

HABITAT SUITABILITY MODELING OF *PEROMYSCUS*
PECTORALIS (WHITE-ANKLED MOUSE) IN VAL VERDE
CO., TEXAS

A Thesis
Presented to the
Faculty of College of Graduate Studies of
Angelo State University

For the Fulfillment of
Requirements for the Degree of
MASTER OF SCIENCE

by
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May 2015
Major: Biology

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ACKNOWLEDGMENTS

I would first like to thank the Texas Parks and Wildlife Department for funding associated with the survey of mammals, reptiles, and amphibians of Devils River State Natural Area-Big Satan Unit. Further funds were provided by the CITR foundation of Angelo State University for a Graduate Research Fellowship. I'd also like to thank the park Superintendent of DRSNA – BSU, Joe Joplin, as well as Mark Lockwood and David Riskind of Texas Parks and Wildlife Department for providing logistic support throughout the project. I am very appreciative of my graduate thesis advisory committee; Dr. Robert C. Dowler, Dr. Loren K. Ammerman, Dr. Nicholas J. Negovetich, and Dr. J. William Dickison for providing the encouragement when needed, as well as the criticisms when appropriate. My advisor, mentor, and friend Dr. Robert C. Dowler, has been my greatest advocate as well as greatest critic. I am forever grateful to him as he taught, and more importantly exemplified, the importance of diligence, honesty, and even levity in the pursuit of my academic endeavors. I am very grateful of Dr. Nicholas Negovetich and Dr. Benjamin Skipper for their assistance with the analysis portion of this project. The number of field and research assistants, colleagues, family and friends who have provided their support throughout this rather arduous project are too many to name individually, and I'd like to sincerely thank all those who made this study possible; in particular my good friend and colleague Austin B. Osmanski. Without his constant support and enthusiasm, the research objectives achieved in this study would not have been possible, and I could not think of a better person to join me afield. Finally I'd like to acknowledge my loving family whom no matter the circumstances has always been a constant source of encouragement and motivation throughout the entirety of my academic, as well as personal, endeavors.

ABSTRACT

The goal of this work was to utilize habitat suitability modeling and spool-and-line tracking to delineate habitat use and distribution of the White-ankled mouse (*Peromyscus pectoralis*), within the Devils River State Natural Area – Big Satan Unit (DRSNA - BSU), in Val Verde County, Texas. Using trapping data from a 21 month period (February 2013 - October 2014), MaxEnt modeling was used to determine which of 7 environmental variables contributed the most to the species distribution at DRSNA - BSU, and a species distribution map was generated. A jackknife test of variable importance determined vegetation series and slope as the highest contributing variables in isolation. Generalized linear modeling was then used to compare trap-line abundance indices to the percentages of individual vegetation series within a buffered area around the trap-line. Positive correlations with higher abundance indices were observed in winter, spring, and fall among a variety of vegetation series. Using spool-and-line tracking, *P. pectoralis* was determined to be highly mobile indicating that this species is capable of dispersing to areas of greater resource availability. Data suggest that vegetative habitat selection of this species varies seasonally and is likely dependent on the degree of seasonal resource availability within each vegetation type and the trophic ecology of *P. pectoralis*.

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INTRODUCTION

Behavioral habitat selection is a complicated phenomenon involving perceptual selectivity by the individual to or away from a specific habitat type (Baccus and Horton 1984). Habitat use is not a random process, but results from multiple choices made by individuals during their activities including foraging, escape from predators, mate searching, and refuge use (Garshelis 2000; Prevedello et al. 2010). The vegetation of a particular habitat has a significant influence on all of these previously listed factors. Small mammal assemblages have consistently shown a strong correspondence with vegetation composition in various environments. Small mammals typically occur within, and move among, habitat patches distinguished on the basis of floristic composition (Monjeau et al. 2011). Vegetative structure determines how and where a small mammal forages, its distribution and abundance, as well as how successful an animal is at using vegetative cover to escape from predators and find refuge (Rosenzweig and Winakur 1969; Jorgensen et al. 1995). In addition to vegetation composition, local geology, geomorphology, pedology, and climate are the principal components that structure a landscape (Klijn and Udo de Haes 1994). These abiotic habitat characteristics are largely responsible for the establishment and development of ecosystems. By quantifying vegetative structure and community metrics within a given area, abiotic variables shaping that landscape (geology, geomorphology, pedology, and climate) are accounted for. The coalescence of these abiotic variables determines the vegetative habitat types, which in turn determine the associated fauna.

The rodent genus *Peromyscus*, commonly known as deer mice, contains species that are known to transmit vector-borne zoonotic diseases, such as Sin Nombre Virus (SNV;

family Bunyaviridae, genus *Hantavirus*). For that reason, these species are often studied to determine habitat suitability and resource selection to assess the risk factors associated with varying habitat variables (Nichol et al. 1993; Childs et al. 1994; Root et al. 1999; Glass et al. 2007). In order to develop disease outbreak mitigation and contingency plans as well as develop management strategies for these rodents, it is essential to have some understanding of their dispersal capabilities and habitat preferences. However within this commonly studied genus, few habitat suitability studies exist for *Peromyscus pectoralis laceianus*, the white-ankled mouse (Kilpatrick 1971; Modi 1978; Baccus and Horton 1984; Etheredge et al. 1989; Mullican and Baccus 1990; Baccus et al. 2009).

The species distribution (Fig. 1) of *Peromyscus pectoralis* is broadly within central-northern Mexico, continuing northward to central and western Texas, additionally reaching into the southern portion of Oklahoma and southeastern New Mexico (Schmidly 1974; Musser and Carleton 2005). Within Texas, *P. pectoralis* can be found in the Edwards Plateau regions, central Great Plains, the northern extent of the south Texas plains, and the Chihuahuan desert regions of west Texas (Schmidly 2004). Known biotic habitat affinities documented in the literature include most commonly oak-juniper associations, desert scrublands, arid grasslands, piñon-juniper/piñon-oak woodlands, and arid and semiarid brush-covered foothills (Schmidly 1974; Geluso 2004) in parts of the U.S. distribution.

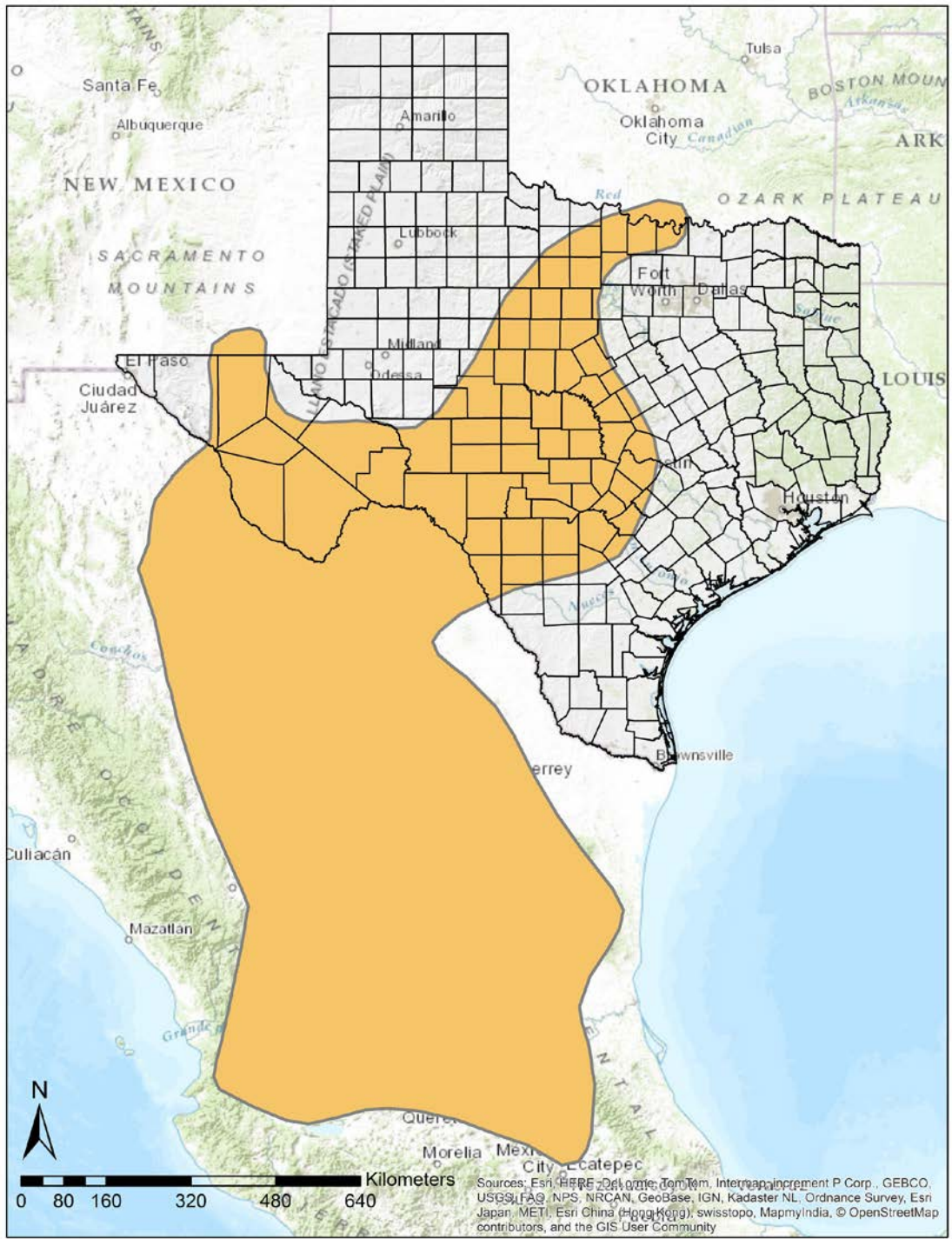


FIG. 1. The species distribution of *Peromyscus pectoralis* is broadly within central-northern Mexico, continuing northward to central and western Texas, additionally reaching into the southern portion of Oklahoma and southeastern New Mexico.

In Mexico (eastern Durango) *P. pectoralis* has been collected in both grassland and desert habitats (Schmidly 1974). Based on capture location data, the most frequently documented abiotic habitat affinity of *P. pectoralis* is rocky areas including cliffs, limestone outcrops, or talus slopes with some form of woody vegetation (Schmidly 1972; Kilpatrick and Caire 1973; Baccus and Horton 1984; Etheredge et al. 1989). In New Mexican populations, this species is captured commonly in rocky situations on eroded walls of arroyos, in draws and canyons, and on nearly flat summits (Geluso 2004).

A substantial amount of basic ecological information concerning range and broad-scale habitat associations exists in the literature for populations of this species (Blair 1940; Borell and Bryant 1942; Davis and Robertson 1944; Goldman and Moore 1945; Blair and Miller 1949; Hooper 1952; Dalquest 1953; Baker 1956; Baker and Greer 1962; Schmidly 1972; Kilpatrick and Caire 1973; Schmidly 1974; Modi 1978); however, there have been few habitat or resource selection studies of *P. pectoralis* in Texas populations (Kilpatrick 1971; Modi 1978; Baccus and Horton 1984; Etheredge et al. 1989; Mullican and Baccus 1990; Baccus et al. 2009). These Texas habitat studies have additionally been limited locally to areas of central (Baccus and Horton 1984; Mullican and Baccus 1990; Baccus et al. 2009) and west-central (Etheredge et al. 1989), north (Kilpatrick 1971), and far west Texas (Modi 1978). To-date there has been a lack of ecological studies conducted on this species in the south-west areas of Texas (Fig. 2). Additionally there has been a deficit in habitat suitability studies conducted in any highly mosaic regions where multiple ecoregions abut, providing a mixture of vegetation regimes (Fig. 2).

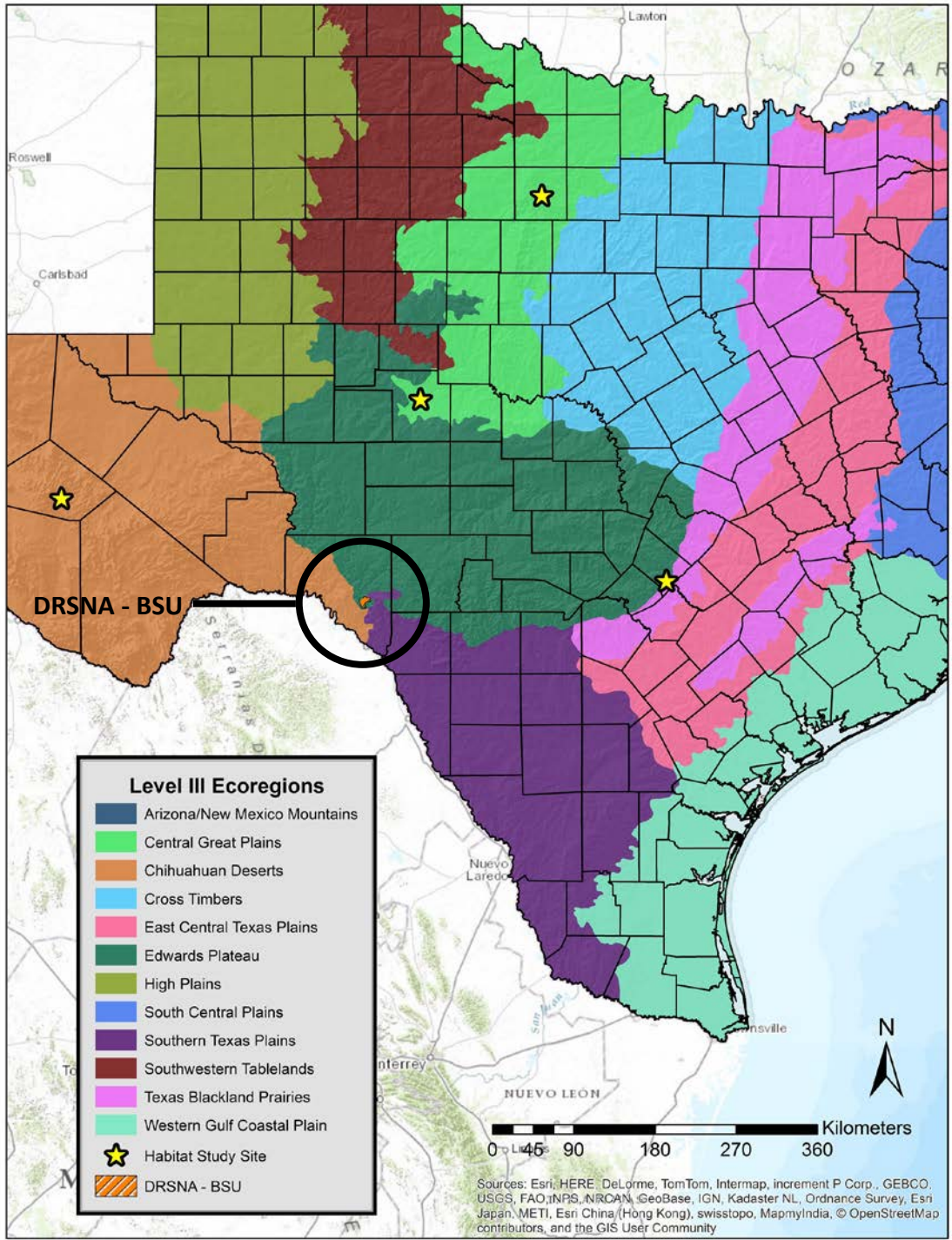


FIG. 2. Map above displays the Level III ecoregions of Texas (Ommerik 1987) as well as the locations of *P. pectoralis* habitat studies conducted in Texas (stars). The black circle surrounds the DRSNA - BSU located at the confluence of the three Level III ecoregions.

Because of the lack of habitat studies in this region, I conducted an in-depth habitat suitability study, comparing multiple habitat parameters consisting of vegetation associations, and geo-edaphic factors to trapping data. Habitat use data collected by Mullican and Baccus (1990) suggest that the pattern of use of microhabitats by *P. pectoralis* is related to inherent selection rather than to interspecific competition. Furthermore, working under the assumption that the spatial distribution of *P. pectoralis* is associated with its habitat requirements, identifying those habitat requirements is an effective means to understanding and accurately predicting the distribution of this species within a mosaic landscape. A patchy mosaic landscape can lead to a problem of conflicting objectives for a foraging rodent. With every foraging opportunity comes the associated element of predation risk. Foragers may not be able to increase energy gain and decrease predation hazard simultaneously, which has been demonstrated to affect habitat choice (Gilliam and Fraser 1987; Newman et al. 1988).

