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Occupancy and Detection of an Endemic Habitat Specialist, the Dunes Sagebrush Lizard (*Sceloporus arenicolus*)

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***Abstract*.—We estimated occupancy and extinction probabilities for the Dunes Sagebrush Lizard (*Sceloporus arenicolus*) for part of its range in Texas, to increase our understanding of the distribution of this species and to evaluate the map that identifies areas according to Very High, High, Low, and Very Low categories of likelihood-of-occurrence. This map, developed using expert opinion, has been vital in establishing conservation policies for the species under the Texas Conservation Plan. From May to August 2014–2016, 100 16-ha sites were surveyed by crews of four observers who searched each quadrant of the sites for all lizards. Lizards were identified to species and GPS locations were recorded for Dunes Sagebrush Lizards. Over 336 surveys, 33 Dunes Sagebrush Lizards were detected during 17 surveys at nine sites in areas classified as Very High likelihood of occurrence. Occupancy probability for the Dunes Sagebrush Lizard in the Very High likelihood-of-occurrence areas was 0.32 ± 0.09 (SE), with a detection probability of 0.52 ± 0.12. Local extinction probabilities were low at 0.12 ± 0.18, with the colonization probability fixed at zero. No Dunes Sagebrush Lizards were detected in the 54% of surveys that occurred outside the currently recognized range. Thus, we are confident in the described range boundaries of the Dunes Sagebrush Lizard. The consistent predictability of occurrence of the Dunes Sagebrush Lizard in likelihood-of-occurrence areas rated Very High suggests recovery and conservation actions in areas that have the highest likelihood of occupancy should have highest priority.**

Key Words.—biodiversity surveys; candidate conservation agreement; endangered species; geographic distribution; geographic range; oil and gas development; Mescalero-Monahans Sandhills ecosystem; Texas Conservation Plan

Introduction

Estimating population parameters of squamates corrected by detection probabilities increasingly has been suggested as important (Refsnider et al. 2011; Durso and Seigel 2015). Squamates have experienced population declines as a result of many causes, including habitat loss and degradation (agriculture, natural resource use, and urban development), pressure from invasive species, and resource harvesting (Gibbons et al. 2000; Böhm et al. 2013; Fitzgerald et al. 2018). Although population declines may be pervasive, they are also hard to detect because reptile population abundances can vary widely over time from natural causes (Fitzgerald 1994; Mazerolle et al. 2007; Hibbitts et al. 2009). Temporal variation in the abundance or occurrence of reptile populations is notoriously stochastic and presumed to be associated with fluctuating environmental conditions (e.g., drought) or variable resources (Dunham 1981). Determining whether a decline is part of natural population fluctuations or driven by human activities poses a challenge for species conservation (Gibbons et al. 2000). Indeed, without baseline data and repeated monitoring to estimate detection probabilities, occupancy, and population parameters, population declines can go undetected until it may be too late to recover the species (Tuberville et al. 2000; Winne et al. 2007; Hibbitts et al. 2009).

Occupancy modeling accounts for imperfect detectability when documenting the presence and absence of species (MacKenzie et al. 2002, 2003). By including detection probability as a parameter, these models address some biases in parameter estimation that occur under the assumption of perfect detection (MacKenzie et al. 2002; Gu and Swihart 2004). This assumption has been shown to be especially problematic for cryptic species with secretive natural histories (Mazerolle et al. 2007). For lizards in particular, occupancy modeling has been used with great success to evaluate the effects of different habitat management practices on populations. For example, Blevins and With (2011) found Eastern Collared Lizards (*Crotaphytus collaris*) had higher occupancy in watersheds that were burned frequently, compared to those that were grazed or not burned. Occupancy modeling has also been used to guide management protocols for species such as the Christmas Island Blue-tailed Skink (*Cryptoblepharus egeriae*; Smith et al. 2012) and the Flat-tailed Horned Lizard (*Phrynosoma mccallii*; Leavitt et al. 2015). Occupancy modeling coupled with population abundance estimates has also proven useful in describing the establishment and dispersal of species, as in the case of the St. Croix Ground Lizard (*Ameiva polops*) that was translocated to Buck Island National Monument, U.S. Virgin Islands (Fitzgerald et al. 2015; Angeli et al. 2018). Aside from these cases, occupancy and detection probabilities have not been reported for most lizard species of conservation concern. For example, while the geographic range and distribution of the Dunes Sagebrush Lizard (*Sceloporus arenicolus*) has been well established (Fitzgerald, L.A., C.W. Painter, D.S. Sias, and H.L. Snell. 1997. The range, distribution and habitat of *Sceloporus arenicolus* in New Mexico. Report submitted to New Mexico Department of Game and Fish. Available from http://www.bison-m.org/documents/24183_Fitzgeraldetal1997.pdf. [Accessed 16 June 2018]), estimates of occupancy and detection have not been previously determined.

