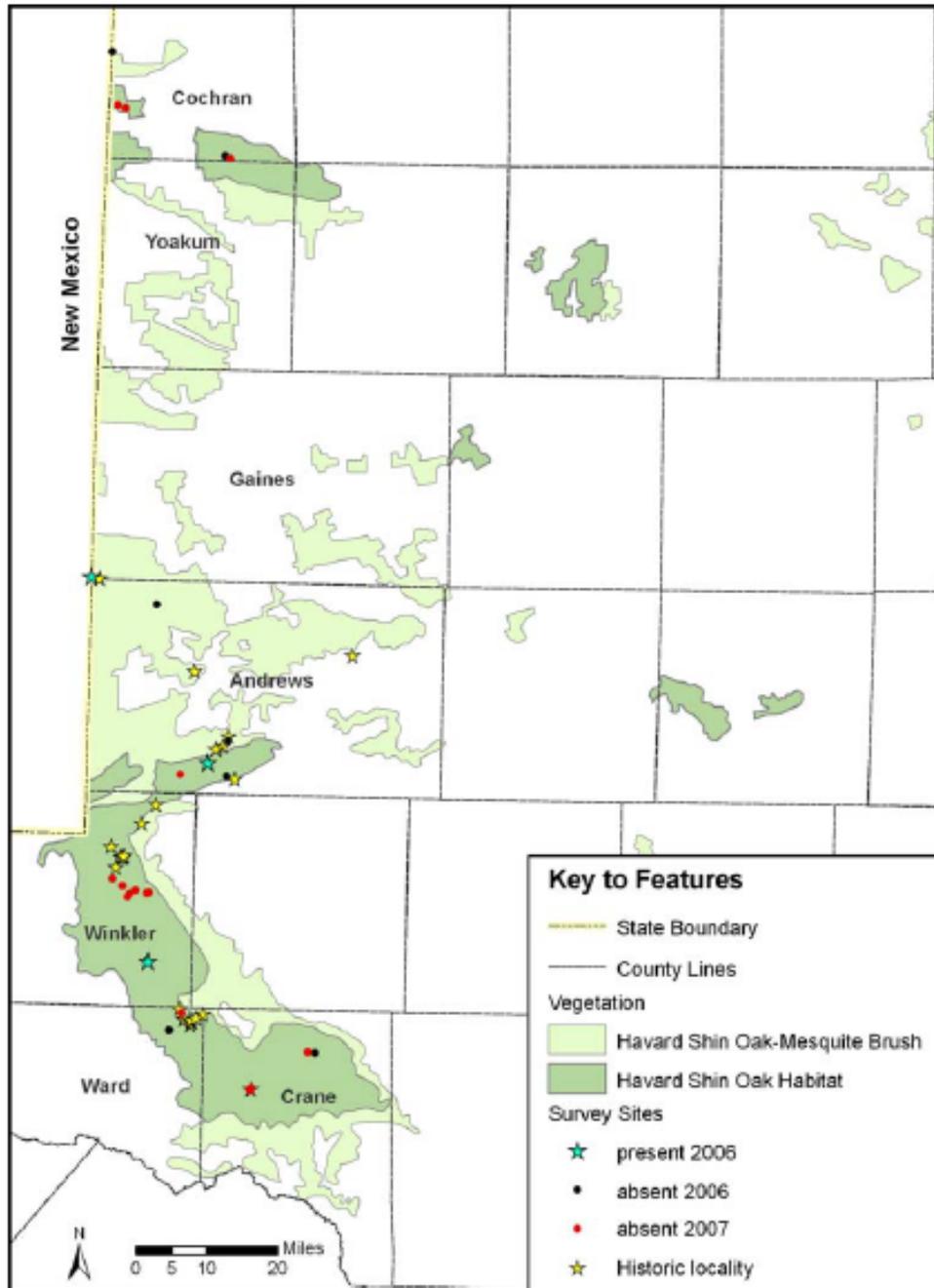


Figure 1. Sample locations for Dunes Sagebrush Lizard (*Sceloporus arenicolus*) from Laurencio et al., (2007).

As noted previously, the spatiotemporal heterogeneity of DSL on the landscape has the potential to influence perceived habitat. Specifically, in this instance, Cochran and Yoakum counties were excluded in the atlas, however, surveys in shinnery oak duneland habitats in New

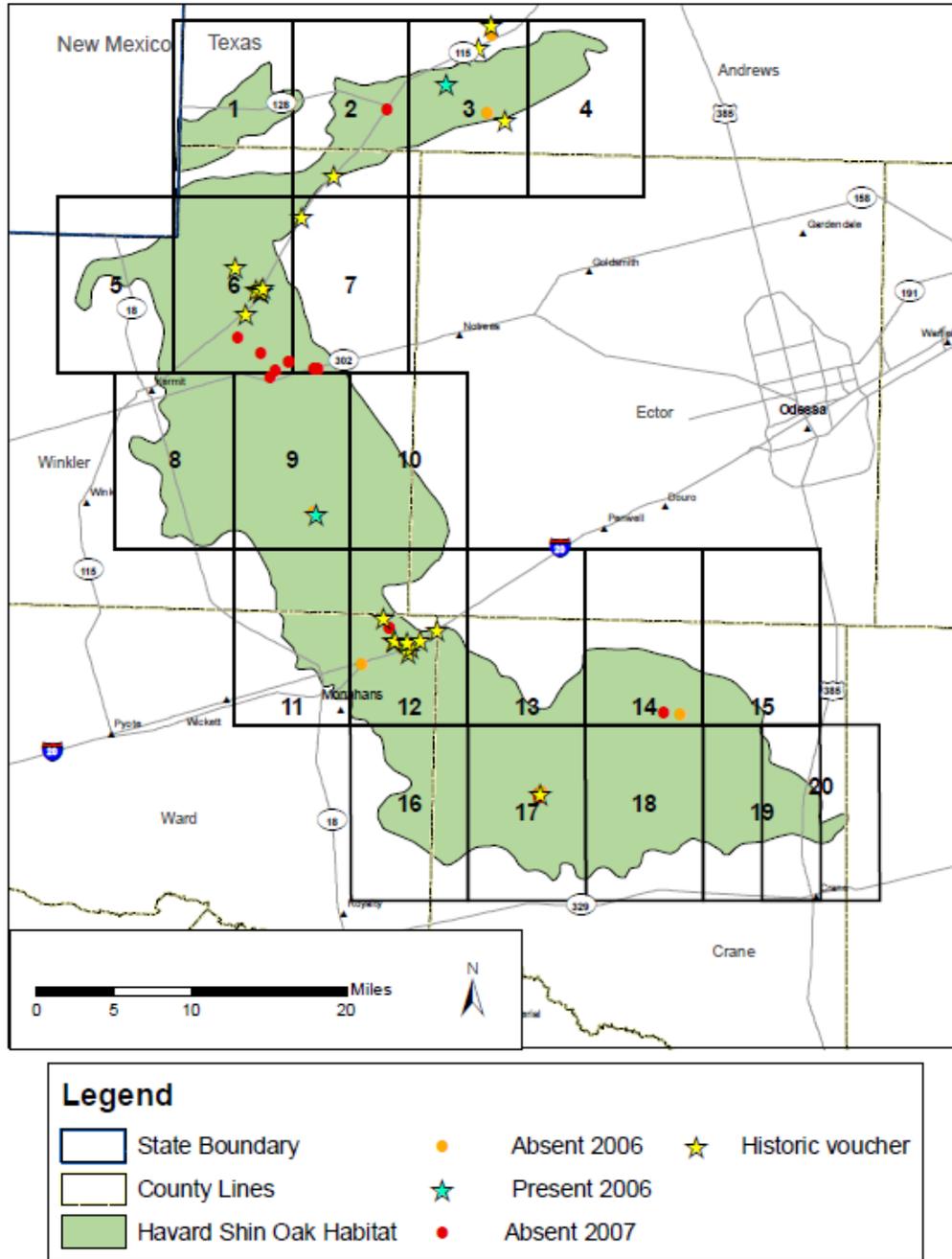


Figure 2. Laurencio et al., (2007) Dunes Sagebrush lizard (*Sceloporus arenicolus*) final habitat distribution map for Texas.

Mexico immediately adjacent to identifiable shinnery oak duneland locations in Cochran county found DSL in 2012. Exclusion of these northern areas of potential DSL habitat based on limited field surveys over limited time frames may have excluded potential DSL habitat areas in subsequent DSL maps (i.e., Hibbitts).

A comparison of the Laurencio et al., (2007) atlas to a modified derivative of two USGS soil layers: 1) Qds and 2) Qsu (Hartmann and Scranton 1992) is informative. These two sand sheet layers represent active or semi-stabilized sand dune deposits with strong relict eolian grain,

including active blowouts with depressed relief and then windblown sand deposits, sand sheets, and dune ridges respectively (Hartmann and Scranton 1992). Taken together these two sand sheet geology layers reconstruct a subtly larger main potential DSL habitat fragment and also include discrete additional segments outlying from the main sand sheet patch (Figure 3).

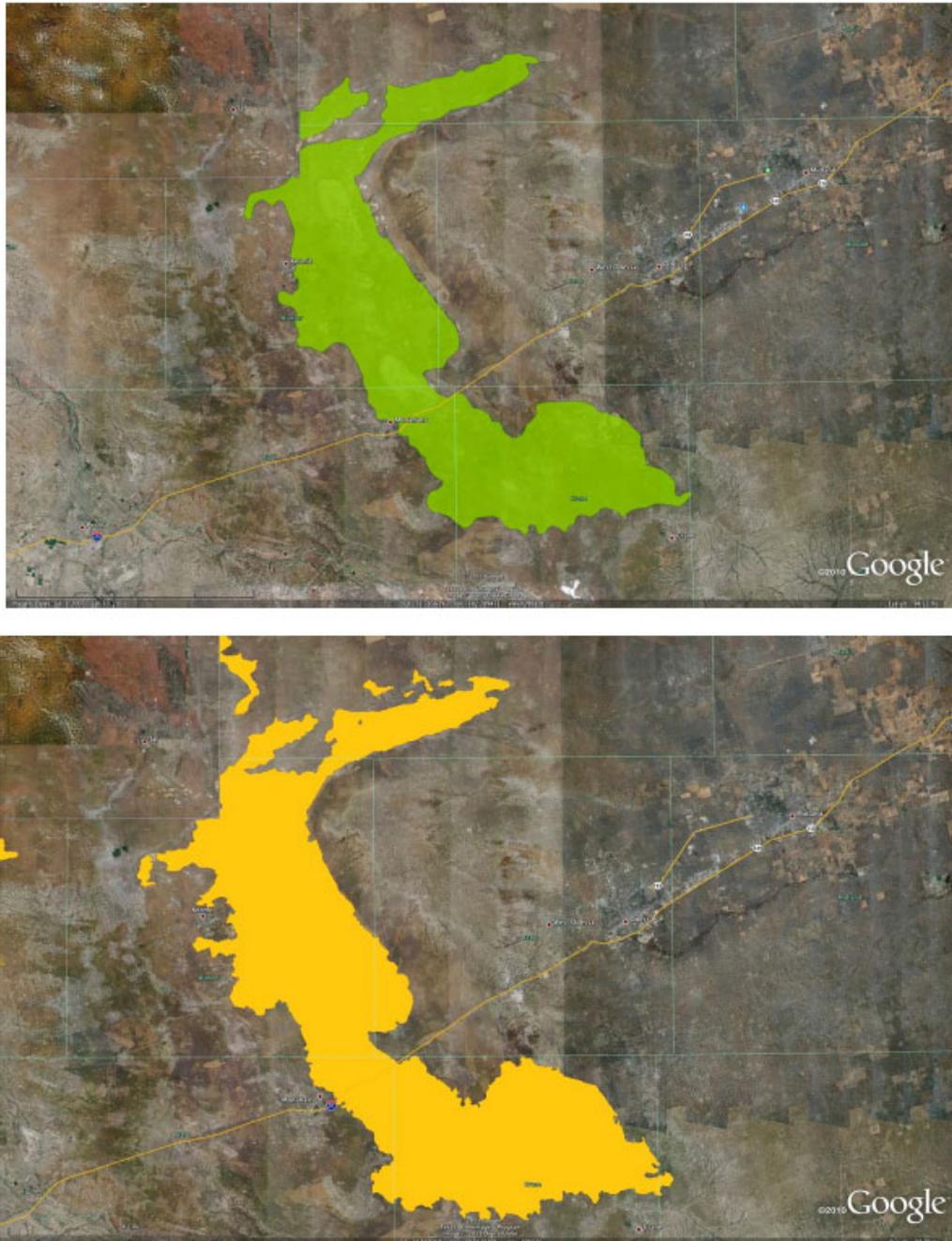


Figure 3. Potential habitat boundary maps for *Sceloporus arenicolus* in Texas. The upper panel (A) represents the Laurencio et al. (2007) map and the lower panel (B) is two sand sheet layers in the region (Geology of Texas, layers Qds and Qsu). Interstate Highway 20 can be seen to bisect this region west of Odessa, TX diagonally for orientation of the figure.

