ON THE USE OF UNMANNED AERIAL VEHICLES TO RAPIDLY ASSESS MICROHABITATS OF TWO TEXAS LIZARD SPECIES, *COPHOSAURUS TEXANUS* AND *ASPIDOSCELIS GULARIS*

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ABSTRACT

We examined the effectiveness of using an unmanned aerial vehicle (UAV) as a tool for the rapid assessment of microhabitat in Texas spotted whiptail (*Aspidoscelis gularis*) and greater earless lizard (*Cophosaurus texanus*). We collected microhabitat data from aerial images captured at lizard sightings along gravel roadways on Devils River State Natural Area – Big Satan Unit (DRSNA-BSU) from July through September, 2014. Point locations of lizard sightings were also compared with DRSNA-BSU environmental maps including: soil type, vegetation type, Normalized Difference Vegetation Index (NDVI), elevation, and slope. Multiresponse Permutation Procedures (MRPP) and Permutational Multiple Analysis of Variance (PerMANOVA) analyses indicated that the spatial distributions of the two lizard species were significantly different. Non-metric Multidimensional Scaling (NMDS) analyses revealed that grasslands, low slopes, and soft soils were correlated with the presence of *A. gularis* while steep slopes, rocky soils, and the xeric plants lechuguilla, sotol, and guajillo were associated with the presence of *C. texanus*. Our data are consistent with other habitat association analyses administered on these two lizards. UAVs provided a new perspective on the study of microhabitat and we recommend them as a method of rapid habitat assessment. Data collection for one individual lizard in the field could be completed in less than three minutes with the use of our UAV, making the technology an ideal technique for gathering habitat data in a short amount of time.

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INTRODUCTION

Biologists today are equipped with an increasingly diverse array of technologies to assist field measurements and calculations (The National Academies 2009). One emerging technology is the use of Unmanned Aerial Vehicles (UAVs), more commonly referred to as drones, combined with imaging systems to monitor populations, habitats and behaviors of wildlife (Jones IV et al. 2006; Martin et al. 2012; Rodríguez et al. 2012). Previous micro-habitat studies have incorporated low-altitude aerial photography using manned aircraft or balloons; however, windy conditions often rendered balloons inadequate and flying aircraft at low altitudes imposes its own inherent risks (Kamada and Okabe 1998; Sasse 2003).The increased affordability of reliable UAVs makes their use practical and innovative for habitat studies (McGwire et al. 2013).

Micro-habitat analyses are vital to understanding a species' resource use (Barbault and Maury 1981). Animals do not follow random dispersal and foraging patterns, but instead show associations with various biotic and abiotic environmental characteristics (García-De La Peña et al. 2012). Species often partition themselves among different micro-habitats both spatially and temporally, because of prey availability, competition, predator avoidance, vegetative cover and substrate type (Angert et al. 2002; Pelegrin et al. 2013). The understanding of both broad-scale and fine-scale habitat characteristics remains a necessity when constructing herpetofaunal management programs (Buckley and Roughgarden 2005).

The Texas spotted whiptail (*Aspidoscelis gularis*) and greater earless lizard (*Cophosaurus texanus*) exhibit some degree of habitat overlap. They both possess high heat tolerances and relatively high field-active body temperatures (*A. gularis*, 38-41°C;

C. texanus, 31-42.1°C), allowing them to remain active while other local lizards find shelter (Bashey and Dunham 1997; Durtsche et al. 1997; Paulissenn 2001; Winne and Keck 2004). These desert adapted lizards were the most frequently encountered vertebrates on the gravel roadways at our study site during daylight hours. This fact may be coincidental or it could indicate an integral part of their respective autecology.

Cophosaurus texanus are known to spend over 90% of their day in solitary positions due to their sit-and-wait foraging style and territorial behavior (Clark 1965; Bulova 1994; Durtsche et al. 1997). Sit-and-wait predators are thought to forage more effectively in open vegetation microhabitats where prey items have less cover to disguise their search image (Shepard 2007). Other conclusions reveal that *C. texanus* may utilize open habitats and perches to detect predators or perhaps assist in intraspecific communication (Durtsche et al. 1997). Conversely, *A. gularis* are more active foragers searching under and around rocks and vegetation (Paulissen 2001; Winne and Keck 2004). Both of these foraging styles could benefit from the edge effect of a gravel road as it would allow for the lizards to easily detect prey visually due to the lack of complex vegetative structure.

Our research was concentrated on collecting adjacent microhabitat data from each incidental lizard occurrence off the gravel roadway. These data provided information on resource usage which will assist in the development of successful reptile conservation and management plans.

METHODS

The study site, Devils River State Natural Area – Big Satan Unit (DRSNA-BSU), is a 17,642 acre property, managed by the Texas Parks and Wildlife Department (TPWD) located along nearly 10 miles of the Devils River in Val Verde County, Texas (Fig. 1). The natural area encompasses three major ecoregions (Fig. 2), the Edwards Plateau, Chihuahuan Desert and the Southern Texas Plains (Griffith et al. 2004). It consists of five major topoedaphic habitat types counting uplands, dry slopes, shallow ravines or dry canyons, mesic canyons, and riparian corridors (Fig.3) with six distinct vegetative series (Fig. 4, 5) spread across the habitats (Keith 2011). The variety of vegetation on the Natural Area is notably diverse considering the homogeneity of the Cretaceous limestone substrate. The DRSNA-BSU boasts some of the most extreme climactic conditions in Texas. High temperatures commonly in excess of 38°C (100°F) coupled with an average rainfall less than 50cm per year creates many physiological challenges to diurnal herpetofauna.

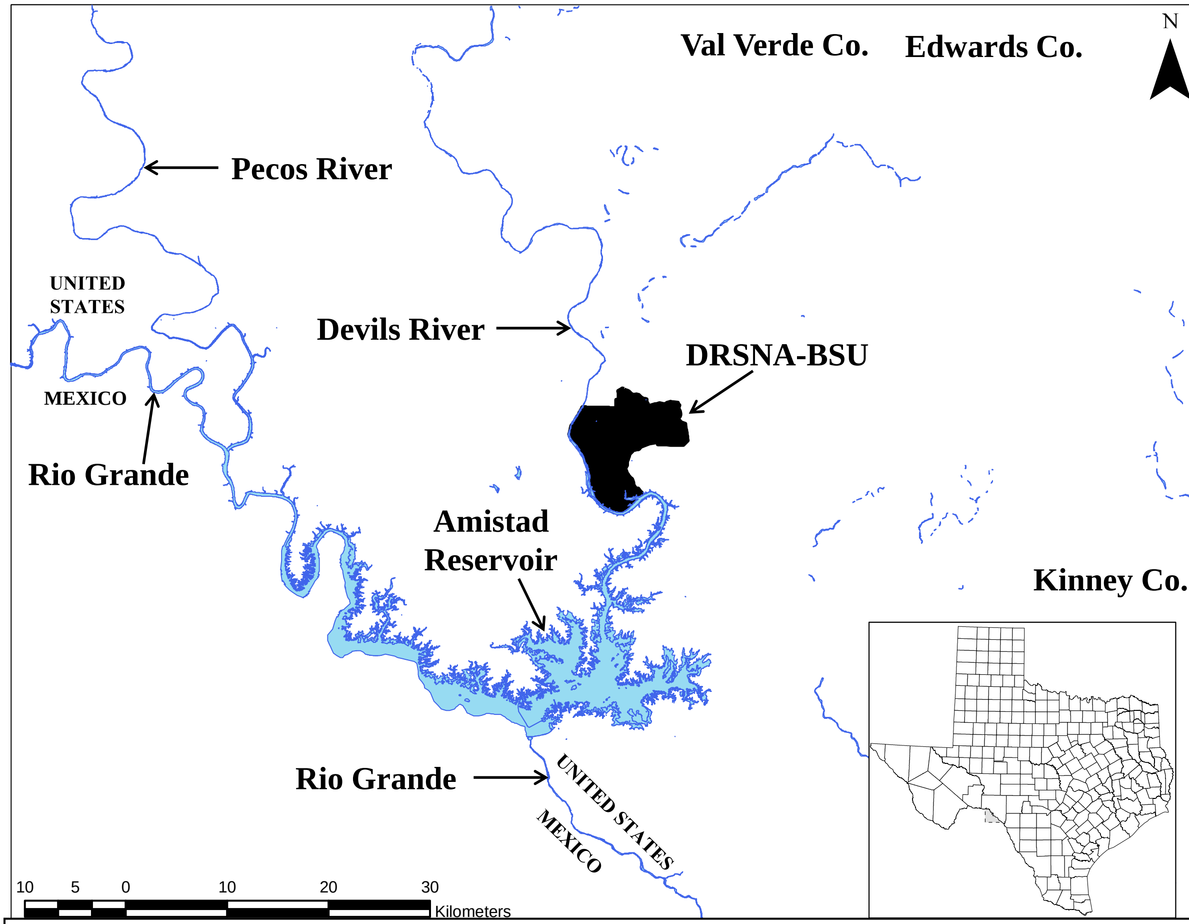

FIG. 1–The Devils River State Natural Area – Big Satan Unit is situated on nearly 10 miles of Devils River bank in Val Verde County, Texas.