It is also important to determine the horizontal as well as vertical movements of this species. This can be accomplished by many methods, one of which is the spool-and-line tracking method. Spool-and-line tracking is an efficient, economical, and accurate mode of collecting data on animal movement patterns (Steinwald et al. 2006). This method has been used to address both ecological and conservation-related topics in a range of organisms, including foraging behavior with *Bettongia tropica* (Vernes and Haydon 2001), nest location with dasyurid marsupials (Woolley 1989), habitat use with *Rattus rattus* (Cox et al. 2000), and habitat search behavior with sciurids (Zollner 2000). However, few spool-and-line studies have been conducted using mice of the genus *Peromyscus*. For the objectives of this study, spool-and-line tracking was used to assess the arboreality and general mobility of *P. pectoralis*.

This study was aimed at identifying particular environments that are suitable for the species. Recent advances in remote sensing of climatic and ecological features via satellites, as well as advances in the mapping of vegetation characteristics such as delineating plant communities, continue to improve the accuracy of describing habitat associations and resource selectivity via habitat suitability modeling (Skov 2000; Peterson 2001; Monjeau et al. 2011). A suite of software programs exist to perform these types of geospatial analyses, each with a myriad of analysis and modeling tools. Due to the availability of detailed environmental data collected and distributed by state, federal, and private entities, together with relatively inexpensive and powerful computers, there has been a rapid expansion in predictive modeling of species environmental requirements and geographic distributions (Phillips et al. 2006). By using presence-only data of a species of interest, and supplying pertinent environmental variables, the species distribution modeling program Maximum Entropy (MaxEnt), can generate a probability distribution of species occurrence (Phillips et al. 2011). MaxEnt additionally provides approximations of the relative contribution that each environmental variable lends to the species distribution model. This allows the researcher to draw supported inferences of what the study animal requires within its habitat, based on the percent contributions of each environmental variable.

Three key demographic and ecological attributes were required to complete this study, and are important to keep in mind as they inherently provide credence to the efficacy of this habitat suitability study. At the study site (1) a large sample size of *P. pectoralis* was expected; (2) a mosaic of habitat types were present within the home ranges of these mice to provide them with “habitat options” as they were active and foraging; and (3) a study area must be rocky throughout, given the saxicolous nature of this species, to control for the

known affinity for rocky areas. The goal of this present work was to utilize MaxEnt to predict the habitat distribution of *P. pectoralis* within my study site and to determine which environmental variables were required to predict this distribution. I assessed the environmental variables that contribute the most to the MaxEnt model by performing a jackknife test, as these are the most influential in terms of delineating habitat selection. A multiple linear regression analysis tested for correlations between the single most influential environmental variable and abundance index. Spool-and-line tracking was utilized to delineate the vertical and horizontal movements of this species to provide a measure of arboreality and mobility.

MATERIALS AND METHODS

Study Site

The Devils River State Natural Area - Big Satan Unit (DRSNA - BSU) formerly known as the South Unit or Devils River Ranch, is a 7,139 hectare property newly acquired (as of 2011) by the Texas Parks and Wildlife Department (TPWD 2012). The purpose of the State Natural Area is to protect the area's natural and cultural resources while providing non-compromising educational and recreational activities for the public. The Devils River, aided by the characteristic karst topography of the area, is one of the most intact spring-fed stream segments in the American southwest, and the State Natural Area offers an undeveloped, natural landscape ideal for ecological studies. DRSNA-BSU is located about 20 miles north of Del Rio, Texas, in Val Verde County, along the Devils River northwest of Slaughter Bend with 10.1 miles of river front (Fig. 3). The property is accessed off of Miers Road, west of US Highway 277. At DRSNA-BSU, due to its location, climate, and geomorphology, an aggregate of habitat types occurs.

This study site has an abundance of *P. pectoralis*, has ubiquitous rocky terrain, and is at the junction of three ecoregions, which meets the previously mentioned criteria for this study. Preliminary trapping at the site indicated that *P. pectoralis* was one of the dominant rodent species sampled within the majority of habitat types.

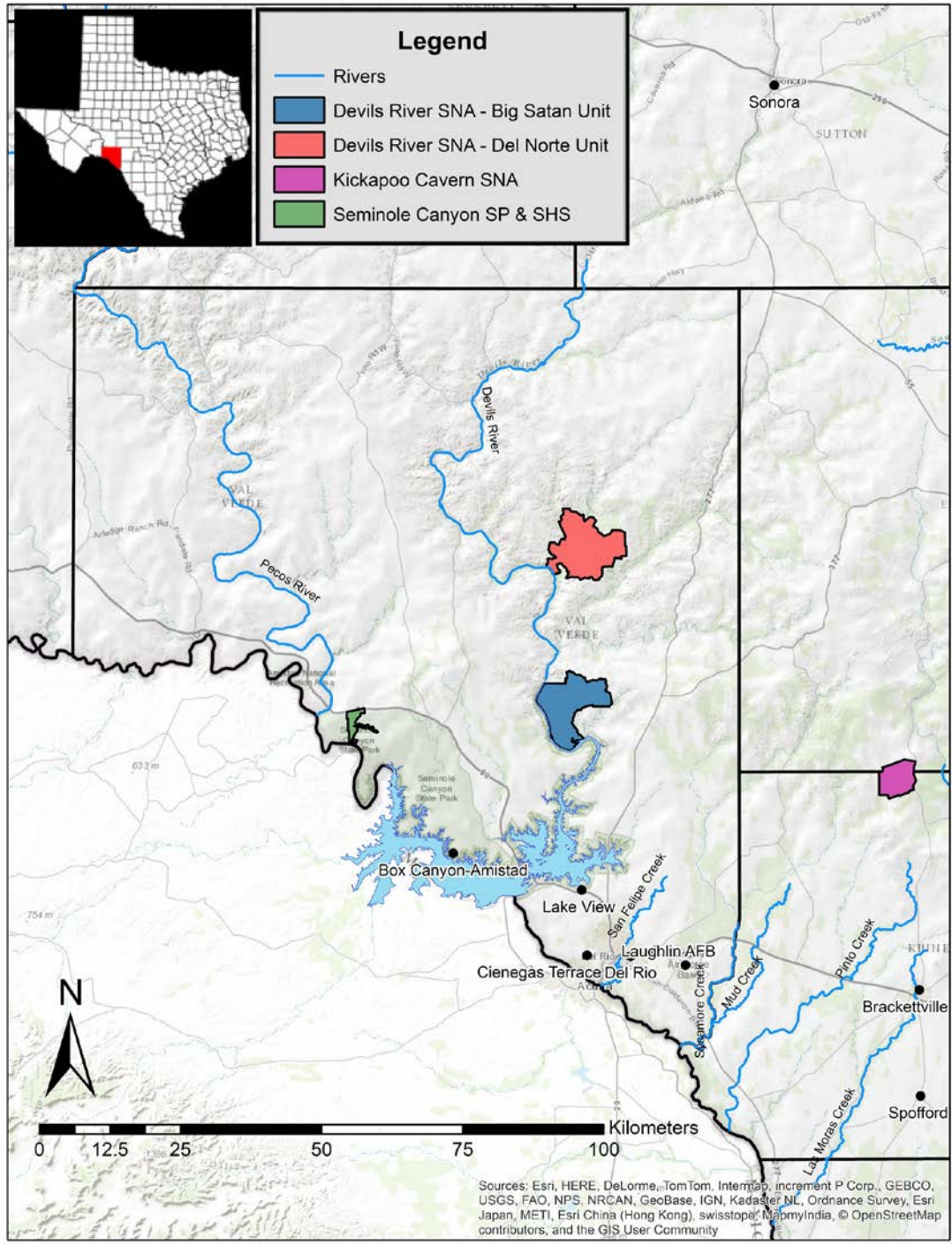


FIG. 3. Map of Val Verde Co. and surrounding area in South Texas, showing the North (Del Norte) and South (Big Satan) units of the Devils River State Natural Area (DRSNA), north of the International Amistad Reservoir and Del Rio, Texas.

The Devils River State Natural Area - Big Satan Unit (DRSNA - BSU) is located at the confluence of three biotic provinces in southern Val Verde County recognized as the Chihuahuan to the west, Balconian to the northeast, and the Tamaulipan biotic province to the southwest (Blair 1950). Level III and IV ecoregions have also been identified for Texas after analysis of the state's geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Omernik 1987; Omernik 1995). The three different level III ecoregions that meet at DRSNA – BSU (Fig. 2) are identified as: Chihuahuan Deserts, Edwards Plateau, and Southern Texas Plains (Griffith et al. 2004). Within DRSNA – BSU, there have been five topoeconomic habitat types identified as follows: uplands, dry slopes, shallow ravines, mesic canyons, and riparian corridors (Keith 2011). With these five topoeconomic categories, inherently the topography within the property varies greatly (Fig. 4-6). The varying topography and the coalescence of multiple vegetation regimes have led to the formation of 14 vegetation series (Fig. 7). These 14 vegetation series were assessed by Keith (2011) in a baseline assessment plant community study conducted at DRSNA – BSU. The vegetation status (Fig. 8) as well as the vegetation stability (Fig. 9) were also assessed and determined by Keith (2011) based on the overall health of the vegetation communities, using classification systems described by Nature Serve (2011). There are ten soil types present at the study site, identified by the US Department of Agriculture's Natural Resources Conservation Service (Fig. 10). These soil types were named and described based on composition and particle size, as well as the slope percentage present (Table 1).

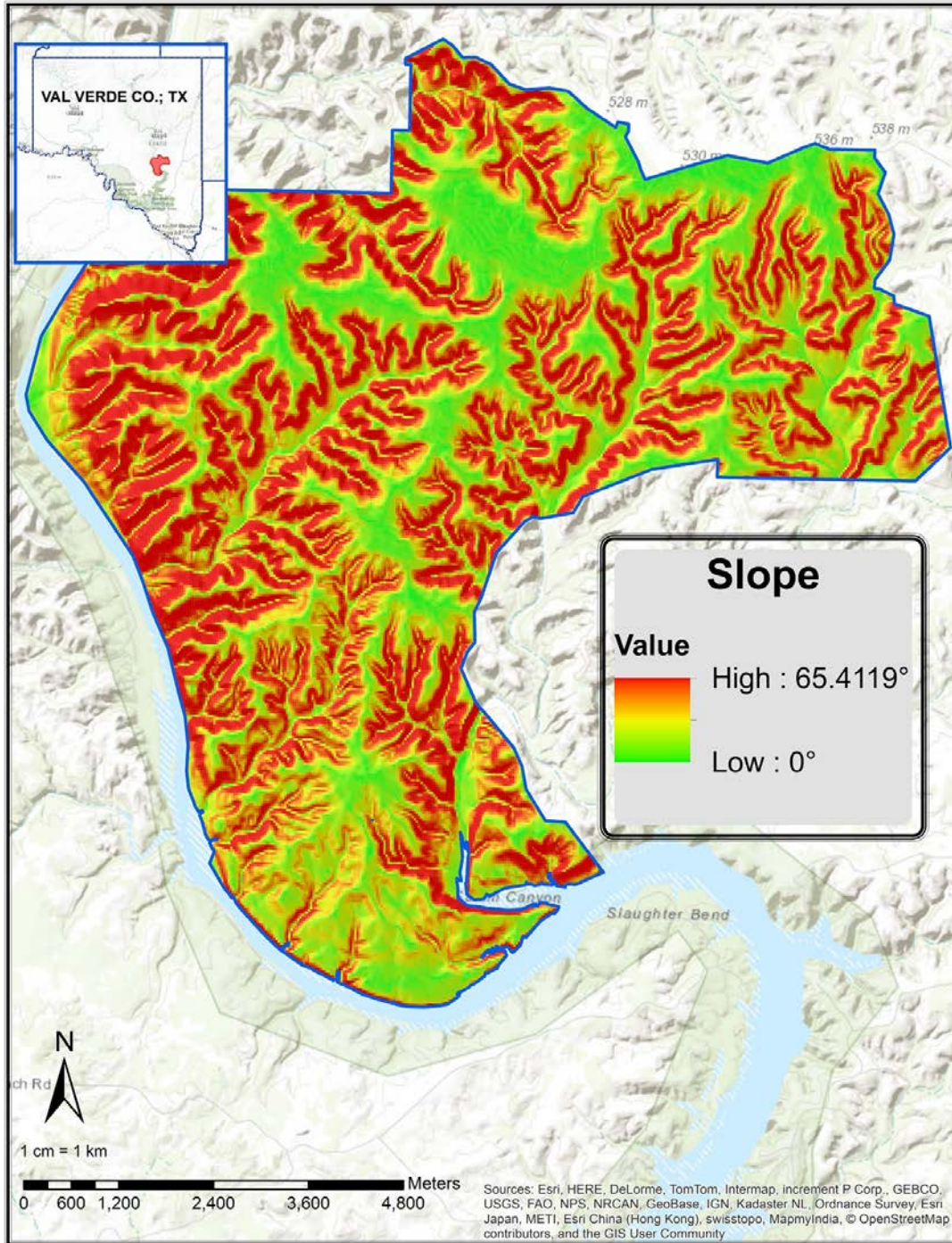


FIG. 4. Map of the Devils River State Natural Area – Big Satan Unit showing the degree of slope present.

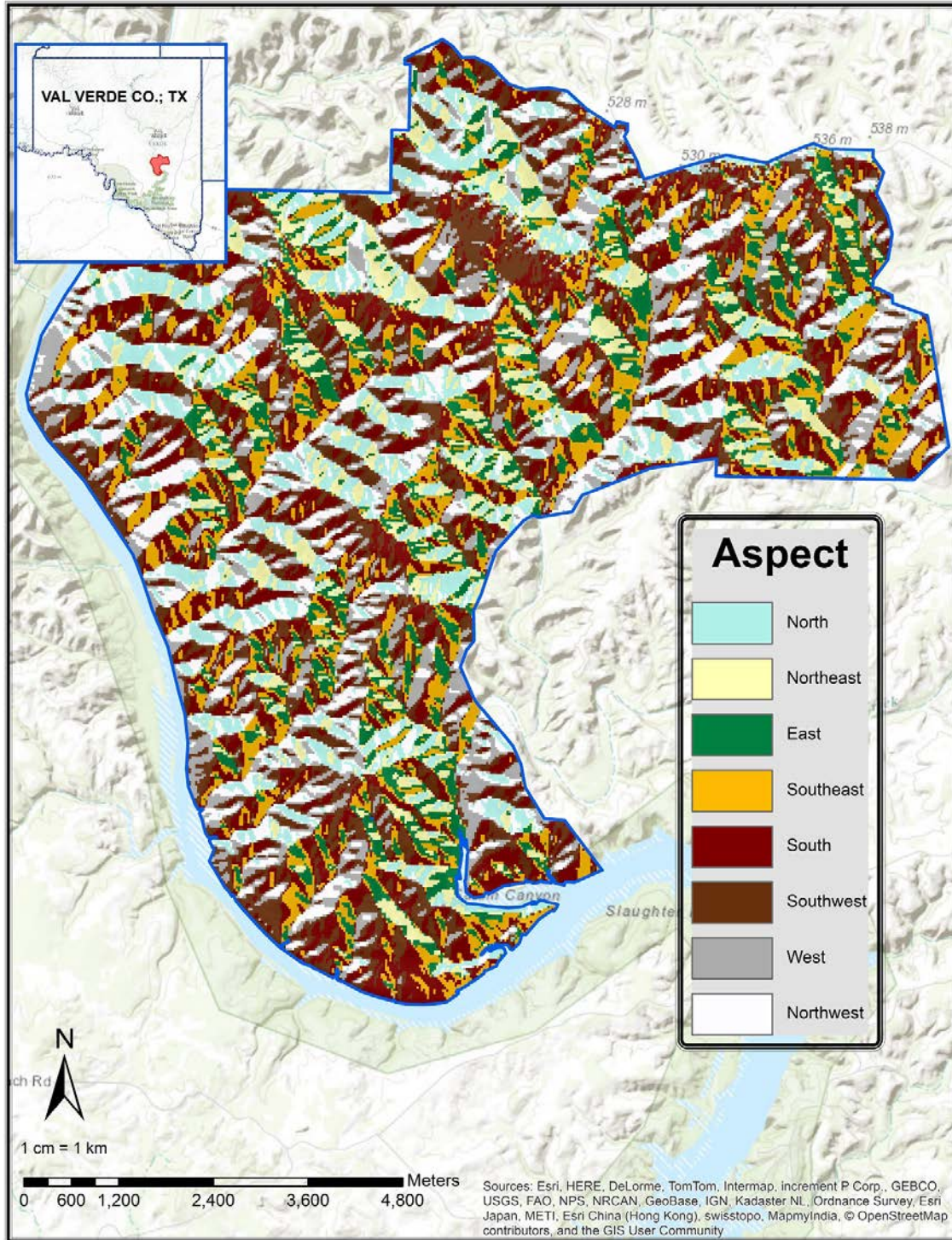


FIG. 5. Map of the Devils River State Natural Area – Big Satan Unit showing the aspect (directionality of terrain) present. The eight total cardinal and intercardinal aspect categories are symbolized as different hues.