The Hibbitts map was prepared by Dr. Hibbitts (Curator of Herpetology, Texas Cooperative Wildlife Collection (TCWC), Texas A&M University). This map was drawn by Dr. Hibbitts by hand selecting potential habitat from aerial maps using historical records for *Sceloporus arenicolus* and his expertise and experience with the species (Figure 4). The spatial extent is similar to the Laurencio et al., (2016) atlas map but notably excludes areas north of Andrews county.

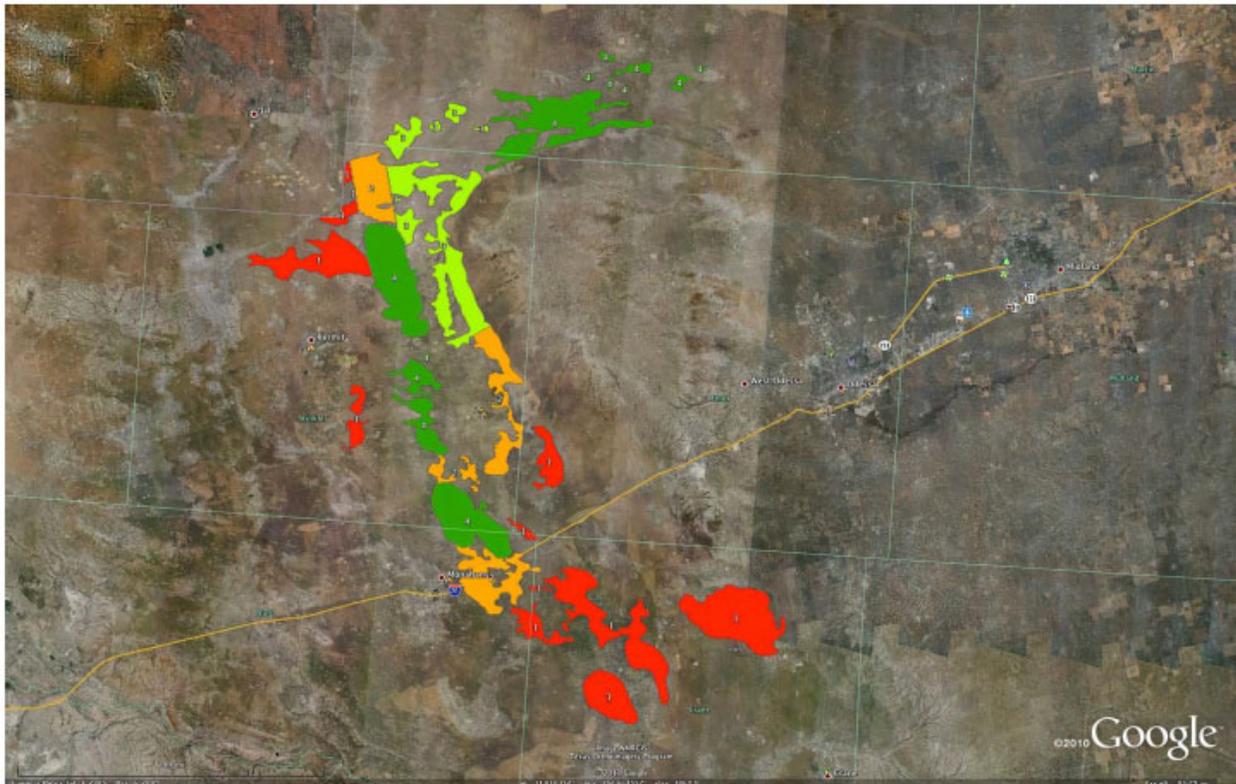


Figure 4. Alternative potential habitat map for *Sceloporus arenicolus* in Texas provided by Hibbitts (2011). This map has boundaries that are hand drawn using museum record occurrence and Hibbitts personal expertise with the lizard in Texas. Color correspond to Hibbitts conclusions with regard to probability of occurrence with red being very low, orange being low, light green being high and dark green representing high probability of occupancy by *S. arenicolus* within that habitat patch.

The Hibbitts map represents a generalized approximation of DSL likelihood of occupancy that is loosely associated with landscape level habitat types based on DSL historical detections from museum records, the Laurencio *et al.*, (2007) survey data from 27 locations in which 3 DSL were detected and survey results from Fitzgerald *et al.*, (2011) conducted over an 8-day period in June 2011 in which DSL were detected at 28 out of 50 sites surveyed. Surveys locations were disproportionally distributed between likelihood of occurrence categories (28 in Very High in which 23 DSL were detected, 4 in High (3 DSL detections), 7 in Low, and 12 in Very Low). It should be obvious that Ryberg et al., (2016) pointedly note:

Currently the distribution of the DSL in Texas is based off of subject matter expert knowledge ... [the Hibbitts map], meaning that the map is not repeatable and the boundaries of the distribution and likelihood of occurrence categories are

subjective. Additionally, the current map is not a habitat quality map but simply a likelihood of occurrence map.

The relationship between DSL detections and Hibbitts likelihood of occurrence categories were defined as:

- Very High – positive detections from multiple surveys or known to have recently contained DSL within the past 20 years based on museum records. Habitat descriptions were *“Shinnery dunes with large open blowouts.” Dune “complexes” (expanses of the same geologic dune formation) could also be identified from aerial photography and, unless survey data was available to indicate otherwise, entire dune “complexes” were considered the same likelihood of occurrence.”*
- High – some historical records or few positive survey results for DSL. Habitat descriptions were similar to Very High but *“areas of good habitat were generally smaller”.*
- Low – areas without known records of DSL observations but spatially in contact with either Very High or High areas on the landscape. Habitat descriptions included *“shinnery dunes with blowouts, some shinnery dunes with sparse blowouts and mesquite flats with blowouts”.*
- Very Low – areas without known DSL records. Habitat descriptions included *“areas usually separated from Very High or High habitat patches by ‘unsuitable habitat’. Areas in contact with High category habitats were obviously of a ‘different dune complex’ and considered to not be ideal for DSL. These dune complexes contained shinnery dunes but with few blowouts or that the blowout were grown in with grasses or mesquite”.*

Notably, it was recognized that *“All areas (Very High to Very Low) likelihood of occurrence can and do have what appears to be areas of good quality Suitable Habitat but other factors such as connectivity and survey results exclude those areas from having higher likelihoods of occurrence”.* This approach, although pragmatic at the time of development, introduces several issues when utilized as the basis for management decisions within the context of the regulatory framework of the TCP. It is known that DSL is a habitat specialist and maintains a patchy distribution across the landscape and does not occupy all potentially suitable habitats. Visual encounter surveys have relatively low probability of detections in non-dune blowout habitats utilized by DSL (e.g., shinnery oak flats). DSL detections can also show high interannual variability for the same physical location as noted in Fitzgerald et al., (2011) where DSL were documented *“... at or near many sites where they were not found or were difficult to find in the past”.* These factors among other issues underscore that the Hibbitts Map is at best an approximation of habitat at the landscape scale primarily driven by known or expected occupancy, assumed habitat suitability differences and constrained by temporally and spatially limited collection efforts due in part to restricted land access over the DSL range in Texas. Other relevant issues in the existing Hibbitts map that directly impact regulatory decisions within the administrative framework of the TCP include:

- Polygons do not encompass known DSL location data as illustrated in Figure 5. This issue is critical to resolve in that failure to incorporate known location data for DSL could result in direct unregulated habitat destruction since these areas fall outside the regulatory polygon boundaries.

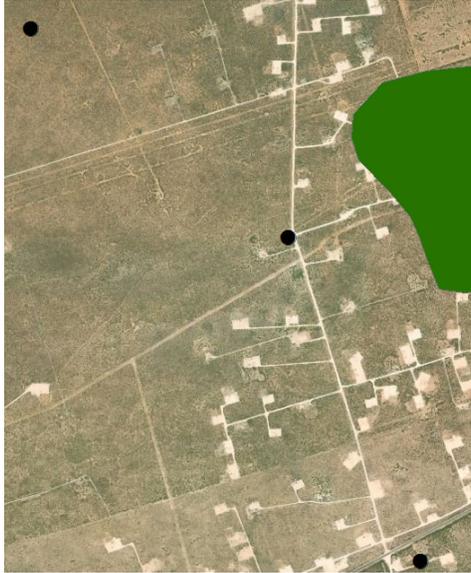


Figure 5. Example of known *Sceloporus arenicolus* location that falls outside any Hibbitts polygon areas.

- Polygons do not always maintain spatial coherence between polygon boundaries and underlying structural landscape features as illustrated in Figure 6. This has a direct consequence on conservation strategy decisions for proposed actions given that an action may be proposed that appears to be outside a given habitat polygon boundary while in fact it is spatially within the feature. This could result in unregulated direct habitat loss along the margins of protected habitat. This also would have the potential to change regulatory requirements including the nature of required mitigation.
- Spatially adjacent self-similar landscape features have different likelihood of occurrence designations and boundaries do not coincide with changes in underlying landscape features as illustrated in Figure 7. Given the differences in regulatory requirements between different categories of likelihood of occurrence, these discrepancies have large implications for proponent specific actions. This includes both regulatory restrictions and potential differences in required mitigation measures.
- Likelihood of occurrence polygons do not identify all potential habitat features over the landscape in Texas as illustrated in Figure 8. This fact remains largely unexplored across the DSL range in Texas and has severe negative implications in that these areas of potentially suitable DSL habitat could be modified or destroyed because they fall outside regulatory boundaries. This also has implications on identification of dispersal corridors between habitat patches that may appear isolated when in fact intervening habitat patches exist.

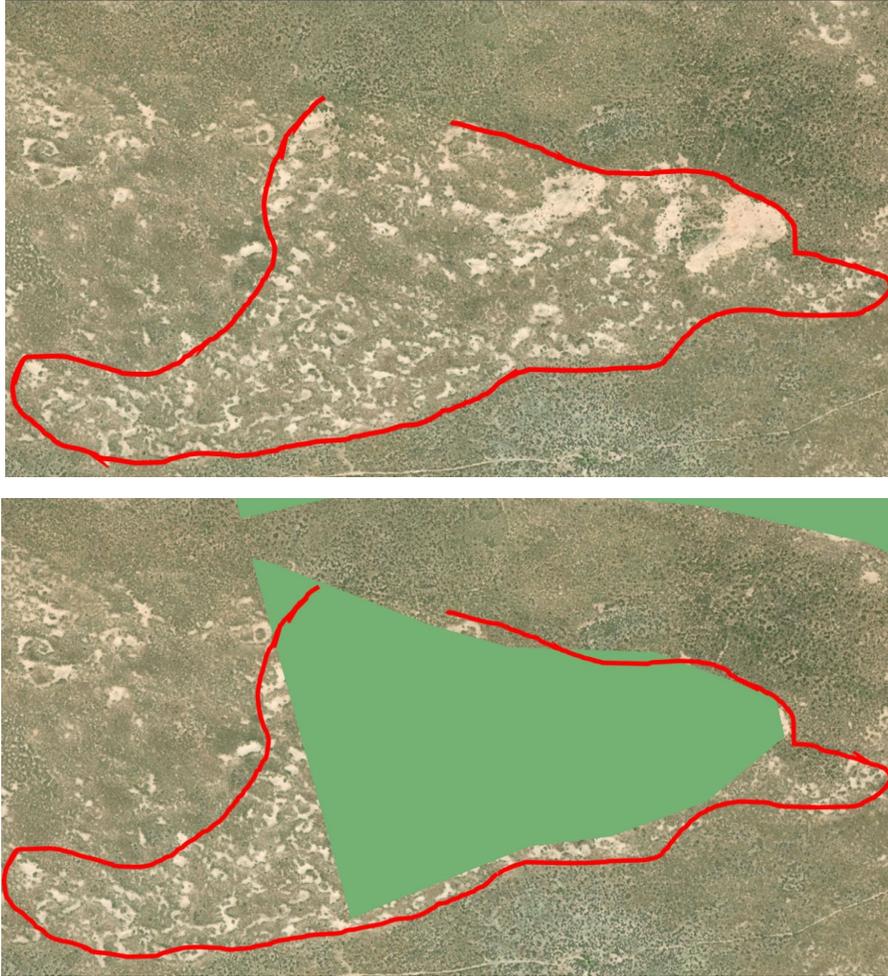


Figure 6. Example of lack of spatial coherence between landscape features and boundaries of Hibbitts polygons for *Sceloporus arenicolus*.

