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OF THE DUNES SAGEBRUSH LIZARD (*SCELOPORUS
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SAGEBRUSH LIZARD (*SCELOPORUS ARENICOLUS*)

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Abstract

Habitat fragmentation is a major driver of biodiversity loss and among reptiles has been attributed as a cause of species decline. The negative effect of habitat fragmentation has also been shown to be worse for species that are habitat specialists. The Dunes Sagebrush Lizard (*Sceloporus arenicolus* Degenhardt and Jones 1972) is a species that specializes on the Shinnery Oak sand dune landform of the Mescalero-Monahans Sandhills ecosystem in western Texas and eastern New Mexico, USA. This landform has been fragmented by roads and well pads used for the extraction of oil and gas resources. The effects of fragmentation on the home range and movements of this species can lead to the effective isolation of populations and increased risk of localized extirpations. We showed that home range size was larger in an unfragmented area and that the average distance of movements was greater. We also observed that roads in the fragmented areas restricted movements of *S. arenicolus*. We concluded that roads can be barriers to movements even though only narrow strips of habitat are altered.

Keywords:

Habitat loss, species decline, Mescalero-Monahans sandhills, Phrynosomatidae, oil and gas development, road ecology, *Sceloporus arenicolus*, Dunes Sagebrush Lizard

Introduction

Habitat fragmentation is a process through which a landscape is broken into a number of smaller, more isolated patches, separated by unsuitable habitat and is always associated with habitat loss (Fahrig 2003). Fragmentation may also alter factors such as solar radiation, wind, and hydrologic regimes, perpetually altering the landscape (Saunders et al. 1991). Fragmentation and loss of habitat are different phenomena, but together are a major driver of biodiversity loss (McGarigal and Cushman 2002; Torres et al. 2016). Habitat modification, including fragmentation, loss, and small-scale changes in microhabitat, has also contributed to species declines (Gibbons et al. 2000; Gardner et al. 2007; Whitfield et al. 2007; Leavitt and Fitzgerald 2013; Walkup et al. 2017). Specialist species are acutely susceptible to habitat alteration due in part to their dependence on one, or few, habitat types (Devictor et al. 2008; Hobbitts et al. 2009), and their adaptation to a relatively stable environment (Futuyma and Moreno 1988).

Surprisingly few studies have been conducted on how habitat fragmentation affects the movements and home range of individuals in vertebrate species (Hinam and St. Clair 2008; Öckinger et al. 2010). Patterns of effects of habitat fragmentation are not clear, in some cases a single species may respond differently to fragmentation (Ewers and Didham 2006). What seems to be important to home range size is the scale of fragmentation, for example, the distance between suitable habitat patches and sizes of those patches. Species may use multiple patches in their home range if they are close enough, which will increase home range size compared to continuous habitat. If the habitat patches are small and separated by large areas of unsuitable habitat, then the predation risks or energetic requirements associated with long movements may force individuals to maintain smaller home ranges in these isolated patches compared to continuous habitat (Grubb and Doherty 1999). Little evidence exists for the effects of habitat

fragmentation on movement and home range size of specialists but theory suggests that habitat specialists with their specific habitat requirements would be more susceptible to negative influences of habitat fragmentation (Debinski and Holt 2000; Hobbitts et al. 2013).

Within the Mescalero-Monahans Sandhills ecosystem of western Texas and eastern New Mexico, USA, fragmentation from oil and gas development results in a landscape with fewer, smaller, and more isolated habitat patches (Leavitt and Fitzgerald 2013). In Texas, well pad density may reach 55 or more well pads per section (1 square mile; 259 ha; Hobbitts et al. 2013), connected by caliche roads (i.e., roads made of calcium carbonate). With an average well pad size of 13,620 m², approximately 30% of native land cover may potentially be converted to caliche well pads in the most densely altered areas. Although habitat fragmentation is a landscape-level process, it can affect processes at the community and population levels, and at the level of individuals' home range size and movement patterns (Smolensky and Fitzgerald 2011; Leavitt and Fitzgerald 2013; Ryberg et al. 2013; Walkup et al. 2017; Hobbitts et al. 2017). Burt (1943) described the home range as the area used by an animal for its normal daily activities, such as locating food, mates, or shelter. In lizards, home range size can be influenced by myriad factors, including availability of food or mates, habitat quality, body size, sex, reproductive status or territoriality (Rose 1982; Ruby and Dunham 1987; Hews 1993; Perry and Garland 2002; Haenel et al. 2003; Manteuffel and Eblmaier 2008). Further, the size of an individual's home range is directly related to the movement necessary to acquire food, mates, or habitat of sufficient quality and quantity. Elucidating patterns of movement and home range within a species can therefore provide insights into its ecological niche. In the case of threatened or imperiled species like the Dunes Sagebrush Lizard, *Sceloporus arenicolus* Degenhardt and Jones 1972, this knowledge is crucial for making informed conservation decisions.

