DISTRIBUTION OF THE TEXAS KANGAROO RAT (*DIPODOMYS ELATOR*) IN TEXAS; WITH COMMENTS ON MICROHABITAT, HABITAT, AND HABITAT MODELING

By

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ABSTRACT

The Texas Kangaroo Rat (TKR, *Dipodomys elato*r) is a species of concern in Texas with sightings in only seven counties in the past 30 years. The decline of TKR has been attributed to habitat loss, although its exact habitat requirements have not been determined. Habitat studies have focused on microhabitat and burrow associations but have failed to create an accurate landscape level habitat model. Multiple species within the genus *Dipodomys* have demonstrated strong associations with certain soil and land-cover classes. My goal was to determine which soil and land-cover classes are associated with TKR and then use these associations to model potential TKR habitat across their historic 11-county range. During the summers of 2016 and 2017, I surveyed with spotlights at night for TKR on public roads throughout its historic range. I found TKR at 75 and 63 locations in 2016 and 2017, respectively, among five counties. For analysis, random points were generated along the roads surveyed in 2016 to create a dataset of points representing TKR absence. A two-group randomization test was used to determine if percent composition of soil and land-cover classes (within 150 m buffers surrounding the points) were significantly different between 2016 presence and absence points. Presence points had a greater proportion of mixed grass/shortgrass prairie land-cover class ($P < 0.1$), cropland land-cover class ($P < 0.05$), clay loam and loam as the topmost soil layer ($P < 0.05$), and friable clay as the underlying soil ($P < 0.05$) than did absence points. A potential habitat model based on where selected land-cover and soil classes overlapped was created using GIS software and the USDA-NRCS Soil and TPWD TEMS databases. This model portrays a more confined range than that shown by previous modeling efforts.

I. INTRODUCTION

The Texas Kangaroo Rat (*Dipodomys elator*; henceforth referred to as TKR) is a member of a large genus of granivorous, saltatorial, burrowing rodents native to various grassland and desert ecosystems in western North America. First described in 1894, the TKR's taxonomic relationship to other members in the genus was formerly a topic of contention among researchers (Merriam 1894). Anatomical data based on tooth morphology indicate TKR is distinct from all other *Dipodomys* species (Dalquest et al. 1992). However, more recent and reliable molecular data has shown that TKR and the central Mexican species, Phillip's Kangaroo Rat (*D. phillipsii*), represent a distinct lineage within this genus that separated approximately three million years ago (Mantooth et al. 2000, Alexander and Riddle 2005).

Since the first field record in 1894 in Clay County, Texas (Merriam 1894), TKR has been documented definitively in a restricted distribution of only 11 counties (Archer, Baylor, Childress, Clay, Cottle, Foard, Hardeman, Montague, Motley, Wichita, and Wilbarger) in Texas and two counties (Comanche and Cotton) in Oklahoma (Bailey 1905, Blair 1949, Packard and Judd 1968, Baccus 1971, Martin and Matocha 1972, Cokendolpher et al. 1979, Baumgardner 1987). A twelfth Texas county, Coryell, has a record from 1953, but this record was likely a misidentification and since has been discounted (Blair 1954, Dalquest and Collier 1964). There have been no reports of TKR in Oklahoma since 1969 despite numerous surveys, and all Oklahoma populations are believed to be extirpated (Baumgardner 1987, Moss and Mehlhop-Cifelli 1990, Martin 2002, Oklahoma Department of Wildlife Conservation 2016). In the most recent range-wide surveys, conducted in Texas during 1985–1987 (Jones et al. 1988) and 1995–2000 (Martin 2002), TKR was found in four and five counties respectively (Fig. 1).

Among kangaroo rats, TKR is unique in its use of clay-based soils (rather than sand) for burrowing, although it also will use a variety of loamy soils (Dalquest and Collier 1964, Roberts and Packard 1973, Martin and Matocha 1991). Historically researchers believed TKR was unique among *Dipodomys* species because its burrow entrances were thought to be built exclusively at the base of mesquite (*Prosopis glandulosa*) shrubs (Bailey 1905, Dalquest and Collier 1964). However, later investigators have found that any landscape feature promoting an accumulation of friable soil can be utilized, whether that feature is plant roots, prairie mounds, or anthropogenic structures (Stangl et al. 1992, Goetze et al. 2007, Nelson et al. 2013). Like other *Dipodomys* species, TKR constructs complex burrow systems that have an average depth of 50 cm and multiple entrances, living chambers, and seed caches (Roberts and Packard 1973). Researchers have noted that TKR habitation is positively associated with the presence of bare ground and sparse grass and forbs (Dalquest and Collier 1964, Martin and Matocha 1972, 1991, Nelson 2013). Limited research on this species' diet (Dalquest and Collier 1964, Chapman 1972, Carter et al. 1985) shows a preference for grass seeds, which is a shared trait among *Dipodomys* species. Native, introduced, and domestic crop species are consumed, and domestic crop species are heavily used. Annual forbs are also eaten, with parts consumed differing among forbs eaten. Plant parts from perennial woody vegetation account for an insignificant part of TKR diet, with prickly pear (*Opuntia* spp.) seeds being the possible exception.

Over the past 50 years, many researchers have speculated on the apparent scarcity of this species, and several assessments of its distribution and abundance have been made. In general, its distribution is thought to have become more restricted and abundance to have declined. Suggested causes have included factors such as the clearing of mesquite brush land and presumably burrowing sites, mesquite encroachment leading to closed canopy vegetation, loss of natural fire regime, lack of natural grazing regime in grasslands, undergrazing by cattle, infrastructure development, and conversion of prairie to monoculture domestic crops (Dalquest and Collier 1964, Martin and Matocha 1972, Hamilton et al. 1987, Stangl et al. 1992, Hafner 1996, Martin 2002). Quantitative research aimed at identifying factors causing TKR decline has focused on the effects of cattle grazing regime, with grazed pastures providing better habitat than adjacent non-grazed pastures (Stangl et al. 1992, Goetze et al. 2007, Nelson et al. 2009, Stasey et al. 2010).

To date, two models have been constructed to identify potential habitat within the historical range of TKR. These models differ in their approach. The older model (Diamond and Shaw 1990) assessed where ideal geologic features, soil types, and land-cover classes for TKR overlapped to estimate potential range. This model suffered from low accuracy and resolution of the data; therefore, the model was constrained by the technology available at that time. A more recent species distribution model (Andersen and Beauvais 2013) was developed through Maxent software with a variety of climactic factors to model the potential range of TKR. This model was imprecise at the local scale and overestimated current and even historically recorded TKR range.

At present, a consensus is lacking regarding the spatial location of suitable habitat and the current extent of the species' distribution within the counties encompassing its historic range. This lack of information, apparent rarity of the species, and small historical range size have resulted in its listing as a category 2 species by the U.S. Fish and Wildlife Service in 1985, as "state threatened" by the Texas Parks and Wildlife Department in 1986, and currently as "vulnerable" by the International Union for Conservation of Nature (Hafner 1996, Martin 2002, IUCN 2017).

My objectives were to (1) create a predictive habitat model based on previous TKR habitat descriptions, (2) survey for TKR presence throughout their historic Texas range based on the predicative model to guide surveys, (3) determine microhabitat features associated with TKR presence, (4) determine landscape scale habitat features associated with TKR presence, and (5) model the extent of viable habitat for TKR throughout their historic Texas range. Such information can be used in future surveying and conservation decisions for this species. To meet these objectives I employed on-the-ground and GIS-based surveying of roadside rights-of-way followed by creation of a viable habitat model by means of GIS software.

II. METHODS

Development of a Predictive Habitat Model

To guide roadside surveying efforts, I used ArcGIS (ESRI 2013) to create a predictive model of potential habitat. This model identified areas where soil and land-cover classes that were deemed suitable for TKR occupancy overlapped. To develop the model I selected suitable soils and land-cover classes based on previous field studies of TKR (Dalquest and Collier 1964, Martin and Matocha 1972, 1991, Roberts and Packard 1973, Stangl et al. 1992, Martin 2002, Goetze et al. 2007, Nelson et al. 2013). I included any land-cover class that was predominately grassland or shrubland and any soil type composed of clay, clay loam, or loam of a sufficient depth (at least 50 cm before encountering a restrictive feature) to allow burrowing and not prone to flooding. I obtained the GIS data for this model from the Natural Resource Conservation Service (NRCS) Web Soil Survey[1] and the Texas Parks and Wildlife Department's (TPWD) Ecological Mapping System.[2] A model of predicted habitat was necessary for efficiency in surveying and to ensure the maximum amount of predicted habitat was included in the surveys. Previous roadside surveys have varied widely in succesfully detecting this species (Jones et al. 1988, Martin 2002, Nelson et al. 2013), possibly because the surveys were not able to target suitable habitat.

Surveying for kangaroo rats

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[1] Natural Resource Conservation Service. "Web Soil Survey." United States Department of Agriculture. Accessed 15 April 2016. https://websoilsurvey.sc.egov.usda.gov/.