The Dunes Sagebrush Lizard is a habitat specialist, endemic to the Mescalero-Monahans Sandhills ecosystem of west Texas and southeast New Mexico, USA. It prefers large, contiguous areas of Shinnery Oak (*Quercus havardii*) dunes, and selects large, deep blowouts with steep sides (Fitzgerald and Painter 2009; Smolensky and Fitzgerald 2011; Hibbitts et al. 2013). Throughout the range of the species, its presence is associated with areas where sand is composed of relatively high proportions of medium or coarse grains (Ryberg et al. 2012, 2015). Research on population dynamics and dispersal patterns revealed that Dunes Sagebrush Lizard populations exhibited source-sink dynamics across contiguous expanses of dunes, and the vital rates of Dunes Sagebrush Lizard populations were directly linked to the configuration of dune blowouts in the landscape (Ryberg et al. 2013; Ryberg et al. 2015).

The Dunes Sagebrush Lizard is affected by large-scale and persistent conservation challenges across its range. The range of the species overlies the Permian Basin, the second largest oil field in the world, where approximately 14% of the crude oil production of the U.S. occurs (Ewing, B.T., M.C. Watson, T. McIntuff, and R.N. McInturff. 2014. The economic impact of the Permian Basin's oil and gas industry. Report submitted to Permian Basin Petroleum Association. Available from http://pbpa.info/wp-content/uploads/2011/08/TTU-FINALREPORT-PermianBasinImpact-08.29.14.pdf. [Accessed 16 June 2018]). Extensive development of well-pad and road networks has led to fragmentation of Shinnery Oak dunes, negatively impacting Dunes Sagebrush Lizard populations (Leavitt and Fitzgerald 2013; Walkup et al. 2017). In highly fragmented areas, the lizard community becomes disassembled, changing from a predictably structured community to one that is randomly structured (Leavitt and Fitzgerald 2013). The habitat specialist Dunes Sagebrush Lizard disappears first, likely due to disruption of population structure (Walkup et al. 2017). The Dunes Sagebrush Lizard exhibits road avoidance behaviors toward even small, rarely traveled roads (Hibbitts et al. 2017), so the network of the road infrastructure appears to disrupt the movement dynamics across the landscape. With the extensive threats to Dunes Sagebrush Lizard populations and habitat in Texas and the impetus from its proposed listing under the Endangered Species Act (U.S. Fish and Wildlife Service 2010), the Texas Conservation Plan (TCP; Texas Comptroller of Public Accounts. 2012. Texas Conservation Plan for the Dunes Sagebrush Lizard (*Sceloporus arenicolus*). Texas Comptroller of Public Accounts, Austin, Texas, USA. Available from https://comptroller.texas.gov/programs/species-economy/success.php#tcp. [Accessed 23 August 2017]) was put into place in 2012. The TCP is a conservation agreement with assurances that relies on voluntary participation built on a partnership among private landowners, industry, and state and federal agencies. The aim of the TCP is to give incentives to participants to avoid habitat conversion for the Dunes Sagebrush Lizard in Texas, thereby minimizing the perceived risks of federal listing of this species.