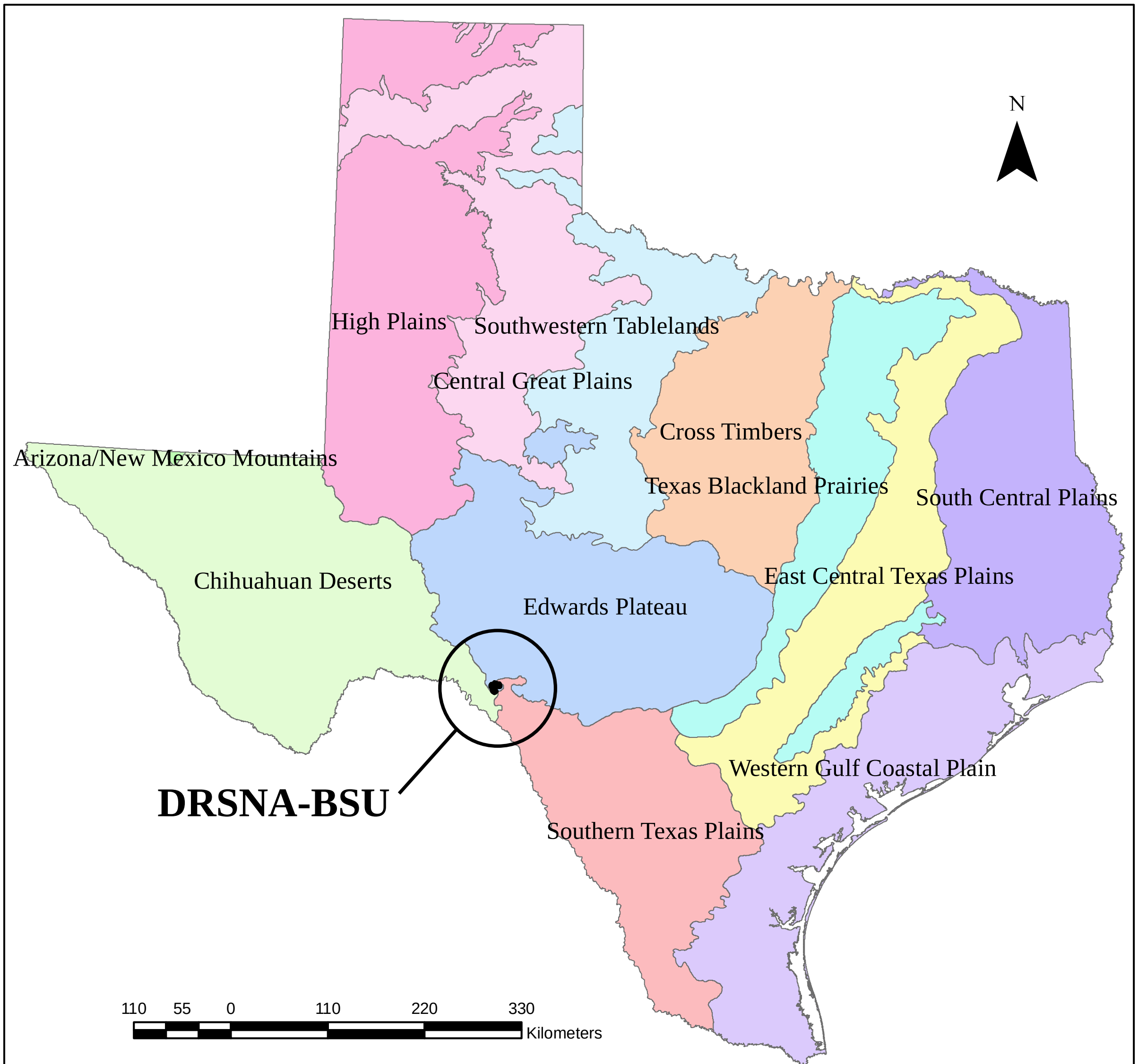

FIG. 2– The Devils River State Natural Area – Big Satan Unit is surrounded by three of the largest ecoregions in Texas, the Chihuahuan Desert, Edwards Plateau, and the Southern Texas Plains (Griffith et al. 2004).

FIG. 3–Aerial photograph of the DRSNA-BSU in Val Verde County, Texas. Dense vegetation occupies most of the canyons on the property and appears darker.

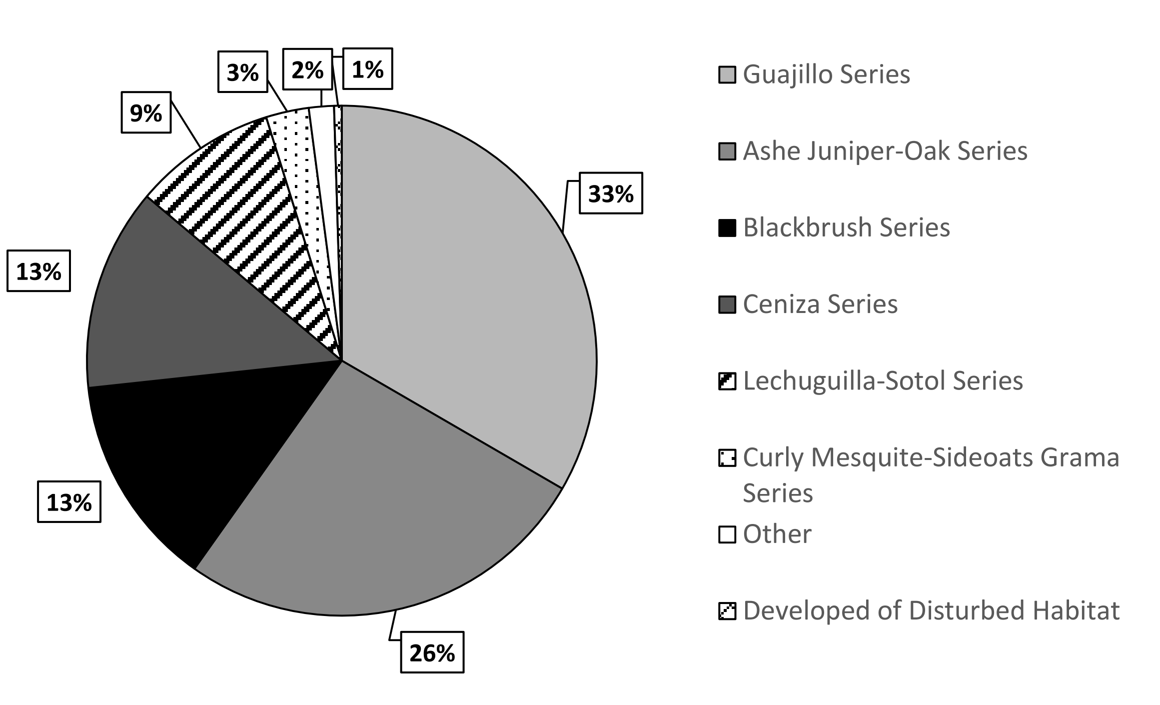

FIG. 4–The seven vegetative series found on the DRSNA-BSU listed in order by acreage: Guajillo (5889.4ac), Ashe Juniper-Oak (4558.3ac), Blackbrush (2379.0ac), Ceniza (2267.6ac), Lechuguilla-Sotol (1600.3ac), Curly Mesquite-Sideoats Grama (480.1ac), Other (280.5ac), and Developed or Disturbed Habitat (85.8ac).

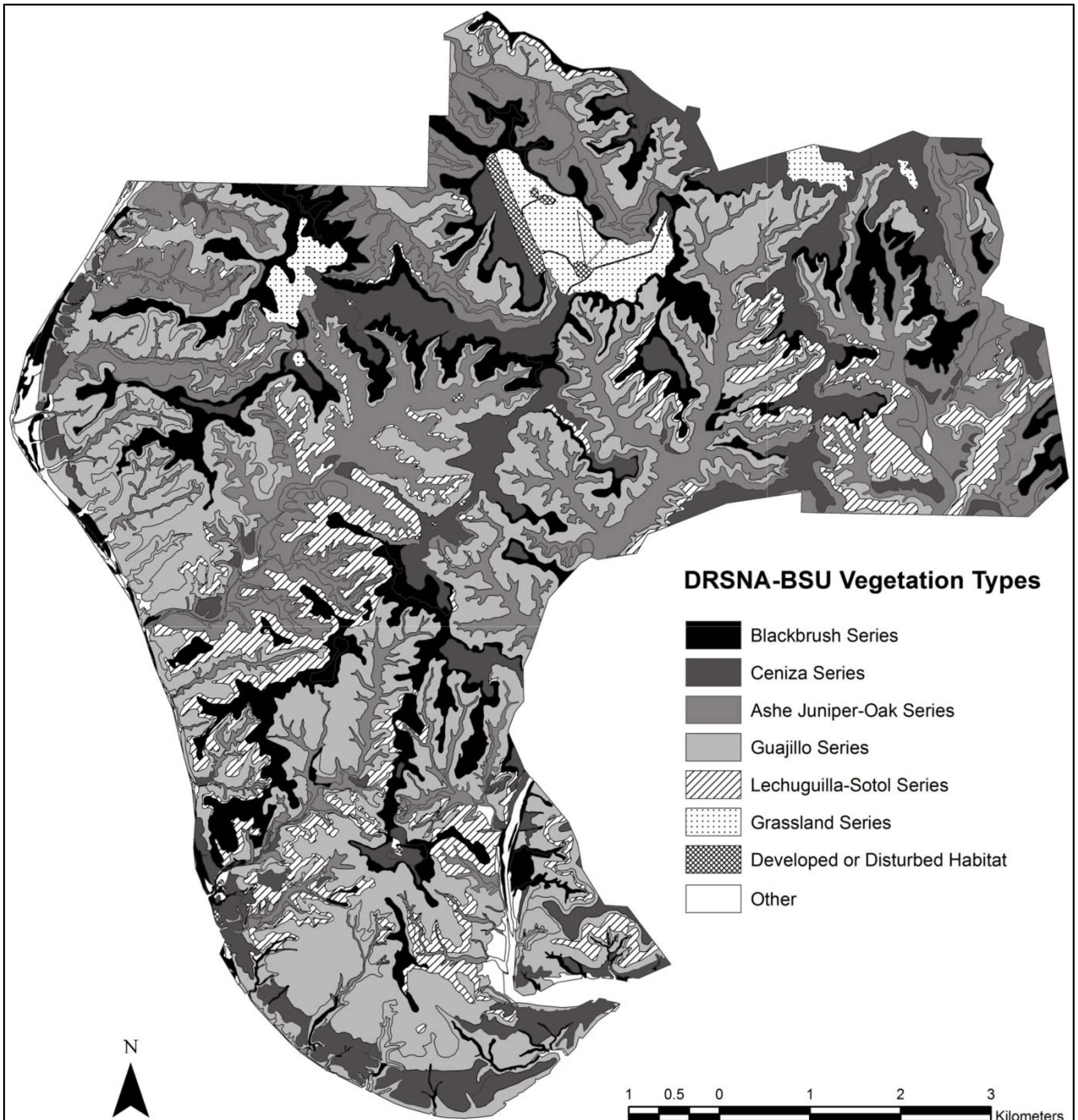

FIG. 5–The six major vegetation types located on the DRSNA-BSU. The Other category mostly includes vegetation types found along the banks of the Devils River: Gammagrass-Switchgrass Series, Netleaf Hackberry-Little Walnut Series, Maidenhair Fern-Lindheimer's Shieldfern Series, Mesquite-Huisache Series, Mesquite-Whitebrush Series, Plateau Live Oak-Netleaf Hackberry Series, Sycamore-Willow Series, Buttonbrush Series, and Other Series.

The vegetation on the study site is heavily influenced by substrate structure and topographic position. Larger woody plant species dominate low elevation localities, while shrubs and succulents find their place among the steep rocky limestone hillsides, and finally mixed grasses reside in high elevation plateaus with adequate topsoil.

It has also been suggested that historical overgrazing left a lasting impression of larger ashe-juniper communities in the upland grasslands (Keith 2011). Other habitat disturbances include dozens of kilometers of gravel roads, residential and commercial buildings, and an airstrip. Increased development of the Natural Area is expected as the TPWD plans to open the property for public use within the next decade. Proposals for clearing additional habitat for public campsites are currently in negotiations.

For this project, slow-moving (5-10 mph) driving transects were selected as the collection method of choice over traditional random-route time-constrained hiking searches. The equipment load required for drone operation and data processing proved cumbersome for arduous mid-day herpetofaunal searches. Confining the search area to specifically the edge of gravel roadways presented an expected handicap in the sampling method as there was higher species diversity documented during time-constrained searches in June, 2014 (n = 10, 38 hours of sampling) as compared to the driving transects from July-October, 2014 (n = 4, 40 hours of sampling). We maintain road transects were the optimal method for this study because the number of positively identified lizard sightings per hour was higher in road transects (n = 146, 3.65 sightings per hour) as compared to random route time-constrained searches (n = 73, 1.92 sightings per hour). It benefitted our study to have lower species diversity with a high overall yield of sightings since we were trying to ascertain the effectiveness of using drone derived aerial photography as a means to quantify microhabitat characteristics. More drone photos for fewer species generated larger sample sizes which made comparisons with current microhabitat data more reliable.

Driving transects were conducted in a series of routes on semi-maintained caliche roadways which adequately sampled most of the study site's landmass and all six major vegetation series (Fig. 6). Driving times ranged from 09:30AM to 20:40PM. Each route was sampled one-way from start to finish avoiding data collection on the same individual twice in one route. Routes were also never surveyed twice in one day. Both micro and macro-habitat characteristics were measured from positively identified lizard sightings that resided on the edge of a gravel road.