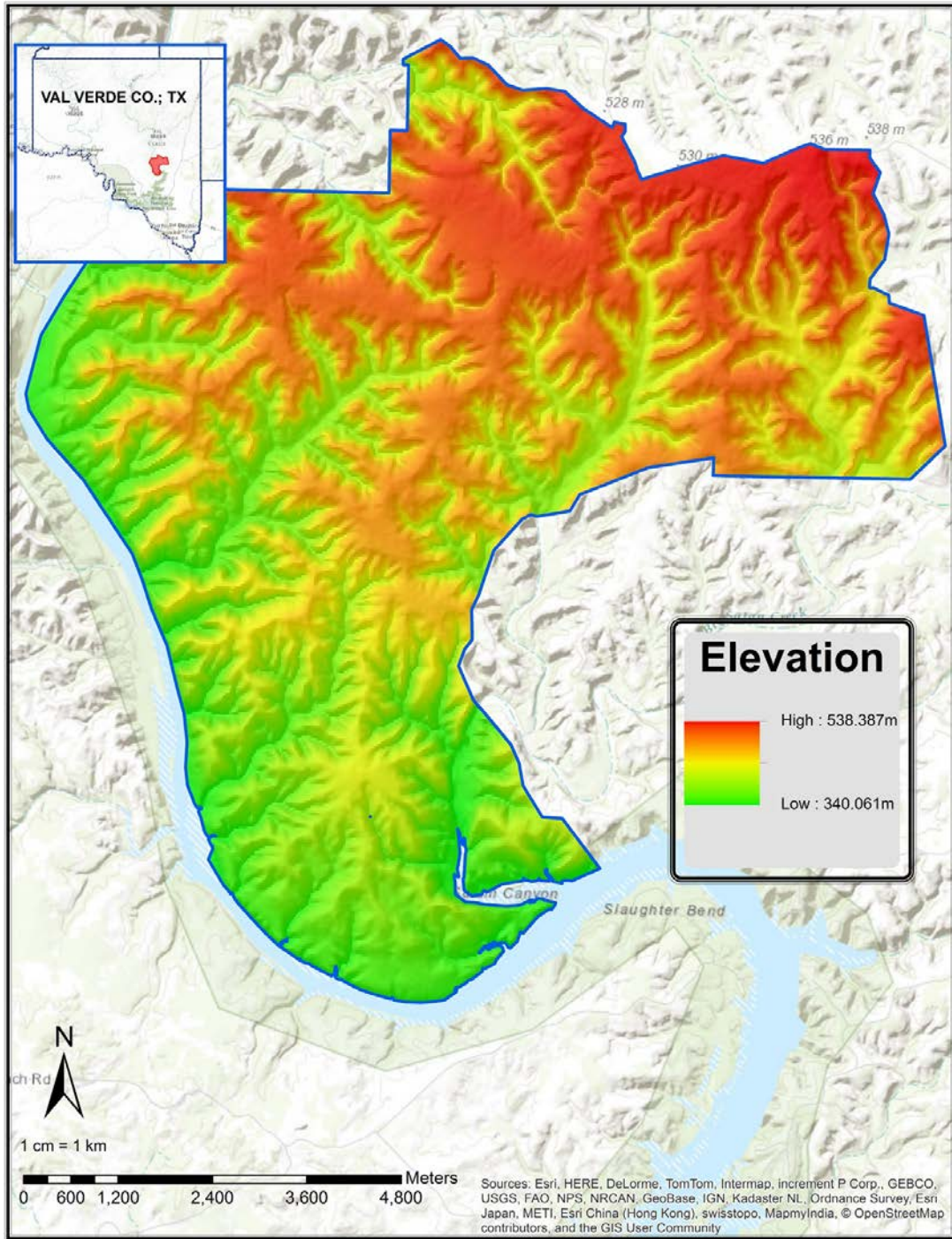


FIG. 6. Map of the Devils River State Natural Area – Big Satan Unit showing the elevation present in meters.

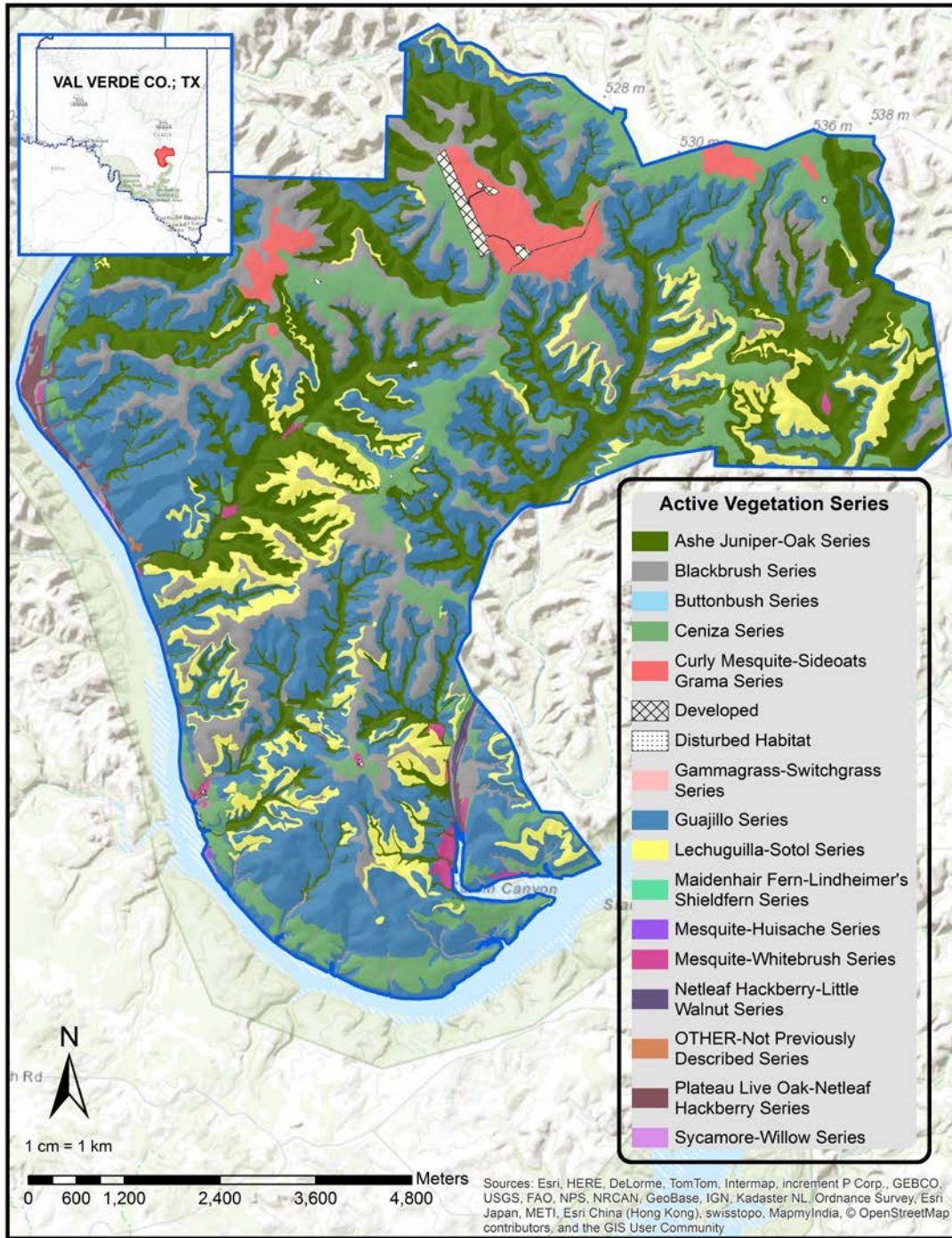


FIG. 7. Map of the Devils River State Natural Area – Big Satan Unit displaying the 15 active vegetation series present, as well as the developed and disturbed areas identified by Keith (2011).

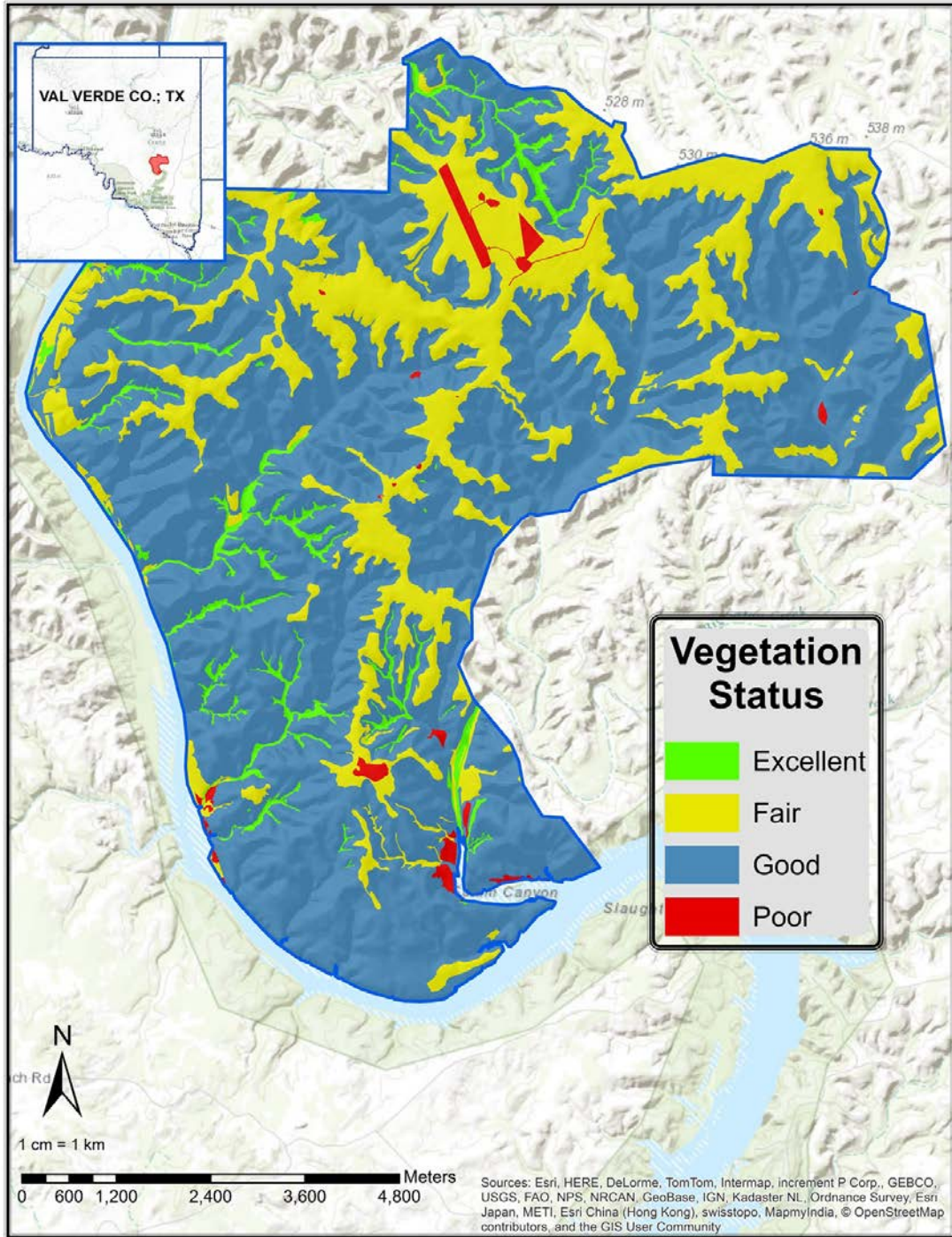


FIG. 8. Map of the Devils River State Natural Area – Big Satan Unit displaying the vegetation status present within the state natural area, identified as excellent, fair, good, or poor vegetative health by Keith (2011).

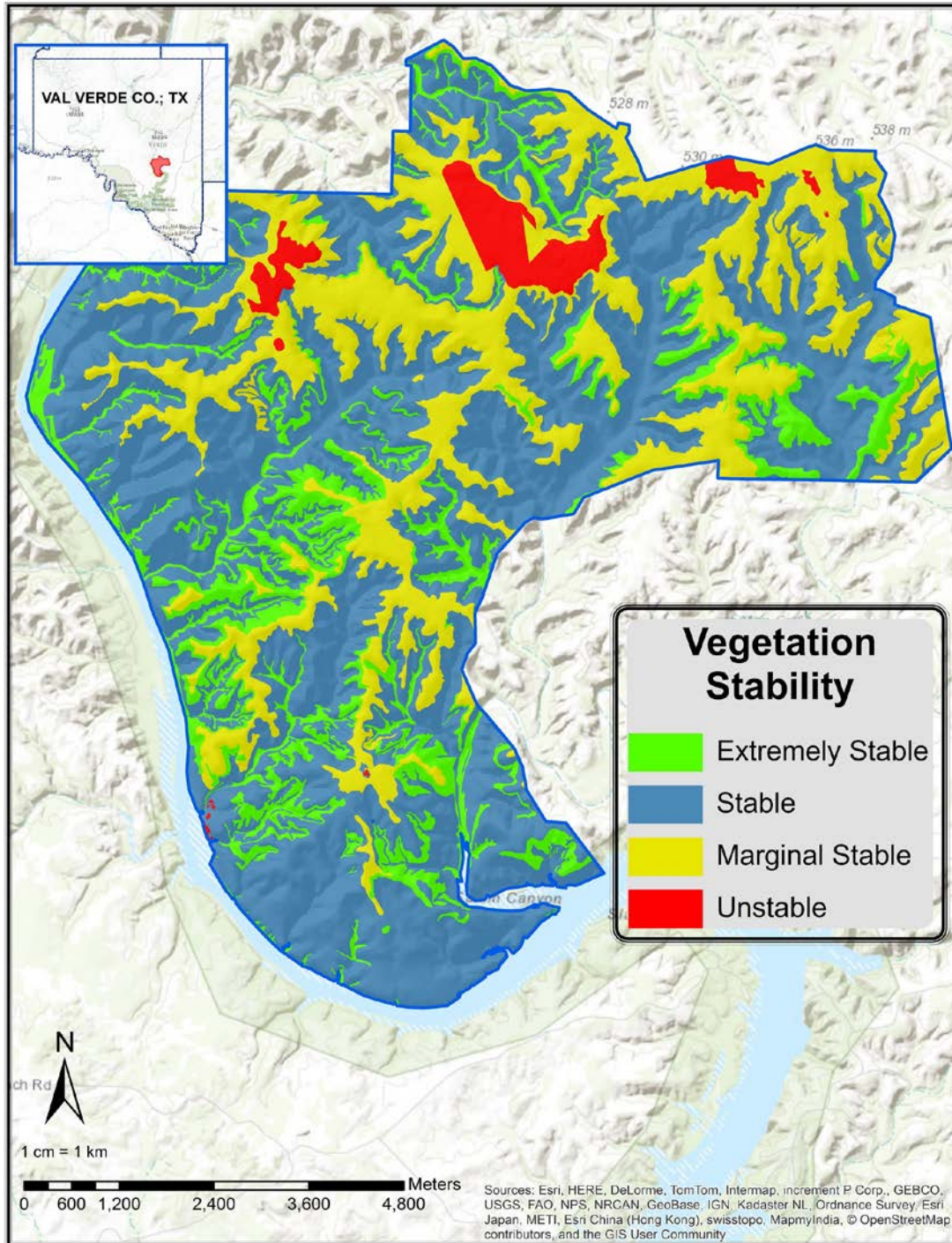


FIG. 9. Map of the Devils River State Natural Area – Big Satan Unit displaying the stability of the vegetation present within the state natural area, identified as extremely stable, stable, marginally stable, or unstable by Keith (2011).