[2] Landscape Ecology Program. "Ecological Mapping Systems." Texas Parks and Wildlife. Accessed 18 April 2016. https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/.

I conducted surveys for TKR May–August 2016 and June–July 2017. These surveys were intended to document only TKR presence, not abundance or density. Since kangaroo rats are nocturnal, surveying for TKR primarily consisted of driving unpaved (earth or gravel) county roads at night at slow speed (<25 kph) and with artificial lights (spotlights) to search road surface, roadside shoulder, and the roadside rights-of-way carefully for TKRs. Artificial lights, which can be directed to roadside rights-of-way, are necessary for detecting TKR because of the species' small size and use of vegetative cover while foraging. This method was used successfully to survey for TKR in early studies of the species and in later range-wide surveys (Dalquest and Collier 1964, Martin and Matocha 1972, Jones et al. 1988, Martin 2002); however, I used this method more extensively than previous studies. I initiated surveys 30 minutes after sunset and terminated surveys at my own discretion due to inclement weather, dangerous road conditions, or surveyor exhaustion. Survey lengths were 3-8 hours, with an average of approximately 5 hours. Spotlight surveys allowed the greatest expanse of road and roadside habitat to be surveyed during the time allotted for the study. Thus, I was able to survey thoroughly in each county of the historical range of TKR (11-county region previously described). I planned survey routes during the 2016 survey season based on the predictive habitat model, with survey effort focused on areas predicted by the model. I intentionally surveyed areas outside of the predicted habitat to ensure as many land-cover and soil classes were surveyed as possible, even though many of these land-cover and soil classes were not expected to support TKR. I focused survey routes in 2017 within viable habitat as based on the model and modified by data from surveys conducted in 2016; that is, results from 2016 helped me further define the habitat of TKR and thus guide survey efforts for 2017. In addition, I planned the 2017 survey routes so that I resurveyed every point location where TKR was detected in 2016. I considered a site to be active in both years if the presence location from 2017 fell within 150 m of the presence location of 2016.

Once I sighted a kangaroo rat during a survey, I made every effort to identify the kangaroo rat in the spotlight beam at <20 m, and occasionally, I captured individuals by hand. Distinguishing between TKR and the sympatric Ord's Kangaroo Rat (*D. ordii*) easily can be done by spotlight at a distance because the white-tipped tail of TKR is prominent, and, when in hand, they are distinguished by four (*D. elator*) versus five (*D. ordii*) toes on their hind feet. Once I identified the kangaroo rat to species, I recorded GPS coordinates for the point at which the kangaroo rat was first spotted and the number of individuals seen. If kangaroo rats were sighted within 50 m of each other, I recorded them as being at the same GPS point. If a definitive species identification was not possible, I recorded the GPS coordinates for the point and attempted a positive species identification by placing a motion sensitive camera at the site. On the day following the initial sighting, the camera was placed at the site overlooking a natural opening in the roadside habitat or at a burrow, if one was found. A birdseed and oats mixture was used as an attractant in front of the camera. I employed motion sensitive cameras for species verification because they can be checked at any time of day, can "capture" multiple individuals of various species. Motion sensitive camera traps have also been shown to have a higher success rate than Sherman traps when used to verify the presence of trap-shy species such as Gulf Coast Kangaroo Rat (*D. compactus*, Phillips 2012). I deployed cameras from 1–3 days depending on how long I remained in the surrounding survey area.

Initially I planned to survey for TKR using camera traps paired with Sherman traps subsequent to locating burrows during daytime roadside surveys. I employed this approach as the primary survey method throughout May and early June of 2016. This method was used to verify the presence of TKR at six sites, but the method proved time consuming and inefficient. Each trapping site required an initial survey to locate burrows, which I conducted from a slow-moving (<15 kph) vehicle. Once I located a probable active burrow, I returned to the site in the late afternoon to set one camera and three Sherman traps. I then visited the site the following morning to check Sherman traps and remove the camera.

Camera traps provided information on TKR intra- and inter-species interactions, TKR burrow usage and maintenance, burrow co-inhabitants and visitors, and predator visitation of burrowing sites. Although the information provided through camera trapping could provide further insight into TKR ecology, I relegated camera trapping to the sole purpose of species identification (verification) after June 2016. I determined that time and survey resources were better spent on covering more survey areas using spotlight surveying throughout the historical range of TKR.

Microhabitat Quantification

At sites with confirmed TKR sightings in 2016, I used the Daubenmire (1959) cover class technique to quantify microhabitat along the roadsides. Microhabitat was quantified for all 75 of the 2016 sightings. I spatially arranged the Daubenmire frames

(Fig. 2) such that 9 frames (in 3 rows of 3) were placed on each side of the road. I used 18 Daubenmire frames, if possible, at each location, with fewer being used if roadside width was <3 m. All Daubenmire frames were placed with the longer axis perpendicular to the road. Within each row, I placed a frame at the road edge, the private land boundary, and the midway point between them. I measured roadside margin width for each of the six rows of Daubenmire frames. For each Daubenmire frame I recorded percent cover of the following cover classes: grasses, forbs, standing dead vegetative material, litter, and bare ground. Within each frame, I measured heights of each of the tallest standing dead vegetative material, grass, and forb. If woody vegetation was present I assessed percent woody canopy cover over the Daubenmire frame by means of a spherical densiometer.

At each site, I used a laser range finder to determine the spatial proximity of trees (>3 m in height) and shrubs (0.5–3 m in height) relative to the original sighting point. I measured and identified the closest tree and shrub located on private property and on the publicly maintained roadside. Distances were grouped into six categories: <25 m, 26–50 m, 51–75 m, 76–100 m, 100–150 m, and >150 m. Woody plants were not identified if they were growing >150 m from the sighting point. I composed a list of dominant vegetative species for each side of the roadway at every sighting location. This list contained any standing dead vegetative material, grass, or forb species that made up a significant portion of its corresponding vegetation class. I included only plants that could be identified to genus or species level. Some newly emerged grasses and forbs or old standing dead species were not included because they could not be reliably identified.

Species designations for vegetation surveys followed the nomenclature of the Ladybird Johnson Wildflower Center.[3]

Landscape Scale Habitat Quantification

I conducted an examination of habitat characteristics of each positive TKR site from the 2016 survey season (ESRI 2013). The habitat analysis included soil and land-cover classes; I obtained soil classification data from the NRCS Web Soil Survey[4] and land-cover data from the TPWD Ecological Mapping System.[5] Using ArcGIS for each 2016 confirmed TKR point I created a circular buffer with a radius of 150 m centered on the latitude and longitude coordinates of the point where each TKR was first sighted (Fig. 3). Within each buffered area, I calculated percent composition of all soil and land-cover classes. Soil classification was divided into two categories: the soil type occupying the top 30 cm of soil and the soil type in the layer directly below. I analyzed the two layers separately. Soils were analyzed based on their structural components and not their county-specific title, as soil nomenclature is not consistent throughout the survey area.

To test whether soil and land-cover classes at positive TKR sites were different from sites where TKR were not found, I created a data set of 300 null points by randomly assigning points along the 2016 survey routes. Null points were selected from areas without positive TKR sightings and at least 1 km from positive points. I created buffers

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[3] Lady Bird Johnson Wildflower Center. "Find Plants." University of Texas at Austin. Accessed 4 October 2017. https://www.wildflower.org/plants-main.
[4] Natural Resource Conservation Service. "Web Soil Survey." United States Department of Agriculture. Accessed 15 April 2016. https://websoilsurvey.sc.egov.usda.gov/.
[5] Landscape Ecology Program. "Ecological Mapping Systems." Texas Parks and Wildlife. Accessed 18 April 2016. https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/.

for these null points and recorded percent composition for the same variables as for the TKR positive points.

In these GIS analyses, some similar land-cover classes were combined to reduce the overall number of land-cover classes used for testing between null and positive points. I combined the land-cover classes of mixed grass and shortgrass prairie, mesquite shrubland and mesquite forest, deciduous shrubland and deciduous forest, urban high and low intensity, marshes and open water, all riparian land-cover classes, and all floodplain land-cover classes. I did not combine any soil classes as they were less numerous and each class was well represented within the survey area.

To test for differences between TKR presence points and null points (presumably absence points), I conducted a two-group randomization test for each of the three data categories: land-cover class, soil top-layer class, and soil bottom-layer class. The two-group randomization involved pooling all presence points and null points and then randomly assigning these points to either the presence (n=75) or null (n=300) dataset. The difference in mean cover percentages (for a given variable) was then determined between these datasets. This process was repeated 10,000 timesin order to produce a null distribution of differences in mean percent cover. The observed percent difference was then compared to this distribution to determine if the observed difference was significantly large as indicated by the proportion of the null distribution that has a greater percent difference; this proportion is essentially a p-value indicating whether a difference greater than the observed could have been obtained by chance alone.

I did not use the 2017 positive sites in this analysis because the survey routes overlapped 2016 survey routes and many TKR presence sites were at the same locations for both years (we thereby avoided spatial pseudo-replication).