Point localities of individuals located on roadways were imported as a layer into ESRI ArcMap and given a 50 meter buffer (7850 m^2) to represent home range; however home range data for *Cophosaurus texanus* and *Aspidoscelis gularis* are non-existent current literature. Consequently, similar species' home range data were utilized to justify the 50 meter ArcMap point buffer. Adult *Aspidoscelis hyperythrus* have been estimated to have a home range approaching 3,500 m^2 and *Aspidoscelis uniparens* up to 1953 m^2 (Bostic 1965; Eifler 1996). Numerous home range estimates of another earless lizard, *Holbrookia maculata*, have been calculated up to 7205 m^2 and 6645 m^2 respectively (Jones and Droge 1980; Hulse 1985).To provide an additional level of independence ensuring that no individuals were counted twice, data were eliminated from the both the micro and macro-habitat datasets if: (1) their buffered area intersected another's and (2) their data were collected on different days.

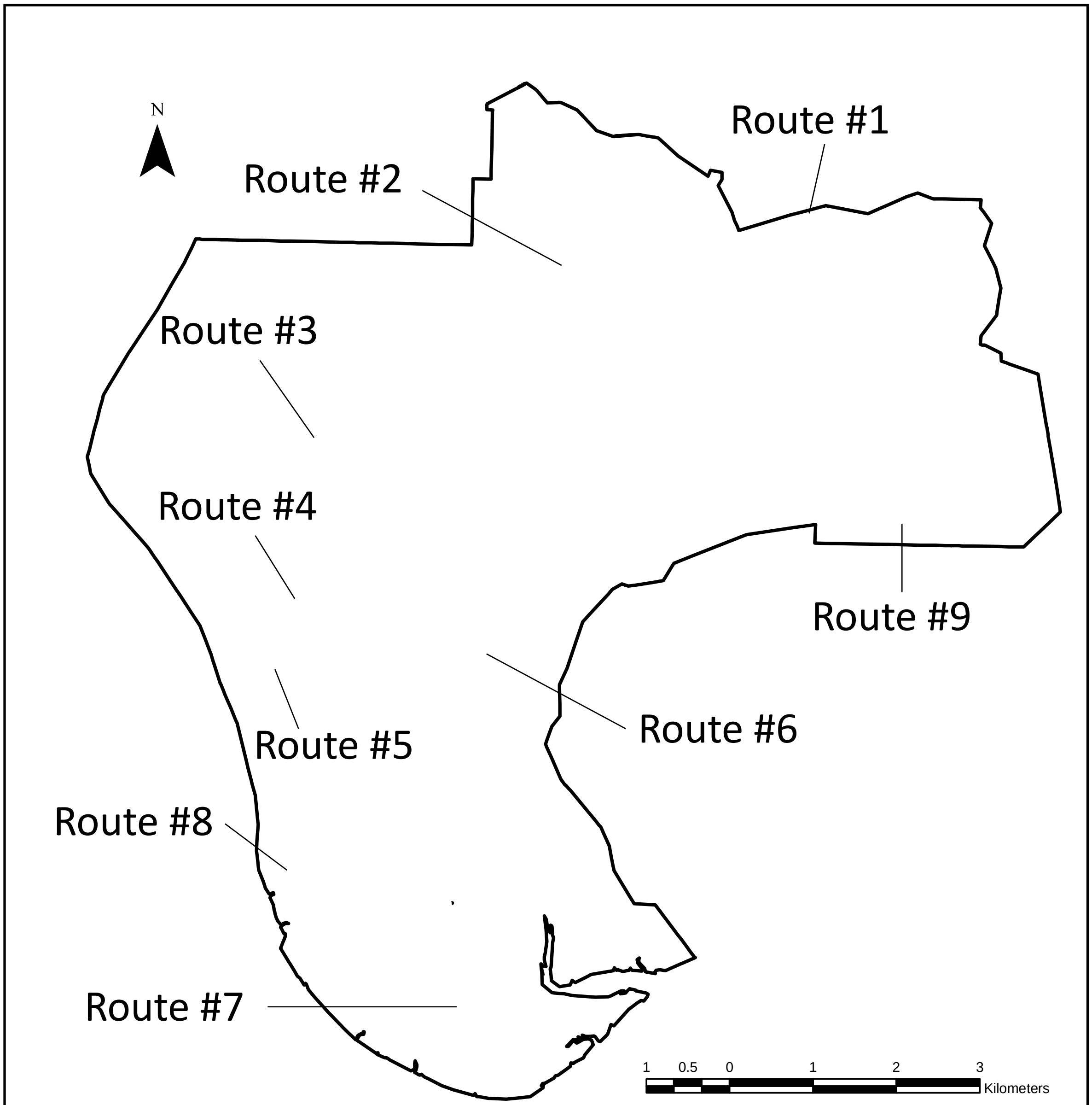

FIG. 6–Aerial view of the route transects on DRSNA-BSU. Route patterns above are used for map distinction only. There are no differences in construction as all roads are made of caliche and graded by the natural area staff.

Microhabitat data collection –

Data collected at each lizard sighting included UTM coordinates, elevation, air temperature, maximum vegetation height and an aerial photograph. Maximum vegetation height was measured from the tallest plant in the 5x10 meter grid at each lizard sighting. A 1 meter wooden plank was placed at the initial lizard sighting location and functioned as a scale bar for aerial photographs. A rectangular 5x10 meter grid was digitally drawn onto aerial images using Adobe Photoshop CS5 and the initial lizard sighting served as the midpoint along the long edge of the grid. Aerial photographs of microhabitats were taken from video stills using a GoPro Hero3 digital camcorder in Narrow View mode mounted under a DJI Phantom Quadcopter drone. The grids were divided into 50 squares each 1 meter in length (Fig. 7). Microhabitat characteristics were quantified at the point of intersection between each line in the grid (66 points).

This model of drone lacks a real-time altimeter on the transponder so visual acuity of the proper altitude was learned through trial and error in test flight. Multiple test flights were conducted to determine the adequate height to capture the entire 5x10 meter grid in the camera's field of view. At the conclusion of each test flight images were downloaded to the computer, the grid overlay was fitted to the 1 meter scale bar, and the decision was made to increase or decrease the drone's relative altitude. Pilots were required to learn the proper altitudinal position of the drone before data were collected.

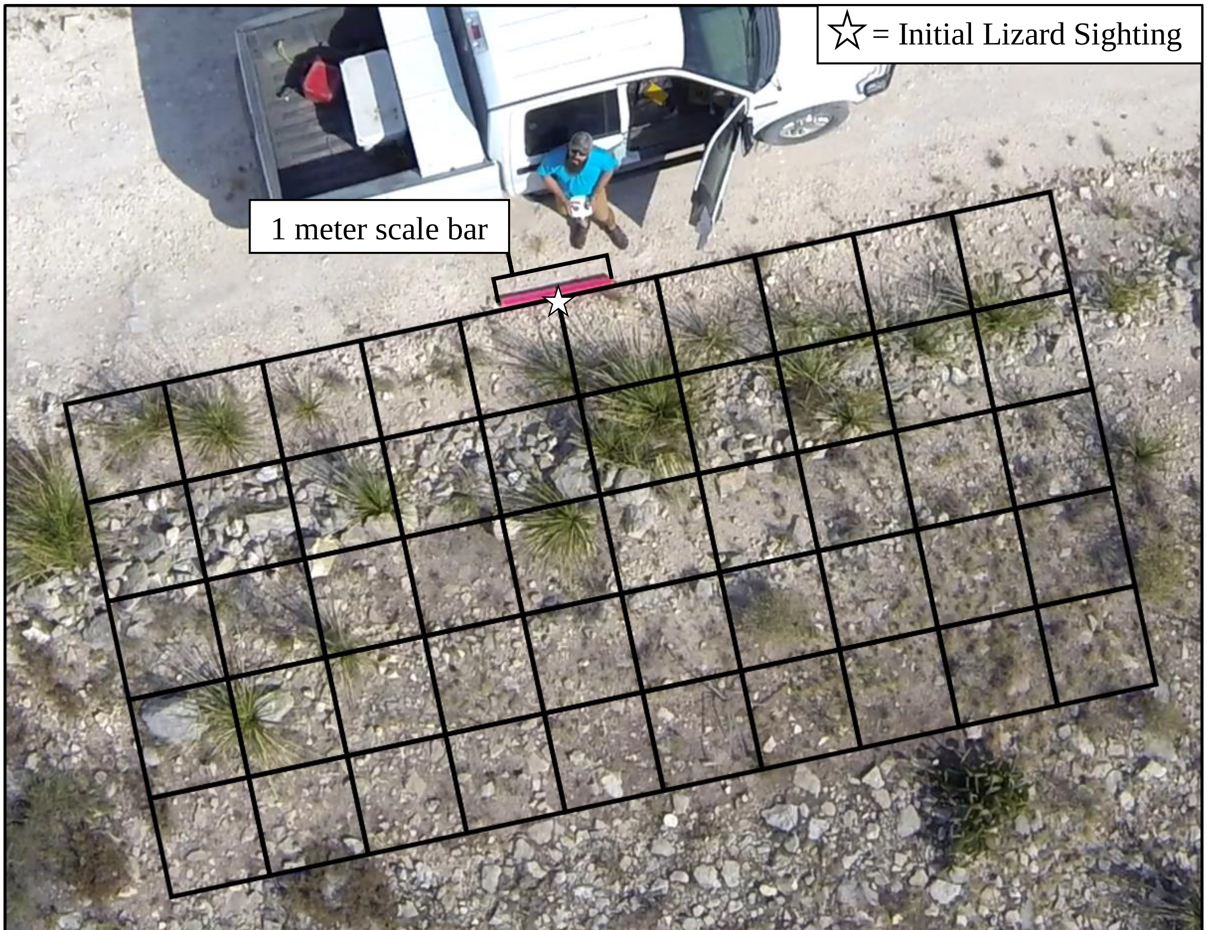

FIG. 7–Aerial view from the GoPro Hero 3 digital camcorder mounted under the DJI Phantom Quadcopter drone. The 66 grid line intersections served as the points for microhabitat data collection.

Microhabitat characteristics included one of the eleven following categories at each point: rock, gravel, soil, grass, cenizo, lechuguilla, sotol, blackbrush, guajillo, ash-juniper, oak. The sum totals for each microhabitat characteristic were added into an Excel (Microsoft 2010). spreadsheet and imported into the statistics program R (R Core Team 2014).

Macrohabitat data collection –

Macro-scale (1-10 meter) habitat associations were analyzed using ESRI ArcGIS software (ESRI 2014). Macro-habitat characteristics included the gradient of hill slope in degrees, the cardinal direction of slope aspect in degrees, the vegetation type, route number, soil type, and the mean normalized difference vegetation index found within each point's respective 50m buffer.