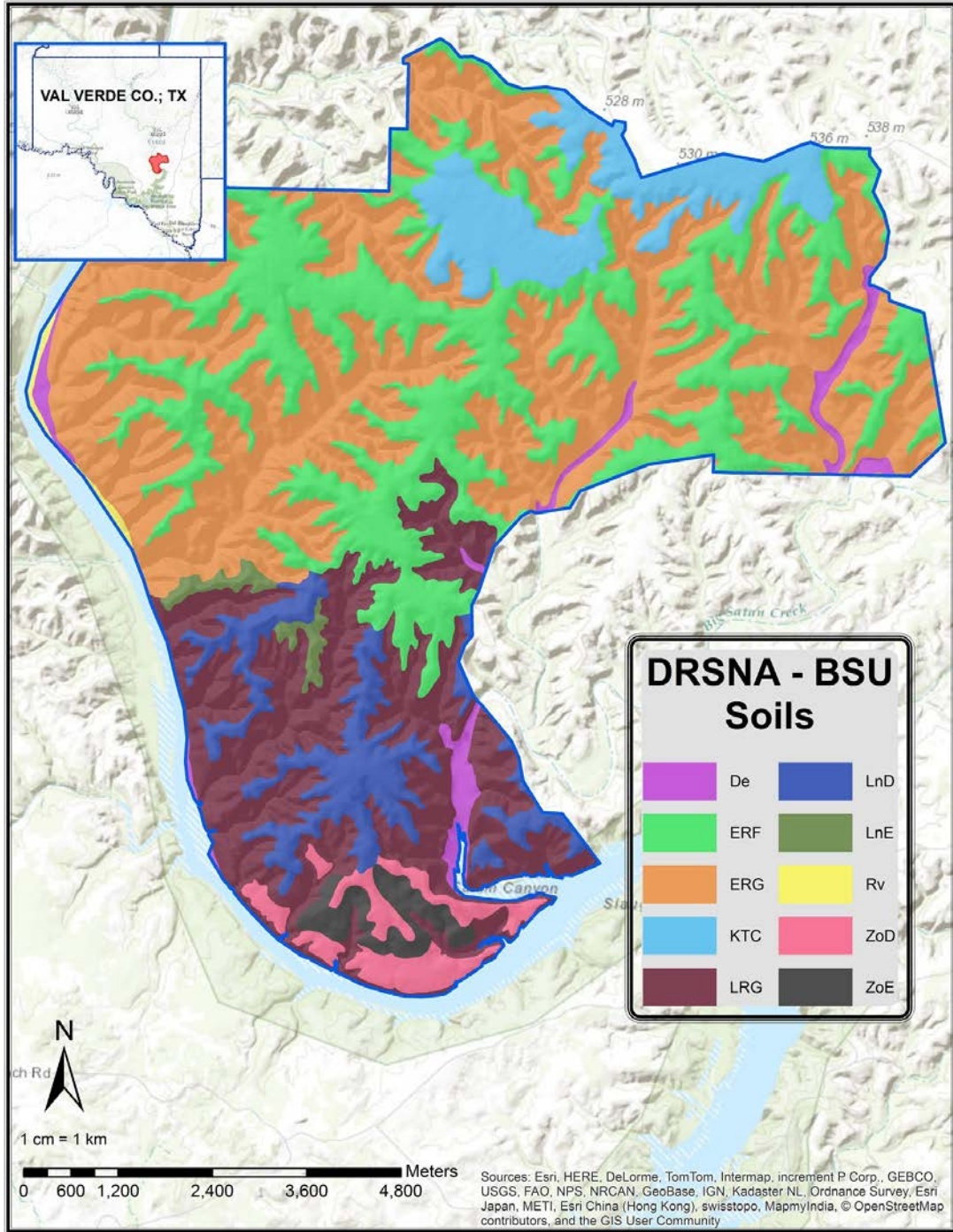


FIG. 10. Map of the Devils River State Natural Area – Big Satan Unit displaying the soil types present identified by the US Department of Agriculture’s Natural Resources Conservation Service. Descriptions of soil types listed in Table 1.

TABLE 1.— Description of the ten soil types present at DRSNA – BSU, identified by the US Department of Agriculture’s Natural Resources Conservation Service.

#	SOIL TYPE LABEL	SOIL TYPE NAME	DESCRIPTION	% SLOPES
1	De	Dev	Very gravely loam	0-3%
2	ERF	Ector-Rock outcrop association	Hilly	NA
3	ERG	Ector-Rock outcrop association	Very steep	NA
4	KTC	Kavett-Tarrant association	Gently undulated	NA
5	LRG	Langtry-Rock outcrop association	Very steep	NA
6	LnD	Langtry	Very cobbly silt loam, very rocky	1-8%
7	LnE	Langtry	Very cobbly silt loam, very rocky	8-15%
8	Rv	Riverwash and Dev soils	NA	0-3%
9	ZoD	Zorra-Rock outcrop complex	NA	1-8%
10	ZoE	Zorra-Rock outcrop complex	NA	8-15%

Live-trapping

Monthly sampling was conducted at DRSNA – BSU with an initial objective to provide TPWD with a baseline assessment of the mammalian fauna within the state natural area. For the purpose of this habitat selection study, capture data were collected from trap-lines, over a 21-month period beginning in February 2013 and ending in October 2014. In efforts to fulfill the baseline assessment objective of this project, trapping effort was not maintained at uniform temporal and spatial intervals, therefore the length of each trap-line transect varied during the study. Trap-lines varied in number of traps placed (22 – 100), as well as arrangement. Some trap-lines were set up in a web-array arrangement for a secondary rodent density estimation study. To account for this variability in the number of traps within a trap-line, abundance indices were calculated per trap-line within each seasonal grouping from captures/trap-night. This, in effect, standardized sampling effort allowing for comparisons to be made across trap-lines and seasons. This also served to provide a measure of selection, as the mice are more often captured in areas where they are most abundant, and they are more abundant in areas where necessary resources are available. As these mice are typically captured in most of the available habitat types, a presence-absence study alone would not be able to measure any degree of selectivity displayed in this species. Because the focus of this study was on the habitat suitability of *P. pectoralis*, it was not necessary for the study to maintain equal survey effort temporally with respect to moon phase, although efforts were made to equalize effort spatially across different habitat types (Upham and Hafner 2013). Upham and Hafner (2013), the most recent moonlight avoidance study, observed no significant differences in *Peromyscus* activity between waxing and waning moon phase, agreeing with other similar studies (Orr 1959; Kotler 1984). Activity patterns of mice within

the genus *Peromyscus* have however been observed to fluctuate seasonally (King 1983; Ormiston 1984; Rizkala and Swihart 2007), thereby influencing trap success. To account for this seasonal influence on activity patterns and trap success, trap-line capture data were compiled as a function of meteorological season. Winter was defined as trapping efforts that take place in December – February, spring was March – May, summer was June – August, and fall was September – November. Sherman live traps (model LFATDG, H. B. Sherman Traps, Inc., Tallahassee, Florida) were used in this study, and placed linearly with approximate 5 m spacing between traps. Traps baited with mixed grain (sunflower seeds, milo, and cracked corn) were set out in the evening prior to sunset, and traps were subsequently checked the following morning. The majority of rodents captured were collected for deposition in the Angelo State Natural History Collections. Rodents were identified to species level, sexed, and evaluated for age class and reproductive condition, prior to specimen preparation. Some rodents were released, and to ensure that each mouse captured was a different individual, a small linear patch of fur (bicolored) above the tail on the dorsal side of the mouse was trimmed until the darker gray colored section of the pelage underneath the wood-brown was exposed. Live mammal trapping and handling conformed to the guidelines of the American Society of Mammalogists (Sikes et al. 2011). Trap-line location, directionality, approximate arrangement and length were recorded for each trap-line during the project. Transect trapping arrangements have been shown to be more efficient than trapping grids in small mammal studies, yielding more total captures, individual captures, and more species than grid arrangements (Pearson and Ruggiero 2003). Results from transects have also been shown to be less sensitive to trap spacing than results from grid trap arrangements (Read et al. 1988).

Spool-and-line Tracking

Arboreality and mobility of *P. pectoralis* was assessed via spool-and-line analysis using 62/P4 Nylon white reverse-spun cocoon bobbins (Imperial Threads Inc., 3145 MacArthur Boulevard, Northbrook, IL 60062). The bobbin (spool) length measured approximately 3.17 cm with a mass of approximately 2 grams per bobbin. The tensile strength of this product is 0.82 kg according to the manufacturer. The bobbin was maintained at $\leq 5\%$ of the total body weight so as to not harm or hinder the rodent as it conducted its natural activities (Macdonald 1978). For example, the average mass of *P. pectoralis* is approximately 31.5 g (Schmidly 2004); therefore, our bobbins were no heavier than 1.6 g. The *P. pectoralis* used for spool-and-line analysis and the spool were both weighed before spooling to ensure proper proportions. The proper spool mass was achieved by un-spooling the bobbins until they reached the target mass. Each bobbin was then wrapped in waterproof medical tape to protect externally exposed thread, and to create a more adhesive surface. The trap-lines were checked in the night (12:00am - 3:00am) for captures when the mice are active. Mice were then identified as *P. pectoralis*, sexed, and weighed prior to applying the bobbin. The bobbin was glued using cyanoacrylate glue to the dorsal side of the rodent longitudinally (Fig. 11), with a drying time of approximately 1 min before releasing the rodent (Cox et al. 2000; Steinwald et al. 2006). Efforts were taken to minimize handling time to reduce stress on the animal. The free end of the line was tied to a surveying flag that was placed at the site of release. As *P. pectoralis* traveled in its respective habitat the line spooled out from the middle of the bobbin providing a way to observe its trail, and arboreal activity (Fig. 12).



FIG. 11. Image displays the affixed spool-and-line apparatus used in this study to ascertain a measure of arboreality and mobility of the *Peromyscus pectoralis* within DRSNA – BSU.



FIG. 12. Shown in this image is an example of the resulting spool-and-line trail of *Peromyscus pectoralis* after one night of activity in an area of dense brush within DRSNA – BSU. The spool-line is highlighted in red for better visibility, and to demonstrate the observed arboreality of this species.

Data for the first 10 m of line was discounted to reduce any release-bias due to flight response and allow the mouse to return to natural foraging and behavior patterns (Cox et al. 2000; Haby et al. 2013). Including this initial 10 m allowance, the mouse must travel a total of 20 m in order to provide accurate activity data. If this 20 m length was not achieved, the individual trial was not used for data analysis because the data from the short distance traveled might not be representative of the actual nightly foraging habits of the mouse. The length of the trail in meters was measured by hand with a surveyors tape until its terminus. The path used by each mouse was examined for arboreal activity by measuring the length of the trail on the ground and in shrubs/trees.

Species Distribution Modeling

The species distribution model chosen for this study was maximum entropy (MaxEnt) for the purpose of generating a probability distribution of *P. pectoralis* based on presence data. During this process MaxEnt generates a probability distribution over pixels in the specified grid, starting from the uniform distribution and repeatedly improving to fit to the data (Phillips et al. 2006). The MaxEnt model used seven environmental raster layers clipped to the area of DRSNA – BSU, and capture (presence) data of *P. pectoralis*. The seven raster layers provided a grid of 10 m² pixels over the 71.4 km² state natural area, with each pixel containing unique environmental information. The continuous layers used in the species distribution model are: slope (Fig. 4), aspect (Fig. 5), and elevation (Fig. 6) obtained from Texas Natural Resources Information System (TNRIS). The remaining four environmental layers used were categorical: active vegetation series (Fig. 7), vegetation status (Fig. 8), vegetation stability (Fig.9) provided by TPWD and mapped by Keith (2011), and soil types (Fig. 10) of DRSNA - BSU provided by the US Department of Agriculture's Natural

Resources Conservation Service. Categorical layers were converted to the raster format for use in ESRI's ArcGIS software (ESRI 2011. ArcGIS Desktop: Version 10.2. Redlands, CA: Environmental Systems Research Institute.), and text attributes were coded so as individual categories were indicated by numbers. The extents of the continuous and categorical raster's were then adjusted so that the cell alignment was identical for all layers. The following settings were used in MaxEnt v.3.3.3k to produce the model: automatic feature selection, regularization multiplier at unity, and maximum 500 iterations (Phillips et al. 2011; Gomez et al. 2014). The MaxEnt model output was then reclassified in ArcGIS. Three percentage classes were chosen that represent prevalence levels at DRSNA – BSU and are as follows: low ($\leq 33\%$), moderate (34% - 66%), and high ($\geq 67\%$). The areas of each prevalence level within DRSNA – BSU were calculated. The percent contribution, and permutation importance of each environmental variable used in the analysis was recorded, and a jackknife test of variable importance was generated within MaxEnt from the training data provided.

Data Management and Analysis

Using ArcGIS, trap-lines were spatially referenced and plotted as poly-lines. Additionally by utilizing detailed aerial imagery, adjustments were made to the trap-lines when appropriate to account for the surface distortion that is associated with map projection. Furthermore, trap-lines were buffered by the known approximate convex-polygon home range of *P. pectoralis* ($A = 3,340 \pm 935 \text{ m}^2$) reported by Mullican and Baccus (1990) in order to focus habitat analysis on the variables that are encountered by an individual. The home range buffers created an area of likely occurrence along the trap line. These buffers were then spatially overlaid with the known active vegetation series of DRSNA – BSU (Fig. 13).