A key component of the TCP is a map of the range of the Dunes Sagebrush Lizard in Texas designating areas in four categories of likelihood of occurrence, from Very High to Very Low. This map indicates the likelihood that Dunes Sagebrush Lizards would be detected by surveys in the mapped categories (Fitzgerald, L.A., C.W. Painter, T.J. Hibbitts, W.A. Ryberg, N. Smolensky, and K.L. Skow. 2011. The range and distribution of *Sceloporus arenicolus* in Texas. Report submitted to Texas A&M Natural Resources Institute, College Station, Texas, USA. Available from https://nri.tamu.edu/publications/research-reports/2011/the-range-and-distribution-of-sceloporus-arenicolus-in-texas/. [Accessed 16 June 2018]). We delineated Shinnery Oak dunes using aerial photography. All the areas on the map contain what appears to be some suitable habitat for the Dunes Sagebrush Lizard. The four categories were created based on known presence in an area, its connectivity to other areas, and on-the-ground assessment of habitat condition (Fitzgerald et al., *op. cit.*). Areas classified

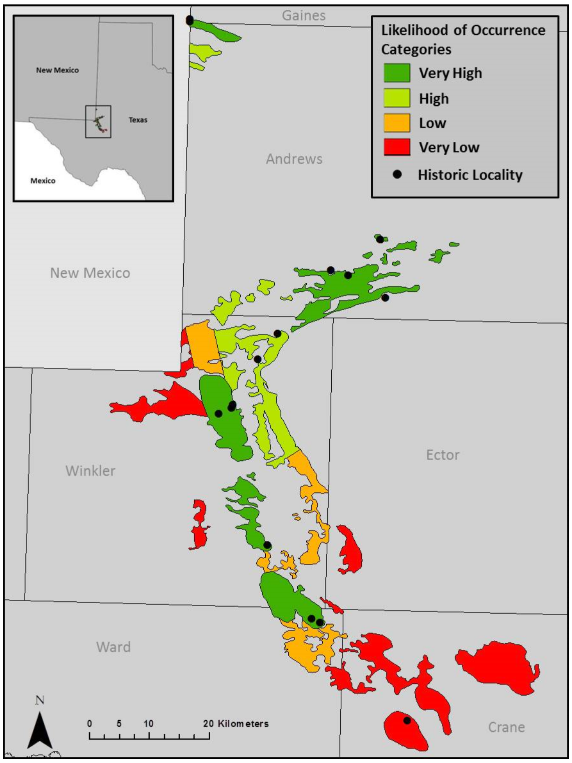

Figure 1. The currently recognized range of the Dunes Sagebrush Lizard (*Sceloporus arenicolus*) in Texas, USA, with historical localities 1958–2010 (more recent records cannot be shown due to landowner confidentiality agreements). Colored areas denote the Likelihood-of-occurrence categories for the Dunes Sagebrush Lizard used in implementing the Texas Conservation Plan.

as Very High or High likelihood of occurrence had known Dunes Sagebrush Lizard records and Shinnery Oak dunes with large open areas devoid of vegetation (blowouts). High likelihood-of-occurrence areas had fewer Dunes Sagebrush Lizard records (i.e., fewer than half the surveys found Dunes Sagebrush Lizards; unpubl. data) and smaller contiguous areas of Shinnery Oak dunes than Very High areas. Areas classified as Low or Very Low likelihood of occurrence were areas where Dunes Sagebrush Lizards had not been found and which contained more disjunct habitat patches separated by unsuitable areas. There is one confirmed locality in Crane County from 1970 (Degenhardt and Jones 1972; University of New Mexico Museum of Southwestern Biology Accession #23627), but the species has not been detected in Crane County since (Fitzgerald et al., *op. cit*.). This map was later incorporated into the TCP to guide management of the species in Texas and acts as a foundation for recovery values (Texas Comptroller of Public Accounts, op cit.); however, because the areas were derived through a qualitative process, the TCP leaders and stakeholders called for continued annual surveys to estimate occupancy of the species in Texas. The results from occupancy surveys would be used to monitor the persistence of Dunes Sagebrush Lizard populations over time.