Statistical Analyses –

Dissimilarity matrices were created from both the micro and macro-habitat data using the vegdist function in R. The non-metric Bray-Curtis dissimilarity index was used as it provides robust results expressing ecological relationships. Multiple Response Permutation Procedure (MRPP) using Bray-Curtis distances at 10,000 permutations and Permutational Multivariate Analysis of Variance (PerMANOVA) using Bray-Curtis distances at 10,000 permutations were used to determine significance between species and habitat at the micro and macro-habitat scales. Non-metric Multidimensional Scaling (NMDS) using Bray-Curtis dissimilarity index was administered to generate unconstrained ordination of habitat data. Data underwent Wisconsin double standardization and square root transformation before ordination as these measures standardize results for large ecological datasets. NMDS has been shown to be the method of choice among community ecologists for recognizing structure among multiple habitat variables in complex systems (McCune and Grace 2002). Environmental vectors were then generated and plotted along with NMDS ordination scores to show strength of correlation.

RESULTS

All nine routes were sampled five times throughout the survey period from July through October, 2014. An estimated 318km were actively sampled over a span of approximately 40 hours. A total of 146 lizards were positively identified during the survey: 123 *Cophosaurus texanus*, 21 *Aspidoscelis gularis*, 1 *Phrynosoma cornutum*, and 1 *Sceloporus undulatus*. *Phrynosoma cornutum* and *Sceloporus undulatus* were removed from the analyses due to low sample size.

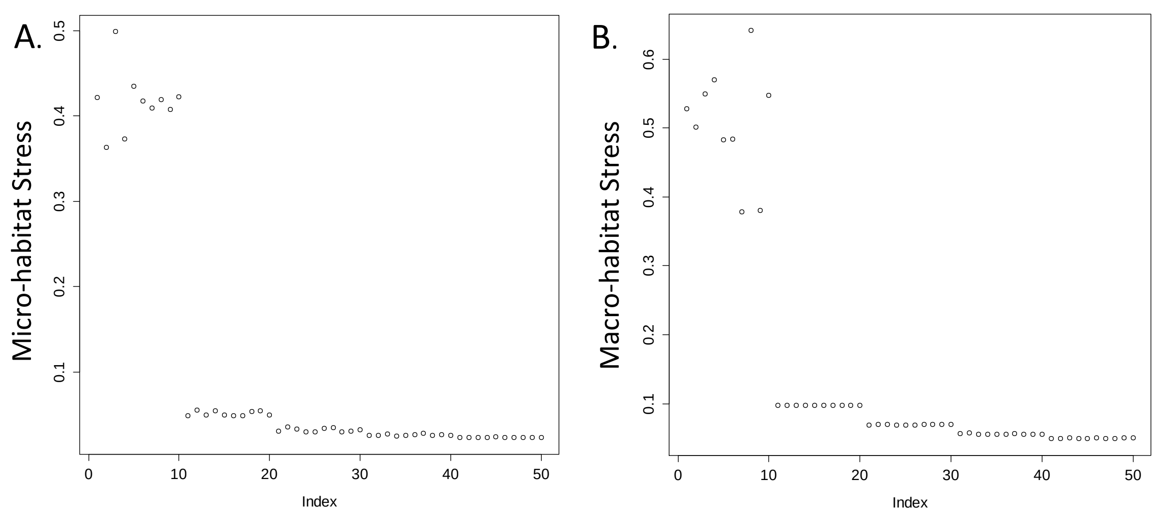

FIG.8 – Plots showing the minimized stress values of both the micro- (A) and macro- (B) habitat datasets from ten random starts at each dimension level (1-5). The first 10 stress values are from the first dimension (index = 1-10), the second 10 stress values are from dimension 2 (index= 11-20), and so on. The figure serves as an appropriate scree plot to show the relative importance of dimensionality in the NMDS ordination for the two datasets.

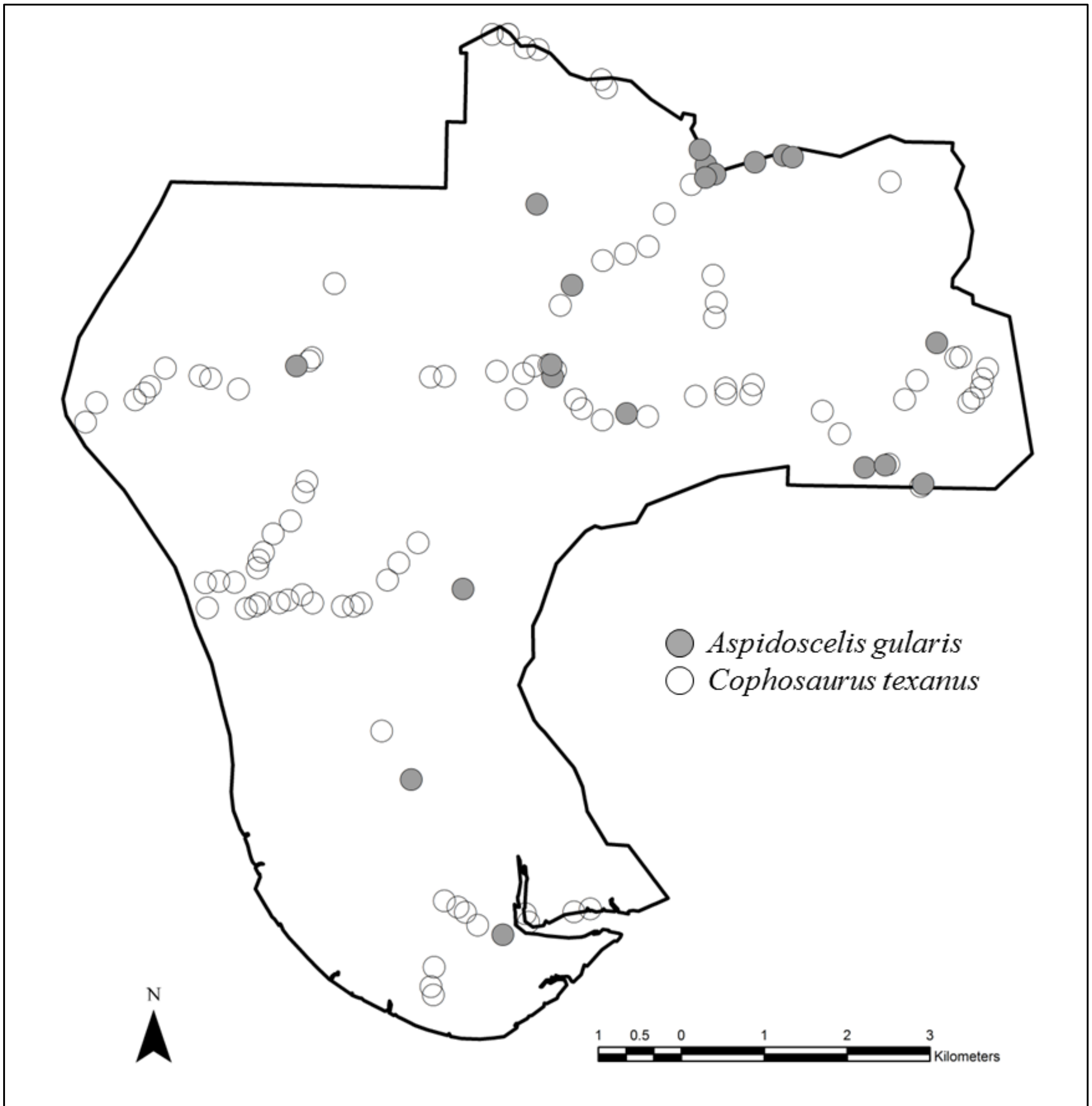

FIG. 9–Points *A. gularis* (n = 20) and *C. texanus* (n = 97) used in macro-habitat analysis. Point diameters do not represent the 50m buffered zones at this scale.

Microhabitat Results –

Microhabitat data were taken from aerial photos via drone for all 146 lizards; however, due to equipment failure and independence filtering only 14 *A. gularis* and 99 *C. texanus* were used in the microhabitat analysis.

A significant difference was observed in habitat associations between *A.gularis* (n = 14) and *C. texanus* (n = 99) (MRPP: $\delta < 0.05$, A = 0.017; PerMANOVA: $p < 0.05$). The NMDS ordination of micro-habitat variables finalized with a stress of 0.1618 in 3 dimensions after 14 iterations. Micro-habitat species centroids show segregation between *A. gularis* and *C. texanus* (Fig. 10b). Vectors fitted to the ordinations show the most influential micro-habitat variables contributing to species segregation.

Aspidoscelis gularis locations were most commonly associated with vegetative microhabitats including mixed grasses and Cenizo (Fig. 10d, 11f, 11e). Soil substrates were also found in correlation with the presence of *A. gularis* (Fig. 10d, 11c). A relationship between higher elevation and the presence of *A. gularis* was also observed (Fig. 12b, 10d). Ordination vectors and r^2 values support these associations (Table 1).

Cophosaurus texanus data showed strong correlations in the presence of Guajillo, Sotol, and Lechuguilla vegetation in their microhabitat (Fig. 10d, 11a, 11b, 11d). Non-vegetative relationships included more rock and gravel substrates as compared to *A. gularis* (Fig. 10d, 11g, 11h). The measurements for maximum vegetation height were also generally larger for the *C. texanus* grid plots (Fig. 12a).