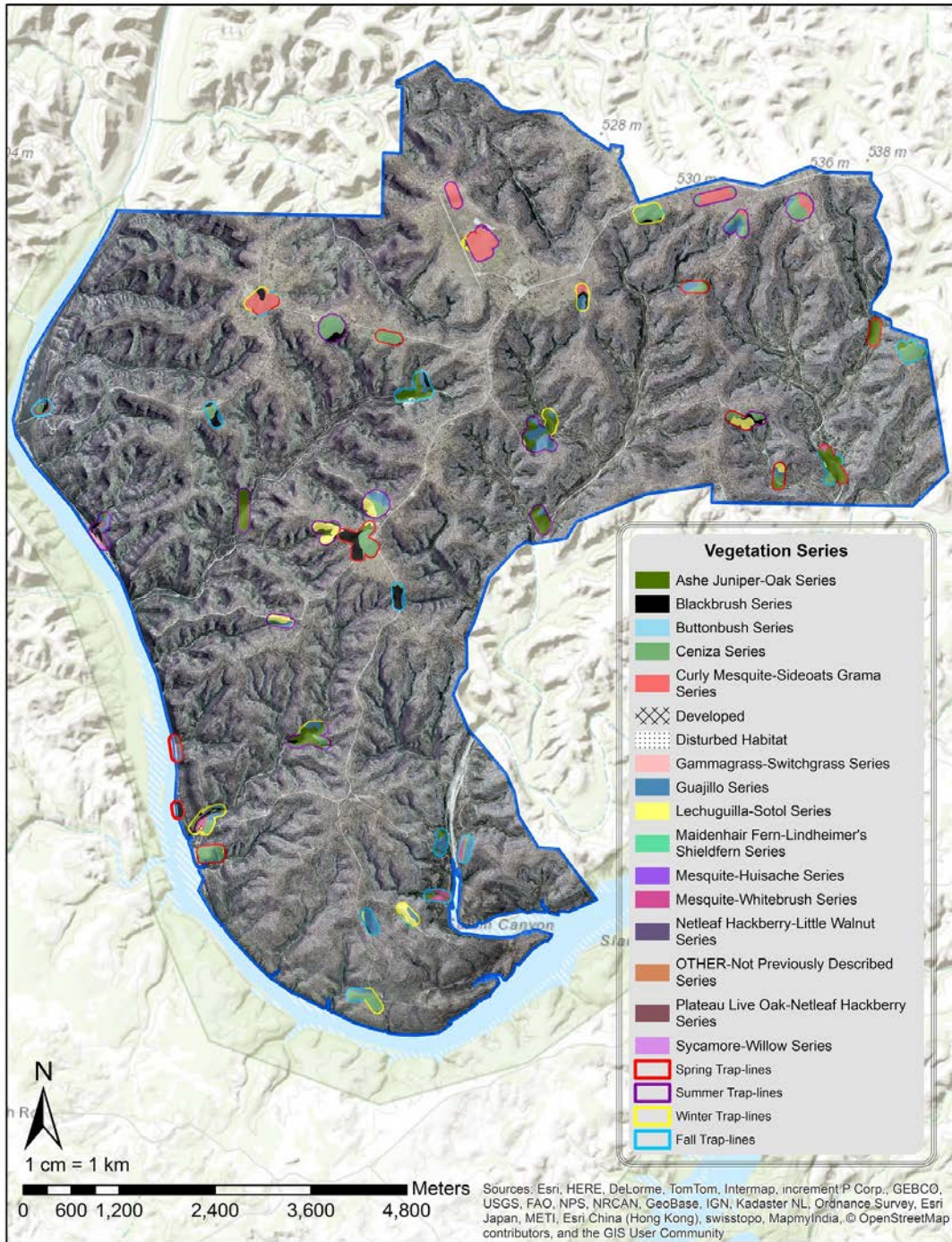


FIG. 13. Map of the Devils River State Natural Area – Big Satan Unit displaying the trap-line vegetation buffers generated to obtain vegetation series percentages within the buffered area. Outlines of trap-lines are color coded seasonally: Winter = yellow, Spring = red, Summer = purple, Fall = light blue.

Based on data analysis, vegetation series was second to slope as the environmental variable that contributed the most to generating the MaxEnt model (Table 2). Data analysis also indicated that *P. pectoralis* was captured with highest frequency in the following vegetation series: Lechuguilla (*Agave lechuguilla*) - Sotol (*Dasyilirion texanum*), Curly Mesquite (*Hilaria belangeri*) - Sideoats Grama (*Bouteloua curtipendula*), Blackbrush (*Acacia rigidula*), Ceniza (*Leucophyllum frutescens*), Ashe Juniper (*Juniperus ashei*) - Oak (*Quercus* spp), and Guajillo (*Acacia berlandieri*) Series. These vegetation series are named by their most common plant species; other species and plant associations within the vegetation series are described in more detail in Table 3. I analyzed the percentage of each vegetation series located within the trap-line buffers using linear modeling in the Program R v.3.1.1 (The R Foundation for Statistical Computing 2014). I used a multiple linear regression analysis within each of the four seasonal groupings (winter, spring, summer, fall) to describe the linear relationship between the percentage of each habitat type within the trap-line buffer and the abundance indices per trap-line. The data for the study as a whole, across all seasons, was also analyzed. I then used the Akaike Information Criterion (AIC) to perform a stepwise model selection to select the most parsimonious vegetation series model that best delineated vegetation specific correlations given mouse abundance indices (Burnham and Anderson 2004). Models were tested for multicollinearity by obtaining the variance inflation factor (VIF) for each vegetation predictor variable. If VIF of a vegetation series was greater than 2.5 within a model, that predictor variable was removed due to multicollinearity. Normality and homoscedasticity of data also were tested in R. P-values less than 0.05 were considered significant for this analysis.

TABLE 2.— Estimate of the relative contributions of the environmental variables to the MaxEnt model, in terms of percent contribution and permutation importance.

VARIABLE	PERCENT CONTRIBUTION	PERMUTATION IMPORTANCE
Slope	29.1	33.2
Vegetation Series	24.2	10.5
Aspect	18.4	18.5
Soil	12.2	12.5
Elevation	10.8	12
Vegetation Stability	3.4	12.3
Vegetation Status	1.8	1

TABLE 3.— Description of the six most common vegetation series present at DRSNA – BSU, with the dominant species and indicator species listed (Keith 2011). The percent each vegetation series occupies within DRSNA – BSU is also given.

#	VEGETATION SERIES	DOMINANT SPECIES	OTHER INDICATOR SPECIES	% OCCUPIED
1	Guajillo	Guajillo	Vasey Oak Slimleaf Heliotrope Texas Sotol Gregg’s Ash/Slim Tridens Wright’s Threeawn	33%
2	Ashe Juniper-Oak	Ashe Juniper Vasey Oak	Texas Mountain Laurel Ceniza Guajillo Blackbrush Agarito	26%
3	Blackbrush	Blackbrush Texas Persimmon	Mesquite Silver Bluestem Ceniza Guajillo	13%
4	Ceniza	Ceniza Texas Persimmon	Evergreen Sumac Texas Sotol Curly Mesquite Tobosa	13%
5	Lechuguilla-Sotol	Lechuguilla Sotol	Guajillo Agarito Rio Grande Stickpea Wright’s Threeawn Ocotillo	9%
6	Curly Mesquite-Sideoats Grama	Curly Mesquite Sideoats Grama	Prickly Pear Ceniza Blackbrush Texas Persimmon	3%
7	Other Vegetation Series	NA	NA	3%

RESULTS

Live-trapping

In total, I used data from 105 trap-lines during this study period, with 160 total *Peromyscus pectoralis* captures (Table 4 – 7). Captures were highest in the winter ($n = 53$) and summer ($n = 48$), lower in the spring ($n = 41$), and lowest in the fall ($n = 18$). However this does not account for trapping effort (Fig. 14b, 15b), as trapping effort greatly increased in the summer months (4767 trap-nights) and waned in the winter (1447 trap-nights), spring (1720 trap-nights), and fall (1789 trap nights). To account for this, abundance indices (AI) per season were calculated from captures/trap-night (Fig. 15c), and the winter months exhibited the highest abundance index (AI = 0.038) with a gradual decline throughout the year as the fall months displayed the lowest abundance index (AI = 0.009). The highest abundance index for trap-lines was seen in winter and spring (AI = 0.14). The seasonal abundance indices, trap-night, and capture averages are displayed in Fig. 15. Low trap success was observed across all seasons and habitat with an overall mean abundance index of 0.018.

TABLE 4.— Winter (December – February) trap-line capture data is displayed with percentages of the five main vegetation series within the trap-line home range buffer.

#	CAPTURES	TRAP - NIGHTS	AI	VEGETATION SERIES					
				LECHUGUILLA -SOTOL	GUAJILLO	BLACKBRUSH	CENIZA	ASHE JUNIPER -OAK	CURLY MESQUITE -SIDEATS GRAMA
1	4	100	0.040	0.00	0.43	0.23	0.00	0.00	0.33
2	0	100	0.000	0.00	0.00	0.00	0.00	0.00	0.84
3	6	100	0.060	0.73	0.27	0.00	0.00	0.00	0.00
4	2	100	0.020	0.00	0.00	0.28	0.00	0.00	0.72
5	0	100	0.000	0.00	0.00	0.01	0.00	0.00	0.99
6	2	100	0.020	0.00	0.00	0.02	0.98	0.00	0.00
7	1	47	0.021	0.03	0.17	0.11	0.40	0.00	0.00
8	3	50	0.060	0.03	0.07	0.20	0.15	0.00	0.00
9	4	50	0.080	0.05	0.40	0.28	0.05	0.04	0.00
10	0	100	0.000	0.00	0.00	0.00	1.00	0.00	0.00
11	2	100	0.020	0.00	0.00	0.11	0.89	0.00	0.00
12	7	100	0.070	0.72	0.00	0.09	0.00	0.19	0.00
13	14	100	0.140	0.73	0.00	0.06	0.00	0.21	0.00
14	0	100	0.000	0.00	0.12	0.01	0.88	0.00	0.00
15	4	100	0.040	0.00	0.19	0.00	0.00	0.81	0.00
16	4	100	0.040	0.00	0.39	0.00	0.00	0.61	0.00

TABLE 5.— Spring (March - May) trap-line capture data is displayed with percentages of the five main vegetation series within the trap-line home range buffer.

#	CAPTURES	TRAP - NIGHTS	AI	VEGETATION SERIES					
				LECHUGUILLA -SOTOL	GUAJILLO	BLACKBRUSH	CENIZA	ASHE JUNIPER -OAK	CURLY MESQUITE -SIDOATS GRAMA
1	3	50	0.060	0.03	0.04	0.00	0.93	0.00	0.00
2	3	50	0.060	0.02	0.06	0.00	0.93	0.00	0.00
3	4	50	0.080	0.01	0.09	0.00	0.89	0.00	0.00
4	1	51	0.020	0.00	0.19	0.00	0.79	0.01	0.00
5	1	150	0.007	0.00	0.00	0.00	0.00	0.00	1.00
6	0	100	0.000	0.00	0.00	0.00	0.00	0.00	1.00
7	0	100	0.000	0.00	0.00	0.02	0.98	0.00	0.00
8	1	150	0.007	0.00	0.00	0.00	0.00	1.00	0.00
9	4	150	0.027	0.63	0.00	0.03	0.31	0.03	0.00
10	6	150	0.040	0.00	0.44	0.00	0.49	0.07	0.00
11	0	22	0.000	0.00	0.00	0.50	0.00	0.00	0.00
12	0	47	0.000	0.00	0.01	0.15	0.84	0.00	0.00
13	0	50	0.000	0.00	0.00	0.74	0.26	0.00	0.00
14	7	50	0.140	0.06	0.00	0.20	0.45	0.26	0.00
15	1	50	0.020	0.02	0.00	0.79	0.19	0.00	0.00
16	2	100	0.020	0.00	0.00	0.00	0.00	1.00	0.00
17	4	100	0.040	0.00	0.00	0.00	0.00	0.89	0.00
18	1	100	0.010	0.00	0.19	0.00	0.03	0.00	0.00
19	2	100	0.020	0.25	0.21	0.00	0.33	0.21	0.00
20	0	50	0.000	0.00	0.00	0.55	0.45	0.00	0.00
21	1	50	0.020	0.00	0.00	0.09	0.91	0.00	0.00

TABLE 6.— Summer (June - August) trap-line capture data is displayed with percentages of the five main vegetation series within the trap-line home range buffer.

#	CAPTURES	TRAP - NIGHTS	AI	VEGETATION SERIES					
				LECHUGUILLA -SOTOL	GUAJILLO	BLACKBRUSH	CENIZA	ASHE JUNIPER-OAK	CURLY MESQUITE-SIDEOATS GRAMA
1	0	46	0.000	0.00	0.00	0.00	0.00	0.00	1.00
2	0	48	0.000	0.00	0.00	0.00	0.00	0.00	1.00
3	1	150	0.007	0.00	0.00	0.00	0.00	0.00	1.00
4	5	50	0.100	0.00	0.00	0.00	0.00	0.00	0.90
5	1	432	0.002	0.00	0.00	0.37	0.62	0.00	0.00
6	5	72	0.069	0.00	0.81	0.00	0.00	0.19	0.00
7	2	72	0.028	0.00	0.69	0.00	0.00	0.31	0.00
8	0	72	0.000	0.03	0.59	0.00	0.00	0.38	0.00
9	0	72	0.000	0.00	0.76	0.00	0.00	0.24	0.00
10	4	250	0.016	0.00	0.60	0.00	0.00	0.40	0.00
11	4	250	0.016	0.00	0.83	0.00	0.00	0.17	0.00
12	0	100	0.000	0.00	0.00	0.00	0.00	0.00	1.00
13	5	100	0.050	0.00	0.00	0.00	0.00	1.00	0.00
14	3	200	0.015	0.64	0.00	0.03	0.29	0.04	0.00
15	5	200	0.025	0.44	0.00	0.26	0.30	0.01	0.00
16	0	48	0.000	0.00	0.02	0.00	0.62	0.00	0.37
17	0	48	0.000	0.00	0.12	0.00	0.55	0.00	0.33
18	0	48	0.000	0.00	0.00	0.00	0.68	0.00	0.32
19	0	48	0.000	0.00	0.09	0.00	0.70	0.00	0.21
20	1	50	0.020	0.00	0.52	0.00	0.41	0.01	0.06
21	0	50	0.000	0.00	0.30	0.00	0.57	0.00	0.12
22	0	100	0.000	0.00	0.00	0.00	0.17	0.00	0.83
23	0	100	0.000	0.00	0.00	0.00	0.10	0.00	0.90
24	2	200	0.010	0.73	0.00	0.06	0.00	0.21	0.00
25	0	200	0.000	0.72	0.00	0.09	0.00	0.19	0.00
26	1	49	0.020	0.57	0.31	0.02	0.00	0.10	0.00
27	0	96	0.000	0.33	0.37	0.00	0.30	0.00	0.00
28	1	96	0.010	0.37	0.35	0.00	0.25	0.02	0.00
29	1	96	0.010	0.32	0.22	0.00	0.46	0.00	0.00
30	0	96	0.000	0.19	0.22	0.00	0.59	0.00	0.00
31	0	250	0.000	0.00	0.04	0.00	0.00	0.96	0.00
32	0	250	0.000	0.00	0.14	0.00	0.00	0.86	0.00
33	0	50	0.000	0.00	0.37	0.26	0.00	0.07	0.00
34	0	50	0.000	0.00	0.08	0.33	0.00	0.00	0.00
35	0	46	0.000	0.00	0.16	0.00	0.03	0.81	0.00
36	1	50	0.020	0.00	0.05	0.09	0.02	0.85	0.00
37	1	50	0.020	0.01	0.08	0.00	0.30	0.60	0.00
38	1	72	0.014	0.00	0.74	0.00	0.00	0.26	0.00
39	0	72	0.000	0.00	0.62	0.00	0.00	0.38	0.00
40	3	100	0.030	0.00	0.02	0.00	0.00	0.98	0.00
41	1	48	0.021	0.00	0.00	0.00	0.75	0.00	0.24
42	0	48	0.000	0.00	0.00	0.00	0.65	0.00	0.35
43	0	96	0.000	0.36	0.39	0.00	0.24	0.02	0.00
44	0	96	0.000	0.22	0.35	0.00	0.43	0.00	0.00
45	0	50	0.000	0.00	0.00	0.00	0.00	0.00	1.00

TABLE 7.— Fall (September - November) trap-line capture data is displayed with percentages of the five main vegetation series within the trap-line home range buffer.