III. RESULTS

Roadside Presence Survey

Over the course of the summer field season of 2016 I recorded 75 positive TKR locations among 5 of the 11 counties surveyed. There were 96 TKR individuals found among these 75 positive points, with a maximum of 4 individuals at a single point. During the summer field season of 2017 I recorded 63 positive TKR locations and 78 individuals, with 3 being the most individuals at one site. All 2016 and 2017 sightings came from the same five counties despite in 2017 surveying new areas throughout the 11-county survey area in 2017 (Fig. 4). During the 2017 resurveying of 2016 sites, I confirmed 19 positive re-sightings for TKR presence (Table 1).

During the 2016 field season I verified TKR presence at 69 sites during roadside spotlight surveys and 6 sites by means of motion sensitive cameras. During the 2017 field season, I exclusively surveyed using the spotlight survey method. Over the course of the 2016 season, I surveyed, in total, 2,370.6 km of roadside within the 11-county survey area. During the summer 2017 field season, I surveyed, in total, 1348.3 km within the 11-county area. In 2017 I surveyed 491.5 km on the same survey routes as 2016; the remaining 856.8 km were surveyed on new survey routes (Fig. 5, Table 2). During the 2017 survey season, 25 of the 44 new TKR detections were on roadways that also had been surveyed in 2016. The 44 new positive TKR points of 2017 were found in close proximity to those of 2016; the greatest distance between a positive TKR point from 2017 and a 2016 point was 5.1 km.

During roadside surveys for TKR, I also observed and recorded *D. ordii* at 70 sites in 2016 and 52 sites in 2017 in 6 of the 11 counties of TKR historic range. Of the

2016 sightings, 11 were from motion sensitive camera trapping and 59 were from spotlight roadside surveys; all 2017 sightings were from roadside surveying.

Microhabitat Quantification

For 2016 TKR presence sites the mean roadside margin width was 6.3 ± 4.9 m (mean ± 1.96 standard deviation), with the narrowest road margin being 1 m and the widest 15 m. Based on overlap of 95% confidence intervals, I found no significant differences in the grass, forb, litter, standing dead vegetation, or bare ground Daubenmire categories among the roadside, mid-margin, and fencerow frame positions. When I compared the five Daubenmire classes of grass, forb, litter, standing dead vegetation, and bare ground, I found no significant differences among them. (Table 3).

Although I did not quantify road surface composition, the county road surface was unpaved in most instances, consisting of local earth or imported gravel surface. The road surface was not categorized using the Daubenmire method as it is always composed of open ground and was the same at all sites. During direct TKR observations, I observed that the road surfaces provided an open area for foraging, dustbathing, and movement adjacent to areas of roadside that the TKR were not directly using.

There were no significant differences in height of tallest grass, forb, and standing dead among roadside, mid-margin, and fencerow Daubenmire positions. I found no significant differences in height among the three vegetation types (Table 4).

Spherical densitometer readings of woody canopy cover at each Daubenmire frame averaged <1%. The distance from the sighting point to nearest shrub and to nearest tree along the roadside right-of-way was over 150 m in 69% and 75% percent of sites, respectively. The remainder of shrub and tree distances were relatively evenly split among the distance classes of >25m, 26–50m, 51–75m, 76–100m, and 100–150m on the roadside rights-of-way (Table 5). Shrubs and trees on private property were located >150 m from the sighting point in 51% and 59% of the sites, respectively. On private property, shrubs were found within 25 m of the sighting point 25% of the time whereas trees were within this range at 15% of sites (Table 5). Woody plants occurring at TKR presence sites included honey mesquite, sugarleaf hackberry (*Celtis laevigata*), lotebush (*Ziziphus obtusifolia*), western soapberry (*Sapindus saponaria*), and eastern red cedar (*Juniperus virginiana*) (Table 6).

The most abundant of the 31grass species at TKR presence sites was the perennial nonnative Johnson grass (*Sorghum halepense*). The annual native red sprangletop (*Leptochloa panicea*) was the second-most abundant. Most of the remaining grass species detected were native perennials. Domestic crop species occasionally were detcected growing opportunistically in roadside rights-of-way (Table 7). Forb species I recorded included 39 species from 14 families, with the families Amaranthaceae, Asteraceae, and Euphorbiaceae having the greatest diversity and prevalence. Most forbs I detected were annual natives, although some sites were dominated by annual nonnatives (Table 8). Standing dead plant species were a mix of grasses and forbs with 46 species from 10 families. Grass species I detected as standing dead vegetation were often cool-season grasses that had already completed their lifecycle by the time surveys started in May 2016. Some species detected as standing dead vegetation were found living at some sites, leading to these species being included in either the grass or forb species list as well as the standing dead vegetation list. The forb families Amaranthaceae and Asteraceae and the grass family Poaceae were the most diverse and prevalent standing dead plant families among sites (Table 9).

Habitat Quantification

I found significant differences between the 2016 positive TKR points and null points for land-cover class, soil top-layer class, and soil bottom-layer class. Land-cover classes that appeared to be “selected” by TKR included mixed grass/shortgrass prairie and domestic row crops. Land-cover classes that were used less than would be expected (based on availability) were mixed grass sandy prairie, mesquite shrubland/woodland, deciduous shrubland/woodland, and Conservation Reserve Program (CRP)/other improved grasslands (Table 10).

Analysis of soil types showed significant differences in soil types present in both the upper layer and lower layer between TKR points and null points. Soil classes that were “selected” (used more than expected) included clay loam and loam on the upper layer and clay in the lower layer. Soils that were presumably avoided (used less than expected) in the upper layer were sand and soils with shallow restrictive features and sandy loam in the lower layer. Soils that were neither selected or avoided were deemed opportunistically used soils (Table 11).

Viable Habitat Model

Based upon the results of the 2016 survey, I created a viable habitat map for TKR by determining where selected land-cover classes overlapped with selected soil classes. The land-cover classes of mixed grass/shortgrass prairie and row crops were combined into a single class of selected land-cover. The upper and lower soil level combinations were classified into three composite classes based on selection by TKR. The composite class 1 includes soil types in which both the upper and lower layers were selected by TKR, composite class 2 contains soils with only the upper layer selected and the lower layer used opportunistically, and composite class 3 contains soils with only the lower layer selected and the upper layer opportunistically used. I constructed the model as three habitat classes based on which composite soil class was overlapping the selected land-cover class.

The viable habitat model based on these three habitat classes accounted for 71.3% of the buffered area around the 2016 positive TKR points and constituted 23% of the 11-county survey area. I examined further the remaining 28.7% of buffered area surrounding the 2016 positive TKR points that did not belong to any of the three habitat classes. I determined that selected land-cover classes with sandy loam as the top soil layer and either sandy loam or clay loam as the bottom soil layer accounted for 9.7% of the buffered area surrounding the 2016 positive TKR points but constituted only 5.9% of the total survey area. Thus, TKR used these soil combinations at a frequency slightly greater than availability, and so I incorporated this combination of selected land-cover classes and opportunistically used soils into the habitat model. This addition allowed the model to account for 81% of the buffered area surrounding the 2016 positive TKR points and 28.9% of the 11-county historical range as potential habitat (Fig. 6). The remaining non-modeled 19% of buffered area surrounding 2016 positive TKR points was composed of many different land-cover classes and composite soil classes, none of which accounted for a percentage of the buffered area around presence points larger than their percent occurrence in the 11-county survey area.

I analyzed the 2017 positive TKR points in the same fashion as the 2016 survey positive TKR points to determine if the potential habitat model fit these points as well. Of the 2017 positive TKR points, 91.7% of the buffered area was included in the modeled habitat (Table 12). I did not find any positive TKR points from 2016 or 2017 with the majority of their buffered area consisting of land-cover or soil classes not included in the viable habitat model.

Habitat overlap between TKR and *D. ordii* was minimal and occurred in only one habitat class, selected land-cover overlapping the opportunistically used composite soil class (Fig. 7). I also found *D. ordii* within habitat not modeled for TKR.

IV. DISCUSSION

Roadside Presence Survey

During the 2017 field season, all positive TKR points were found in areas of modeled habitat based upon the TKR detections of 2016. My repeat detection rate (19 out of 75 sites) between 2016 and 2017 indicates that roadside surveys are a viable method for detecting TKR presence. That no detections in 2017 were made more than 5.1 km away from 2016 detections would suggest that this species is absent over much of the surveyed area. In addition, counties where TKR were not detected by my surveys match the findings of previous studies except for Archer and Motley Counties, which had positive detections in surveys by Martin (2002) in 1996–2000. Martin's sites were resurveyed by Nelson in the late 2000s, and no sightings were made in either county (Nelson et al. 2013). Much of the new survey area that I surveyed in 2017 was potential habitat, but the additional surveyed area did not lead to additional detections, even within counties with known presence. While consistently detecting TKR at and near positive 2016 TKR points, the lack of sightings in 2017 in new TKR habitat and new counties may indicate that the species is absent over much of its former range but remains locally abundant in a few areas of viable habitat.