Our goal in this study was to create an occupancy model for the Dunes Sagebrush Lizard to increase our understanding of the pattern of presence and absence of the species. We also estimated the local extinction and colonization probabilities for Dunes Sagebrush Lizard populations to help understand how metapopulation dynamics may affect the distribution of this species. We provide the first estimates of detection probabilities related to the current survey protocols for this species. Finally, we used the occupancy model results to lend quantitative insights into the previously established areas of likelihood of occurrence.

Materials and Methods

We generated 16-ha survey sites over the range of the Dunes Sagebrush Lizard in Texas and we randomly selected a subset of those generated sites to be surveyed. Most of the habitat of this species in Texas is on private land, so our survey sites were limited to areas we had permission to access. In total, we selected 100 sites for surveys in four of the six counties with historical records of Dunes Sagebrush Lizards (Andrews County, n = 50 sites; Crane County, n = 20 sites; Ward County, n = 13 sites; Winkler County, n = 17 sites) and which contain the majority of Dunes Sagebrush Lizard habitat in Texas (Fig. 1). We concentrated sites in areas of Very High likelihood of occurrence (n = 33) and areas outside of suitable habitat (n = 54), with fewer surveys in the other categories of occurrence (Low, n = 5; Very Low, n = 8; Fig. 1). We had very few surveys in the Low and Very Low categories because the properties we could access had small amounts of these areas. We did not have any sites in the High category because we did not have access to properties in these areas.

We also surveyed areas considered to be outside of suitable habitat that were 0.3–3.6 km from the nearest range boundary. Some of these areas did contain Shinnery Oak dunes, but not all of them. These were surveyed to more rigorously understand boundaries of the range of the species in Texas.

Teams of qualified observers surveyed each site multiples times from 2014 to 2016. We targeted May through August for surveys, which represented the months of peak lizard activity (Fitzgerald and Painter 2009). During each survey, four observers (five observers participated in three surveys) divided the survey site into quadrants and one observer walked their quadrant searching for lizards for approximately 30 min. Surveys continued until the whole quadrant had been searched and did not stop when a Dunes Sagebrush Lizard was found. Surveys took place 0830–1300, corresponding to the morning activity period of the

Dunes Sagebrush Lizard. One observer per quadrant reduced the possibility of duplicate observations of the same lizard and lessened chances that a lizard would be disturbed before it was detected. All lizards were identified to species and recorded. Locations where Dunes Sagebrush Lizards were found were recorded with a Global Positioning System (GPS) unit (standard user precision only).

Using multi-season occupancy models, we estimated occupancy (ψ), detection probability (p), colonization probability (γ) and local extinction probability (ε) for the sites in the Very High likelihood-of-occurrence areas (the only area in which we had both detection/non-detection data; MacKenzie et al. 2003). We designed eight *a priori* models to assess annual variation in the colonization, local extinction, and detection probabilities. Then, because estimates of colonization were so low in those eight models, we added four more models where colonization probability was fixed at 0 (the assumption that no sites were colonized during the course of this study). We aggregated survey data into two sessions each year, from May to late June and late June to early August. As not all sites were surveyed each session, missing surveys were coded with a period (.), which resulted in large confidence intervals around some of the parameter estimates. Models were ranked via Akaike's Information Criterion corrected for small sample size (AIC_c), where the effective sample size was the number of sites included in the analysis (n = 33), and the best models were determined based on ΔAIC_c < 2.0 (Burnham and Anderson 2002). All models were fit using program PRESENCE (Hines 2006). While the effectiveness of goodness-of-fit tests for multi-season models is debated, we used a parametric bootstrap (n = 5,000) with a Chi-square statistic to test goodness-of-fit of the most complex model (i.e., subglobal model), where P > 0.050 indicated a good fit (Burnham and Anderson 2002; MacKenzie and Bailey 2004), using the parboot function in the Unmarked package (Fiske and Chandler 2011) in R (R Core Team 2017).