#	CAPTURES	TRAP – NIGHT	AI	VEGETATION SERIES					
				LECHUGUILLA - SOTOL	GUAJILLO	BLACKBRUSH	CENIZA	ASHE JUNIPER-OAK	CURLY MESQUITE-SIDEOATS GRAMA
1	0	46	0.000	0.00	0.00	0.00	0.00	0.00	1.00
2	0	100	0.000	0.00	0.70	0.00	0.00	0.28	0.00
3	1	50	0.020	0.00	0.45	0.00	0.25	0.00	0.00
4	0	98	0.000	0.75	0.25	0.00	0.00	0.00	0.00
5	0	50	0.000	0.00	0.00	0.00	0.00	0.00	1.00
6	0	50	0.000	0.00	0.00	0.04	0.00	0.00	0.96
7	0	98	0.000	0.00	0.14	0.00	0.00	0.20	0.00
8	1	100	0.010	0.00	0.28	0.00	0.72	0.00	0.00
9	4	100	0.040	0.09	0.88	0.03	0.00	0.00	0.00
10	1	100	0.010	0.00	0.09	0.00	0.00	0.85	0.00
11	0	50	0.000	0.00	0.36	0.02	0.00	0.62	0.00
12	1	50	0.020	0.00	0.42	0.18	0.00	0.40	0.00
13	1	49	0.020	0.00	0.00	0.07	0.93	0.00	0.00
14	5	100	0.050	0.00	0.15	0.77	0.08	0.00	0.00
15	0	48	0.000	0.00	0.11	0.45	0.43	0.01	0.00
16	0	50	0.000	0.03	0.15	0.13	0.29	0.00	0.00
17	1	50	0.020	0.03	0.13	0.21	0.27	0.00	0.00
18	0	100	0.000	0.02	0.02	0.00	0.37	0.59	0.00
19	0	100	0.000	0.03	0.02	0.00	0.00	0.96	0.00
20	2	100	0.020	0.04	0.01	0.00	0.00	0.87	0.00
21	1	100	0.010	0.00	0.00	0.00	0.94	0.06	0.00
22	0	100	0.000	0.00	0.00	0.00	0.94	0.06	0.00
23	0	100	0.000	0.00	0.00	0.00	0.74	0.26	0.00

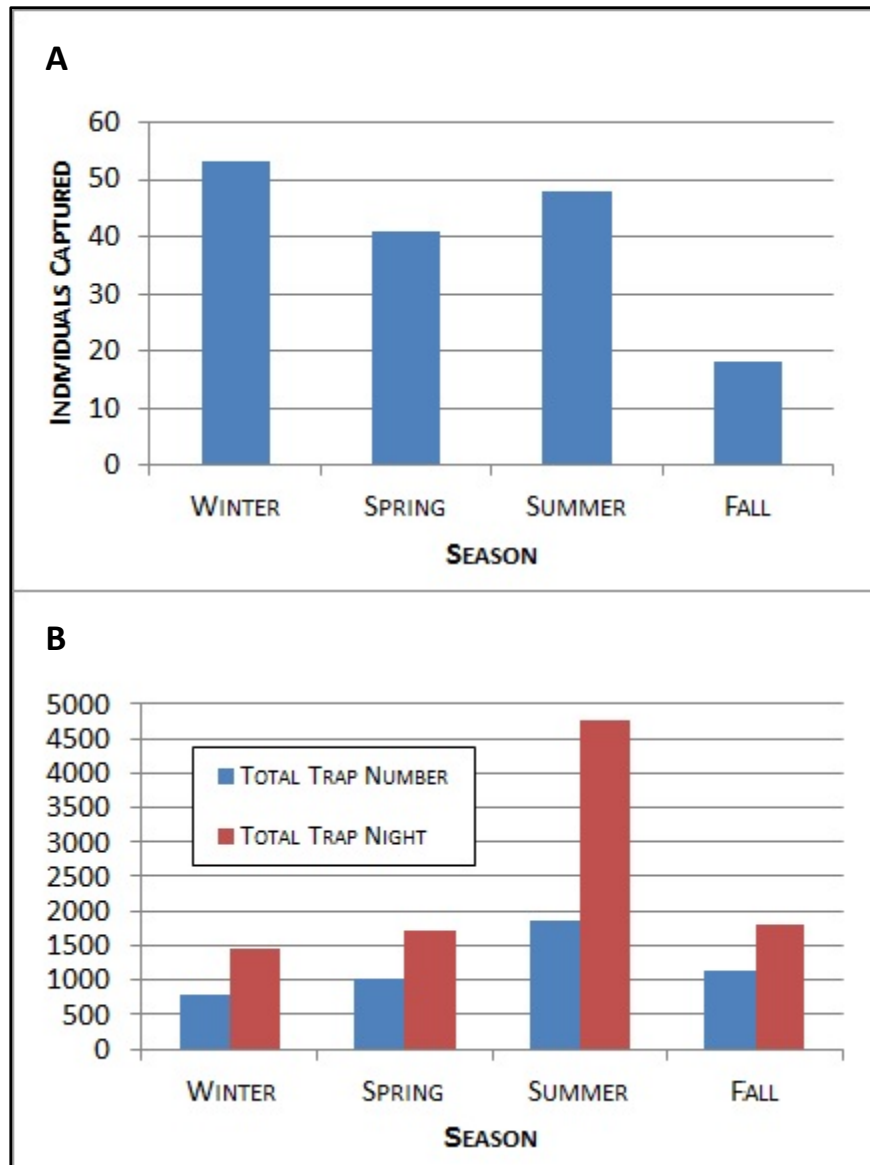


FIG. 14. Trap capture and effort data from February 2013 – October 2014 displaying A) the seasonal capture totals of *Peromyscus pectoralis* at DRSNA – BSU, and B) the seasonal trap-number and trap-night data totals.

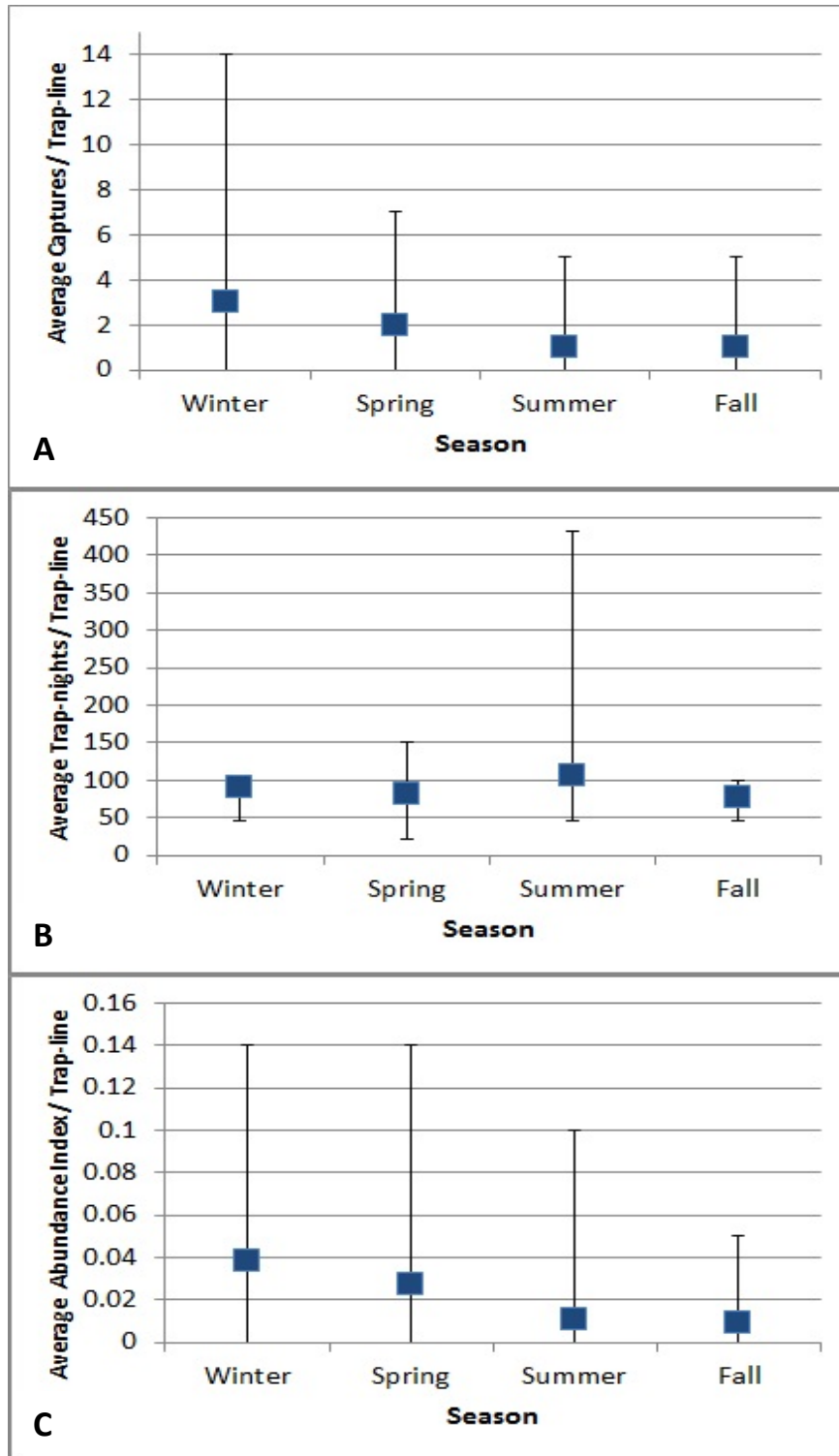


FIG. 15. Graphs displaying seasonal capture data from February 2013 – October 2014 of *Peromyscus pectoralis* from DRSNA- BSU with the minimum and maximum shown with error bars. A) Seasonal capture averages B) Seasonal trap-night averages C) Seasonal abundance index averages.

Spool-and-line Tracking

Overall spool-and-line tracking success was 45%; out of 22 individual spool-fitted mice, only 10 mice traveled longer than the 20 meter threshold allotted to produce accurate and informative arboreality data (Table 8). The seasonal distribution of these spool-and-line trials were varied with three in winter, two in spring, four in summer, and one in the fall. The total length of the spool-and-line trails ranged from 32 – 72.6 m, with an average of 50.34 m. The measured length of spool-line that was in vegetation or on a vegetative structure ranged from 1 – 18 m, with an average of 8.12 m of arboreal activity. All mice exhibited some degree of arboreality; however, the percent of arboreal activity ranged from 3 – 36%, with 16% being the average arboreality for *P. pectoralis* recorded at DRSNA - BSU. Most common species of plant that *P. pectoralis* climbed included: guajillo (*Acacia berlandieri*), blackbrush (*Acacia rigidula*), Ashe juniper (*Juniperus ashei*), sotol (*Dasyllirion wheeleri*), lechuguilla (*Agave lechuguilla*), Texas persimmon (*Diospyros texanus*), agarito (*Berberis trifoliolata*), ceniza (*Leucophyllum frutescens*), and javelina bush (*Condalia ericoides*). The frequency of arboreal activity with respect to each of these plant species was not recorded.

TABLE 8.— Results of the ten successful spool-and-line trials at DRSNA – BSU with total length of spool-and-line trail, as well as the length and percent of arboreal activity. Each spool-and-line trial was conducted over a period of one night.

#	SEASON	VEGETATION SERIES	TOTAL TRAIL LENGTH (m)	LENGTH ARBOREAL (m)	PERCENT ARBOREAL
1	Winter	Blackbrush	58	16	0.28
2	Winter	Lechuguilla-Sotol	40	3	0.08
3	Winter	Lechuguilla-Sotol	55.5	4	0.07
4	Spring	Ashe Juniper-Oak	50	18	0.36
5	Spring	Guajillo	32	9	0.28
6	Summer	Guajillo	50.5	7.5	0.15
7	Summer	Guajillo	72.6	11.2	0.15
8	Summer	Blackbrush	50.5	7.5	0.15
9	Summer	Lechuguilla-Sotol	61.3	4	0.07
10	Fall	Ceniza	33	1	0.03
Average:			50.34	8.12	0.16

Species Distribution Modeling

The species distribution predicted by the MaxEnt model at DRSNA – BSU (Fig. 16) placed moderate probabilities of occurrence (logistic output) in the uplands, dry south-facing slopes that are not very steep ($\leq 20^\circ$), and high probabilities of occurrence in the mesic canyon woodlands and riparian corridors. The model classified 62.5% of the property (4464 hectares) as having low prevalence, 35% of the property (2430 hectares) as having moderate prevalence, and 3.5% of the property (257 hectares) as having a high prevalence of *P.*

pectoralis (Fig. 17). The area under the receiver operating characteristic (ROC) curve, or AUC (Fig. 18b), of the MaxEnt model indicated that the *P. pectoralis* data provided was a good fit to the model (AUC = 0.816), as an AUC = 0.5 would indicate a model no better than random. The omission rate for *P. pectoralis* lies closely to the predicted omission line, which again indicated that our training sample data were a good fit for the model (Fig. 18a). The environmental variable that provided the highest percent contribution (PC) to the model was slope (PC = 29.1%) followed by vegetation series (PC = 24.2%), and then aspect (PC = 18.4%) with the other variables providing less contribution to the spatial distribution of *P. pectoralis* displayed by the model (Table 2). When the response of *P. pectoralis* distribution was graphed against the continuous environmental variables (aspect, slope, elevation), no distinct linear correlations were observed (Fig. 19); however, slope displayed a steep decline in probability of occurrence when degrees of slope exceeded 20° (Fig. 19b). The probability of *P. pectoralis* presence also distinctly increased to over 80% at three elevational ranges (Fig. 19c). Vegetation stability (PC = 3.4%) and status (PC = 1.8%) both had very low percent contribution to the model. The jackknife test of variable importance (Fig. 20) identified vegetation series as the variable that had the most influence on species distribution

when used in isolation, followed by slope and then soil. The environmental variable that decreases the regularized training gain the most when omitted is slope, followed by aspect and then soil.

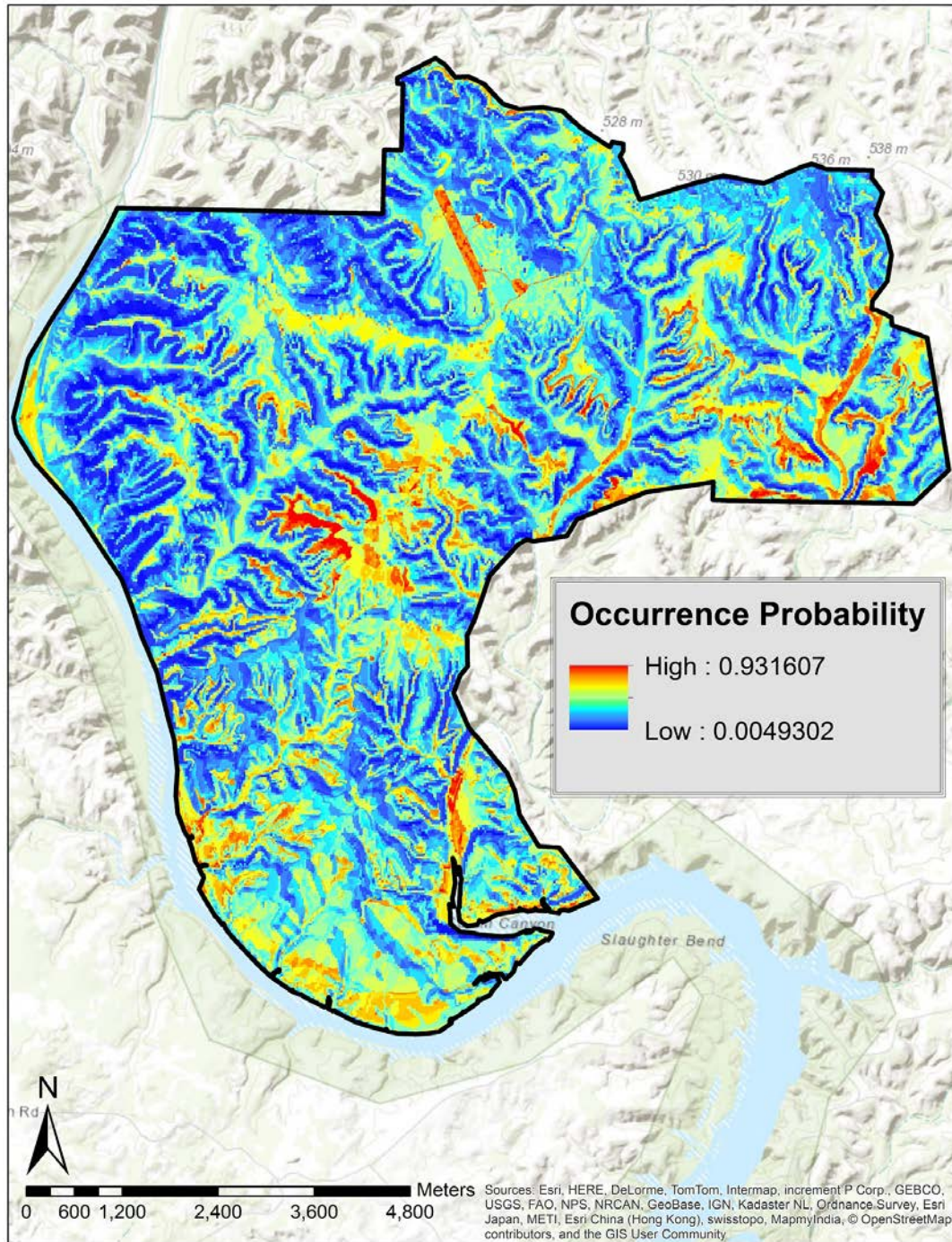


FIG. 16. MaxEnt suitability model displaying the distribution of the probability of occurrence of *Peromyscus pectoralis* within DRSNA – BSU. Warm colors indicate areas of higher predicted occurrence probabilities.