Microhabitat Quantification

Plant communities found at TKR locations contained a variety of native, invasive, and domestic crop species. Previous dietary studies on TKR have shown that larger grass seeds are preferred, and two larger seed producing species, the nonnative Johnson grass and domestic wheat (*Triticum aestivum*), were common at the TKR presence locations

(Chapman 1972). Johnson grass thrives in disturbed habitat such as roadsides and was the most prevalent grass among sites. The standing dead stalks of domestic wheat were common on roadsides adjacent to cropland, and fallow wheat fields made up most of the cropland on private property adjacent to presence points. Texas Kangaroo Rats were detected at some points where the only nearby vegetation was wheat growing on private property; the roadside had been disked and/or treated with herbicide.

The roadside habitat in which I found TKR was highly variable among and within sites. This is reflected in the large confidence intervals of all Daubenmire cover classes and plant height means. This lack of difference between tested groups likely is attributable to a mix of factors resulting from the nature of roadside sampling itself. Once I sighted a TKR, its initial location was used as the GPS point, and the microhabitat analysis was based on this point. Sampling of the microhabitat surrounding the TKR presence points may not accurately reflect the microhabitat actually used by TKR as I did not observe how TKR were using that microhabitat.

Most sightings were adjacent to cropland or cattle pastures in active use. Roadside habitat was often markedly different from and had greater heterogeneity than adjacent private property, and TKR presence and activity in some of these settings seemed to be limited to public roadsides. Owing to restricted access, I was unable to examine microhabitat on adjacent private property that might be used by TKR. I observed TKR foraging and having intraspecific interactions on unpaved road surfaces, which provided bare ground in areas directly adjacent to heavily vegetated roadsides. At other sites, roadside habitat was densely vegetated but the grassland immediately adjacent on private land was sparse with ample bare ground for TKR use. At some sites, roadside and private property habitat were heavily vegetated except for the fence line, which was kept open (clear) by grazing and hoof action from cattle. At such sites, TKR tracks and runs were seen paralleling the fence and roadside. Human disturbances, such as mowing, disking, and maintenance of gate entrances, provided areas of bare ground and sparse grass and forbs that were surrounded by heavily vegetated, unmanaged roadside at many positive TKR points. Determining finer-scale microhabitat utilization by TKR along roadsides is needed to assess which roadside microhabitat features promote TKR presence and whether roadside habitat adjacent to cropland is used differently from roadsides adjacent to pastureland.

Although roadside habitat often did not match previous descriptions of TKR habitat, I detected no TKR in areas where domestic row crop fields extended to the road margins. This suggests that roadside margins are beneficial to TKR in areas of agricultural use. Upon their release at the roadside on two occasions, I observed TKR running down internal fence lines that separated crop fields on private property.

I did not find a close association between TKR presence and mesquite trees or shrubs as has been previously noted. Many sites did not have trees within the view shed, and most sites did not have a woody plant within 150 m of the positive TKR point. Although woody vegetation was not present at most sites, woody structures in the form of fence posts and/or telephone poles were present at the majority of sites. These structures were occasionally associated with burrow openings.

Burrow quantification was not an objective of this study, but I encountered roadside burrows, often when the sighted TKR ran back to them during spotlight surveys. Burrows were made in a variety of microhabitats in the roadside margin, with bare slopes, bare level ground, bases of bunch grasses, shrub bases, fence posts, brush piles, burrow kick out from larger mammals, and disked ground all being used.

Habitat Quantification

The habitat analysis for TKR provided evidence that the species selects for mixed grass and short grass prairie, as would be expected based on previous habitat association studies. However, mixed grass sandy prairie, gypsum-breaks grassland, Conservation Reserve Program (CRP) land, improved grassland, and savannah grassland were not selected by TKR even though these habitat types are relatively open with little or no canopy. Mixed grass sandy prairie and breaks grassland likely are not selected because of the soils that underlie these grasslands, which are sand based and possess restrictive features, respectively. Other grasslands that are not selected, CRP land, improved grassland, and savannah grassland, might not be used because of the dense nature of the ground-level vegetation of these grasslands. Furthermore, savannah grassland does not occur within counties in which TKR was detected in this survey.

The selection by TKR for cropland was not expected and may be an unintended effect of roadside surveying. Many areas of cropland contain narrow margins of grasses, forbs, and bare ground at the roadside, and it was in these margins and the adjacent roadway that TKR were observed. Research on the Stephen's Kangaroo Rat (*Dipodomys stephensi*) has shown that domestic crop field edge likely is utilized for foraging and occasionally burrowing, but crop field interior is not used when crops are standing (Price and Endo 1989). Spillage from domestic grain crops likely provides an abundant food source for TKR, facilitating their ability to survive on the margin of domestic crop fields if the tilled fields do not extend to the road edge.

The selection by TKR for clay loam and loam soils in the upper soil layer was expected based upon previous analyses of soil types present at TKR presence locations. The lack of use of clay soils on the upper layer was not expected but may result from the hard nature of high clay content soils, which likely inhibits burrowing.

Viable Habitat Model

The viable habitat model provides a representation of where viable habitat may exist, but further on-the-ground surveys would be needed to verify if a specific area or location truly contains viable habitat. This is particularly true for domestic crop fields, as crop field edges are likely the only part of a crop field that promotes TKR habitation, even though the habitat area predicted from the model may sometimes include entire monoculture fields. In this regard, the model overestimates viable TKR habitat as crop field edges make up a small proportion of cropland and, as previously stated, TKR likely does not use the vast interior of crop fields. Mixed grass prairie is also a very inclusive, non-specific land-cover classification, with everything from areas of mostly bare ground with sparse, short bunch grasses to areas of dense Johnson grass mixed with large forbs and a minimum of bare ground. In addition, plant composition of these fields can change over short time spans resulting from changes in cattle stocking rates and rotation, mechanical clearing, and rainfall variation among years. These factors can affect when and where viable habitat with sufficient bare ground for TKR exists within the mixed grass prairie land-cover class. For these reasons, the viable habitat model should be used to determine where on-the-ground surveys for viable habitat and TKR presence should be conducted and should not be interpreted as a model for currently viable/occupied habitat. After all, very few species saturate all their available habitat.

Another inherent limitation of the model is that it is based on static land-cover data even though the landscape is dynamic. That is, land-cover class designation can change over time, in some cases short time periods. Some of the mixed grass prairie pastures encountered had small mesquite shrubs, which given time and lack of brush control will change from pasture into a mesquite shrubland and eventually mesquite woodland. This change will impact its value as TKR habitat and remove viable habitat from the model. In a similar fashion, mesquite pastureland in which mesquite is chemically or mechanically removed would add viable habitat to the model as the land returns to a mixed grass prairie land-cover designation. For this reason, this model should be updated whenever a new land-cover dataset is released by TPWD, so the model can reflect more accurately on-the-ground conditions.

TABLES

Table 1. Texas Kangaroo Rat detections during roadside surveys in each county during the 2016 and 2017 seasons and sites with presence detected both seasons.

County	**2016 Presence Points**	**2017 Presence Points**	**Presence Detected 2016 and 2017**
Archer	0	0	0
Baylor	0	0	0
Childress	3	5	2
Clay	0	0	0
Cottle	17	15	5
Foard	0	0	0
Hardeman	11	11	3
Montague	0	0	0
Motley	0	0	0
Wichita	26	4	3
Wilbarger	18	28	6
Total	**75**	**63**	**19**

Table 2. Kilometers surveyed in each county in 2016, new road kilometers surveyed in 2017, and kilometers surveyed during both years in roadside surveys for presence of Texas Kangaroo Rat.

County	**2016 Road Survey**	**2017 New Road Survey**	**2017 Repeated Road Survey**
Archer	213.9	97.5	5.3
Baylor	154.2	90.6	0
Childress	248.0	54.2	55.0
Clay	140.5	55.7	1.0
Cottle	222.6	48.6	84.3
Foard	138.7	91.7	22.2
Hardeman	299.2	115.7	90.6
Montague	100.1	53.1	1.0
Motley	141.8	49.1	63.4
Wichita	272.6	105.1	74.7
Wilbarger	439.0	95.4	93.0
Survey Total	2370.6	856.8	491.5

Table 3. Daubenmire class microhabitat analysis summary. Percentages are derived from Daubenmire cover class data. Values include the mean ± 1.96 standard deviations.

Cover Class	Roadside	Mid-margin	Fencerow	Average
Grass	17.9 ± 45.5	27.2 ± 59.2	26.1 ± 60.9	23.6 ± 56.1
Forb	14.2 ± 33.4	11.5 ± 28.5	7.9 ± 23.5	11.3 ± 29.3
Litter	17.4 ± 42.8	14.4 ± 36.8	7.6 ± 24.8	13.2 ± 36.6
Standing Dead	16.5 ± 35.8	13.7 ± 33.0	7.9 ± 21.9	12.7 ± 31.7
Bare Ground	30.0 ± 67.5	32.4 ± 68.7	52.4 ± 75.8	38.2 ± 73.4

Table 4. Vegetation height microhabitat analysis summary. Values are in centimeters. The height value is the mean ± 1.96 standard deviations.