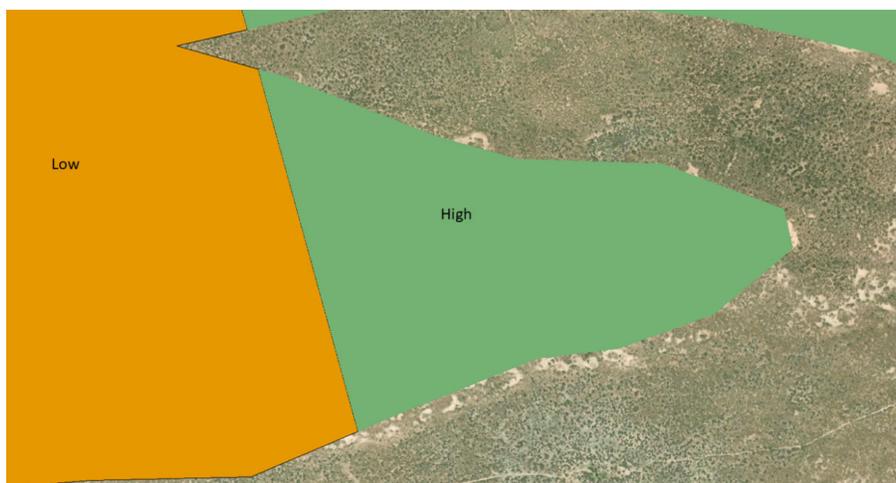


Figure 7. Different likelihood of occurrence designations of *Sceloporus arenicolus* from Hibbitts for spatially self-similar landscape features where habitat class boundaries do not coincide with underlying landscape features.

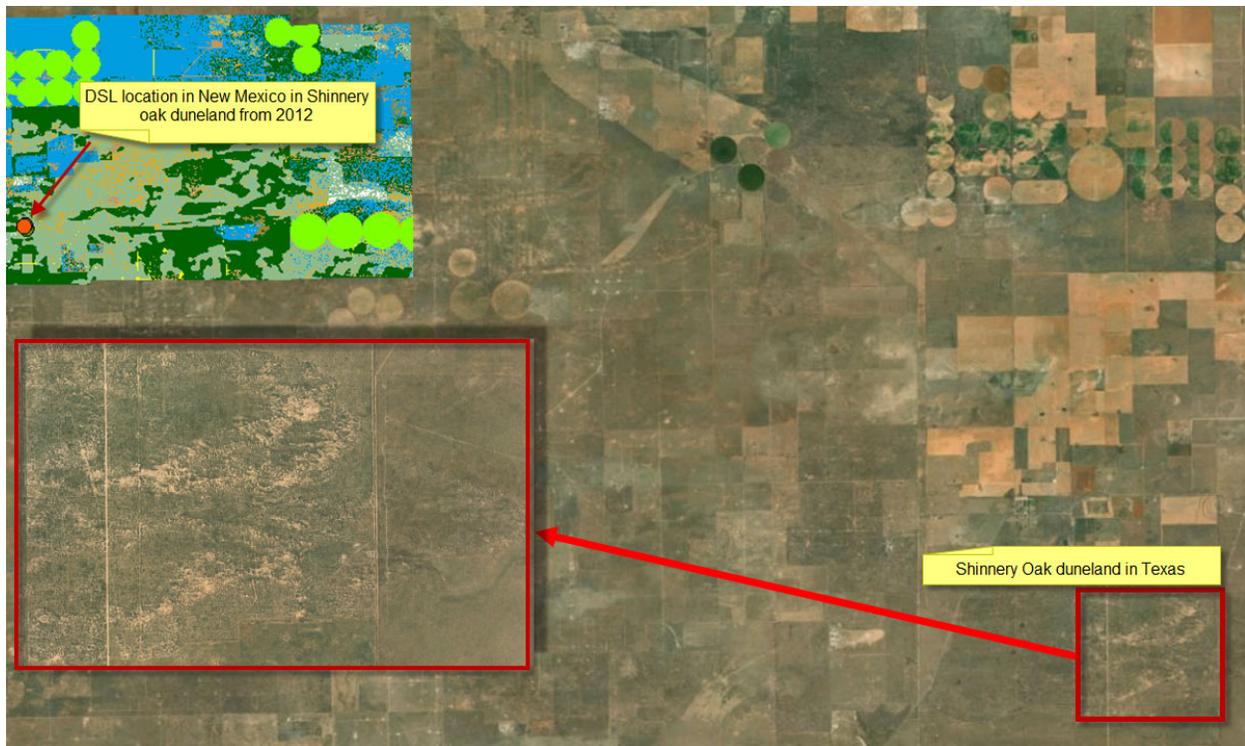


Figure 8. Northern boundary of New Mexico model showing *Sceloporus arenicolus* locations (orange circles) within shinnery-oak dunelands and similar adjacent landscape features in Texas not identified by Hibbitts polygons.

The TCP anticipated that this map would be updated (Section 8.3 Adaptive Management, page 34) by ‘refining and validating DSL Habitat map(s), including dispersal corridors’. Also, as noted in Fitzgerald et al., (2011):

“The map showing 4 categories of likelihood of occurrence was based on coarse criteria of known occupancy, historical occupancy, and obvious connectivity of shinnery dune areas. We recommend refinement of habitat occupancy maps as more information becomes available”.

However, refinements to actual ‘occupancy maps’ is confounded by the low detection probabilities of DSL across all 4 occupancy habitat types as well as documented variability in temporal survey results (daily, seasonal and inter-annual) for a given site as noted in Fitzgerald et al., (2011):

“An important outcome of the present study is that we documented the presence of S. arenicolus at or near many sites where they were not found or were difficult to find in the past (e.g., Laurencio et al. 2007). In the Laurencio et al. (2007) study, for example, S. arenicolus was not found in Monahans Sandhills State Park even though the species was known there since the 1960s. Sceloporus arenicolus was not detected there again until summer 2010, despite multiple searches over several years (Fitzgerald 2010). Letter and photographs to Texas Parks and Wildlife). Since 2010, Sceloporus arenicolus has been found in the park with regularity. We suspect the species was always present in the park in low numbers, making it difficult to find during 2006-2009. However we can not reject the alternative explanation that the species could have been temporarily absent,

and individuals had dispersed and recolonized areas of Monahans Sandhills State Park”

Walkup et al., (*in press*) note that availability bias (assumed lizard presence) can impact the effectiveness of survey methodologies (e.g., visual encounter surveys versus pitfall trapping) confounding occupancy modeling. They further note that it is likely, at least in the High likelihood of occurrence habitat category, that DSL may be present at some non-surveyed locations and cannot discount that DSL may be present in the Low and Very Low likelihood habitats. This is consistent with historical observations in which DSL are known from designated Very Low likelihood habitat in Crane County. Walkup et al., (*in press*) also note that current states of occupancy are not indicative of future states of occupancy, especially since dispersal rates and their mechanisms are not well understood.

Texas A&M Habitat Suitability Model

Habitat requirements have been studied at several spatial scales ranging from microhabitat use (Hibbitts et al. 2013), blowout characteristics (Fitzgerald et al. 1997), and regional landscape scale patterns related to habitat configuration (Ryberg et al. 2013). Although microhabitat use related to sand grain size or slope characteristics of blowouts are important, their utility to modeling at broad spatial scales covering the range of DSL in Texas is limited by available data. As noted previously, observability and patchy distribution spatially and temporally confounds the application of quantitative habitat data for modeling DSL habitat suitability. For example, available data on DSL habitat characteristics suitable for use in quantitative habitat modeling is provided in TAMAR (2016). TAMAR extracted habitat characteristics from one hundred and seventy-five 400 m² sample plots surveyed for DSL using VES techniques. Sample plot attributes were derived from classified 1-meter resolution NAIP imagery to quantify the percent contribution of shinnery-oak, sand, mesquite, caliche, and grass. Rugosity and rugosity mean were derived from the National Elevation Database (NED) and the Shuttle Radar Topography Mission (SRTM) data. These data represent 100 locations in which DSL were detected and 75 locations with non-detections of DSL (Figure 9).

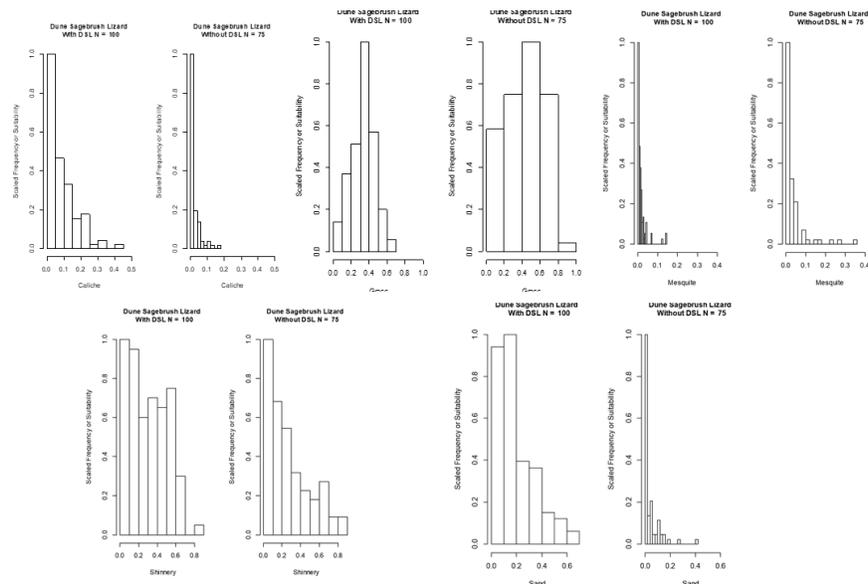


Figure 9. Comparison of scaled frequencies of modeled habitat variables between locations with and without Dunes Sagebrush Lizard (*Sceloporus arenicolus*) observations (TAMAR 2016).

What is striking is how similar the habitat attributes are for surveyed locations in which DSL were observed versus survey locations where DSL were not observed. Caliche, sand, shinnery oak, and rugosity mean values were found to be significant using binary logistics regression. However, Ryberg et al., (2016) note that the large sample plot size included heterogeneous land cover (e.g., caliche road/well pads) and introduced spurious artifacts to the model results. In particular, the significant positive relationship with percent caliche suggesting an increased probability of DSL presence with increased caliche cover. This is counter to other published literature on negative implications of caliche roads and well pads on DSL habitat quality and dispersal mechanism (e.g., Sias and Snell 1996; Leavitt *et al.*, 2011).

The use of 400 m² raster cells to represent the model domain in GIS was to maintain consistency between the underlying data used to construct the model but also introduced spatial bias in model results compared to underlying landscape features. Model results also showed significant differences between corresponding suitability and corresponding spatial coherence to likelihood of occurrence polygons as illustrated in Figure 10. This figure also highlights the following issues with the modeling results:

- Raster cells do not maintain spatial coherence with the underlying structure of the landscape features.
- Spatial distribution of suitability values can be significantly different compared to corresponding Hibbitts polygon boundaries.
- Computed attributes of adjacent raster cells can result in very different suitability categories within the same underlying landscape feature (see single Very High suitable raster cell).

Ryberg et al., (2016) also notes major differences between the Hibbitts polygons versus the suitability model results across the range of DSL habitats. This includes disagreement between high likelihood of occurrence polygons that have very low predicted suitability in Winkler County and generally lower suitability values for much of the low likelihood of occurrence polygons. Overall, the spatial extent of the suitability model is much more expansive than the Hibbitts polygon coverages as would be expected given the use of broader remote sensing data in conjunction with suitable soil layers in the region. The suitability base modeling also predicted more extensive regions of very high suitable habitat within western Andrews and northern Crane County compared to very low suitability likelihood of occurrence polygon coverage based on the Hibbitts polygons.