Sceloporus arenicolus is a small phrynosomatid lizard endemic to the Mescalero-Monahans Sandhills ecosystem (Degenhardt et al. 1996). The species is a psammophilic habitat specialist restricted to Shinnery Oak (*Quercus havardii* Rydb.) sand-dune landforms, which consist of parabolic dunes and depressions called blowouts that are created from an interaction between wind, sand, and the dune-stabilizing Shinnery Oaks (Fitzgerald and Painter 2009; Laurencio and Fitzgerald 2010; Ryberg et al. 2015). Across these landforms, the spatial configuration of blowouts constrains or facilitates movements of *S. arenicolus*. Within an area, groups of interacting individuals occur in neighborhoods, whose size is a function of population density and movements (Ryberg et al. 2013). Larger neighborhoods exhibit higher recruitment and population diffusion rates, acting as sources for smaller neighborhood sinks with negligible recruitment. Thus, population persistence in this species depends on diffusion dispersal throughout interconnected habitat patches (Ryberg et al. 2013; Walkup et al. 2017). Dispersal among isolated habitat patches is effectively zero over both short and long time frames (Chan et al. 2009; Leavitt 2012).

We undertook the present study to evaluate the prediction, based on previous work, that fragmentation of Shinnery Oak sand-dunes by well pads interconnected with roads would restrict movements of *S. arenicolus* with concordant effects on home range size. Our objectives for this study were threefold. First, we analyzed variation in movements and home range size between male and female *S. arenicolus*. Second, we analyzed variation in movement and home range between lizards in fragmented and unfragmented areas. Third, we evaluated the specific role of caliche roads as barriers to localized movements.

Materials and Methods

Study Site

The study area was located near Andrews, Texas (975 m to 1010 m elevation). We chose sites known from previous surveys to contain *S. arenicolus* (Hibbitts et al. 2013). We selected three independent sites that varied in the degree of landscape fragmentation and their proximity to, or distance from, caliche roads. One site was approximately 7 ha in area, bisected by a caliche road, and abutted three caliche well pads. It was located in a section with 61 well pads, among the highest density of roads and well pads in the area. We note that this degree of fragmentation was not replicated in our study design. It has been well studied that populations of *S. arenicolus* are depressed or locally extinct in fragmented landscapes, and it is difficult to find extant populations to study in fragmented habitats (Smolensky and Fitzgerald 2011; Leavitt and Fitzgerald 2013; Ryberg et al. 2013; Walkup et al. 2017; Hibbitts et al. 2017). The site in the fragmented area was located in the same dune system and was within 7.5 km of two unfragmented sites more distant from roads. While we recognized the lack of a fully replicated study design could limit our conclusions, our results do allow meaningful conclusions to be made as to how landscape characteristics, especially roads and well pads, affect behaviors and movements of individuals. A second site was approximately 4.5 ha in area and 100 m from the nearest road, which was a small dirt 2-track used for ranch vehicles. The third site was approximately 1 ha, within a larger chain of dune blowouts. The nearest road was another small 2-track, located 50 m away. The latter two sites were located in a square mile section with only 6 well pads, which is considered a relatively low degree of fragmentation based on other research on the species (Leavitt and Fitzgerald 2013).

Radiotelemetry

We captured 36 lizards by noose or pitfall trap to use as subjects for radio tracking. Upon capture, we marked all lizards with a unique toe-clip and affixed a 0.3 g radio transmitter (Model R614, Advanced Telemetry Systems) directly to the middle of the back of each lizard using cyanoacrylate glue, with the whip antenna extending posteriorly (Sabo 2003). We relocated lizards using a scanning receiver (Model R410, Advanced Telemetry Systems, Inc., Isanti, MN) and a 3-element Yagi antenna. Alternative methods to toe-clipping for identifying individual lizards were investigated. The only reasonable alternative method that would not cause distress would be photo identification, but this species is mostly patternless making the identification of individuals using this method difficult. Toe-clipping is a method of permanent marking for lizards that has been systematically reviewed (Perry et al. 2011) and approved by the Society for the Study of Amphibians and Reptiles. We had approval from our Institutional Animal Care and Use Committee (AUP 2012-105).