Vegetation Type	Roadside	Mid-margin	Fencerow	Average
Grass	27.8 ± 69.9	32.9 ± 70.4	23.4 ± 60.2	28.0 ± 67.3
Forb	29.3 ± 74.1	23.8 ± 66.6	11.5 ± 42.5	21.6 ± 64.3
Standing Dead	30.9 ± 59.2	25.1 ± 56.5	15.0 ± 39.1	23.8 ± 53.9

Table 5. Woody plant distances from Texas Kangaroo Rat sighting locations. Distance is measured in meters.

Category	<25m	26-50m	51-75m	76-100m	100-150m	>150m
Roadside Shrub	11%	8%	5%	3%	4%	69%
Roadside Tree	8%	5%	3%	7%	2%	75%
Private Property Shrub	25%	12%	8%	0%	4%	51%
Private Property Tree	15%	9%	7%	4%	6%	59%

Table 6. Woody plant species found at Texas Kangaroo Rat presence sites. Percentages do not add to 100% as species identification was not made at distances of >150m.

Species	Scientific Name	Roadside Shrub	Roadside Tree	Private Property Shrub	Private Property Tree
Honey Mesquite	*Prosopis glandulosa*	25%	18%	44%	37%
Sugarleaf Hackberry	*Celtis laevigata*	1%	5%	0%	1%
Lotebush	*Ziziphus obtusifolia*	5%	0%	4%	0%
Western Soapberry	*Sapindus saponaria*	0%	1%	1%	3%
Eastern Red Cedar	*Juniperus virginiana*	0%	1%	0%	0%

Table 7. Grass species prevalence at Texas Kangaroo Rat presence sites.

Common Name	**Scientific Name**	**Percent of Sites Present**
Johnson Grass	*Sorghum halapense*	64
Red Sprangletop	*Leptochloa panicea*	54.7
Bermuda Grass	*Cynodon dactylon*	34.7
Stinkgrass	*Eragrostis cilianensis*	28
Common Witchgrass	*Panicum capillare*	28
Silver Bluestem	*Bothriochloa laguroides*	18.7
White Tridens	*Tridens albescens*	18.7
Sand Dropseed	*Sporobolus cryptandrus*	16
Tumblegrass	*Schedonnardus paniculatus*	13.3
King Ranch Bluestem	*Bothriochloa ischaemum*	12
Common Sandbur	*Cenchrus spinifex*	12
Tumble Windmill Grass	*Chloris verticillata*	12
Mediterreanean Lovegrass	*Eragrostis barreleri*	12
Vine Mesquite	*Panicum obtusum*	10.7
Sideoats Grama	*Bouteloua curtipendula*	9.3
Purple Threeawn	*Aristida purpea*	5.3
Jungle Rice	*Echinochloa colona*	5.3
Western Wheatgrass	*Pascopyrum smithii*	5.3
Buffalograss	*Buchloe dactyloides*	4
Plains Lovegrass	*Eragrostis intermedia*	4
Texas Grama	*Bouteloua rigideseta*	2.7
Hooded Windmill Grass	*Chloris cucullata*	2.7
Finger Feathergrass	*Chloris virgata*	2.7
Southwest Cupgrass	*Eriochloa acuminata*	2.7
Hairy Woollygrass	*Erioneuron pilosum*	2.7
Cane Blustem	*Bothriochloa barbinodies*	1.3
Rescue Grass	*Ceratochloa cathartica*	1.3
Grain Sorgum	*Sorghum bicolor*	1.3
Sudangrass	*Sorghum x drummondii*	1.3
Corn	*Zea mays*	1.3

Table 8. Forb species prevalence at Texas Kangaroo Rat presence sites.

Common Name	**Scientific Name**	**Family**	**Percent of Sites Present**
Horseweed	*Conyza canadensis*	Asteraceae	58.7
Spurge	*Chamaesyce sp.*	Euphorbiaceae	56
Pigweed	*Amaranthus palmeri*	Amaranthaceae	37.3
Western Ragweed	*Ambrosia psilostachya*	Asteraceae	26.7
Russian Thistle	*Salsola sp.*	Amaranthaceae	24
Silverleaf Nightshade	*Solanum elaeagnifolium*	Solanaceae	22.7
Kochia	*Bassia scoparia*	Amaranthaceae	17.3
Prarie Broomweed	*Amphiachyris dracunculoides*	Asteraceae	17.3
Common Sunflower	*Helianthus annuus*	Asteraceae	16
Velvetleaf Gaura	*Oenothera curtiflora*	Onagraceae	16
Indian Rushpea	*Hoffmannseggia glauca*	Fabaceae	13.3
Saw-leaf Daisy	*Grindelia papposa*	Asteraceae	10.7
Devils Claw	*Proboscidea louisiana*	Pedaliaceae	8
Yellow Wood Sorrel	*Oxalis stricta*	Oxalidaceae	6.7
Carolina Horsenettle	*Solanum carolinense*	Solanaceae	6.7
Buffalo Bur	*Solanum rostratum*	Solanaceae	6.7
Purple Bindweed	*Ipomoea cordatotriloba*	Convolvulaceae	5.3
Sow Thistle	*Sonchus sp.*	Asteraceae	4
Buffalo gourd	*Cucurbita foetidissima*	Cucurbitaceae	4
Velvet Bundle flower	*Desmanthus velutinus*	Fabaceae	4
Ground Cherry	*Physalis sp.*	Solanaceae	4
Prarie Sunflower	*Helianthus petiolaris*	Asteraceae	2.7
Texas Bindweed	*Convulvus equitans*	Convolvulaceae	2.7
Prarie Tea	*Croton monanthogynus*	Euphorbiaceae	2.7
Wild Poisnettia	*Euphorbia cyathophora*	Euphorbiaceae	2.7
Evening Primrose	*Oenothera sp.*	Onagraceae	2.7
Lambsquarters	*Chenopodium sp.*	Amaranthaceae	1.3
Giant Ragweed	*Ambrosia trifida*	Asteraceae	1.3
Burdock	*Arctium sp.*	Asteraceae	1.3
Mexican sagewort	*Atemisia ludoviciana*	Asteraceae	1.3
Firewheel	*Gaillardia pulchella*	Asteraceae	1.3
Gray Gold Aster	*Heterotheca canescens*	Asteraceae	1.3
Camphor Weed	*Heterotheca subaxillaris*	Asteraceae	1.3
Marsh Fleabane	*Pluchea odorata*	Asteraceae	1.3
Texas Sleepy Daisy	*Xanthisma texanum*	Asteraceae	1.3
Sand Bells	*Nama hispidum*	Hydrophyllaceae	1.3
Skullcap	*Scutellaria sp.*	Lamiaceae	1.3
Prickly Poppy	*Argemonbe albiflora*	Papaveraceae	1.3
Purselane	*Portulaca oleracea*	Portulacacae	1.3

Table 9. Standing dead vegetation prevalence at Texas Kangaroo Rat presence sites.

Common Name	**Scientific Name**	**Family**	**Percent of Sites Present**
Brome	*Bromus sp.*	Poaceae	64
Horseweed	*Conyza canadensis*	Asteraceae	26.7
Southern Peppergrass	*Lepidium austrinum*	Brassicaceae	26.7
Wheat	*Triticum aestivum*	Poaceae	26.7
Johnson Grass	*Sorghum halapense*	Poaceae	24
Red Sprangletop	*Leptochloa panicea*	Poaceae	21.3
Russian Thistle	*Salsola sp.*	Amaranthaceae	18.7
Rescue Grass	*Ceratochloa cathartica*	Poaceae	18.7
Prarie Broomweed	*Amphiachyris dracunculoides*	Asteraceae	17.3
Common Sunflower	*Helianthus annuus*	Asteraceae	14.7
Wild Oats	*Avenua fatua*	Poaceae	14.7
Bermuda Grass	*Cynodon dactylon*	Poaceae	12
Stinkgrass	*Eragrostis cilianensis*	Poaceae	12
Pigweed	*Amaranthus retroflexus*	Amaranthaceae	9.3
Little Barley	*Hordeum pusillum*	Poaceae	9.3
Thistle	*Cirsium sp.*	Asteraceae	8
Plantain	*Plantago sp.*	Plantaginaceae	8
Kochia	*Bassia scoparia*	Amaranthaceae	6.7
Tumblegrass	*Schedonnardus paniculatus*	Poaceae	6.7
Silverleaf Nightshade	*Solanum elaeagnifolium*	Solanaceae	6.7
Saw-leaf Daisy	*Grindelia papposa*	Asteraceae	5.3
Field Mustard sp.	*Brassica sp.*	Brassicaceae	5.3
Common Witchgrass	*Panicum capillare*	Poaceae	5.3
Jointed Goat Grass	*Aegilops cylindrica*	Poaceae	4
Sixweeks Grass	*Vulpia octoflora*	Poaceae	4
Firewheel	*Gaillardia pulchella*	Asteraceae	2.7
Sand Dropseed	*Sporobolus cryptandrus*	Poaceae	2.7
White Tridens	*Tridens albescens*	Poaceae	2.7
Carolina Horsenettle	*Solanum carolinense*	Solanaceae	2.7
Buffalo Bur	*Solanum rostratum*	Solanaceae	2.7
Lambsquarters	*Chenopodium sp.*	Amaranthaceae	1.3
Texas Parsley	*Polytaenia texana*	Apiaceae	1.3
Western Ragweed	*Ambrosia psilostachya*	Asteraceae	1.3
Plains Dozedaisy	*Aphanostephus ramosissimus*	Asteraceae	1.3
Basket-Flower	*Centaurea americana*	Asteraceae	1.3
Sow Thistle	*Sonchus sp.*	Asteraceae	1.3
Texas Sleepy Daisy	*Xanthisma texanum*	Asteraceae	1.3
Beebalm sp.	*Monarda sp.*	Lamiaceae	1.3
Velvetleaf Gaura	*Oenothera curtiflora*	Onagraceae	1.3
King Ranch Bluestem	*Bothriochloa ischaemum*	Poaceae	1.3
Sideoats Grama	*Bouteloua curtipendula*	Poaceae	1.3
Common Sandbur	*Cenchrus spinifex*	Poaceae	1.3
Tumble Windmill Grass	*Chloris verticillata*	Poaceae	1.3
Canada Wildrye	*Elymus canadensis*	Poaceae	1.3
Virginia Wildrye	*Elymus virginicus*	Poaceae	1.3
Plains Lovegrass	*Eragrostis intermedia*	Poaceae	1.3