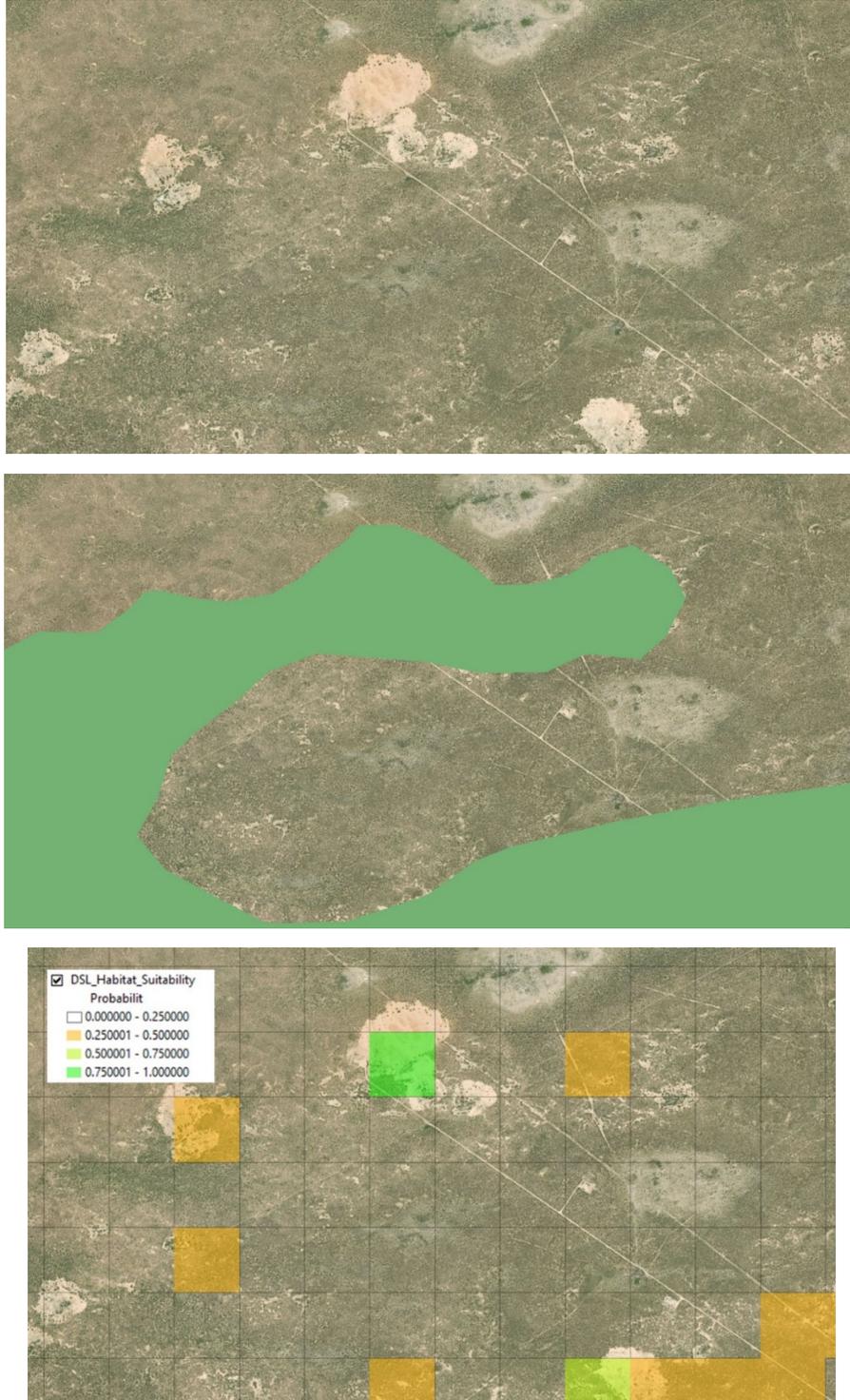


Figure 10. Texas A&M Dunes Sagebrush Lizard (DSL; *Sceloporus arenicolus*) habitat suitability model results compared to Hibbitts High likelihood of occurrence polygon. Top image shows underlying landscape feature, middle image shows the Hibbitts designated High likelihood of occurrence polygon while the bottom image shows the A&M DSL habitat suitability model results [400 m² raster cells]. (Note, 0.0-0.25 = Very Low (clear); 0.25-0.5 = Low (yellow); 0.5-0.75 = High (light green); 0.75-1.0 Very High (dark green)).

New Mexico DSL Modeling

A summative overview of DSL biology and natural history within the context of defining landscape level features as a basis for modeling DSL habitat in New Mexico can be found in Johnson et al., (2016) and will not be repeated here. The New Mexico DSL habitat model is best described as a landscape feature model derived from land cover/vegetation classifications aggregated into a defined set of 15 discrete Map Units (or landscape features) shown in Table 1 (Johnson et al., 2016). The New Mexico model relied on a combination of vegetation and land cover classification using 1-meter 2011 and 2014 NAIP imagery, followed by ‘heads up editing’ to aggregate landscape-level features based on the image classification in combination with professional judgement to define the boundaries of specific landscape scale features as illustrated in Figure 11.

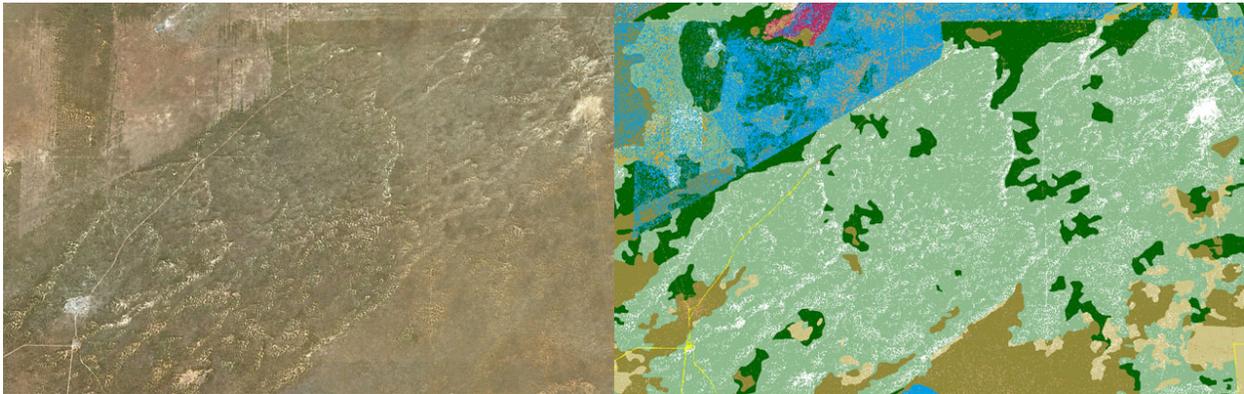


Figure 11. Example of the New Mexico Dunes Sagebrush Lizard (*Sceloporus arenicolus*) habitat model results aggregated to landscape level feature classes.

The New Mexico DSL habitat model was comprised of 15 distinct Map Units (Table 1).

Table 1. New Mexico DSL Map Units (Johnson et al., 2016). Bold and underlined Map Units were identified as DSL habitats.

Map Unit	Description
<u>1</u>	<u>Shinnery oak Duneland</u>
<u>2</u>	<u>Shinnery oak – Honey Mesquite Duneland</u>
<u>3</u>	<u>Blowout (incorporated into Duneland Map Units)</u>
<u>4</u>	<u>Blowout Disturbed (incorporated into Duneland Map Units)</u>
<u>5</u>	<u>Dune</u>
<u>6</u>	<u>Barren Sandy</u>
<u>7</u>	<u>Shinnery oak Shrubland</u>
8	Shinnery oak – Honey Mesquite Shrubland
9	Honey Mesquite Shrubland
10	Escarpment Shrubland
11	Mesquite Trees
12	Grassland
13	Human Disturbance
14	Agriculture
15	Mixed Escarpment

The New Mexico modeling effort did not assign differential suitability to these 15 land cover classes rather identified which landscape features were considered to represent DSL habitat categorized into Suitable, Treated/Fragmented, Potentially Restorable, Occupied, and Connectivity. The identification of DSL habitats was supported by 1278 DSL observations from New Mexico between 1961 and 2014. These data were further screened for locations with known spatial accuracy ≤ 6 meters (636 observations) representing Recently Occupied Areas. These point data were supplemented with polygon data from Painter (1997), and Smolensky and Fitzgerald (2011). Germane to the current modeling effort in Texas, we followed Johnson et al., (2016):

“Absence of data does not indicate absence of DSL. Likewise, negative surveys do not definitively establish absence of lizards. Therefore, it would be inaccurate to assign unoccupied status to areas of suitable habitat where occurrence data are lacking. Even where thorough surveys and trapping have established that DSL are not currently present, DSL could move into or through areas of suitable habitat in the future. For this reason, historically- and recently- occupied areas are depicted as point and polygon locations on the Suitable Habitat map. We did not attempt to model historical, current, or predicted distribution, as information on DSL dispersal rates and patterns is scanty and occurrence data are incomplete, especially for private lands.”

The implications of incomplete occurrence data related to access to private lands is especially true for Texas and has hampered the systematic collection of data across the assumed range of DSL in Texas (e.g., see discussion Walkup et al., *in press*).

DSL Observations and Land Cover Change Detection

DSL observation data from New Mexico include 1278 DSL locations collected between 1961 to 2014. The reported underlying uncertainty distances for these DSL mapped locations ranged from 6 to 10,637 meters. We screened observations to remove any location data that could not be verified to be within a known location radius of six meters. The resulting 636 DSL locations collected between 2005 and 2014 were plotted on the 1-meter NAIP imagery corresponding to the closest year of data collection and compared to the locations plotted on the 2011 or 2014 NAIP imagery used in the New Mexico model. Each pairwise comparison was made at a 300-meter diameter sample plot to screen any DSL observations in which the land cover or vegetation had been altered between the date of collection and the NAIP imagery used in the New Mexico model classifications (see Figure 12). This would confirm that the landscape features extracted were actually representative of the year of detection and enable us to exclude any points where changes to the landscape since that original lizard detection had occurred so as to prevent bias to the subsequently extracted data.

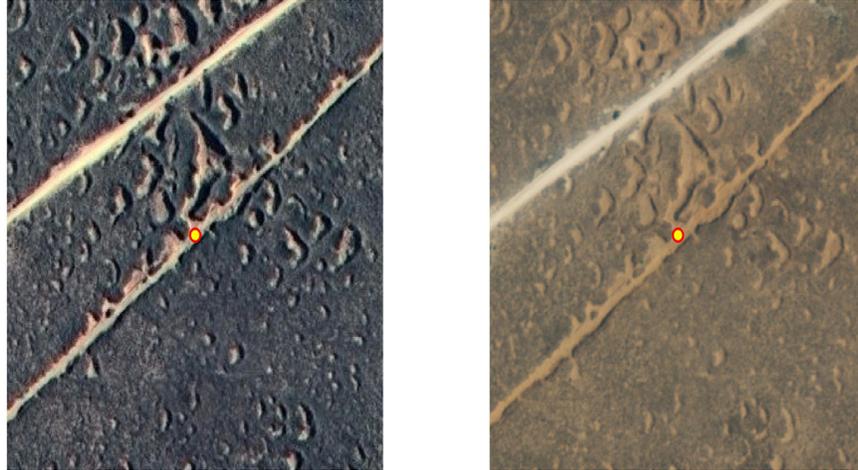


Figure 12. Example of temporal change detection assessment between date of collection and imagery used in DSL habitat model in New Mexico.

None of the 636 DSL locations were excluded based on these pairwise comparisons between dates of collection and imagery used in the development of the New Mexico DSL model. The 636 DSL locations were plotted onto the 1-meter New Mexico model habitat classification GIS layer and the corresponding habitat classes (i.e., map unit type) were then extracted using the point in polygon method in ArcMap 10.3. DSL locations were associated with several landscape features:

- Barren, sandy
- Blowout
- Blowout disturbed
- Dune
- Grassland
- Human disturbance
- Mesquite
- Mesquite shrubland
- Shin oak - mesquite duneland
- Shin oak - mesquite shrubland
- Shin oak duneland
- Shin oak shrubland

This review showed that the vast majority of DSL observations (98%) were found in Shinnery oak duneland and blows (inclusive within dunelands). This review clearly reinforced the dominance of landscape level features from known DSL locations throughout its range in New Mexico and provided the conceptual basis for delineation of landscape features in Texas.

Implications on DSL Habitat Modeling in Texas

We believe that occurrence for the species is likely to be determined in more counties than currently known within Texas, including Cochran, Yoakum, and more extensively within Andrews at the northern boundary of the county with Gaines County. Additionally, the detection of DSL in shinnery oak dunelands in New Mexico in 2012 that are adjacent to these habitat features in Cochran County Texas suggest that the potential for DSL occurrences some 80 miles north of Andrews and Gaines County is possible.