During June-August, 2012 and May-August, 2013, we tracked lizards three times per day for thirty days, or until transmitters were lost due to shedding or predation. The average number of locations per day did not differ by sex (male: $n = 20$, mean = 2.69, standard deviation = 0.28; female: $n = 16$, mean = 2.69, standard deviation = 0.30) or by fragmentation treatment (unfragmented: $n = 24$, mean = 2.66, standard deviation = 0.29; fragmented: $n = 12$, mean = 2.75, standard deviation = 0.28). We located lizards during their prime activity period (0900-1100), during the hottest part of the day (1400-1600), and in the evenings (1800-2000). During each relocation, we attempted to visually locate the lizard to confirm its position, and to record its behavior. We recorded locations in the field using a handheld GPS unit (Garmin Model 60csx) with an accuracy of ± 3 m.

Data Analyses

We used ESRI ArcInfo 10.1 (ESRI, Redlands, CA) and the adehabitatHR package in R v. 2.15.1 to calculate the following home range estimators and movement parameters: 100% minimum convex polygons (MCP), 50% and 95% fixed kernel density estimators (KDE), and mean distance moved per day (i.e. average of total path length per day). Because home range estimators are sensitive to the number of relocations, we only included lizards with at least 25 locations in the analyses (Schoener 1981; Stone and Baird 2002). We found no relationship between number of sightings and home range estimates by sex (male [MCP $y = 9.05x + 443.02$, $r^2 = 0.04$; 95% KDE $y = -10.34x + 2198.4$, $r^2 = 0.02$; 50% KDE $y = -2.56x + 476.48$, $r^2 = 0.03$]; female [MCP $y = 6.08x + 209.39$, $r^2 = 0.12$; 95% KDE $y = -23.05x + 2734.8$, $r^2 = 0.19$; 50% KDE $y = -5.05x + 582.48$, $r^2 = 0.17$]) or by fragmentation treatment (unfragmented [MCP $y = 13.10x + 386.63$, $r^2 = 0.04$; 95% KDE $y = -4.42x + 1295.6$, $r^2 = 0.04$; 50% KDE $y = -2.83x + 407.43$, $r^2 = 0.26$]; fragmented [MCP $y = 5.55x + 304.57$, $r^2 = 0.09$; 95% KDE $y = -16.51x + 2674.6$, $r^2 = 0.04$; 50% KDE $y = -3.36x + 537.91$, $r^2 = 0.04$]) indicating that the minimum number of sightings per individual was sufficient for home range estimation and comparison. The least-squares cross validation (LSCV) method of selecting the smoothing parameter, recommended by Seaman et al. (1999) failed to minimize the Mean Integrated Squared Error (MISE) for most lizards; therefore we used the reference bandwidth instead. Kernel methods are known to perform poorly in home ranges that contain distinct boundaries (e.g. cliffs, rivers, ponds) (Getz and Wilmsers 2004; Getz et al. 2007). Our study site contained no physical barriers to lizard movements. Sampling lizards three times a day results in spatial autocorrelation; however, attempting to remove autocorrelation through subsampling may reduce the biological relevance of the home-range estimates as well as remove information about movement patterns

(De Solla et al. 1999; Börger et al. 2006; Fieberg 2007; Kuhn et al. 2014; Melville et al. 2015). Therefore, we decided to include all of our data in our analysis of home range.

We conducted two-way ANOVA tests in R v 2.15.1 to assess the effects of sex and habitat type (fragmented vs. unfragmented) on each of the parameters listed above. Home range variables were not normally distributed so they were log transformed before conducting the ANOVA. Data were homoscedastic according to Box's M test for equal variances among groups. To determine the effect of caliche roads and well pads on movements we used a chi-squared test (χ^2) with Yates correction. We used satellite imagery (DigitalGlobe 2015) to calculate the amount of caliche versus non-caliche soil surface at our fragmented site and compared expected versus observed movements that crossed caliche or ended on caliche.

Results

We tracked lizards for an average of 28.0 days (range: 10-36) and collected an average of 60.2 relocations per lizard (range: 26-90) (Table S1). Over the course of the study, four of the 36 lizards were lost to snake predation (1 *Arizona elegans* Kennicott in Baird 1859, 3 *Coluber (Masticophis) flagellum* (Shaw 1802)) and 10 others shed their radios prior to the end of the 30-day tracking period. Throughout the duration of the study, we observed that one lizard crossed a caliche road in a spot that was covered with wind-blown sand.