Table 10. Soil class randomization test results between Texas Kangaroo Rat presence and null points. Positive % difference and a *p*-value less than 0.05 indicate a selected soil class.

Soil Class	Percent Difference	P-Value
Clay Loam Top layer	28.8	0.01
Clay Loam 2nd layer	-15.7	0.11
Loam Top Layer	36.7	0.01
Loam 2nd Layer	-53.1	0.14
Sandy Loam Top Layer	-16.9	0.25
Sandy Loam 2nd Layer	-61.1	0.03
Sand top layer	-99.9	<0.01
Sand 2nd layer	-74.5	0.63
Silt Loam top layer	-40.0	0.12
Silt loam 2nd layer	-96.0	0.64
Clay Top layer	-75.1	0.11
Clay 2nd layer	37.1	<0.01
Soils with water regime	-14.4	0.38
Soils with restrictive feature	-54.9	0.04

Table 11. Land-cover class randomization test results between Texas Kangaroo Rat presence and null points. Positive % difference and a *p*-value less than 0.1 indicate a selected vegetation class.

Vegetation Class	Percent Difference	P-Value
Row Crops	29.9	<0.01
Mixedgrass/Shortgrass Prairie	18.2	0.06
Mixedgrass Sandy Prairie	-99.6	<0.01
Mesquite Shrubland/ Woodland	-62.4	<0.01
Deciduous Shrubland/ Woodland	-97.8	<0.01
CRP/Other Improved Grasses	-99.1	0.02
Savanna Grassland	-99.4	0.06
Urban High/Low Intensity	-33.7	0.10
Riparian	-15.6	0.37
Floodplain	-22.8	0.29
Marsh/Water	-23.3	0.61
Barren	37.2	0.26
Breaks Grassland	-48.0	0.26
Juniper	-87.1	0.26

Table 12. Potential habitat model classes within survey area and encompassed within buffered area surrounding Texas Kangaroo Rat presence locations.

Model Class	Percent of 11 county area	Percent of 2016 buffered habitat	Percent of 2017 buffered habitat
Selected land-cover overlying selected soils in both layers	7.6	37.3	46.6
Selected land-cover overlying selected soils in the top layer	11.8	29.8	36.6
Selected land-cover overlying selected soils in the bottom layer	3.6	4.2	1.5
Selected land-cover overlying opportunistically used soils	5.9	9.7	7
Total Modeled Habitat	28.9	81	91.7

FIGURES

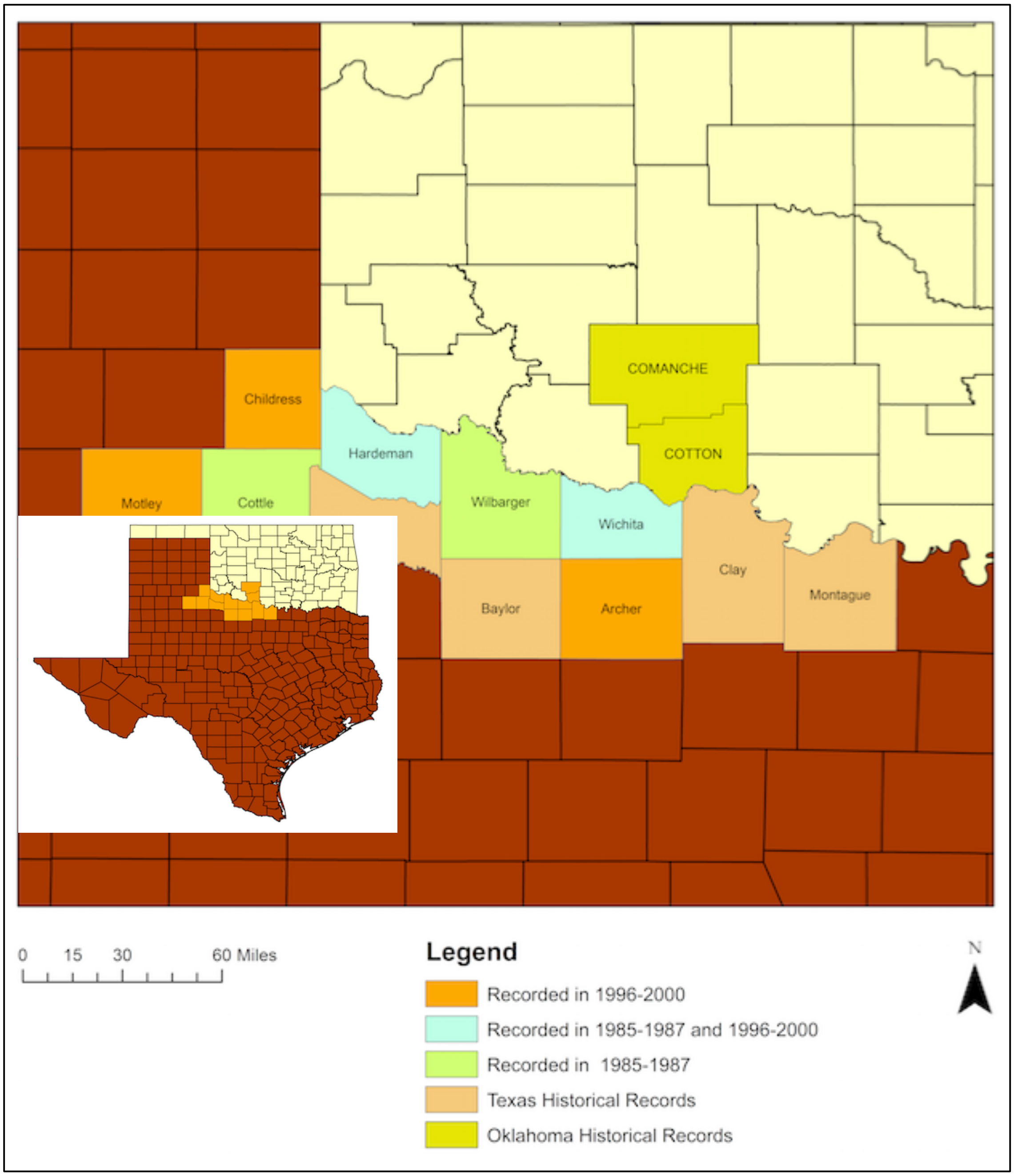


Figure 1. Historical Range of Texas Kangaroo Rat in Texas and Oklahoma and past range-wide survey success within Texas.