The Hibbitts map although generally based on delineation of landscape features, suffers from inconsistencies between polygon boundaries and the underlying landscape features. It also likely excludes potential DSL habitat both within its existing boundary as well as excluded areas north of Andrews and Gaines counties. The A&M suitability model is broadly similar to the Hibbitts map but is inconsistent spatially in defining DSL habitat in part due to the nature of the underlying data derived from 400 m² survey plots and subsequent use of 400 m² raster cells to do not maintain coherence with landscape features.

We note that the Hibbitts map as a derivative of Laurencio *et al.*, (2007) in which surveys at 27 locations with 3 DSL detections and data from Fitzgerald *et al.*, (2011) in which 28 DSL detections were obtained from 50 survey sites over an 8 day period represents a relatively small data set. The New Mexico DSL model clearly shows that designation of DSL suitable habitat in terms of landscape level features provides a pragmatic resolution over large spatial scales. The integration of land cover classification in terms of vegetation in conjunction with recognized landscape boundaries was effective in defining DSL habitat based on heads-up editing of classified imagery. We also note that the New Mexico model is supported by over a thousand DSL observations covering a wide spatial area and longer sampling periods compared to Texas.

Texas DSL model

The approach undertaken broadly parallels the analytical framework utilized in the development of the New Mexico DSL model (Johnson *et al.*, 2016) which relied on image classification and heads up editing to define landscape feature boundaries with relevance to DSL habitats. We extended the New Mexico approach by incorporation of image segmentation using Object Based Image Analysis techniques as noted below. Suitable DSL habitats types were derived from a cross walk of defined landscape features in New Mexico. The use of landscape features to define DSL habitat versus alternative analytical methods such as presence/absence models, is in part due to the lack of suitable DSL observation data within Texas that spans the range of available habitat types, the cryptic nature of the species, temporal variations in apparent abundance at specific locations and difficulties related to detection probabilities across most known habitat features utilized by DSL (Walkup *et al.*, *in press*).

The use of landscape level features is further supported by the fact that given habitat heterogeneity and DSL habitat specialization, individuals are distributed in patches across suitable habitat distributed within larger landscape features, and as found for many highly specialized species, areas of apparently suitable habitat are unoccupied. This also is reinforced by the likelihood that presently unoccupied but suitable habitat does not preclude its occupancy in the future as noted in Walkup *et al.*, (*in press*).

We adopted a landscape modeling paradigm that parallels the approach in Johnson *et al.*, (2016):

- (1) *define suitable and unsuitable DSL habitat by reviewing published literature, previous modeling approaches and consulting experts;*
- (2) *using remote sensing data, identify vegetation and other land cover types that provide the spatial and thematic foundation for a DSL habitat map in Texas,*
- (3) *conduct field reconnaissance to verify land cover types and provide quantitative data for the mapping process, and*
- (4) *create a DSL habitat map with map units and supporting spatial data layers relevant to the ecology of the DSL.*

DSL Habitat Suitability Categories

We adapted the New Mexico DSL habitat model definitions based on 'Suitable Habitat', that included four main map units. These landscape features all have documented DSL occurrence data. The first two landscape features represent essential DSL habitat associated with breeding, rearing, and foraging while the remaining two represent dispersal corridors when adjacent to the first two categories (Johnson et al., 2016; Painter 2004, Fitzgerald et al., 2005, Leavitt et al., 2011):

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.

Shinnery Oak Duneland (High Suitability)

It is widely reported that DSL are best described as a habitat specialist associated with open sand areas that are stabilized by shinnery oak (*Quercus havardii*). These areas have been identified as sites in which DSL forage, breed, and establish home ranges (Degenhardt *et al.*, 1996, Fitzgerald *et al.*, 1997, Snell *et al.*, 1997, Johnson *et al.*, 2016). At a landscape level, these areas are classified as shinnery oak duneland habitats in which the spatially included areas of wind-eroded open sand areas are referred to as 'blowouts'. These habitats are associated with the majority of existing DSL observational data from New Mexico as well as Texas. Given observation data, we have included large active dunes and barren sandy areas when an inclusion within this category.

Dunes

Systematic sampling of large open active dunes is very limited although both museum records and recent survey data clearly document DSL within the interior of large open dune fields (Figure 13). In most cases, DSL appear to be associated with proximity to shinnery oak patches (~1 to 2 meters) but not exclusively as shown the Figure 2x.



Figure 13. Example of Dunes Sagebrush Lizard (*Sceloporus arenicolus*) observation from interior of a large active dune.

Barren Sandy

These areas are represented by seasonally barren swales, dirt roads, pipeline scars, non-caliche road and drill-pad disturbance areas, especially when covered by windblown sand (Figure 14). When these areas are contained within or adjacent to larger landscape features they provide connectivity between other suitable habitats. It is interesting to note that a large number of DSL observations in New Mexico are represented by these features and likely related to DSL observability based on visual encounter surveys. These areas are considered inclusions to duneland and shrubland landscape features.

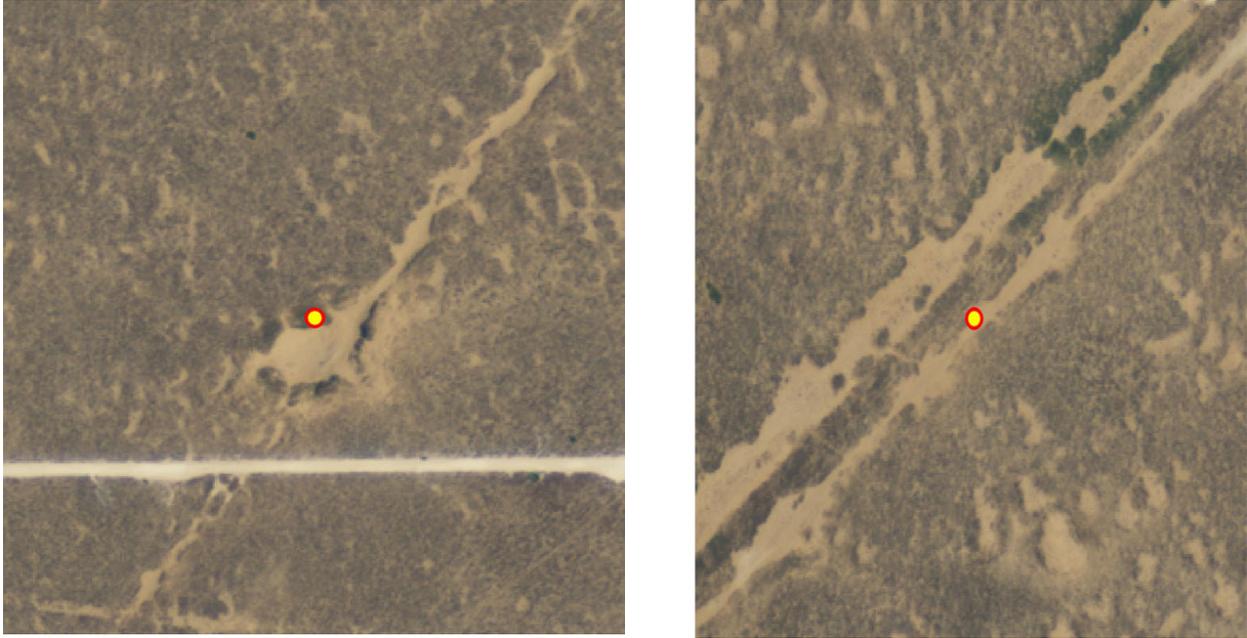


Figure 14. Examples of barren sandy features with observed use by Dunes Sagebrush Lizard (*Sceloporus arenicolus*).

Mixed attributes and ephemeral grasses and forbs

In addition, site level descriptions associated with DSL detections suggest somewhat wider characteristics than 'shinnery oak dunelands'. A careful review of individual site descriptions associated with DSL detections from Fitzgerald et al., (2011, Table 2) indicates:

- Shinnery oak, mixed grasses, mesquite
- Shinnery oak; blowouts lacking; open sand between dunes flat and with mesquite, grasses, and tamarisk
- Shinnery oak habitat near Hwy best habitat but dry and sparse south; open areas dominated by mesquite, grasses and soapberry
- Shinnery oak extensive; large, open blowouts with numerous grasses; mesquite sparse
- Shinnery oak; extensive dunes and blowouts; mostly open but some with extensive grasses and mesquite
- Shinnery oak; large dunes with grasses in bottom of blowouts
- Large open sandy area with small band of shinnery oak around the edge
- Shinnery oak dunes good habitat; grasses abundant in blowouts; mesquite hummocks
- Shinnery oak dunes isolated; mixed with shinnery oak flats; oil and gas development dense in area
- Shinnery oak extensive; large, open dunes with large blowouts surrounded by numerous grasses
- Shinnery dunes with big blowouts, some of the largest blowouts with mesquite at bottom

These descriptions highlight that defining habitat suitability for DSL based on remotely sensed imagery needs to consider inclusions of other vegetation such as mesquite, grass and forbs. It is also noted that use of remote sensing data may reflect differential attributes of grass and forb coverage in sand blowout areas depending on image collection dates and antecedent climatic conditions such as drought versus wet periods as illustrated in Figure 15.

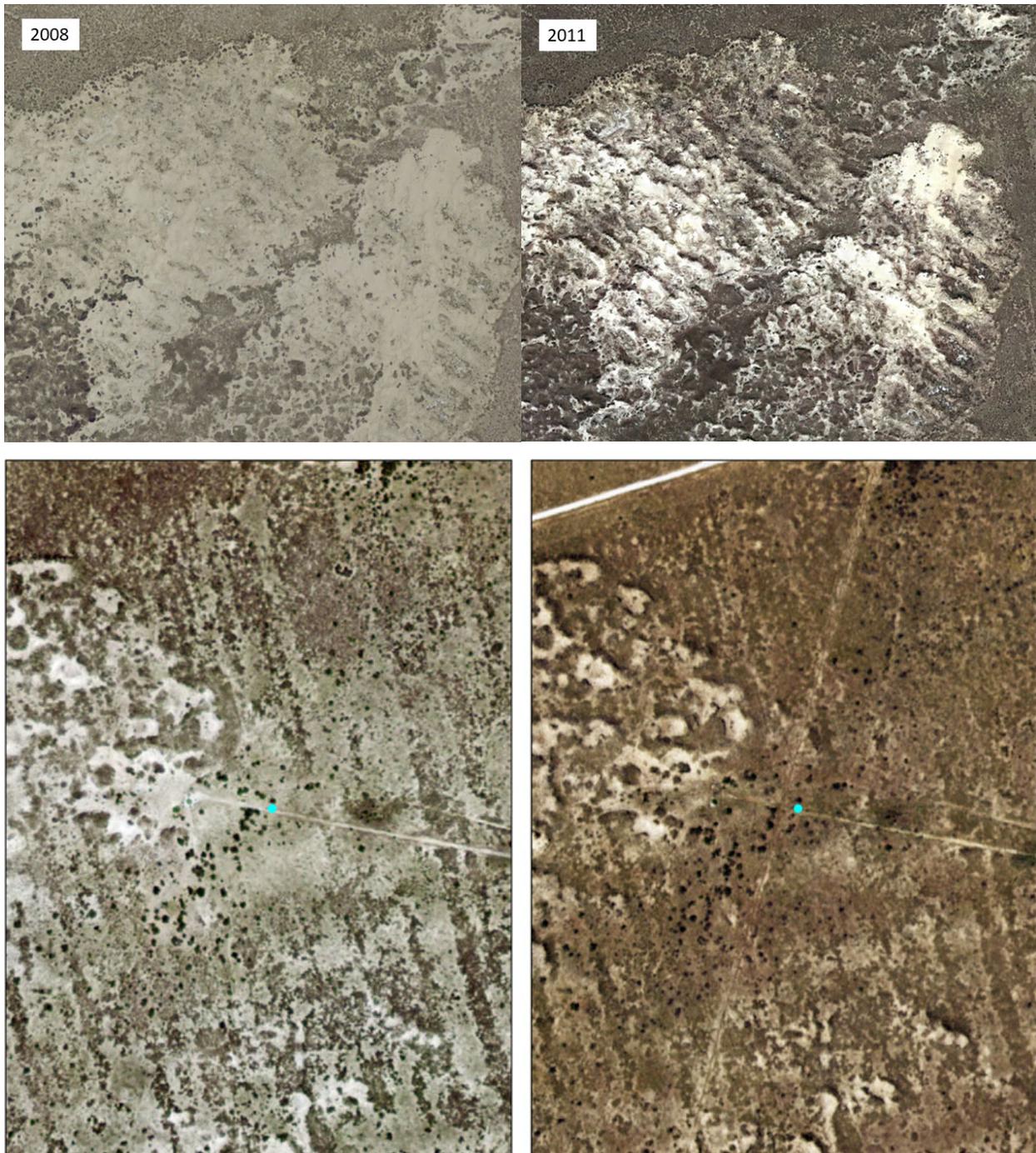


Figure 15. Example of differential grass and forb coverage in response to antecedent moisture conditions in a shinnery oak dune complex of west Texas.