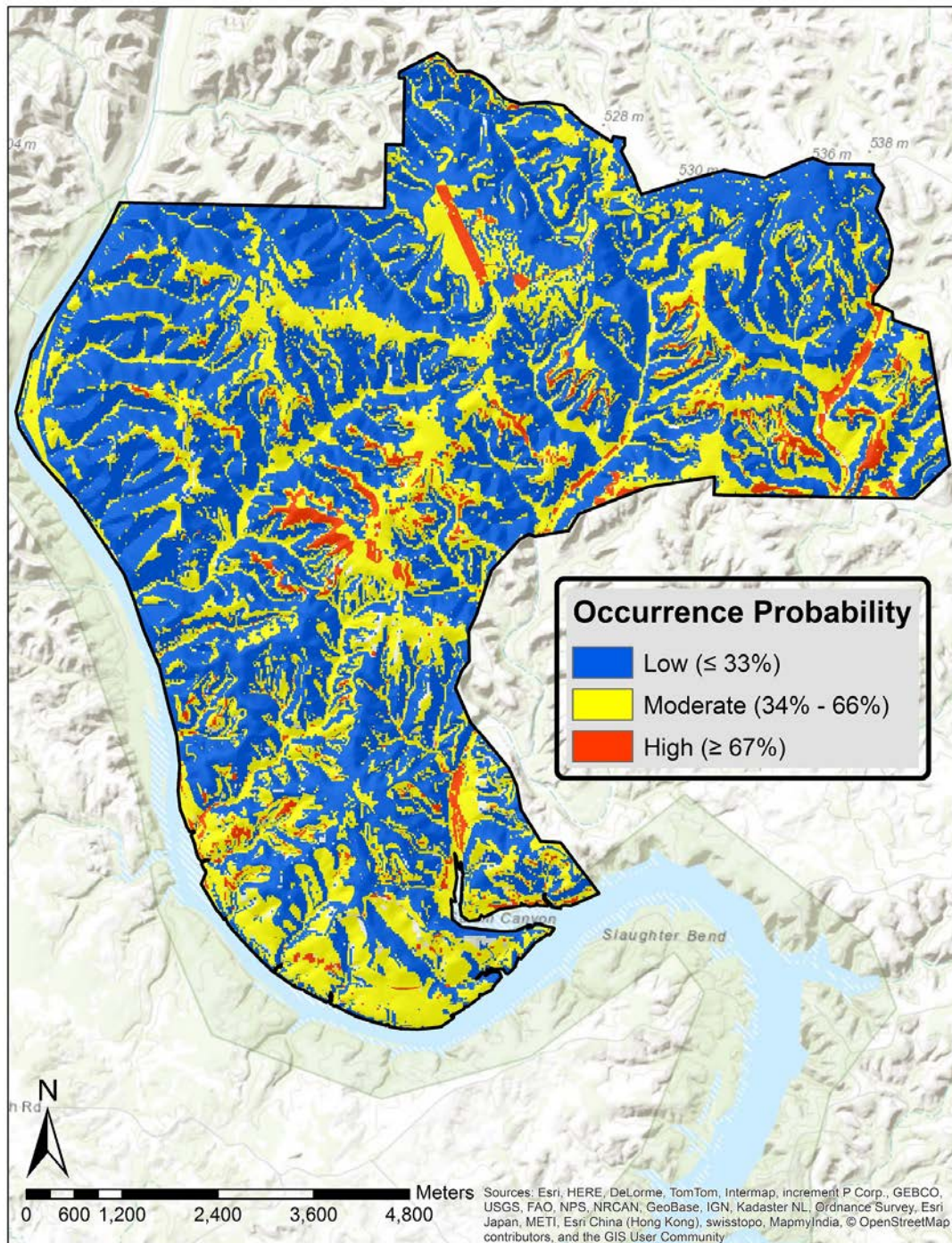


FIG. 17. MaxEnt suitability model after reclassification in ArcGIS, displaying the distribution of the probability of occurrence of *Peromyscus pectoralis* at DRSNA – BSU within three prevalence classes. Warm colors indicate areas of higher predicted occurrence probabilities.

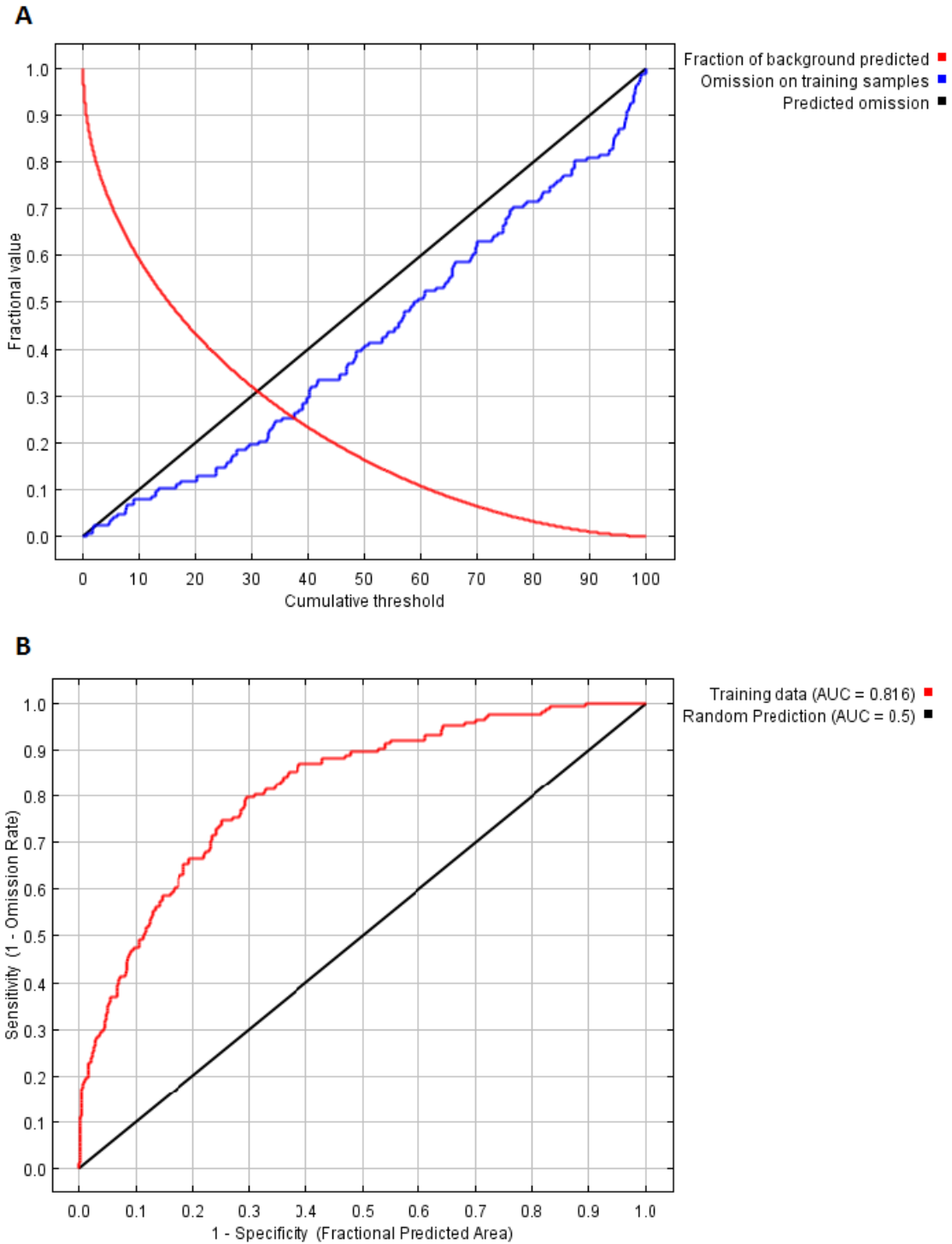


FIG. 18. A) Graph displaying the analysis of omission for the MaxEnt model generated; shows the omission rate and predicted area at different thresholds. B) Graph displaying the Area Under the Receiver Operating Characteristic (ROC) Curve or AUC used for assessing model performance. A predicted (random) AUC would equal 0.5. The data provided has an AUC = 0.816, indicating better model performance.

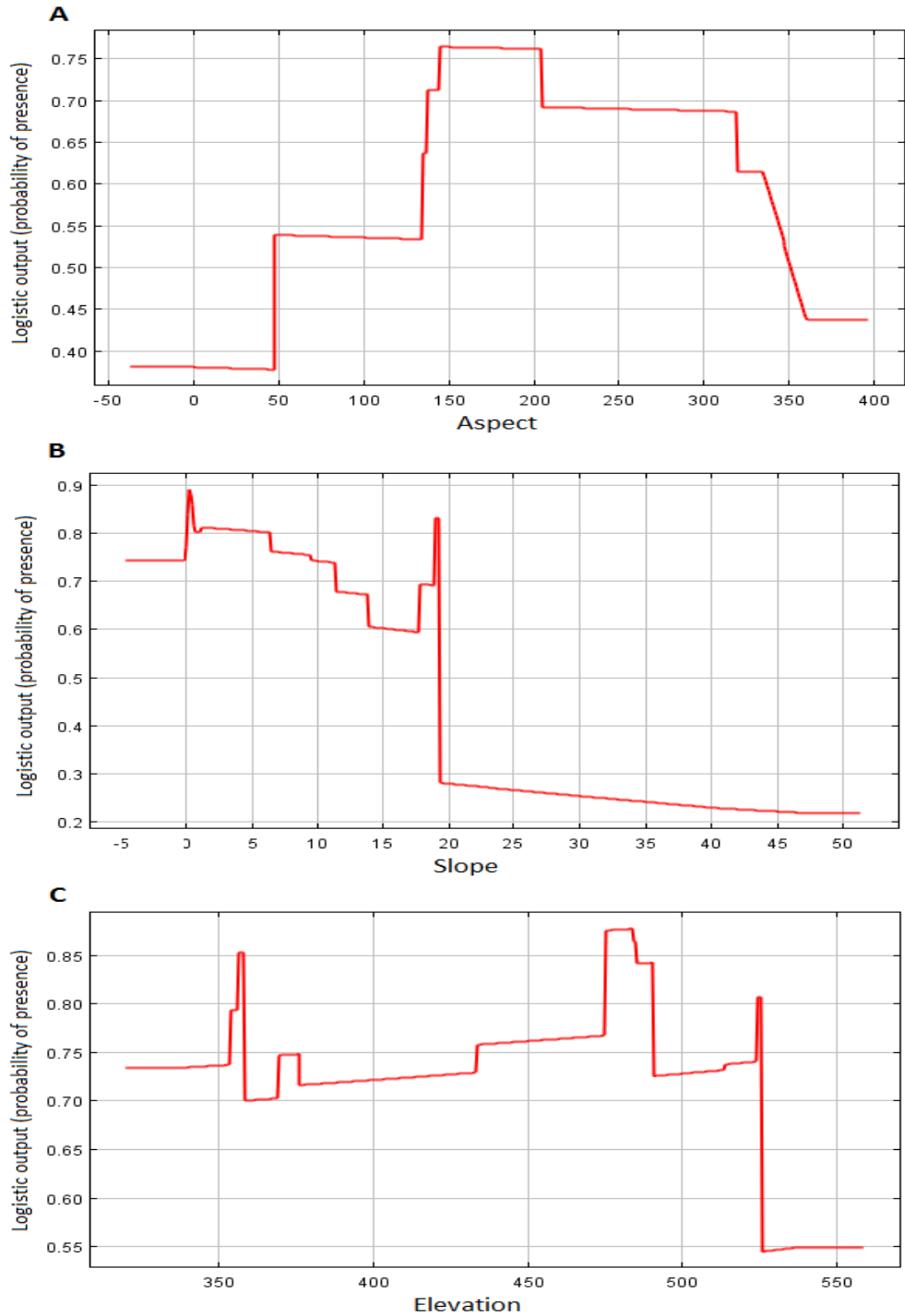


FIG. 19. Graphs depicting the response of *Peromyscus pectoralis* to layers in MaxEnt analysis. A) Graph displaying the response of *P. pectoralis* to the aspect layer used in the MaxEnt analysis. North = 0-22.5° & 337.5-360°; East = 67.5-112.5°; South = 157.5-202.5°; West = 247.5-292.5°. B) Graph displaying the response of mouse to varying degrees of slope. C) Graph displaying response of mouse to changes in elevation.

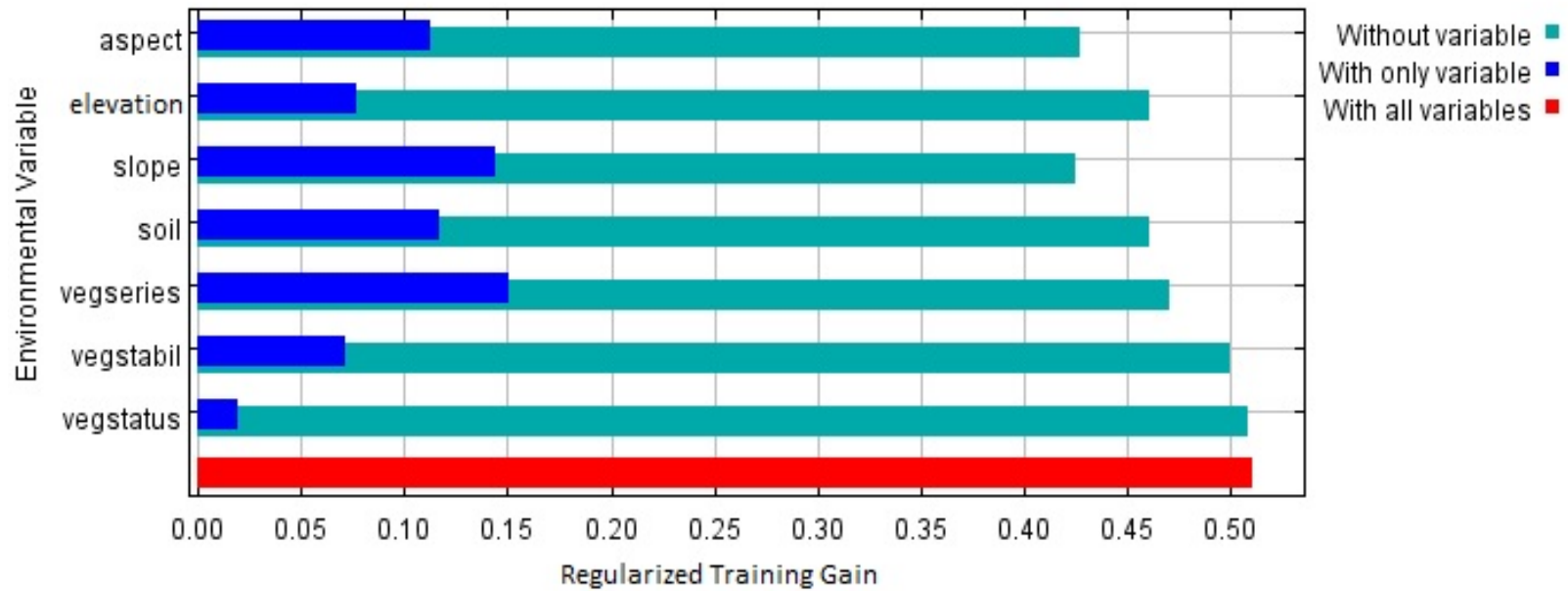


FIG. 20. Jackknife test displaying the regularized training gain for *Peromyscus pectoralis* of each environmental variable used in the MaxEnt model. The jackknife test analyzes each environmental variable's importance to the generation of the species distribution model.