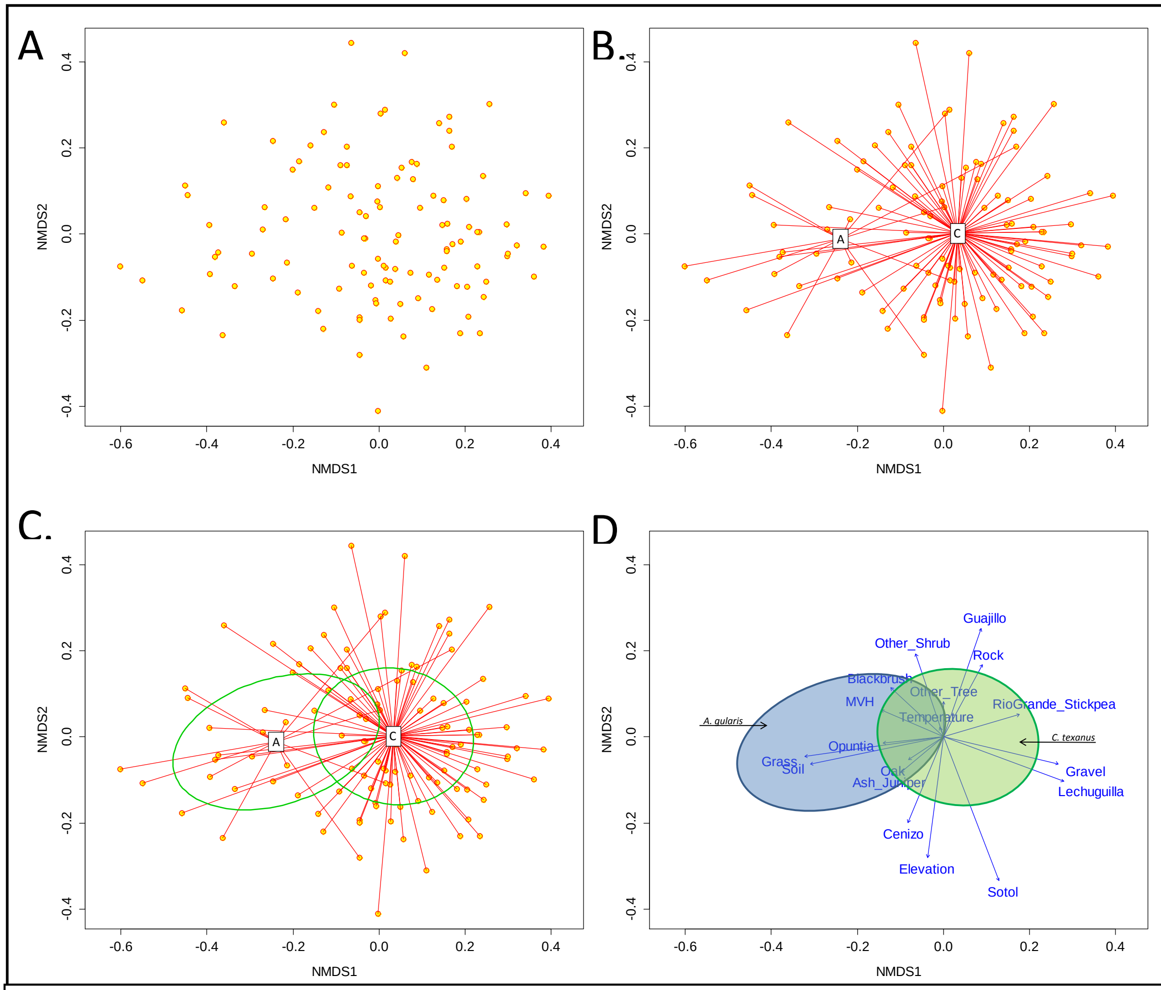

FIG.10 – The NMDS micro-habitat ordination diagram results: (A.) Distribution of ordinations within the micro-habitat dissimilarity matrix. (B.) Ordinations correlated with their respective species, "A" = *A. gularis*, "C" = *C. texanus*. (C.) Dispersion ellipses added to ordination diagram using the standard deviation of point scores. The weighted correlation of point scores was used to determine the primary axis of the ellipse. (D.) Micro-habitat environmental variable vectors added to the ordination plot. Length and directionality of vectors displays the micro-habitat variable influence upon species.

TABLE 1–Micro-habitat characteristics listed in order of importance by r^2 value. The micro-habitat 3-dimensional ordination vector coordinates are listed under their respective columns (NMDS 1, 2, and 3). Increasing r^2 value along with the directionality of vector coordinates shows the micro-habitat characteristic's influence upon species.

Micro-habitat Characteristic	NMDS1	NMDS2	NMDS3	r2
Rock	0.2392137	0.4411329	-0.8649732	0.5742
Guajillo	0.2417274	0.6906215	0.6816229	0.5244
Sotol	0.3589775	-0.932341	-0.0433068	0.5049
Soil	-0.8782594	-0.1791312	-0.4433648	0.4867
Maximum Vegetation Height	-0.4192016	0.1824626	0.8893691	0.4615
Grass	-0.9665037	-0.1375736	-0.2166659	0.4366
Elevation	-0.1179944	-0.9009888	-0.4174884	0.3788
Lechuguilla	0.9323976	-0.3445547	0.109164	0.3537
Gravel	0.9595428	-0.223805	0.1708477	0.3059
Cenizo	-0.3297804	-0.7947089	0.5095908	0.2462
Other_Shrub	-0.3061281	0.9252153	0.2241925	0.1724
Ash_Juniper	-0.5084944	-0.4260294	0.7482863	0.1467
RioGrande_Stickpea	0.9282097	0.2733967	0.252351	0.1436
Oak	-0.4410422	-0.2861678	0.8506408	0.1329
Opuntia	-0.7659459	-0.079233	-0.638004	0.1317
Blackbrush	-0.7283187	0.6808217	-0.0776768	0.1107
Other_Tree	0.0038083	0.5691221	0.8222442	0.0815
Temperature	-0.3288981	0.9420643	0.065886	0.0022

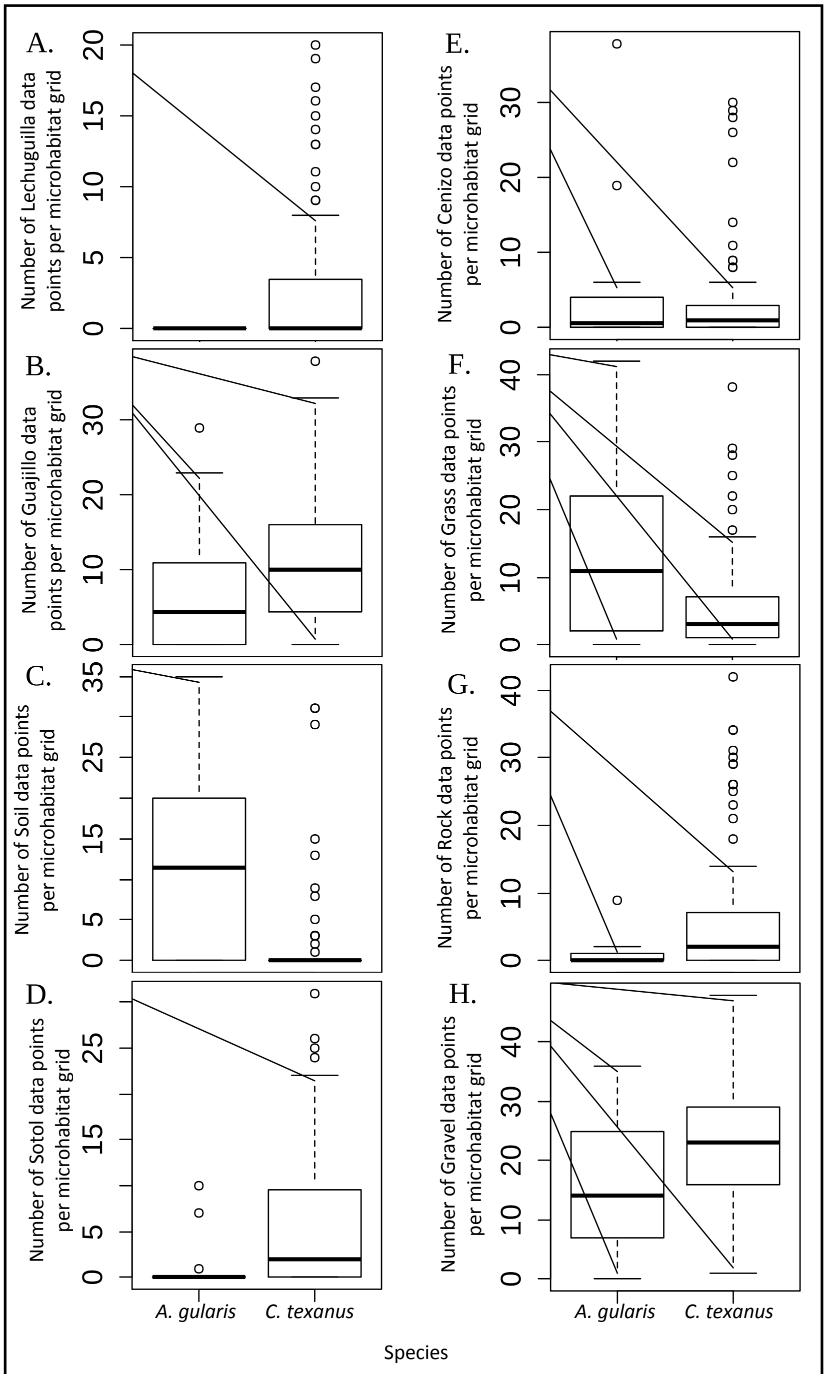

FIG.11 – Boxplots of the top eight r^2 values for microhabitat grid variables.

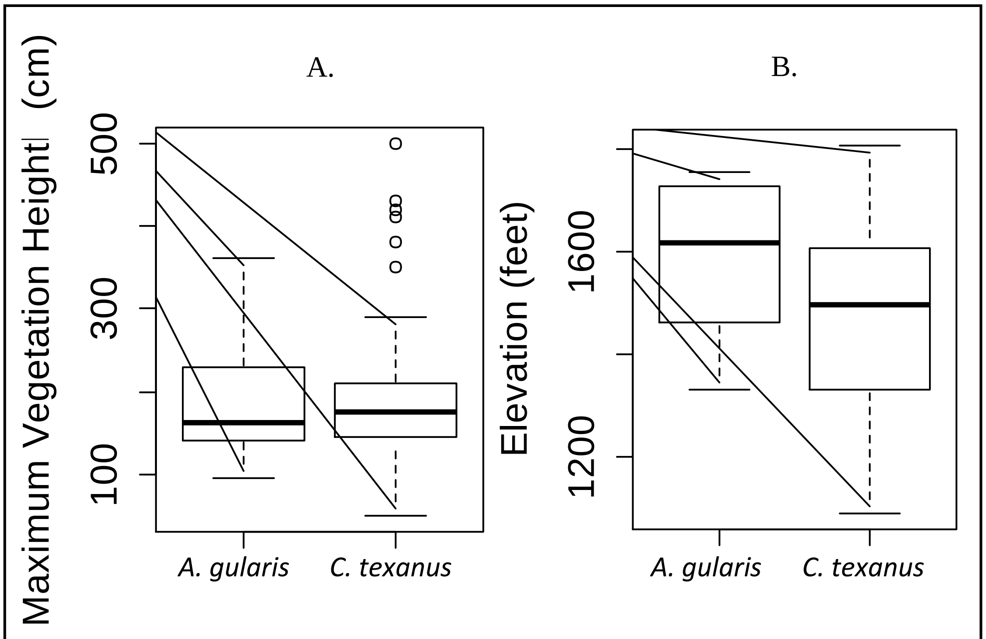

FIG.12 – Boxplots of the top two r^2 values for microhabitat non-grid variables.

Macrohabitat Results –

Macro-habitat data were collected at all *A. gularis* and *C. texanus* locations. Points were removed upon failure to meet the 50 meter buffer independence requirements resulting in a macro-habitat dataset consisting of 20 *A. gularis* and 97 *C. texanus* respectively.

A random dataset of 500 points was generated in ArcMap following the 50 meter independence rule. These randomized data were placed within spatial boundaries of the nine routes and fitted with all macrohabitat characteristics of the macro-habitat lizard dataset. This 500 point dataset was generated and utilized to compare *A. gularis* and *C. texanus* distribution patterns to a random distribution.

A significant difference was observed in habitat associations between *A. gularis* ($n = 20$), *C. texanus* ($n = 97$), and the random dataset ($n = 500$) (MRPP: $\delta < 0.05$, $A = 0.004$; PerMANOVA: $p < 0.05$). NMDS of macro-habitat variables produced ordinations within 2 dimensions reaching a stress of 0.2658 after 43 iterations. Macro-habitat species centroids show segregation between *A. gularis*, *C. texanus*, and the random dataset (Fig. 13b). The fitted vectors on the NMDS ordination plot display the most influential macro-habitat variables contributing to species habitat segregation (Fig. 13d).