Shinnery Oak – Honey Mesquite Duneland (Intermediate I Suitability)

Johnson *et al.*, (2016) cite C. Painter (pers. Comm.) that DSL have been found within Shinnery Oak dominated dunelands with honey mesquite (i.e., Shinnery Oak – Honey Mesquite Duneland landscape features). We include barren sandy areas when they exist as an inclusion within this category. Johnson *et al.*, (2016) note that it is uncertain at what density of honey mesquite might become a limiting factor to DSL. Quantitative assessment of the percent honey mesquite

versus locations with and without DSL detections suggest that when the percent aerial coverage of mesquite at a study site (400 m²) is greater than about 5 percent there appears to be reduced detections of DSL (Figure 16).

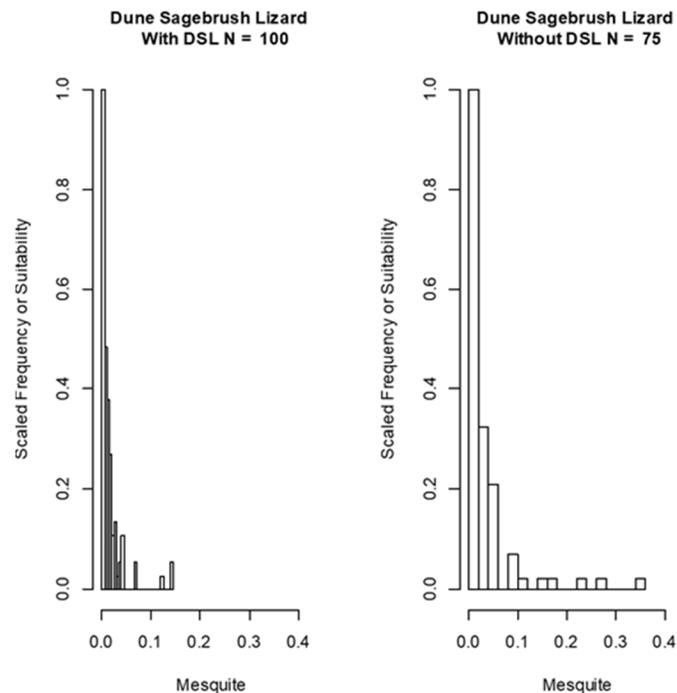


Figure 16. Scaled frequencies of the percent mesquite at sample plot with and without *Sceloporus arenicolus* detections (from Texas A&M AgriLife Research 2016).

Based on these data, we set the threshold for mesquite at 5 percent for classification of this landscape feature. We also note that this landscape feature can have inclusions of dunes and barren sandy areas.

Shinnery Oak Shrubland/Flats (Intermediate II Suitability – Dispersal Habitats)

Most studies report that DSL are almost exclusively found within shinnery oak duneland habitats and specifically located in or immediately adjacent to blowouts. For example, Fitzgerald *et al.*, (2005) reports that 90% of 169 DSL captures were within 20 meters of a 5 meter diameter blowout, while 40% were located within a blowout or less than three meters from a blowout. However, it should be noted that a careful examination of Fitzgerald *et al.*, (2005) indicates that the pit fall trapping transects “... ***provided good trapping coverage of all the habitats in the study area including edges of dune complexes, areas of shinnery oak flats, and sand dune blowouts (emphasis added)***”. DSL were captured in all sampled habitat types (except transect 8 which was an area treated with tebuthiuron herbicide) which included shinnery oak flats (Fitzgerald *et al.*, (2005); Table 3). Their radio tracking data also documented a female traversing ~200 meters of shinnery oak habitat including shinnery oak flats and returning to her home range two days later assumed to be related to an egg laying event and not a dispersal event. Although these movements across non-shinnery oak dune blowout habitats occur, they appear to be rare. However, we note that extensive radio tracking or pit fall trapping within these habitat types is very limited in spatial scope or temporal breadth and represents an important applied research question. Field surveys conducted in 2017 by Texas State University also documented a DSL utilizing a shinnery oak flat in association with a shinnery oak

duneland complex (M. Forstner, unpublished data). Johnson et al., (2016) consider shinnery oak shrubland (flats) to represent dispersal habitat for juveniles and females seeking egg deposition sites and is supported by observations in Fitzgerald et al., (2005) and Painter (2004).

The Spatial Context and Characteristics of Dispersal Habitats

The importance of other landforms such as shinnery oak – honey mesquite dunelands, shinnery oak shrublands, and the spatial context of specific barren/grassland features (i.e., located between shinnery oak duneland areas) have been identified as important landcover components related to dispersal (Painter 2004; Johnson et al., 2016; Dunes Sagebrush Lizard Research Team (DSLRT) 2016). DSLRT cites to the Texas Conservation Plan (TCP) use of a 200 meter buffer around suitable habitat to protect dispersal corridors which effectively connects two habitat patches separated by 400 meters. Based on guidelines developed by Painter (2004), Johnson et al., (2016) considered potential dispersal corridors of shinnery oak shrublands that are 500 meters wide connecting patches of shinnery oak dunelands that were within 2,000 meters. Johnson et al., (2016) specifically note:

Painter's recommendation is justified based on monitoring data from pitfall traps, which suggest that shinnery "flats" (the Shin-oak Shrubland map unit) are important as dispersal corridors for juvenile DSL and females seeking egg deposition sites. In addition, experts consulted by Painter (2004) suggested that it would be imprudent to consider any currently unoccupied patch of suitable habitat (Shin-oak Duneland and appropriately located patches of Shin-oak Shrubland) within the overall range of the species or along the edge of the range as being useless to DSL.

In addition, use of these 'dispersal habitats' has been suggested to relate to gene flow between isolated DSL populations. These dispersal mechanisms through these habitats include rare occasional long-distance dispersal movements and more common shorter movements by multiple individuals over moderate distances. As noted by Chan et al., (2009):

Whether gene flow is maintained by cumulative shorter movements of many individuals across generations, longer dispersal of individuals, or both, preservation of large tracts of shin-oak habitat with blowouts are necessary to "maintain historical levels of connectivity, prevent local extinction, and avoid the loss of genetic diversity due to genetic drift in reduced populations"

Chan et al., (2009) provides a measure of genetic exchange and thus an indication of dispersal movement characteristics over thousands of years and indicates connectivity that minimally encompasses at least 9 miles. This underscores the need to consider the spatial context of identification of dispersal corridors that maintain spatial connections between 'islands' of suitable DSL habitat (i.e., shinnery oak duneland and shinnery oak – honey mesquite duneland) by protecting shinnery oak shrubland (flats) patches.

Shinnery Oak - Honey Mesquite Shrubland and Grasslands [Low Suitability]

This landscape feature has co-dominate shinnery oak and mesquite on flat or undulating topography often as a transition between Shinnery Oak shrubland and Mesquite shrubland at the margin of shinnery oak dominated duneland habitat. This is categorized as low suitability habitat only when in spatial contact with adjacent shinnery oak duneland and shinnery oak – honey mesquite duneland as it has the potential to function as dispersal habitat.

Shinnery Oak Dynamics

Inclusion of shinnery oak – honey mesquite shrublands are in part considered based on Dzialak *et al.*, (2013) who documented the dynamic nature of shinnery oak over decadal periods within New Mexico and Texas. These landscape features are dynamic and responsive to prevailing wind patterns, moisture gradients, elevation gradients, sand availability and anthropogenic disturbance. Shinnery oak – honey mesquite shrublands as well as other identified features can and have changed their characteristics and spatial distributions. Patch size and total extent of shinnery oak complexes increased between 1986 to 2011 in Texas but decreased in New Mexico. However, patch isolation increased in Texas during this same time period. The dynamic nature of these systems was attributed to:

“Prevailing wind and gradients in moisture and elevation establish an annual resultant drift potential in eastern and northeastern portions of the system (Muhs and Holliday 2001) which, in turn, influences the spatial distribution of sand shinnery oak as well as local features, such as dune blow-outs, nested hierarchically within the shinnery oak system.”

Obviously patch isolation has implications on DSL dispersal mechanisms and therefore protection of dispersal habitats is important especially when considering increasing patch isolation. They also note that loss of shinnery oak tended to occur in smaller more isolated patches which highlights the concerns related to habitat fragmentation.

Study Area – Priority Quads

The initial modeling effort was confined to 31 quadrangles selected to cover the current TCP permit area (Figure 17). Additional quads covering the likely expanse of the potential DSL range in Texas are being processed for inclusion in the Beta Texas DSL model. Identification of these additional quads is utilized the results from Dzialak *et al.*, (2013), overlays of suitable soil and geology layers and visual inspection of landscape features using a variety of available remote sensing imagery.

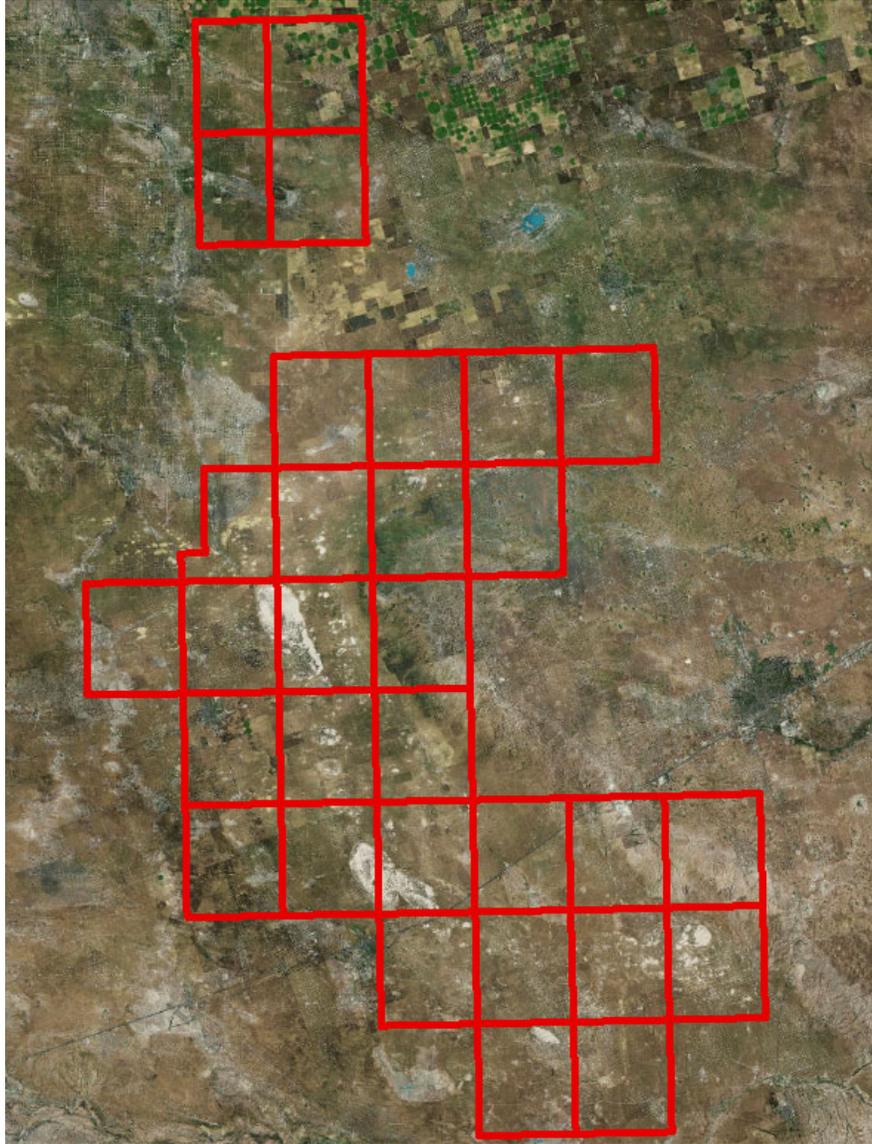


Figure 17. Texas *Sceloporus arenicolus* model spatial extent showing the location of the priority quads analyzed for the Alpha version of the model.

Source Imagery

We utilized 1-meter resolution National Agricultural Imagery Program data from 2016 (NAIP2016) comprised of 4 spectral bands (Band 1-Red; Band 2-Green; Band 3-Blue; Band 4-Near Infrared). Although imagery from other remote sensing platforms were available, NAIP imagery was utilized to remain consistent with base imagery used in the New Mexico DSL model.