Results

From May 2014 to August 2016, we conducted 339 Dunes Sagebrush Lizard surveys at 100 sites over most of the range of the species in Texas (Table 1). We conducted an average of 3.39 surveys (range, 2–5 surveys) per site and we had 33 detections of Dunes Sagebrush Lizards during 17 surveys at nine sites over the three years, all of which were in the Very High likelihood-of-occurrence category. In contrast, Dunes Sagebrush Lizards were not detected in 322 surveys at 91 sites. We detected Dunes Sagebrush Lizards on every visit (four surveys) at only one site in Andrews County. We found Dunes Sagebrush Lizards in three of four surveys at each of two sites in Andrews County, and two of three surveys at a third site in Winkler County. At the remaining five sites (three in Andrews County, one in Winkler County, one in Ward County), we detected the Dunes Sagebrush Lizard only once despite conducting 2–4 surveys at each site.

The time to first sighting of the target species varied among surveys. We detected Dunes Sagebrush Lizards within 60 person-minutes (e.g., four observers searching for 15 min) during nine of the 17 positive surveys, and between 60 and 120 person-minutes in six of these 17 surveys. In the remaining two positive surveys, we detected Dunes Sagebrush Lizards after 128 and 144 person-minutes. The average time to detection was 65 ± 39.5 (SD) person-minutes (range, 5–144 person-minutes, n = 17). The duration of surveys where a Dunes Sagebrush Lizard was found ranged from 120 to 163 person-minutes (mean search time = 142 ± 12.2 person-minutes, n =17), while surveys where a Dunes Sagebrush Lizard was not detected ranged from 100 to 170 person-minutes (mean search time = 128 ± 10.7 person-minutes, n = 322). In the surveys < 120 min, the four observers had thoroughly covered all potential habitat in the survey area.

No Dunes Sagebrush Lizards were detected during the 183 surveys on sites that fell outside the known range of the Dunes Sagebrush Lizard in Texas (Fig. 1). Additionally, no Dunes Sagebrush Lizards were detected in 37 surveys at five sites in Low and eight sites in Very Low likelihood-of-occurrence areas. Because there were no detections in these areas, we elected not to estimate occupancy probabilities for the Low, and Very Low likelihood-of-occurrence areas, as well as any survey sites that fell outside these areas; non-detection and non-occupancy are confounded in areas with no detections.

Because we only had detections in the Very High likelihood-of-occurrence areas, our multi-season occupancy model was limited to the 33 sites in the Very High likelihood-of-occurrence model. Based on the

Table 1. Number of surveys conducted for the Dunes Sagebrush Lizard (*Sceloporus arenicolus*) in Texas, USA, 2014–2016 by likelihood-of-occurrence class. Surveys conducted outside the predicted areas of occurrence are also included.

Likelihood of Occurrence	2014	2015	2016	Total	Proportion	Dunes Sagebrush Lizards Detected
Very High	42	45	32	119	35.1%	33
High	0	0	0	0	0.0%	—
Low	0	9	4	13	3.8%	0
Very Low	0	16	8	24	7.1%	0
Outside	58	75	50	183	54.0%	0
Total				339	100.0%	33

Table 2. Top candidate models of the multiple-season occupancy analysis for the Very High likelihood-of-occurrence areas in the Texas, USA, range of the Dunes Sagebrush Lizard (*Sceloporus arenicolus*) during 2014–2016. Abbreviations are initial occupancy, ψi, probability of colonization, γ, probability of local extinction, ε, probability of detection, *p*, number of parameters, K, Akaike's Information Criterion corrected for small sample sizes, AIC_c, yearly estimates, yr, and constant, c.