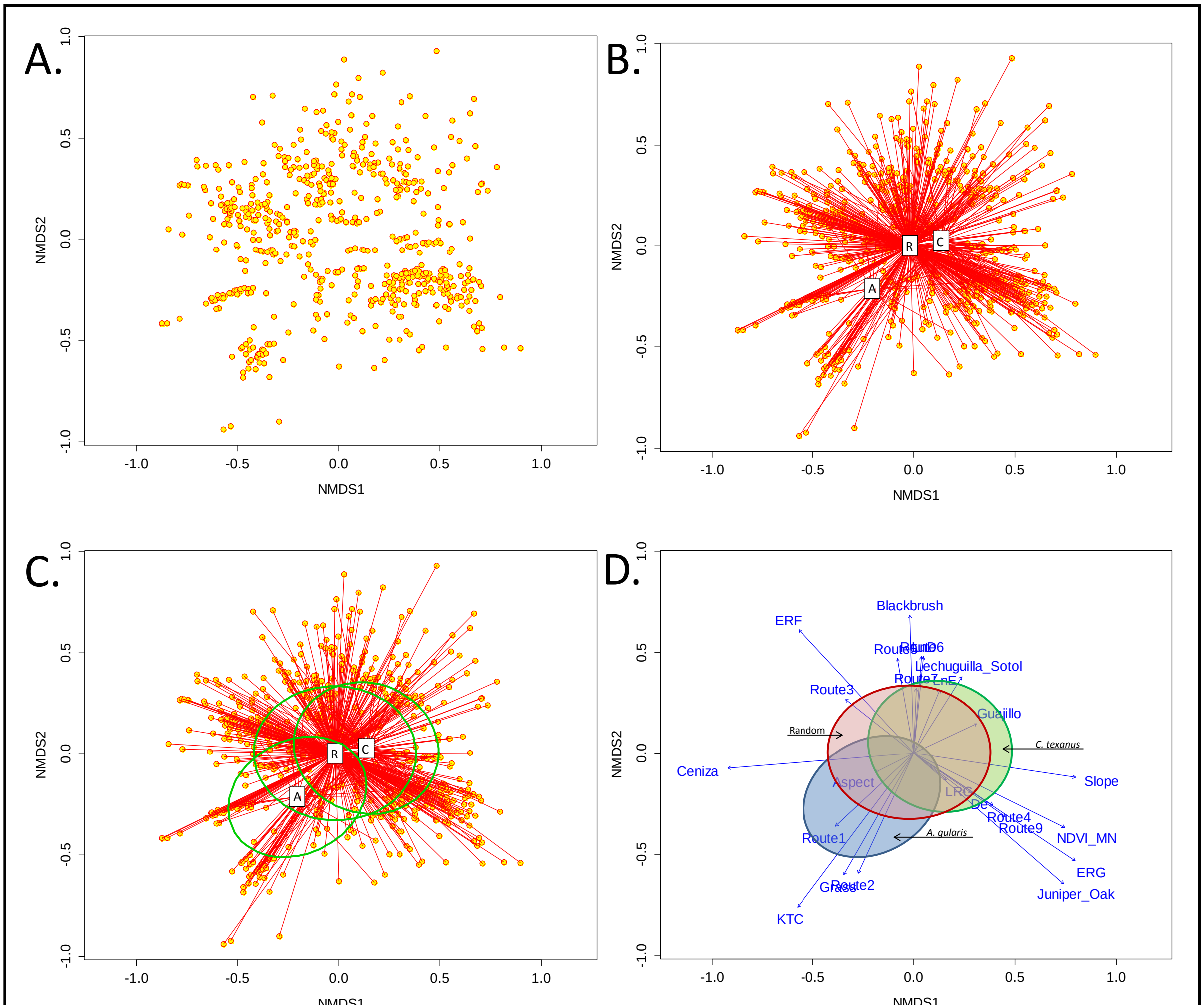

FIG.13 – The NMDS macro-habitat ordination diagram results: (A.) Distribution of ordinations within the macro-habitat dissimilarity matrix. (B.) Ordinations correlated with their respective species, “A” = *A. gularis*, “C” = *C. texanus*, “R” = Random. (C.) Dispersion ellipses added to ordination diagram using the standard deviation of point scores. The weighted correlation of point scores was used to determine the primary axis of the ellipse. (D.) Macro-habitat environmental variable vectors added to the ordination plot. Length and directionality of vectors displays the macro-habitat variable influence upon species.

A. gularis was found to reside in areas of lower slopes with loose soil and smaller NDVI indexes whereas *C. texanus* localities were associated with steeper slopes, rocky substrates, and higher average NDVI indexes (Fig. 14, 15, 16).

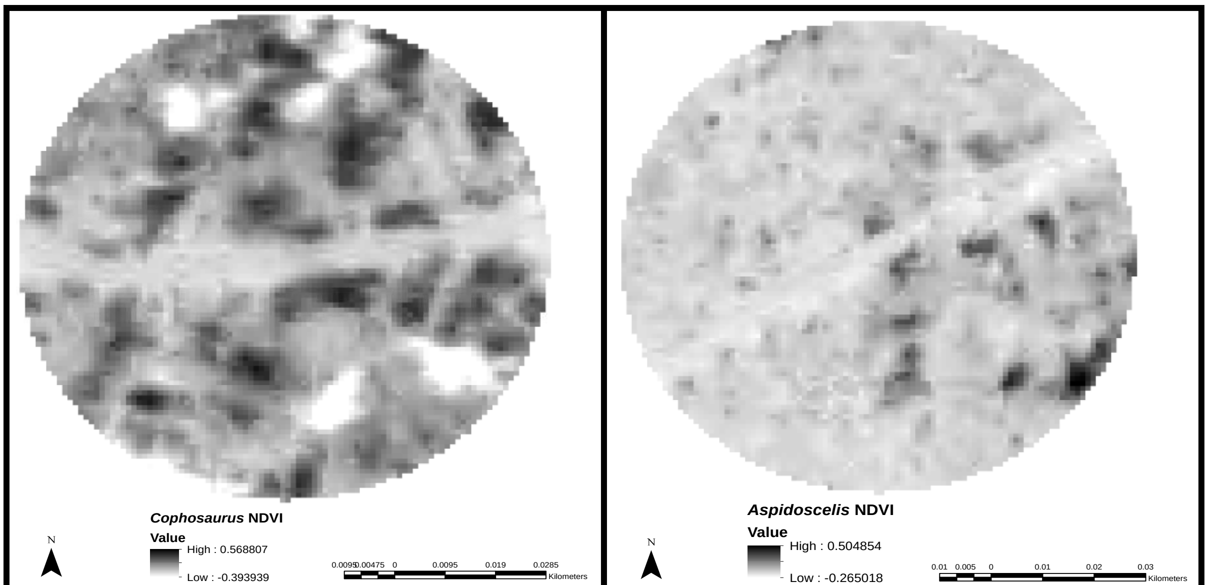

FIG.14 – Circles represent the 50m buffered areas of one *C. texanus* and one *A. gularis* location. The circle is filed with Normalized Difference Vegetation Index (NDVI) values at a 1m scale. Darker values represent higher vegetative reflectance while lighter values represent non-vegetative areas.

Vectors belonging to broad scale vegetative series presented numerous influences on the datasets. *A. gularis* were more associated with Cenizo and Grassland vegetative series than either *C. texanus* or the random dataset (Fig. 17c, 13d). *C. texanus* and the random dataset were correlated equally with the Ashe Juniper-Oak series creating a negative vector association with *A. gularis* as it was proportionately less influenced by the Juniper-Oak series (Fig. 13d, 17c). Localities for *C. texanus* were more associated with the Blackbrush and Lechuguilla-Sotol vegetative series as compared to the *A. gularis* and Random dataset (Fig. 13d, 17c).

Soil typed associations revealed that *A. gularis* was strongly correlated with Kavett-Tarrant association (KTC), while *C. texanus* and the Random dataset were not (Fig. 13d, 17b). Localities for *C. texanus* resided in the hilly, Ector-Rock outcrop association (ERF) and very steep, Ector-Rock outcrop association (ERG) soil types more frequently than either *A. gularis* or the Random dataset (Fig. 13d, 17b).

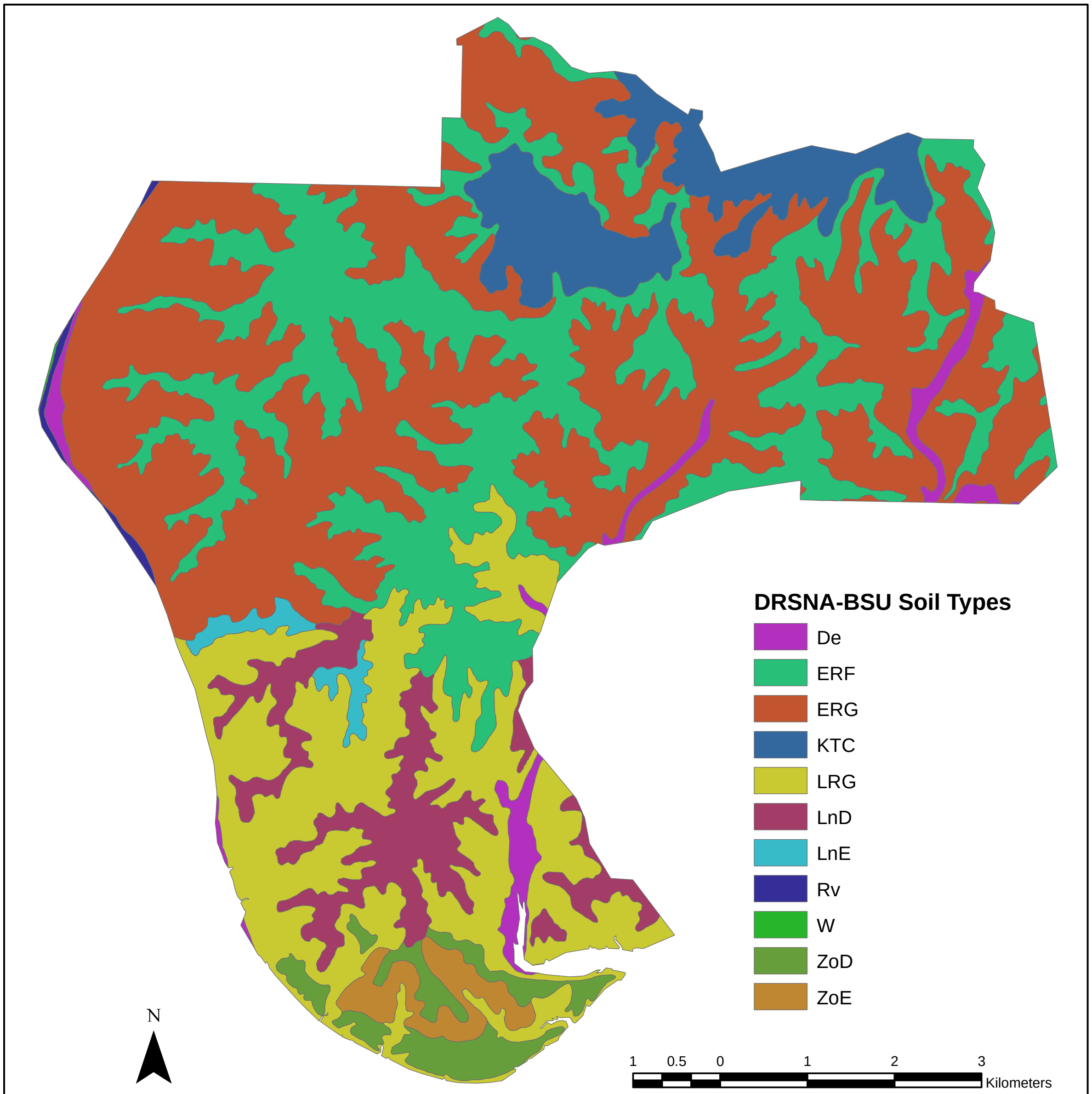

FIG.15 – This figure represents the diversity of soil types outlined by the Web Soil Survey provided by the US Department of Agriculture's Natural Resources Conservation Service (Version 3, 18 December 2014). De = Dev very gravelly loam, 0-3% slopes, frequently flooded; ERF = Ector-Rock outcrop association, hilly; ERG =Ector-Rock outcrop association, very steep; KTC = Kavett-Tarrant association, gently undulating; LRG = Langtry-Rock outcrop association, very steep; LnD = Langtry very cobbly silt loam, very rocky, 1-8% slopes; LnE = Langtry very cobbly silt loam, very rocky, 8-15% slopes; Rv = Riverwash and Dev soils, 0-3% slopes, frequently flooded; W = Water; ZoD = Zorra-Rock outcrop complex, 1-8% slopes; ZoE = Zorra-Rock outcrop complex, 8-15% slopes.