We mosaiced each NAIP2016 7.5' quarter quad tiles into single 7.5' quads and computed and stored as 8-bit unsigned integer the associated NDVIs for each quad using Equation 1:

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

Suitable Soils

To reduce both processing time and constrain the spatial coverage, the United States Department of Agriculture Natural Resources Conservation Service 1-meter Soil Survey Geographic Database (SSURGO) for the project area was used to clip NAIP imagery to remove unsuitable soil/land cover classes from the analysis. This approach parallels Ryberg et al., (2016) to use soils to remove unsuitable DSL habitat. Available literature on suitable soil properties and previous modeling results for DSL habitat based on incorporating suitable soil layers in the analysis were used as an initial guideline (Johnson et al., 2016; Fitzgerald et al., 2011; Hibbitts based TCP Permit Area/Likelihood of Occurrence Map; Texas A&M AgriLife Research, 2016). An iterative procedure was used to systematically exclude soil classifications and compare the remaining spatial areas against previous modeling results as well as the NAIP2016, Google Earth and ArcMap imagery. Given differential classifications of soil types by county, exclusion of soil types was conservative (i.e., soil types were retained if exclusion would eliminate potential DSL landscape level features). The final soil type classifications used to mask the NAIP2016 imagery are provided in Table 2.

Table 2. Final SSURGO soil types retained in the development of the Texas DSL habitat model.

US_L4NAME	Common Name
Arid Llano Estacado	High Plains: Active Sand Dunes
Arid Llano Estacado	High Plains: Sand Prairie
Arid Llano Estacado	High Plains: Sandhill Shinnery Duneland
Arid Llano Estacado	High Plains: Sandy Shinnery Shrubland
Chihuahuan Basins and Playas	High Plains: Active Sand Dunes
Chihuahuan Basins and Playas	High Plains: Sand Prairie
Chihuahuan Basins and Playas	High Plains: Sandhill Shinnery Duneland
Llano Estacado	High Plains: Active Sand Dunes
Llano Estacado	High Plains: Sand Prairie
Llano Estacado	High Plains: Sandy Shinnery Shrubland
Shinnery Sands	High Plains: Active Sand Dunes
Shinnery Sands	High Plains: Sand Prairie
Shinnery Sands	High Plains: Sandhill Shinnery Duneland
Shinnery Sands	High Plains: Sandy Shinnery Shrubland

During delineations of defined Landscape Feature classes within the Texas DSL habitat model, the 'barren' soil type classification was manually included when the ground based soil polygon was in fact sand and/or a dune feature rather than unsuitable barren areas.

Segmentation

Object-based image analysis (OBIA) is a technique used to group pixels into representative sizes and shapes. The approach is often favored over pixel-based analysis because it generates objects (i.e., homogenous pixel groupings) of varying scales within an image that represent meaningful features in an image. OBIA is a two-step process: first, an image is segmented into pixels that share similar spectral and spatial characteristics, and then the segments are classified according to a relevant land cover classification. In this case, we

implemented the first step of OBIA by segmenting the NAIP imagery using the Large Scale Mean Shift (LSMS) algorithm.

The LSMS algorithm generates a vector data file (i.e., a shapefile) that contains segments as discrete spatial objects which share similar spectral properties based on radiometry (e.g., brightness values) within a variable search neighborhood. LSMS works by specifying a range radius, spatial radius, and a minimum segment size. The range radius is a threshold on spectral signature Euclidean distance used to compare neighboring pixels for segment inclusion. Specifying higher values for range radius results in increased smoothing between landscape features since pixels can have much higher or lower spectral values compared to neighboring pixels. In other words, a high range radius value will result in the loss of edges associated with the matrix of cover types in an image. A low range radius value will result in less smoothing (averaging) of pixels within a segment and can produce additional noise (i.e., false edges between landscape features that aren't ecologically-relevant). A challenging component of image segmentation is selecting an appropriate range of spectral values that completely captures landscape features without including too many landscape features in the same segment.

The spatial radius parameter corresponds to the radius of a moving spatial neighborhood used for averaging pixel values considered for segment inclusion. Higher spatial radius values result in increased smoothing and greater processing time because a large neighborhood (the number of pixels surrounding a central pixel) includes more pixels for Euclidean distance comparisons considered by the range radius. The two radius parameters are essential for extracting meaningful segments that correspond to scale-relevant landscape features (e.g., dune blowouts, mesquite trees, shinnery oak patches, etc.). Pixels are included in segments if they are within the spatial radius (e.g., within five pixels of a central pixel of interest) and the average value for the neighborhood does not exceed the range radius). It is important to note that the neighborhood associated with the spatial radius "moves" across and down the image as the algorithm segments the imagery.

The final parameter is the minimum segment size. This criterion is applied after the initial segmentation to ensure small segments are not included in the final output vector file. If, after segmentation, the number of pixels in a segment is lower than the specified value, the small segment is merged with an adjacent segment that has the closest spectral value. After several trial runs using NAIP quads with different land covers and landscape configurations, we applied a range radius of 10, spatial radius of 5, and a minimum segment size of 1000 (Figure 18). These parameters provided us with the most ecologically-relevant segmentation across all NAIP images comprised of different cover types and configurations. The algorithm was run as a batch process using by running a Python script within the OrfeoToolBox environment.

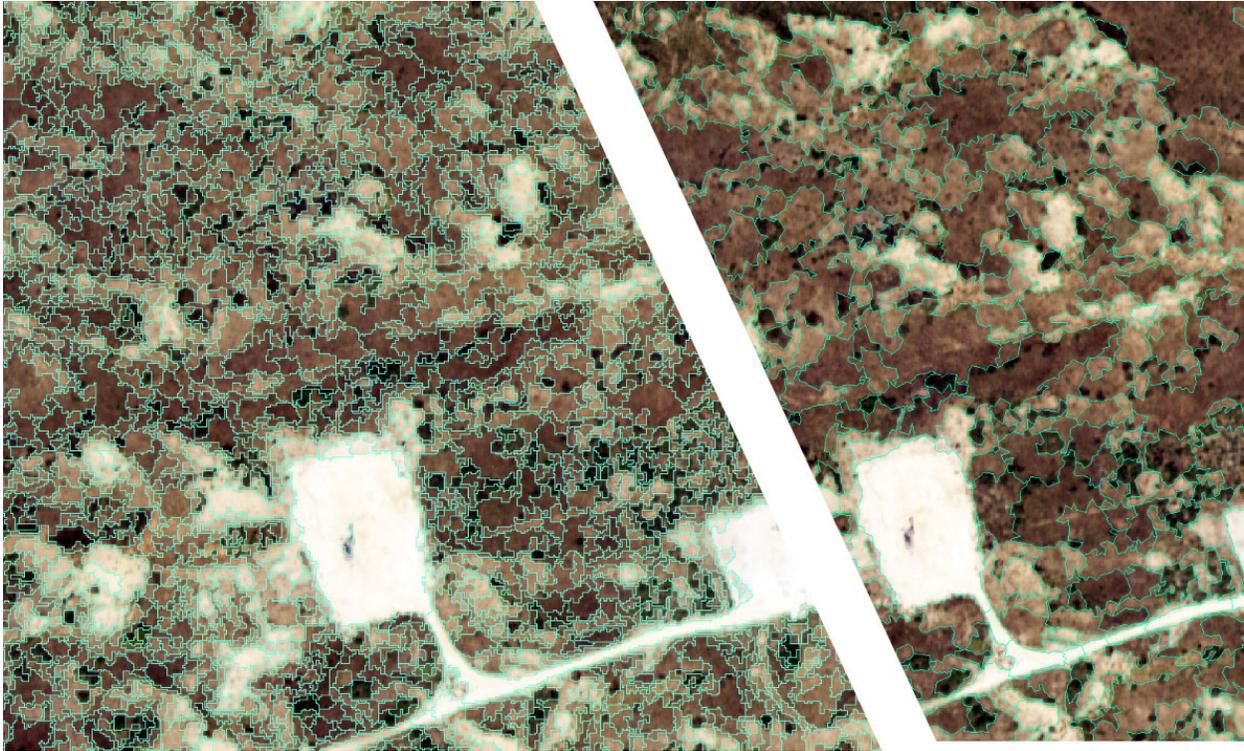


Figure 18. Example of fine scale (left) versus coarser scale (right) segmentation results.

Unsupervised Classification

Image classification allows analysts to convert spectral values in an image to meaningful cover class information. In general, image classification can be grouped into two different methods: supervised and unsupervised. Using supervised classification, the analyst identifies pixels of known land cover types to train a specific algorithm to recognize similarities in pixel spectral properties. The output of a supervised classification is a fully-classified land cover map. The NAIP2016 imagery is not radiometrically corrected and a wide variance in radiometric properties were evident across the project area. Preliminary supervised classification results using the collected ground truth data from drone imagery did not produce satisfactory results. This was due to the wide variance in radiometric properties between NAIP2016 imagery throughout the study area and constraints on ground truth data collection that was specifically tied to selected lizard survey plots. Survey plots targeted landscape features associated with Low to High DSL suitable habitat conditions across the range of the species in Texas constrained by land access. Drone based ground truth data also served the dual purpose to obtain a digital record of the lizard survey sites and used to overlay survey tracks to estimate aerial coverage of survey site characteristics. Vegetation and land cover type ground truth data were collected from each survey plot independent of the lizard survey tracks.

Unsupervised classification takes a different approach to data-to-information conversion. Using unsupervised classification, the image is processed using a clustering algorithm that groups pixels that share similar spectral properties into discrete classes. After the clustering process, the analyst then labels the output clusters based on the land cover classification used for the project. We implemented the Iterative Self Organizing Data Analysis Technique Algorithm (ISODATA) to perform unsupervised classification of pixels in the NAIP imagery.

ISODATA works by first calculating the mean and standard deviation of the input layers and orienting initial cluster centers along this arbitrary axis. The number of cluster centers is specified by the user prior to running the algorithm. We selected a range of 70-100 clusters to account for the number of land cover classes, spectral variability within the same land cover class, and the differences in image acquisition conditions (e.g., time of day and day of year). Once the initial axis is computed, image pixels are added to existing clusters based on the minimum distance to a cluster average. During this process, cluster averages are recomputed as pixels can move from one cluster to another if the minimum distance is less than the previous cluster assignment. This process continues until one of two conditions is met; the convergence threshold is achieved, or the algorithm run a specified number of iterations.

The convergence threshold refers to the number of pixels that must remain in their assigned cluster between iterations. Convergence ranges from 0-1, where 0 means that all pixels changed clusters and 1 means that all of the pixels remained in the same cluster between iterations. A higher convergence threshold indicates better spectral stability (i.e., well defined and stable clusters). The number of iterations refers to how many times pixels are added to recalculate cluster means. In general, it is desirable to have more iterations than necessary because the convergence threshold needs to be met before the algorithms stops processing. Once either condition is met, all remaining pixels are assigned to a cluster based on the minimum distance to means decision rule. For this project, we specified a convergence threshold of 0.98 and 100 iterations.

Ground Truth Data and Land Cover Recoding

Ground truth data was collected at 73 different 400 m² plots using a Phantom Pro quadcopter during 2017. Image resolution was 1-5cm/pixel. At each site, GPS was used to mark replicate vegetation, different sand properties, well, roads, etc. (Figure 19). An additional GPS enabled 123 ground based photos were collected in June 2018 to assist in land cover recoding of classified imagery (Figure 20). Attempts were made to utilize the Texas A&M vegetation ground truth data (1895 points) but was abandoned given apparent issues with the reported survey point location data. This included points with a specific designated attribute (e.g., caliche) plotting onto a different ground based attribute in the imagery and in several cases the indicated coordinates plotted outside of Texas (e.g. Mexico). Repeated attempts at coordinate transformations were unable to rectify these spatial issues.

Additional drone imagery from 28 sites were collected in 2018 containing 656 total ground truth points with an average of 24 points per sample location. Additional sites for drone flights are targeted for fall 2018 and spring 2019 to support model validation as part of the Beta Texas DSL model development.



Figure 19. Example of drone imagery outlining survey area (left) and example vegetation ground truth points (right).



Figure 20. Example of ground based ground truth imagery.