Model	K	AIC_c	ΔAIC_c	AIC_c Weights	Cumulative Weights
ψi γ = 0 ε(c) p(c)	3	87.80	0.00	0.57	0.57
ψi γ = 0 ε(yr) p(c)	4	90.26	2.46	0.17	0.74
ψi γ(c) ε(c) p(c)	4	90.39	2.59	0.16	0.90
ψi γ = 0 ε(c) p(yr)	5	93.02	5.22	0.04	0.94
ψi γ(c) ε(yr) p(c)	5	93.05	5.25	0.04	0.98
ψi γ(c) ε(c) p(yr)	6	96.03	8.23	0.01	0.99
ψi γ=0 ε(yr) p(yr)	6	96.03	8.23	0.01	1.00

parametric bootstrap, the subglobal model fit the data marginally well (*P* = 0.42; Burnham and Anderson 2002; MacKenzie and Bailey 2004). The top model was the null model with colonization probability fixed at 0 (Table 2). Occupancy probability from the top model was 0.32 ± 0.09 (SE; 95% CI = 0.13–0.50), detection probability was 0.52 ± 0.12 (95% CI = 0.28–0.76), and local extinction probability was 0.12 ± 0.19 (95% CI = 0.00–0.49).

Discussion

This study provides the first estimates of occupancy and colonization-extinction dynamics for the Dunes Sagebrush Lizard in a portion of its range. Our top occupancy model, with detection-corrected estimates of occupancy probabilities, suggests that Dunes Sagebrush Lizards occupied approximately a third of the sites we surveyed in the Very High likelihood-of-occurrence areas. This low occupancy probability in the Very High likelihood-of-occurrence areas could be a result of the resolution of the Likelihood-of-occurrence map, source-sink population dynamics of the Dunes Sagebrush Lizard, or simply a characteristic common to many endemic habitat specialists.

Because the polygons of the Likelihood-of-occurrence map covered broad areas, there is some heterogeneity in the habitat represented within these areas. Thus, we would expect that not every site in the Very High likelihood-of-occurrence categories would be occupied based on the heterogeneous landscape alone. The Dunes Sagebrush Lizard is known to prefer relatively large dunes with correspondingly large blowouts; areas with large dunes and blowouts are more topographically complex with steep slopes, loose sand, and thermally favorable microsites (Fitzgerald and Painter 2009; Hibbitts et al. 2013; Fitzgerald et al., *op. cit.*). While these large dune complexes are a dominant feature in the Very High likelihood-of-occurrence areas, they are not the only landscape type in those areas. Our 16-ha sites were randomly chosen because our goal was to estimate occupancy within the Very High likelihood-of-occurrence area. For this study, we chose to avoid bias in occupancy estimates by not using targeted surveys aimed at the largest dune complexes (i.e., areas of interconnected dunes with blowouts; MacKenzie et al. 2006). Thus, our sites often contained elements of the landscape not preferred by the Dunes Sagebrush Lizard (e.g., mesquite flats, caliche roads, and oil and gas well pads), which could contribute to lower occupancy in Very High likelihood-of-occurrence areas.

Map resolution and landscape heterogeneity cannot completely account for low occupancy. Many of the sites where Dunes Sagebrush Lizards were not detected contained large expanses of Shinnery Oak dunes with blowouts. Previous research on the population dynamics and dispersal of the Dunes Sagebrush Lizard revealed that populations exhibited source-sink dynamics across contiguous occupied habitat (Ryberg et al. 2013), and that vital rates of Dunes Sagebrush Lizard populations were linked to the configuration of dune blowouts in the landscape (Ryberg et al. 2015). Thus, it is also plausible that the relatively low occupancy probabilities observed were in part due to metapopulation dynamics in this species playing out across the landscape. Due to constraints on dispersal in the Dunes Sagebrush Lizard, we suggest that localized extinctions and slow to nonexistent colonization would also result in low occupancy probabilities even among sites with large, deep contiguous blowouts that are preferred by the Dunes Sagebrush Lizard.