TABLE 2–Macro-habitat characteristics listed in order of importance by r^2 value. The macro-habitat 2-dimensional ordination vector coordinates are listed under their respective columns (NMDS1 and NMDS2). Increasing r^2 value along with the directionality of vector coordinates shows the macro-habitat characteristic's influence upon species.

Macro-habitat Characteristic	NMDS1	NMDS2	r2
Juniper Oak	0.754197	-0.656648	0.5117
ERG	0.832338	-0.554268	0.4865
KTC	-0.602318	-0.798256	0.4826
Ceniza	-0.997038	-0.076912	0.4542
ERF	-0.681543	0.731778	0.3722
NDVI MN	0.897715	-0.440577	0.3671
Slope	0.989269	-0.146104	0.3466
Grass	-0.498279	-0.867017	0.255
Blackbrush	-0.027036	0.999634	0.2491
Route2	-0.423427	-0.90593	0.2263
Route9	0.823337	-0.567552	0.1603
Route1	-0.731828	-0.681489	0.1481
Route6	0.079641	0.996824	0.1229
LnD	0.098948	0.995093	0.1228
Route5	-0.168259	0.985743	0.1209
Route4	0.836953	-0.547276	0.1163
Lechuguilla Sotol	0.529472	0.848327	0.1068
Route3	-0.783188	0.621784	0.0986
Guajillo	0.904383	0.426722	0.0629
LnE	0.379825	0.925058	0.0618
Route7	0.037514	0.999296	0.0553
De	0.796133	-0.605122	0.0542
Aspect	-0.901713	-0.432336	0.0233
LRG	0.773731	-0.633514	0.0227
ZoD	-0.119762	0.992803	0.0196
Mesquite	0.991623	0.129168	0.0143
Route8	0.577812	-0.81617	0.0092
Live Oak Hackberry	0.93274	0.36055	0.0039
ZoE	0.752393	0.658714	0.0036
Hackberry Walnut	0.986615	-0.163066	0.0031

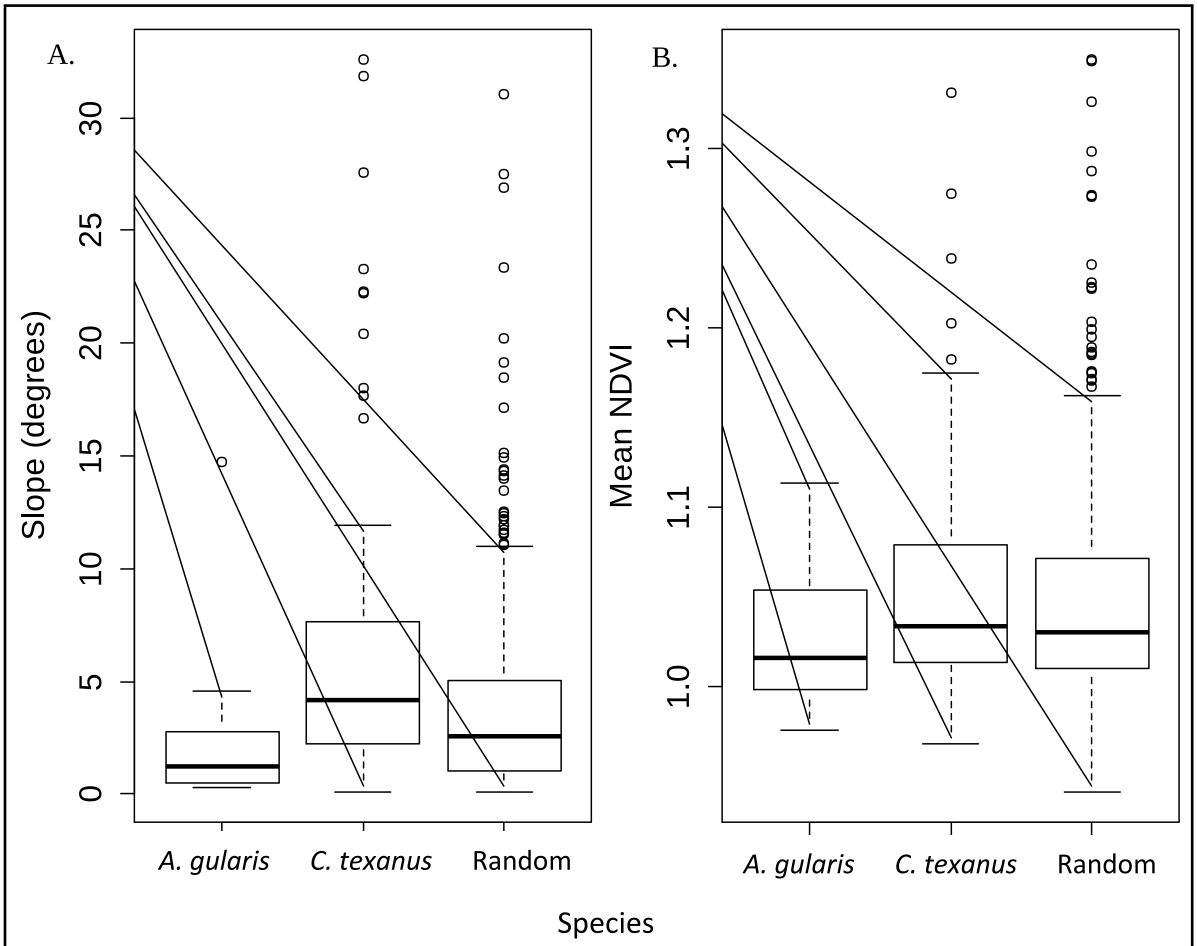

FIG.16 – Boxplots of the Slope and Mean NDVI values for macro-habitat variables.

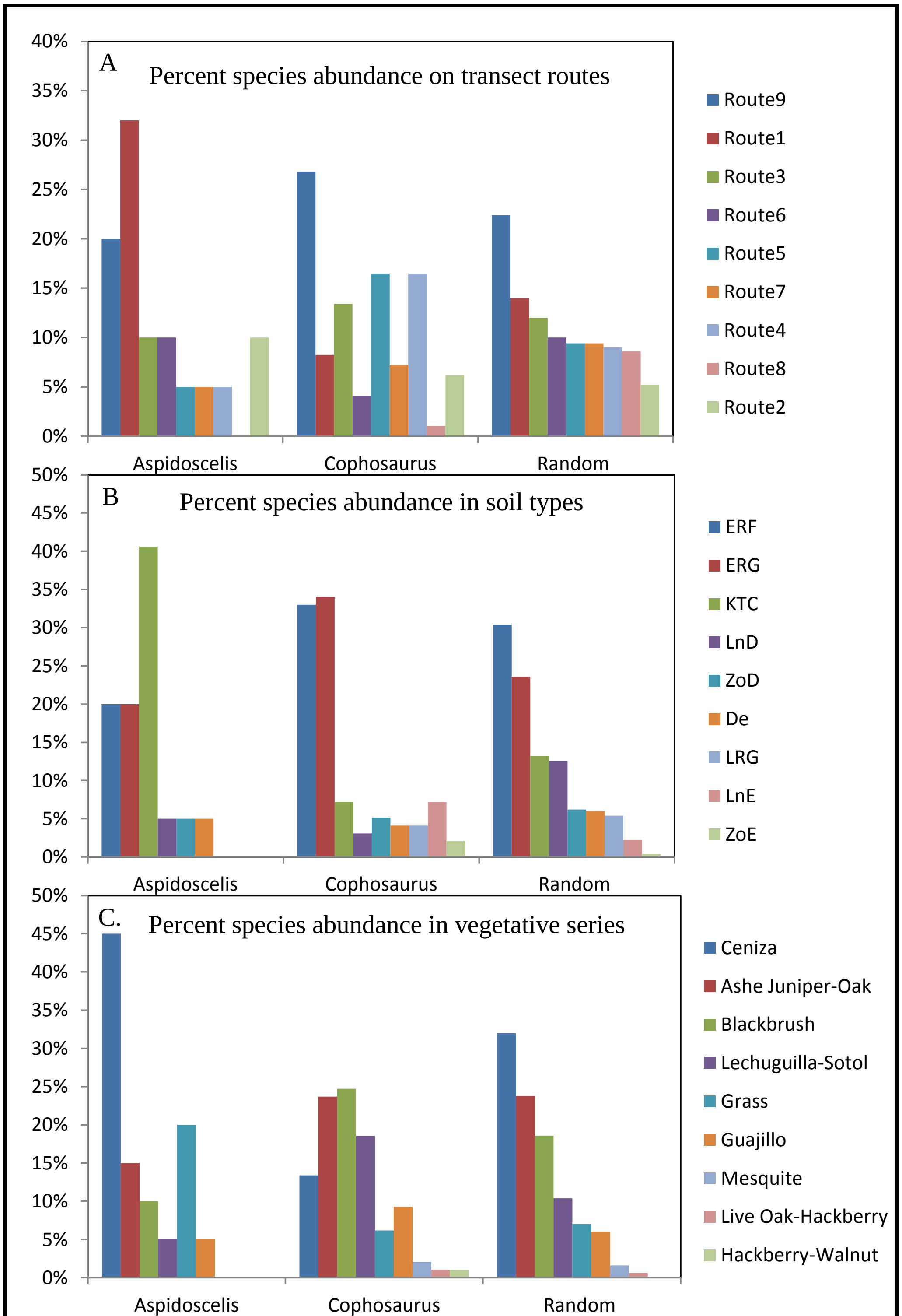

FIG.17 – Barplots showing percent abundance within Vegetative Series, Routes, and Soil Types of the macro-habitat dataset.