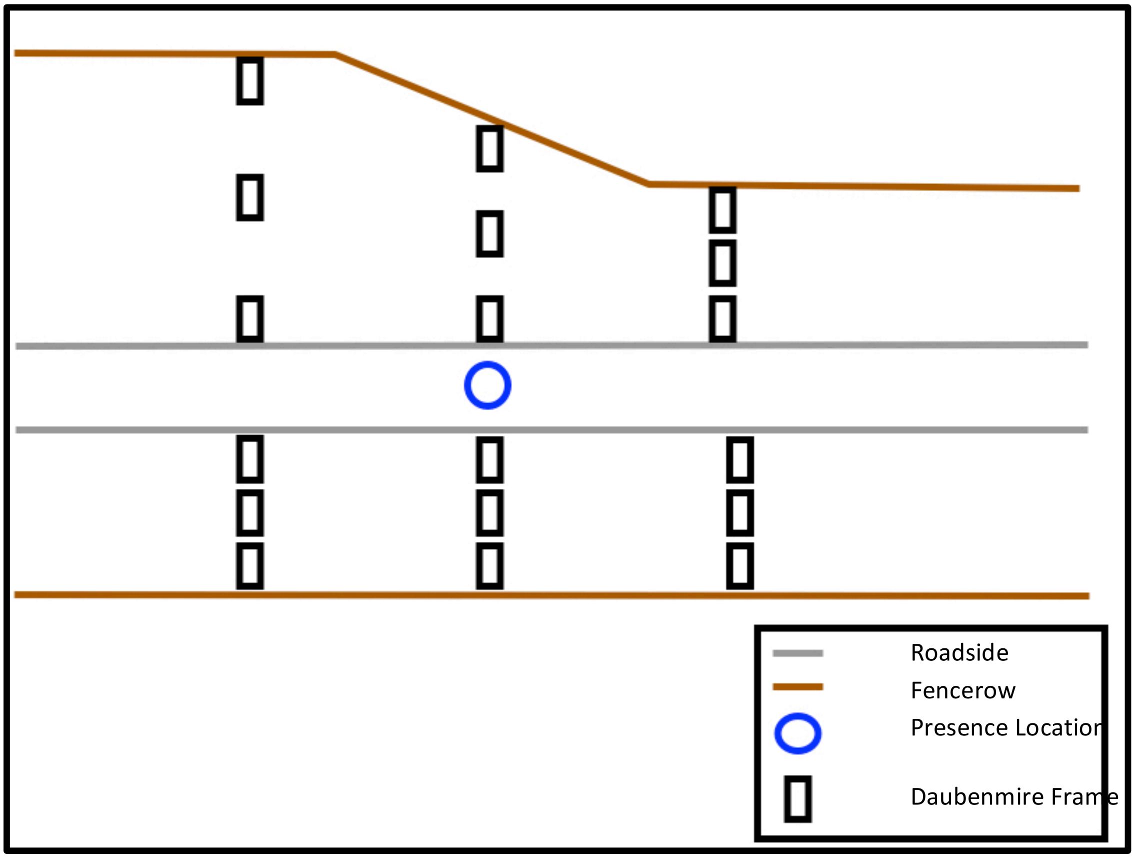


Figure 2. Roadside microhabitat survey design. Daubenmire frame rows are spaced with 5 m between rows.

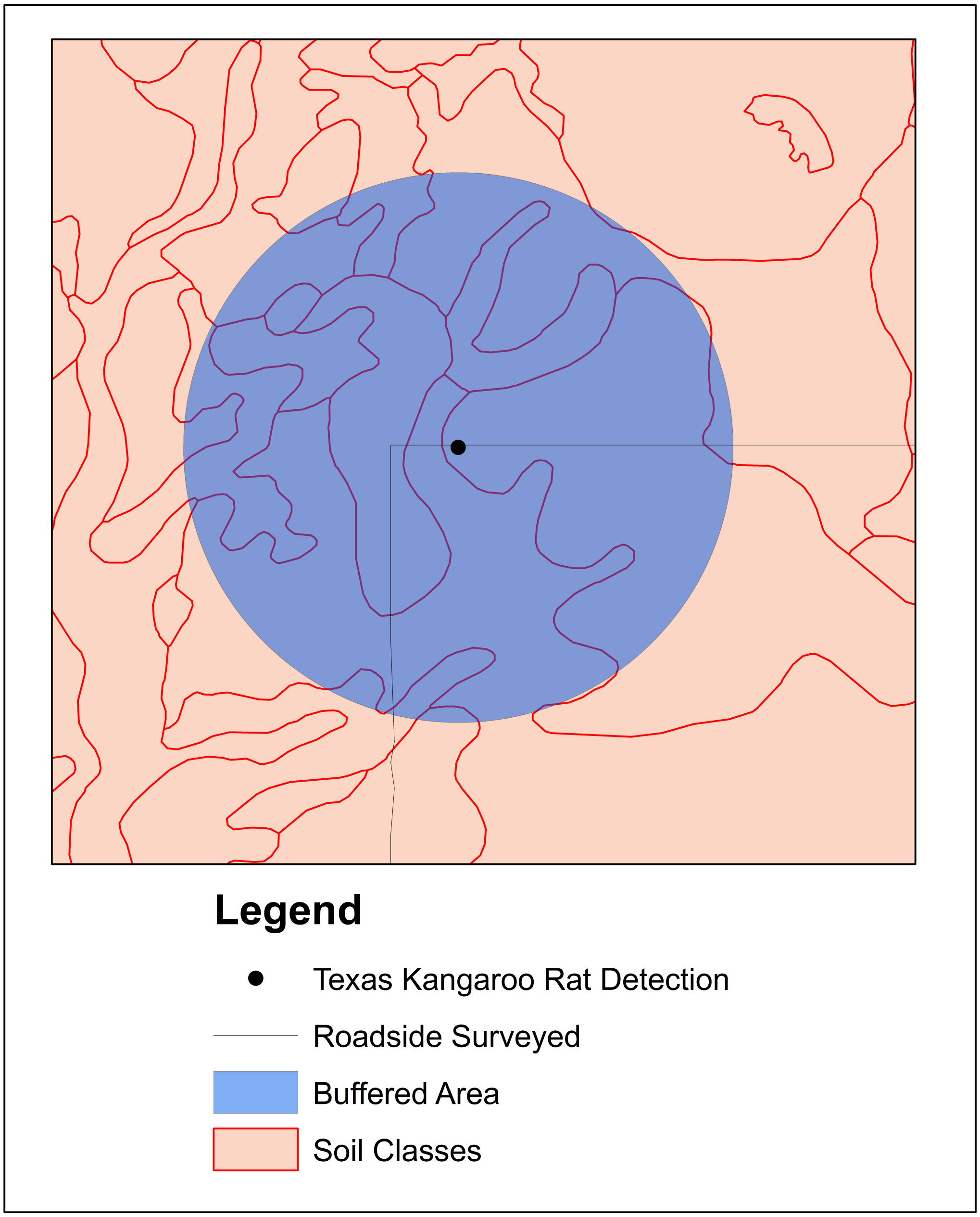


Figure 3. Presence point example showing buffered area overlying soil classes.

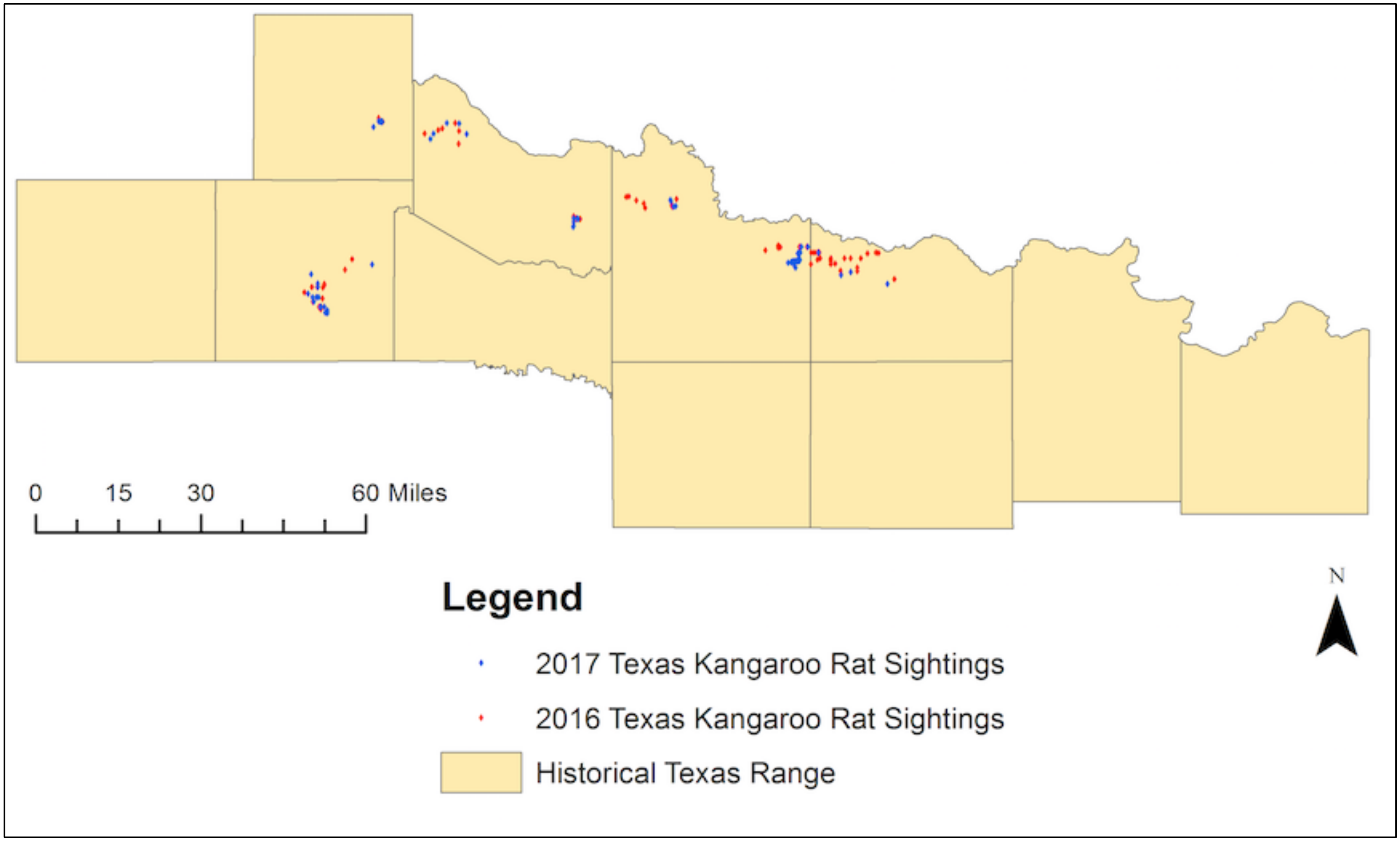


Figure 4. Presence locations for Texas Kangaroo Rat during the 2016 and 2017 survey seasons.