Regression Analysis

An analysis of all trap-lines over the course of the entire study, when not subdivided into seasonal categories, failed to yield any significant correlations ($p > 0.05$) between AI and vegetation series; however, the seasonal regression analysis provided multiple positive correlations (Table 9). All the variables in the winter best-fit model yielded positive correlations with specific vegetation series: Lechuguilla-Sotol Series ($P = 0.0001$), Blackbrush Series ($P = 0.0466$), and the Ashe Juniper-Oak Series ($P = 0.0168$). The spring trap sessions yielded one significant positive correlation with the Lechuguilla-Sotol Series ($P = 0.0019$). Summer trap sessions yielded no significant results from the best-fit model. Both variables in the fall model yielded positive correlations: Blackbrush Series ($P = 0.0036$), and the Guajillo Series ($P = 0.0369$).

TABLE 9.— Table below displays the results of the best habitat model for the regression analysis, performed with vegetation series as independent predictor variables.

TERM	R²	β	SE	P
Winter Model	0.713			
Lechuguilla-Sotol Series		0.024	0.004	0.0001*
Blackbrush Series		0.019	0.008	0.0466*
Ashe Juniper-Oak Series		0.013	0.004	0.0168*
Spring Model	0.448			
Lechuguilla-Sotol Series		0.021	0.006	0.0019*
Guajillo Series		0.010	0.007	0.1624
Ashe Juniper-Oak Series		0.006	0.004	0.1784
Summer Model	0.011			
Ceniza Series		-0.003	0.002	0.2681
Ashe Juniper-Oak Series		0.001	0.002	0.5390
Fall Model	0.381			
Guajillo Series		0.022	0.009	0.0369*
Blackbrush Series		0.042	0.013	0.0036*
Whole Study Model	0.047			
Lechuguilla-Sotol Series		0.025	0.013	0.0625
Curly Mesquite-Sideoats Grama Series		-0.011	0.008	0.1497
*Significant Correlation				

DISCUSSION

A MaxEnt species distribution model was applied to the distribution of *P. pectoralis* at the Devils River State Natural Area – Big Satan Unit (Fig. 16). These models have four advantages compared to simply mapping the existing results, as they allow associations of the dependent variables with many environmental factors simultaneously, identify the most relevant environmental factors affecting the distribution, permit extrapolation of the probabilities of occurrence to nonsampled areas, and provide maps that can be used in the design of action plans or wildlife conservation efforts (Gomez et al. 2014). The distribution of *P. pectoralis* predicted at DRSNA – BSU responded most to slopes that were between 3 and 20° (Fig. 4, Fig. 19b). This would suggest that this species is present most commonly on slopes $\leq 20^\circ$, although they have been captured in areas with slopes $\geq 20^\circ$ within DRSNA – BSU with minimal frequency. Slope was also identified by the jackknife analysis as the environmental variable that decreased the regularized training gain the most when it was omitted from the model (Fig. 20). This indicated that slope provided the most information for predicting the species distribution of *P. pectoralis*, which is not present in the other environmental variables. Mullican and Baccus (1990) utilized the fluorescent powder tracking technique as a means to identify the horizontal and vertical movements of *P. pectoralis* within its habitat in a central Texas study. These authors set traps along the talus, low slope, bases of cliffs ($\geq 45^\circ$) and discovered that the mouse left 89.5% of its fluorescent-pigment trail on the ground, 9.5% on cliffs, and 1.0% in shrubs and trees. The percentage of trail on cliffs was low; however 78% of the mice spent some time on the cliffs, indicating that although they are more common in areas of medium to low slopes, they may still be captured on high slope areas. Etheredge et al. (1989) determined that captures were most

associated with sloping limestone ledges, and Baccus & Horton (1984) came to similar conclusions stating that this species was highly associated with slopes and ledges. However these authors do not mention or directly measure the degree of slope that this species is associated with, and the slope preference determined in this study ($\leq 20^\circ$), in conjunction with other associated environmental variables, should serve as the standard for predicting presence of *P. pectoralis*.

The species distribution was also influenced by aspect (PC = 18.4%) in a greater proportion than elevation, vegetation status and stability (Fig. 19, Table 2). The most influential aspect was the south-facing areas of the landscape at DRSNA – BSU, which are universally rocky. South-facing slopes are commonly drier and warmer in the Northern Hemisphere, compared to the cooler and moister north-facing slopes (Mustaphi and Pisaric 2013). That observed importance of aspect should be expected given the broad-scale arid and semi-arid species distribution of *P. pectoralis* in inland northern Mexico, and west and central Texas (Schmidly 1974). Some fine-scale preferences are also known regarding the species occurrence in dry and rocky habitats (Modi 1978; Schmidly 1974). The increased response of *P. pectoralis* to over 80% occurrence at three distinct elevation ranges identified by the model (Fig. 19c) is most likely an artifact of the effects of topography (Fig. 6) on the vegetation (Fig. 7), given the lower percent contribution of elevation to the generation of the model (PC = 10.8%). The elevation induced spikes in the distribution model at around 355m, 480m, and 525m, correspond to woodland areas of the mesic canyons, rocky slopes with xeric vegetation, and the shrub-covered uplands.

As for the four categorical environmental variables tested, the contribution of vegetation series (PC = 24.2%) and soil type (PC = 12.2%) was substantially more important

to the species distribution model (Table 2) than vegetation status (PC = 1.8%) or vegetation stability (PC = 3.4%). Given the low contributions of vegetation status (Fig. 8) and vegetation stability (Fig. 9) to the species distribution model, they likely do not directly play a role in the habitat requirements of the species. The identification of vegetation stability and status will however be important when constructing biological management programs. An understanding of the environmental mechanisms that drive changes in a landscape is inherently linked to the understanding of which areas are stable or unstable, and less or more susceptible to the encroachment of competitive or invasive species.

Based on the model, the enhanced contribution of vegetation series demonstrated that the distribution of *P. pectoralis* is highly correlated with vegetation type. The jackknife test for variable importance evidences this, as the vegetation series variable, when used in isolation, provided the most useful information of any variable for predicting the species distribution of *P. pectoralis* (Fig. 20). To better delineate which particular vegetation series were most important to the distribution, as well as which vegetation series were being selected by *P. pectoralis*, it was necessary to run a multiple linear regression comparing the abundance index of each trap-line to the vegetation series percentages present within the adjacent home ranges of that trap-line (Table 9). Analyzing the capture data this way is more encompassing than an analysis that draws conclusions solely from the point locations of each mouse capture and environmental variables recorded from that point. *Peromyscus pectoralis* are very mobile (Table 8) and have been recorded to shift home ranges over time (Mullican and Baccus 1990).

Based on the spool-and-line analysis portion of this study it is known that these mice can travel at least 72.6 linear meters in one night (Table 8). *Peromyscus pectoralis* was

shown to spend a substantial percentage of time in trees and shrubs (Fig. 12) during its normal foraging behaviors, with an average percent of arboreality of 16%. Etheredge et al. (1989) studied a population of *P. pectoralis* in sympatry with *P. attwateri*, a species that does not occur at DRSNA – BSU, using fluorescent powder tracking. In that population *P. attwateri* spent 69% of the time in trees, compared to *P. pectoralis* which was found to use the woody vegetation only as escape cover while spending 54% of the distance traveled on limestone ledges. My data suggest that in the absence of this competitor, *P. pectoralis* displays a higher degree of arboreality. The spool-line of mouse #4 (Table 8) was followed as it climbed an Ashe juniper tree to an approximate height of 1.8 m, and set the record for longest distance traveled in shrubs and trees (36%). Mullican and Baccus (1990) tested the horizontal and vertical movements of this species in the absence of *P. attwateri* using florescent powder tracking and observed mice climbing to a mean height (± 1 SD) of 120 ± 44.4 cm which is similar to the maximum height achieved in this study; however, these authors observed a far lower frequency of arboreality compared to the population at DRSNA – BSU. Only 1.0% of the pigment trails overall were in trees and shrubs in the central Texas population studied by Mullican and Baccus (1990) compared to the mice in my study traveling an average of 16% in trees and shrubs. My sample size was however low and varied both temporally by season, and spatially by habitat type. Further research will be required to identify habitat specific changes in arboreality, as well as the mechanism behind the higher degree of arboreality displayed by *P. pectoralis* in my study. Data on which species of plant that facilitated the arboreal behavior of *P. pectoralis* was not recorded during this study; however, arboreality anecdotally appeared to be more related to presence of woody vegetation within each vegetation series, rather than the actual species of that vegetation.

Further studies can explore this as a means to provide more detailed information of vegetative habitat selection, and should take into account the problems I encountered with the spool-and-line tracking method. The low success of the spool-and-line trials was due to four recurring issues. The first and most directly related reason for the low spool-and-line sample size was low trap success; at best during the spool-and-line trials I encountered 0.04 captures/trap-night. It is also important to point out that there were inherently fewer captures during the night-time trap check, compared to the trap-captures of the following morning. It can be described as a balancing act of checking the trap-lines early enough in the night to allow for the optimal trail distance achieved, versus checking the traps later in the night to obtain more captures, and therefore more chances of successful trap-lines. The third issue with the spool-and-line trials was the tendency for the spool bundle itself (Fig. 11) to detach from the mouse during nightly activities. This was due to either the cyanoacrylate glue not fully bonding to the dorsal pelage of the mouse before release, or the simple action of the mouse traveling through dense vegetation. The fourth and final issue encountered with the spool-and-line trials was the abundance of thorny, sharp, and abrasive plant species and rocks at DRSNA – BSU. Because of this, spool-lines tended to break often, and soon. All of these factors contributed to the low success rate for spooling *Peromyscus* at my study site.

The results of the regression analysis provided many season-specific significant positive correlations to individual vegetation series (Table 9). When all capture data from the project as a whole were analyzed, no significant correlations were identified (all p – values > 0.05). This result is potentially because of the seasonal effect on trap success (Fig. 14) or unknown interaction effects. Sample size however is too low to test for interaction effects. As the trap-line data was subdivided seasonally, significant positive correlations with vegetation

series were observed. The mechanism behind these vegetation series correlations is most likely related to the dietary requirements of the species. The trophic ecology of populations of *P. pectoralis* in central Texas have been assessed by quantitatively evaluating stomach contents using relative-occurrence evaluation and histomicroscopic methods (Baccus et al. 2009). *Peromyscus pectoralis* are primarily frugivorous/granivorous herbivores with omnivorous tendencies. A significant positive correlation was observed for the Blackbrush vegetation series during the fall and winter months, which is an undocumented vegetation affinity for the species. The Blackbrush vegetation series consists of two dominant species, blackbrush and Texas persimmon (*Diospyros texanus*), with both exhibiting the most direct impact on that habitat. The Texas persimmon bears fruits that are a common food item for a variety of Texas wildlife. They likely serve as a food source for *P. pectoralis* during the fall and winter months when insect activity is low. Baccus et al. (2009) observed a diet consisting of 88.4% of fruits and seeds in winter, and 86.2% of fruits and seeds in fall, with a few individuals consuming Texas persimmon fruits in the winter. In that study, the authors state that there were no Texas persimmon trees occurring along the trap-line and few in the area which might account for the low number of individuals that had ingested the fruit. The authors hypothesized that Texas persimmon laden raccoon (*Procyon lotor*) scat may have been the source of seed access to those few individuals. This interaction may infer that, had the mice been in an area with Texas persimmon, a higher percentage of their diet would have consisted of its fruit.

Winter trap sessions additionally yielded a positive correlation with the Ashe Juniper-Oak vegetation series. An association between *P. pectoralis* and Ashe juniper is well supported in the literature. Baccus et al. (2009) observed in winter, only Ashe Juniper

(*Juniperus ashei*) berries and green sumac berries were the important food staples of the study population. Our data suggest that when this food resource is available (Ashe juniper berries), the abundance indices of *P. pectoralis* should increase in areas with higher percentages of Ashe juniper. The other dominant species in the Ashe Juniper-Oak series is the plateau live oak (*Quercus fusiformis*), also known as the Texas live oak. Although this association in particular is present at capture sites in multiple habitat studies (Baccus and Horton 1984; Etheredge et al. 1989; Mullican and Baccus 1990), Etheredge et al. (1989) found that when comparing powder trails of this species to the congeneric *P. attwateri*, *P. pectoralis* used the vegetative structures of the plateau live oak very little and preferred the limestone ledges that were available, indicating that the plateau live oak itself may not be associated with *P. pectoralis* distribution. The Ashe Juniper-Oak vegetation series fills the mesic canyons of DRSNA – BSU (Fig. 7), and lines rocky drainages that receive runoff from rainfall events. This vegetation series is typically located in areas of low slope and ideal habitat for *P. pectoralis*. The fall and winter fruit provided in this habitat is an important resource that most likely draws individuals of this highly mobile species (evidenced from spool-and-line trials) from the surrounding areas, as a result increasing the local abundance index. This movement of individuals to areas of higher resource availability is commonly seen in rodents and would explain the significantly higher winter abundance indices found in this habitat, as well as in the Blackbrush vegetation series.

The abundance indices of winter trapping sessions were also positively correlated with the Lechuguilla-Sotol Series, at a time when the mice have been demonstrated to have the highest frugivorous/granivorous tendencies based on resource availability. This association is also significant in the spring months, at a time when the central Texas

populations of *P. pectoralis* have a diet consisting of 30-60% animal matter in early-late spring (Baccus et al. 2009). This dietary shift observed in spring is significant and exemplifies the opportunism of this species, as the mice begin to consume the increasingly available insects and arachnids. Animal matter consumption continues throughout the summer and represents a major food source at 40% of consumed foods. Animal matter consumption declines to less than 10% in the fall and winter months as insect availability decreases. The Lechuguilla-Sotol Series is another novel vegetation affinity, with none of the dominant or indicator species within this series explicitly known to be foraged upon by *Peromyscus* mice. Possible resources provided by this vegetation series include Wright's threeawn (*Aristida purpurea*), foliage of guajillo (*S. berlandieri*), Rio Grande stickpea (*Calliandra conferta*), or even the offshoots, seeds or seedlings of the lechuguilla (*A. lechuguilla*) as they are known (NPIN: Native Plant Database 2014) to be eaten by deer (*Odocoileus* spp) and javelina (*Pecari tajacu*).

Summer trap sessions yielded no significant correlations with vegetation series, which could be a result of low trap success. Alternatively the switch to animal matter consumption (primarily insects and arachnids) in the summer (40% of diet) would in effect decrease the dependence on vegetation-based resource selection. In the fall months, the Guajillo and Blackbrush vegetation series were positively correlated with higher abundance indices. The Guajillo series is the most common vegetation series, covering 33% of DRSNA – BSU. The abundance of this habitat type may perhaps be causing this association by sheer dominance of the present plant communities, as this is again another undocumented habitat affinity for this species, although other possible resources may be provided by the associated indicator species listed in Table 3. Guajillo (and blackbrush) could also potentially be an

important aspects of this species' habitat preferences, as previous studies of *P. pectoralis* were in areas where these species were not an important component of the habitat.

A habitat suitability and selection study of this nature has not been conducted for this species and provides many novel habitat associations previously unknown due to the lack of in-depth habitat studies. The MaxEnt model was effective in calculating the slope, aspect, and elevation ranges that were most relevant to the distribution of *P. pectoralis*. MaxEnt was also effective at producing a species distribution map approximately depicting the areas where higher abundance indices would be expected based on vegetation series correlates produced by the regression analysis. The species distribution map of *P. pectoralis* at DRSNA – BSU produced by the model could be used by TPWD for management purposes as a spatially referenced baseline of this species' relative abundance. My data suggest that vegetative habitat selection by *P. pectoralis* is seasonal and most likely dependent on the degree of resource availability within each vegetation type. This highly mobile species is capable of dispersing to an area of greater resource availability, and furthermore the fluctuation of abundance indices within the various habitat types described can be explained through the paradigm of trophic ecology. 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). In addition, seasonal movements, like those of *P. pectoralis* to areas of greater food availability, have been demonstrated in other *Peromyscus* species (King 1983; Ormiston 1984; Rizkala and Swihart 2007). The pattern of habitat selection by *P. pectoralis* has been evidenced to be related inherently to selection rather than competitive interactions (Etheredge

et al. 1989; Mullican and Baccus 1990). Data from this study further supports this aspect of the ecology of *P. pectoralis*.

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