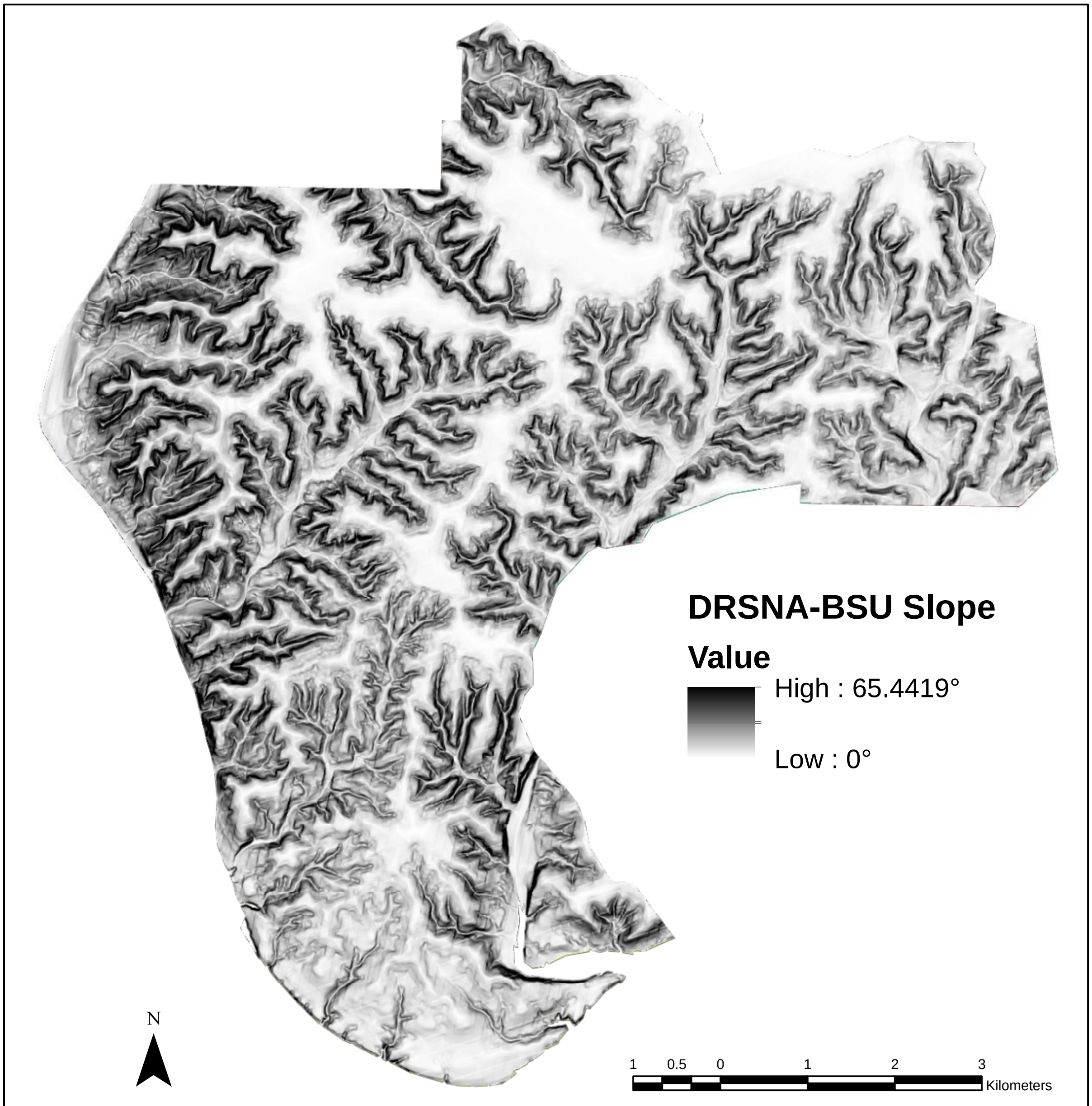

FIG.18 – Aerial view of the slope gradients on DRSNA-BSU. Darker colored areas represent steep slopes while lighter colored regions are generally flat to slightly undulating.

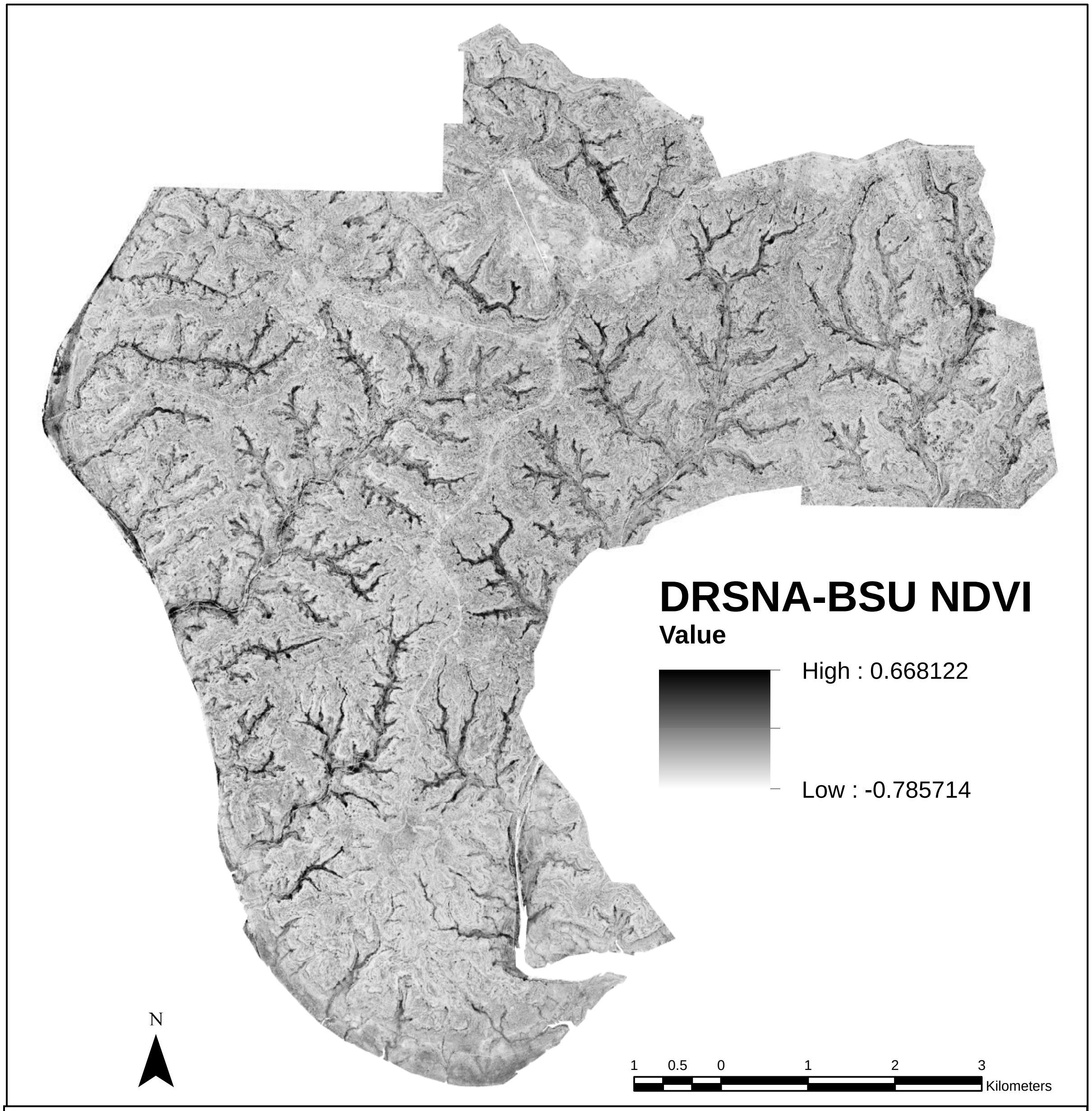

FIG.19 – Aerial view of the NDVI gradients on DRSNA-BSU. Darker colored areas represent dense vegetation while lighter colored regions sparse to nonexistent vegetation.

DISCUSSION

Choice of habitat among *A. gularis* and *C. texanus* depended upon multiple environmental variables including both biotic and abiotic characteristics. A clear distinction and correlation was observed in the habitat occupied by *A. gularis*. The DRSNA-BSU is geologically dominated by the early-Cretaceous Salmon Peak Limestone formation which follows typical erosional patterns. Upland escarpment areas of higher elevation with relatively flat undulating terrain have experienced soil development via decaying plant material and limestone breakdown. These soils are relatively thin, alkaline, and are often interrupted by small limestone outcrops protruding to the surface (Woodruff and Wilding 2008). The upland soil does provide ideal habitat for mixed grasslands including *Hilaria belangeri* (Curly-Mesquite) and *Bouteloua curtipendula* (Sideoats Grama). As with most western Edward's Plateau regions, Ashe-Juniper intrusion has occurred over the past century due to livestock overgrazing (Keith 2011). The micro-habitat dataset suggests that *A. gularis* might be avoiding larger woody vegetation as only 4 out of 924 total grid points were marked as "Ash-Juniper". More data are needed to provide additional support on the relationship from *A. gularis* and woody vegetation in this area. The preference for flat, grassy, upland escarpments is the main correlation in habitat data for *A. gularis* (Fig. 17c, 16a, 13d, 12b, 10d).

In contrast, *C. texanus* has a noticeable relationship with steeper terrain, rocky substrates, and more complex vegetative structure (Fig. 16, 14, 10d). The high vegetation association of *C. texanus* with plants like Guajillo, Lechuguilla, and Sotol show a distinction between *A. gularis* (Fig. 11a, 11b, 11d). These plants provide a larger maximum vegetation height as compared to *A. gularis* grasslands and their respective NDVI reflectance is above that for Curley-Mesquite and Sideoats Grama (Fig. 12a, 14).

Even with the trends of habitat segregation, there is overlap between the two species. Data collection revealed that 6 *C. texanus* individuals inhabited the grassy uplands typical of *A. gularis*. On one particular road transect, a *C. texanus* was found less than a half meter away from an *A. gularis* individual. This incidence helped foster the idea that these lizards can, and will, overlap both spatially and temporally. Competition between these two species for resources such as solar refugia, predator avoidance cover, or arthropod food sources needs further investigation.

The use of drones and road transects as a method for measuring microhabitat demonstrated an effective means for collecting data. More lizards were observed per search hour during driving transects than walking transects. Drone imagery provided a unique method for quickly gathering low-altitude aerial imagery and quantifying the microhabitat data. The microhabitat data produced from the drone survey is in accordance with the historical analyses of *C. texanus* as previous studies have also shown significant correlations between the species and lechuguilla, sotol, and rocky habitats (Punzo 2007). These drone data also replicated previous microhabitat associations observed from *A. gularis* studies. Sandy soils and grass were correlated with the presence of *A. gularis* showing additional support for our method (Paulissen 2001). Drones are becoming increasingly more energy efficient, flying for longer periods of time and carrying more payload than ever before. Drones and their attachments are predicted to be the new revolution in traditional ecological studies as higher resolution imagery techniques become smaller, lighter, and less expensive (The National Academies 2009).

Many techniques are used in ecology to accurately measure micro-habitat variables. The use of a drone to collect low-altitude aerial imagery of micro-habitat area also proved to be an efficient field methodology. After a dozen trials, the total time for data collection on one individual lizard became three minutes or less. At each individual lizard sighting an aerial image was captured; GPS coordinates were recorded along with the maximum vegetation height and temperature data all within three minutes. The use of a drone resulted in more efficient research as less time was spent collecting micro-habitat data in the field.

These results and conclusions attempt to quantify the habitat utilization along gravel roadways of the DRSNA-BSU. The question remains though, are the lizards selectively preferential towards the open spaces offered by gravel roadways cleared of vegetation? If yes, why would they be utilizing the roadways? Prevailing hypotheses consider areas with low vegetative structure may benefit foraging as arthropods may be easier to detect without vegetation in the field of view (Shepard 2007). Perhaps sexual displays during mating season can be observed over longer distances if less complex vegetative structure inhibits vision. Also, territoriality displays may be more effective if used in exceedingly open areas. The data collected from this study can serve as a baseline to answer these questions as it provides researchers with likely habitats in which to conduct roadway edge effect experiments.

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