Low occupancy probabilities may be characteristic of many narrowly endemic habitat specialists. Habitat specialists typically exhibit patchy distributions, which reflect the distribution of habitat patches. Habitat specialists may also not occur in all available patches. As such, when habitat for these species is considered at larger landscape scales, the species may not be present in all available habitats (With and Crist 1995; Holt 1997). The occupancy probabilities that we calculated for the Dunes Sagebrush Lizard fell well within the range of occupancy probabilities seen in other studies of narrowly endemic lizard habitat specialists. We find that other habitat specialists tend to have lower occupancy probabilities than do lizards considered to be habitat generalists. This trend is reflected especially among lizards that specialize in sandy habitats, such as the Florida Sand Skink (*Plestiodon reynoldsi*; ψ = 0.36–0.45; Rizkalla et al. 2015) or the Sand Lizard (*Lacerta agilis*) in England (Sewell et al. 2012). Occupancy probabilities for the Sand Lizard throughout southeast England ranged from 0.14–0.32; these estimates were much lower than those for a more widespread habitat generalist, the Common Lizard (*Zootoca vivipera*; ψ = 0.76–0.81), from the same study (Sewell et al. 2012). Additionally, occupancy probabilities of the more generalist species, the Toad-headed Agama (*Phrynocephalus versicolor*) in Mongolia, exhibited an inverse relationship to rocky outcroppings, where occupancy probabilities increased from 0 to 0.95 as the proportion of rocky habitat decreased from 1 to 0 (Murdoch et al. 2013). However, more research is needed to better understand generalities in lizard occupancy that may be related to life-history characteristics, like degree of habitat specialization.

Our estimates of local extinction probability were fairly low, with high variability around the mean (0.14 ± 0.18 SE). Colonization probabilities were incredibly low (0.008 ± 0.098 SE) for our third ranked model. Thus, we felt that holding them to zero, as in the top two models, in this analysis was justified and helped to reduce variation around the other parameters. Very low colonization rates were unsurprising, considering the patchy distribution of the Dunes Sagebrush Lizard. For example, Dunes Sagebrush Lizards were collected from Crane County in 1970 (Degenhardt and Jones 1972; University of New Mexico Museum of Southwestern Biology Accession #21298, #23627), but the species has not been found there since despite multiple surveys at and surrounding the historical locality (Laurencio, D., L.R. Laurencio, and L.A. Fitzgerald 2007. Geographic distribution and habitat suitability of the Sand Dune Lizard (*Sceloporus arenicolus*) in Texas. Report submitted to Texas Parks and Wildlife Department, Austin, USA. Available from https://tpwd.texas.gov/business/grants/wildlife/section-6/docs/amphibians_reptiles/e64_final_report.pdf [Accessed 16 June 2018]; Fitzgerald et al., *op. cit.*; this study). Population genetic studies also lend some support to this idea. Chan et al. (2009) found that genetic structure within and among populations of the Dunes Sagebrush Lizard revealed a pattern of very low inter-population migration and recent reductions in some populations.

Given the large number of surveys outside of the likelihood-of-occurrence polygons, we are confident in concluding the Dunes Sagebrush Lizard likely does not occur outside the currently recognized range boundaries in Texas. The range of the species is also clearly limited by extent of the shinnery dunes landform. Unfortunately, because we could not get access to habitat located on private lands, there were no surveys in the High likelihood-of-occurrence areas, and we were unable to estimate probability of occupancy in this category. Although the Very High and High likelihood-of-occurrence areas contain patches of Shinnery Oak dunes with large dunes and blowouts that Dunes Sagebrush Lizards prefer, there were very few historical localities in the High category versus many in the Very High category, which led to the difference in categorization of these areas. Though we expect occupancy to be less in the High likelihood-of-occurrence areas compared to the Very High areas, it is also probable that Dunes Sagebrush Lizards are present at some locations that have never been surveyed. Having more sites distributed among all the categories, and three or more surveys/site each season, would strengthen future occupancy analyses conducted in this system (MacKenzie 2005).