After the ISODATA algorithm clustered pixels into spectrally-similar groups, each cluster was recoded to a land cover class based on drone imagery, supporting ground truth data, and visual image interpretation. Final land cover classes were recoded into eight categories (Figure 21):

1. Developed/Caliche/Disturbed - Includes well pads, caliche roads, silage ponds, areas in preparation for development
2. Sand
3. Mesquite
4. Shinnery Oak

5. Other vegetation - Includes Rabbit brush, sagebrush, cactus, yucca, etc. which are only distinguishable when they occur in relatively large patches separate from mesquite, shinnery oak, and grass
6. Cultivated - Includes plant-based agricultural croplands (both active and fallow)
7. Barren/Gravel - Includes areas with very sparse vegetation that isn't sand;
8. Water

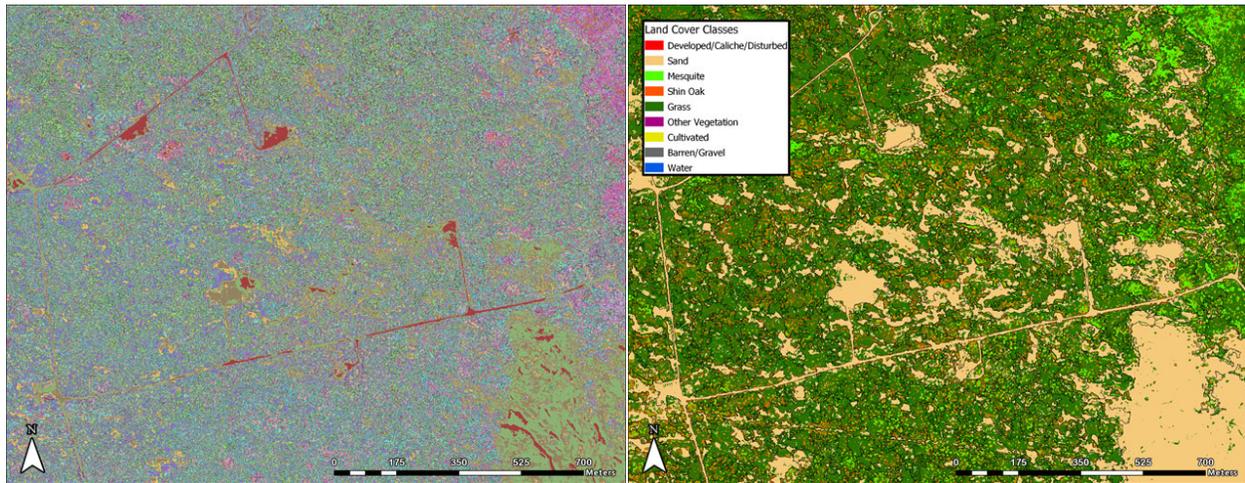


Figure 21. Example of initial ISODATA classification results (left) and subsequent land cover recoding (right).

Accuracy Assessment

To provide an assessment of the accuracy of the land cover classification, a mosaic of the individual classified maps will be created to provide a comprehensive map of the study area. Ground truth data from drone imagery collected during 2017 and 2018 and the supplemental ground based photography are being used for preliminary accuracy assessments. In addition, ground based photo and drone flights will be targeted for the fall of 2018 and spring of 2019 based on the preliminary accuracy assessment results. The accuracy assessment follows standard assessment protocols (Jensen 2005), where sample size is determined by an objective statistically-derived sample size using (Congalton et al. 1983) to obtain a classified map accuracy of 85% with a 10% allowable error. Final accuracy statistics will include overall accuracy and Kappa coefficient of agreement as well as user and producer accuracies.

Delineation of Landscape Features and Initial Validation

The combination of segmentation and recoded vegetation classification were used with heads up editing paralleling the New Mexico modeling approach to define the boundaries of these DSL habitat polygons (High, Intermediate I and II, and Low categories).

Once the polygons boundaries and categories were assigned, 25 percent of the Fitzgerald et al., (2011) DSL detection locations were randomly extracted and projected onto the polygon layer. We gave deference to use of DSL detections given the documented low probability of detection by habitat types and temporal variability (intra- and interannual). DSL locations (polygon location and category) were reviewed by Forstner in light of previous survey experience and published records. Based on this preliminary review, adjustments to some polygon boundaries and suitability categories were made. Once this step was completed, the remaining DSL location data from Texas were overlaid on the map polygons. Of the 75 percent

of DSL locations utilized from recent collection efforts, all but three were contained within the High habitat classification while the remaining three locations were contained in the Intermediate I category. No DSL locations were found in Intermediate II or the Low quality habitat categories. This was expected given use of DSL known detections. However, we note that DSL detections are known from Intermediate II and Low habitat suitability classes from historical collection and museum records. Collections records from New Mexico are also known to occur in these later two categories.

The Alpha DSL habitat suitability map (Figure 22) is expected to be refined based on additional ground truth data to resolve classification uncertainties in some areas as well the inclusion of the remaining quads being analyzed. We also anticipate that some polygons may change categories based on updated ground truth data from areas lacking ground truth data. Access to these sites are being sought and are targeting larger spatial areas in which no ground truth are currently available or where the accuracy assessments suggest additional data would improve the classification accuracy. Additional modifications are possible based on the outcome of the connectivity analysis which may modify the spatial extent of some designated dispersal corridors or changes necessary due to the degree of habitat modification from well pad/roads and/or treatment areas.

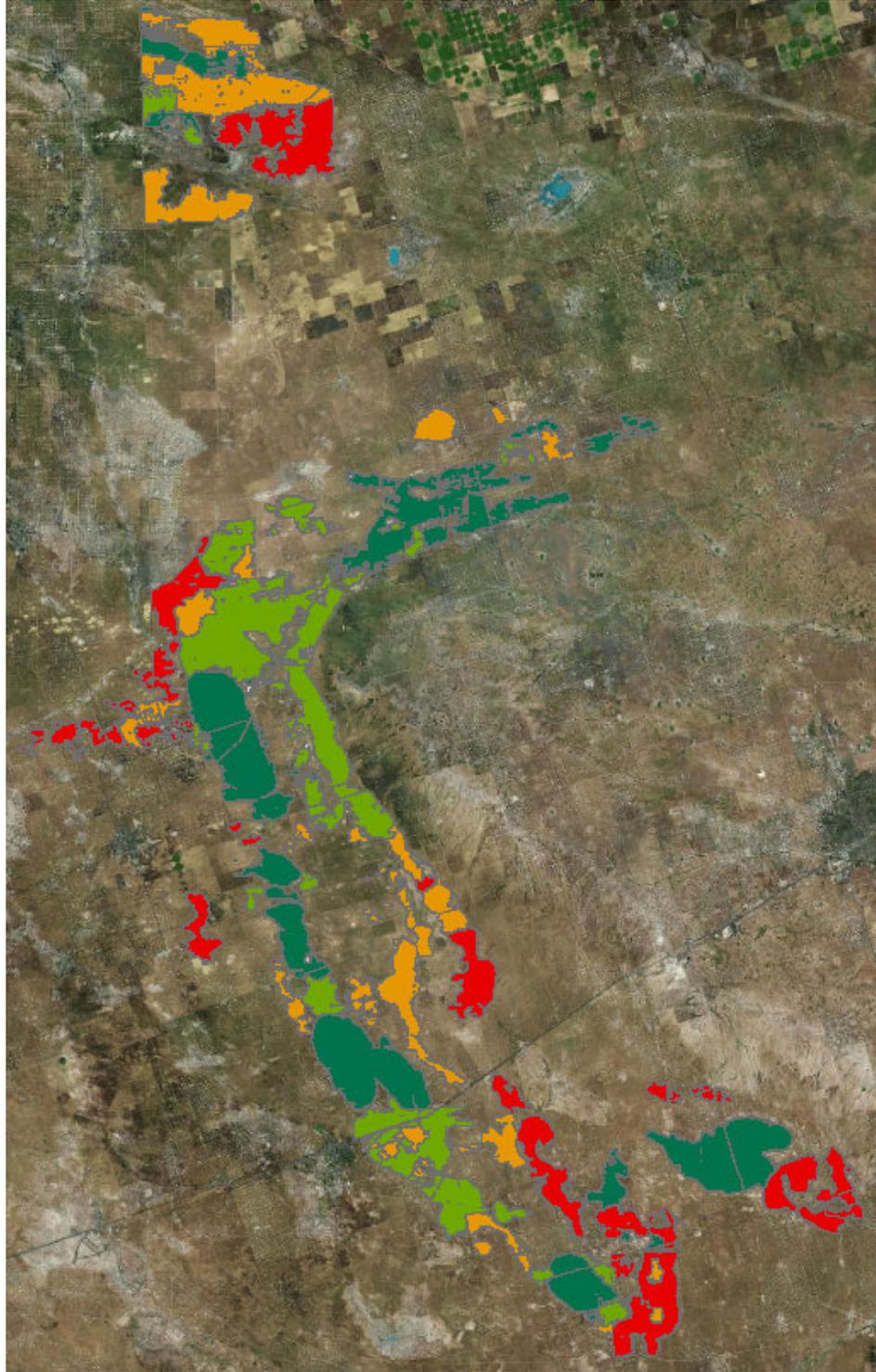


Figure 22. Alpha Dunes Sagebrush Lizard (*Sceloporus arenicolus*) habitat suitability map. Dark green = High suitability, Light Green = Intermediate I suitability, Orange = Intermediate II suitability, Red = Low suitability).

Table 3 shows a comparison between the Hibbitts, Texas A&M, and the Texas DSL habitat model acreage by the equivalent habitat categories.

Table 3. Acreage of the Hibbitts, Texas A&M, and Texas DSL habitat model by equivalent habitat category designations.

	Hibbitts Likelihood	Proportion	A&M Suitability	Proportion	TxState	Proportion
Very High	64293	0.33	79548	0.17	90308	0.31
High	31876	0.16	42858	0.09	64790	0.23
Low	32572	0.16	56775	0.12	63081	0.22
Very Low	68865	0.35	279921	0.61	69148	0.24
Total	197606	1.00	459102	1.00	287327	1.00

Summary

The existing modeling effort identified key landscape level features associated with DSL habitat suitability that parallels the modeling of suitable DSL habitat conducted in New Mexico. Identification of high, intermediate I and II and low categories help prioritize conservation measures for the DSL that are directly related to key habitats and DSL life history requirements. We believe the shift in proportion in the habitat categories modeled by Texas State represents a more detailed delineation and hence, more realistic evaluation of the importance of these different habitat suitability categories compared to previous modeling efforts (Table 3).

The modeling includes consideration of the dynamic nature of the shinnery oak ecology that is dynamic over space and time throughout Texas and recognizes a general trend for increased isolation of patch sizes that highlights the need to consider dispersal corridors as part of conservation measures. The recognition that patch size is dynamic and isolated patches of shinnery oak have been shown to be at risk of loss underscores the importance of protecting larger scale landscape features of suitable DSL habitat represented by our defined DSL habitat suitability.

We believe that protection of high and intermediate I and II habitats are a priority given the degree of existing and projected habitat fragmentation. This is particularly relevant in minimizing habitat fragmentation of high and intermediate I habitat categories. This also recognizes the observed increased shinnery oak patch size isolation in Texas over the last three decades.

Modeling results provide a spatially explicit delineation of landscape level features that provide the spatial context to protect ecologically relevant habitat patches. This includes the articulation of dispersal habitats necessary to protect the long-term genetic integrity of DSL populations in Texas.

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Appendix A: DSL Habitat Type Examples

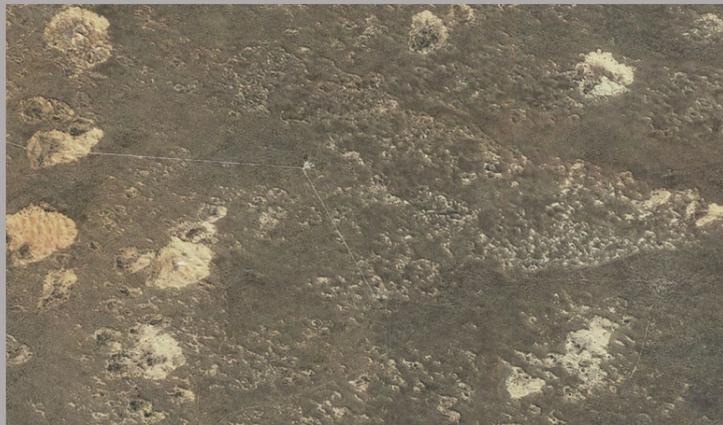
Shinnery Oak Dunes



Shinnery Oak Dunes



Shinnery Oak Dunes



Shinnery Oak Flat



Shinnery Oak Flat



Shinnery Oak/Grass Flat



Shinnery Oak/Grass Flat



Shinnery Oak/Mesquite Dunes



Shinnery Oak/Mesquite Dunes



Shinnery Oak/Mesquite Dunes



Mesquite Flat



Mesquite Flat



Mesquite/Grass Flat



Mesquite/Grass Flat