When using MCP, 95% KDE, or 50% KDE males had higher mean home range size than females and moved greater distances per day (Table 1). Habitat significantly affected MCP size (fragmented vs. unfragmented) (Fig. 1; $F_{1,32} = 5.23$, $p = 0.028$), with individuals in fragmented habitat exhibiting larger home ranges than those in unfragmented habitat. Although male MCP sizes tended to be larger than those of females, the difference was not significant ($F_{1,32} = 2.05$, p

= 0.162), nor was there any interaction between habitat and sex ($F_{1,32} = 0.52, p = 0.477$). We did not observe a significant effect of sex ($F_{1,32} = 3.89, p = 0.057$), habitat ($F_{1,32} = 2.86, p = 0.100$) or an interaction effect ($F_{1,32} = 1.70, p = 0.201$) on 95% KDE size. Males had significantly larger 50% KDE home ranges than females ($F_{1,32} = 9.07, p = 0.005$), but no effect of habitat ($F_{1,32} = 1.43, p = 0.241$) or interaction effect ($F_{1,32} = 1.70, p = 0.201$) was observed (Fig. 2). Males moved significantly greater distances per day than females ($F_{1,32} = 4.90, p = 0.030$), and lizards in fragmented areas moved significantly greater distances per day than those in unfragmented areas ($F_{1,32} = 6.34, p = 0.017$), but no interaction was observed between habitat type and sex ($F_{1,32} = 0.11, p = 0.746$) (Fig. 3).

We observed 3 movements by the same individual (*S. arenicolus* 32) at the same location on one caliche road (Fig. 4). The road at the crossing location had a thin (approximately 5cm) covering of wind-blown sand over the caliche. This crossing rate, 3 out of the total 799 movements made by all lizards in the fragmented site, was significantly less than the expected crossing rate based on the total percentage of available habitat that had a caliche substrate ($\chi^2 = 46.534, p < 0.001$).

Discussion

Our results illustrated that home range size and length of daily movements of *S. arenicolus* were altered at a site that was fragmented from oil and gas development. Specifically, lizards at the fragmented site exhibited larger MCP home ranges and moved greater distances on a daily basis. Additionally, we found differences between the sexes, with males having significantly larger core home ranges and moving significantly greater distances than females.

At the 50% KDE level, which is representative of an individual's core area of use (White and Garrott 1990), males had significantly larger home ranges than females across all sites. Among many lizard species, males have larger home ranges than females (Perry and Garland 2002). This is particularly true among species in the genus *Sceloporus* (Ferner 1974; Smith 1985; Abell 1999); Abell (1999) reported home ranges of male *Sceloporus virgatus* Smith 1938, four times larger than those of females. This has been attributed to female home ranges being primarily determined by energetic requirements, while males must also gain access to mates (Hews 1993; Perry and Garland 2002). Abell (1997) found that a male *S. virgatus* in close spatial proximity to a female was more likely to sire most, or all, of the female's clutch, therefore a larger male home range may correlate with greater reproductive success. Although we did not examine the specific reasons for larger male home ranges in *S. arenicolus*, it is clear that this observation conforms to a larger pattern among species of *Sceloporus*.

Movements of *S. arenicolus* also varied between sexes, with males moving significantly greater distances per day than females. This result might also be related to reproductive activity. All of our observations took place during the breeding season, and we assumed that most, if not all, of the females were gravid at some point during the study. The added mass of eggs can hinder speed and mobility (Shine 2003) and affect behavior. Female *S. arenicolus* have been observed to bask more frequently as they approached time of nesting (Michael T. Hill pers. comm.). In contrast, male lizards may move more to increase their likelihood of encountering a mate or to defend territory.

Observations collected at the fragmented site showed the minimum convex polygon of home range size was larger, and movements were greater there than in the other sites. The apparent, and striking, difference between the sites was the presence of the road and well pads,

which impeded movements of individual lizards. We did not test for specific mechanisms that may explain greater home range size in this context; however, the literature points to the role of density-dependent interactions and resource availability. In many species, home range size is negatively correlated with lizard density (Whiting 1999; Haenel et al. 2003). However, no single factor adequately explained variation in home range size in those studies. Similarly, Manteuffel and Eblmaier (2008) experimentally manipulated density in *S. virgatus* populations and found smaller home ranges within the high density group. As *S. arenicolus* abundance has been shown to be lower in fragmented habitat than in unfragmented habitat (Leavitt and Fitzgerald 2013; Walkup et al. 2017), it is likely that larger *S. arenicolus* home ranges at our fragmented site were related to the low lizard densities observed there.