Detection probability of the Dunes Sagebrush Lizard in the Very High likelihood-of-occurrence areas was fairly high (0.52 ± 0.12 SE). Other approaches for estimating population parameters for Dunes Sagebrush Lizards have yielded similar findings. Smolensky and Fitzgerald (2010) derived a detection probability of 0.489 ± 0.065 (SE) using double-observer visual surveys and distance sampling transects at sites in New Mexico that were known to be historically occupied. An intensive five-year study using pitfall traps at 27 historically occupied sites in New Mexico returned detection probabilities ranging from 0.50 to 0.85 during the breeding season (Daniel Leavitt et al., unpubl. data). Unfortunately, because non-occupancy and non-detection are confounded, we were unable to estimate a detection probability for the rest of our survey sites where no Dunes Sagebrush Lizards were detected. If Dunes Sagebrush Lizards occur at sites in Low and Very Low likelihood-of-occurrence areas, it is likely they will be present in the largest areas of shinnery dunes and at relatively low abundances. To determine if Dunes Sagebrush Lizards occur in these areas, we suggest directing effort towards surveys at more sites, with fewer surveys per site, as the best way to get estimates of detection and occupancy in those areas (MacKenzie and Royle 2005).

Variation in effectiveness of survey methodologies leads to variation in detection probabilities (Zylstra et al. 2010; Michael et al. 2012; Rodda et al. 2015). One source of this variation stems from availability bias, where lizards that are not active are unavailable to be detected. Availability bias violates the base assumption that all lizards on the transect line are available for detection (Buckland et al. 2001) and is a known problem in the use of distance sampling methodologies to estimate population densities for many species, including the Dunes Sagebrush Lizard (Smolensky and Fitzgerald 2010). Another important source of variation in detection probabilities of lizards is seasonal and daily activity patterns. Lizard activity patterns vary by day, season, and among years (e.g., Seddon et al. 2011; Gebauer et al. 2013; Lardner et al. 2015; Rizkalla et al. 2015). Previous research showed seasonal variation in detection of the Dunes Sagebrush Lizard with detection probabilities lowest in midsummer (July), after the breeding season, but before emergence of juveniles (Daniel Leavitt et al., unpubl. data). Detections in our surveys took place during May, June, and July, indicating that within season variation in activity may not have had the same impact on active surveys as it does in pitfall trapping studies. To fully understand the influence of seasonal activity on lizard detection, a study using repeated surveys during the year at a number of sites would be needed. However, in terms of conservation and management, it is clear that occupancy surveys yield the most useful information when conducted during the peak activity season.

In summary, our results suggest our survey method was fairly effective for finding the Dunes Sagebrush Lizard where suitable habitat for this narrowly distributed habitat specialist was present. Because of the requirement of the species for Shinnery Oak dunes with interconnected blowouts and rugose (i.e., bumpy) topography, it was found entirely in the Very High likelihood-of-occurrence category. It is important that surveys be conducted in the High likelihood-of-occurrence areas because the species has historically been found in portions of these areas and habitat condition is similar to that in the Very High areas in some places. To add more certainty to our findings, additional surveys are needed in the Low and Very Low likelihood-of-occurrence areas to estimate occupancy and detectability of the Dunes Sagebrush Lizard in these areas. Although we cannot conclude the species is absent from these areas, it is fairly certain that Dunes Sagebrush Lizards are absent or very uncommon throughout the Low and Very Low likelihood-of-occurrence areas, especially given the long-term accumulation of surveys from independent studies (Laurencio et al. *op. cit.*; Fitzgerald et al. *op. cit.*; this study). Because of the dynamics of colonization and local extinction that occur over very long-time scales, it is critical to recognize that the current state of occupancy may not necessarily reflect the future state at a site. Periodic monitoring of the occurrence of Dune Sagebrush Lizards throughout their range will be necessary to document extinction and colonization of suitable habitat in the future. This is the first report of occupancy and detection for the Dunes Sagebrush Lizard using standardized surveys and can serve to inform future monitoring aimed at understanding how land use may impact the distribution of the species.

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