An alternative, non-exclusive, hypothesis to explain larger home range size in the fragmented area is that quality and quantity of resources may be diminished there (food, refugia, cover, thermally favorable sites), forcing lizards to range over larger areas and move greater distances to access resources. Hews (1993) observed female *Uta palmeri* Stejneger 1890, shifting their home ranges in response to supplemented food resources, suggesting that individual space use can be directly linked to resource availability. In this study, we believe *S. arenicolus* may have had larger MCP home ranges in fragmented habitat due to habitat alteration caused by fragmentation which essentially reduces the availability of preferred microhabitats (Hibbitts et al. 2013). This may have forced individuals to traverse unpreferred microhabitats to reach preferred microhabitats (e.g., steep slopes [Hibbitts et al. 2013], coarse sand-grain size [Ryberg and Fitzgerald 2015], high soil moisture [Ryberg et al. 2012]). In contrast, results from the core area analysis (50% KDE) were not significantly different between fragmented and unfragmented areas, suggesting that adequate resources were available in the habitat patches being used by the

lizards. This apparent contradiction could be explained by virtue of the fact that the MCP derives its shape from the outermost locations, and can often include areas not actually used by an individual (Worton 1987). The core area (50% KDE) estimates likely excluded outermost locations where individuals crossed unpreferred microhabitats without spending substantial time in those areas. This hypothesis is supported by the fact that lizards at our fragmented site moved greater distances than in the other two unfragmented areas.

As mentioned, we only verified through telemetry one individual *S. arenicolus* crossing a caliche road during the course of this study, which included 799 relocations of 14 lizards in the fragmented site. To the best of our knowledge, this individual only crossed the road in a place where sand had covered the caliche road surface. Moreover, at this site the Shinnery Oak sand dune habitat, which is required by *S. arenicolus*, was touching the road on both sides. This observation is consistent with the results of an experimental study of road-crossing behavior in *S. arenicolus*, which demonstrated that individuals avoid the caliche road surface, even when the road is small, flat, and immediately adjacent to dune blowouts in occupied habitat (Hibbitts et al. 2017). This observation is worth emphasizing because in many areas of oil and gas extraction within the Mescalero-Monahans Sandhills ecosystem, caliche roads are constructed in a grid-like network. This network of roads is the major source of fragmentation of the habitat used by *S. arenicolus* (Hibbitts et al. 2017), and it also disrupts the self-organized shinnery oak sand dune blowout landforms (Ryberg et al. 2015). In general, roads are frequently cited as being barriers to dispersal that can have a significant effect on populations, and may increase the chances of localized extinctions through the effective isolation of populations within smaller and lower quality habitat patches (e.g., Torres et al. 2016). In our study, it was clear that road-crossing movements did not occur regularly and would likely not be sufficient to sustain the population

size (Leavitt and Fitzgerald 2013), demographic structure (Walkup et al. 2017), and resulting source-sink diffusion-dispersal dynamics (Ryberg et al. 2013) necessary to prevent localized extinction of *S. arenicolus* in areas fragmented by roads.

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Tables

Table 1. Measures of mean (SD) home range size and distance moved per day for radio-tracked Dunes Sagebrush Lizards (*Sceloporus arenicolus*) in unfragmented and fragmented sites, and for males and females.

	MCP (m ²)	95% KDE	50% KDE	Distance/day (m)
Unfragmented				
(n = 24)	633.6 (364.9)	1154.0 (646.2)	253.0 (159.3)	21.6 (6.3)
Fragmented				
(n = 12)	1219.6 (1044.4)	2061.5 (2046.7)	393.0 (402.5)	26.7 (6.7)
Females				
(n = 16)	614.8 (362.6)	1009.9 (580.1)	176.0 (93.2)	20.8 (6.1)
Males				
(n = 20)	1000.3 (874.1)	1813.8 (1646.1)	398.5 (320.5)	25.3 (6.8)

Figure captions

Fig. 1. Male and female Dunes Sagebrush Lizard (*Sceloporus arenicolus*) home range size (MCP) in fragmented and unfragmented habitat

Fig. 2. Male and female Dunes Sagebrush Lizard (*Sceloporus arenicolus*) core area home ranges based on 50% KDE estimation in fragmented and unfragmented habitat.

Fig. 3. Male and female Dunes Sagebrush Lizard (*Sceloporus arenicolus*) distance moved per day in fragmented and unfragmented habitat.

Fig. 4. Home-range (MCP) of Dunes Sagebrush Lizard (*Sceloporus arenicolus*) individuals #32 and #37. Individual 32 was the only *S. arenicolus* to cross a caliche road (dark line). This crossing was made at a sand-covered portion of the caliche road. Individual 37 moved directly parallel to the road, but never crossed it. No individuals were observed on caliche surfaces.

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FIG.—1.

FIG.—2.

FIG.—3.

FIG.—4.