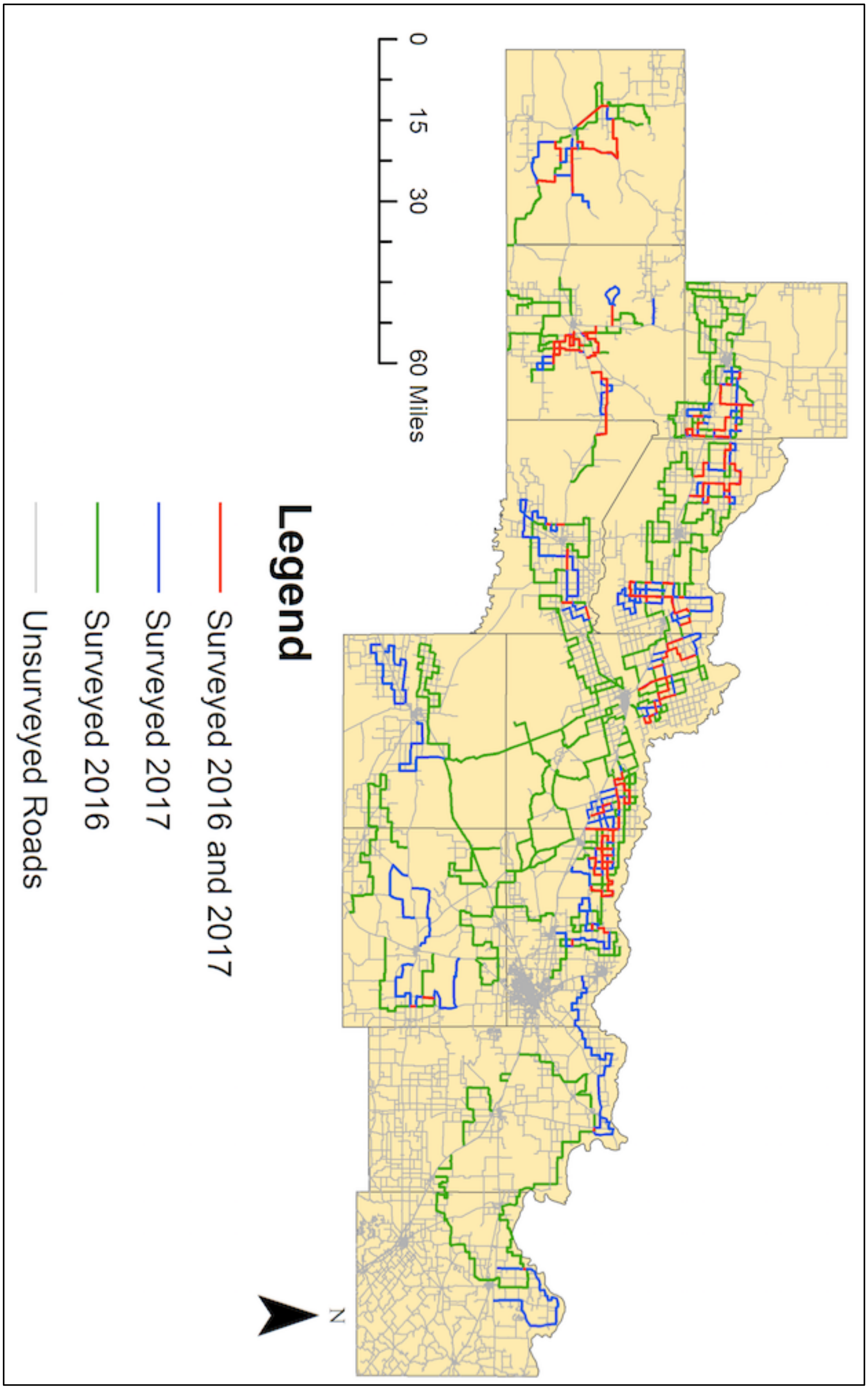


Figure 5. Roadside spotlight survey routes during the 2016 and 2017 survey seasons.

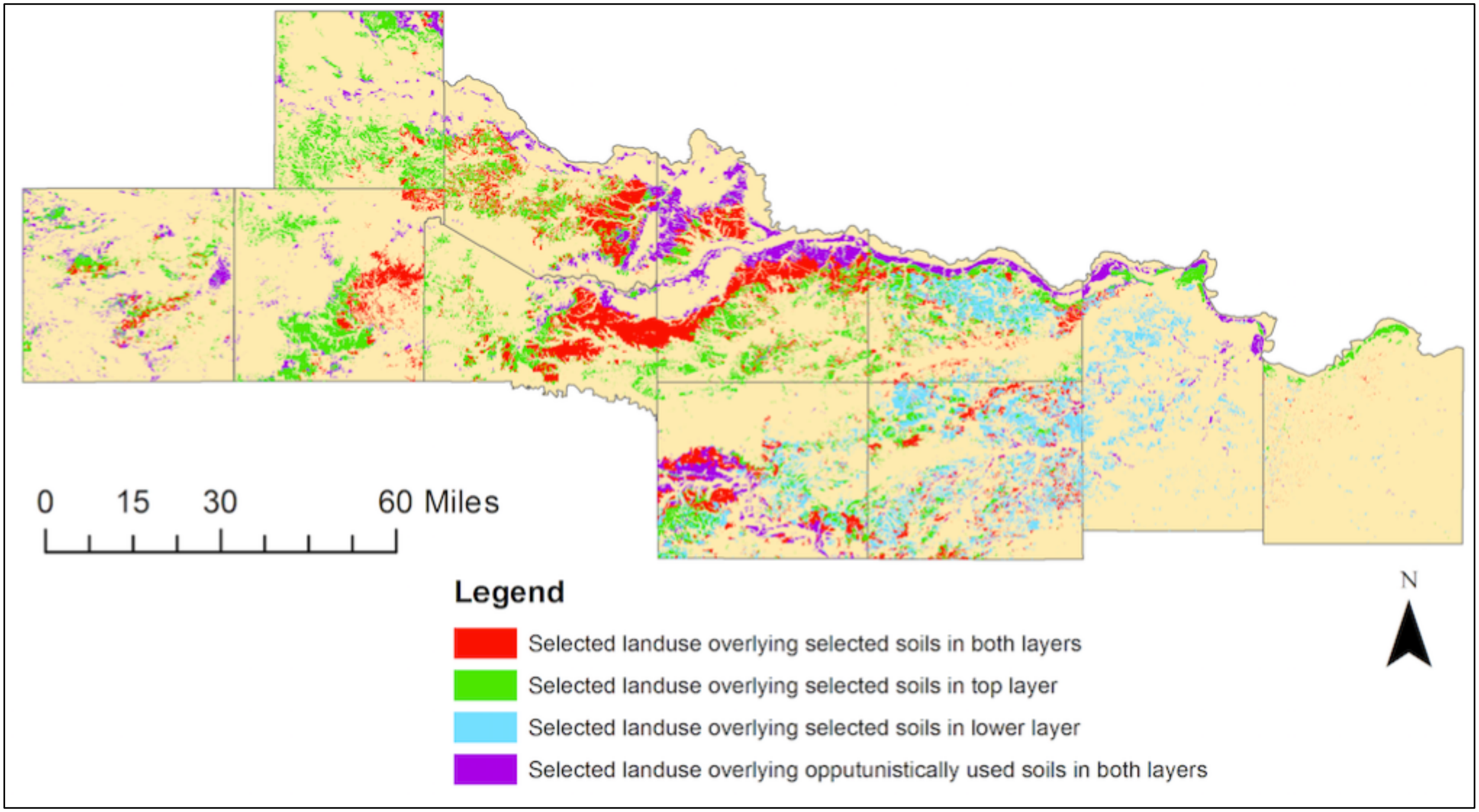
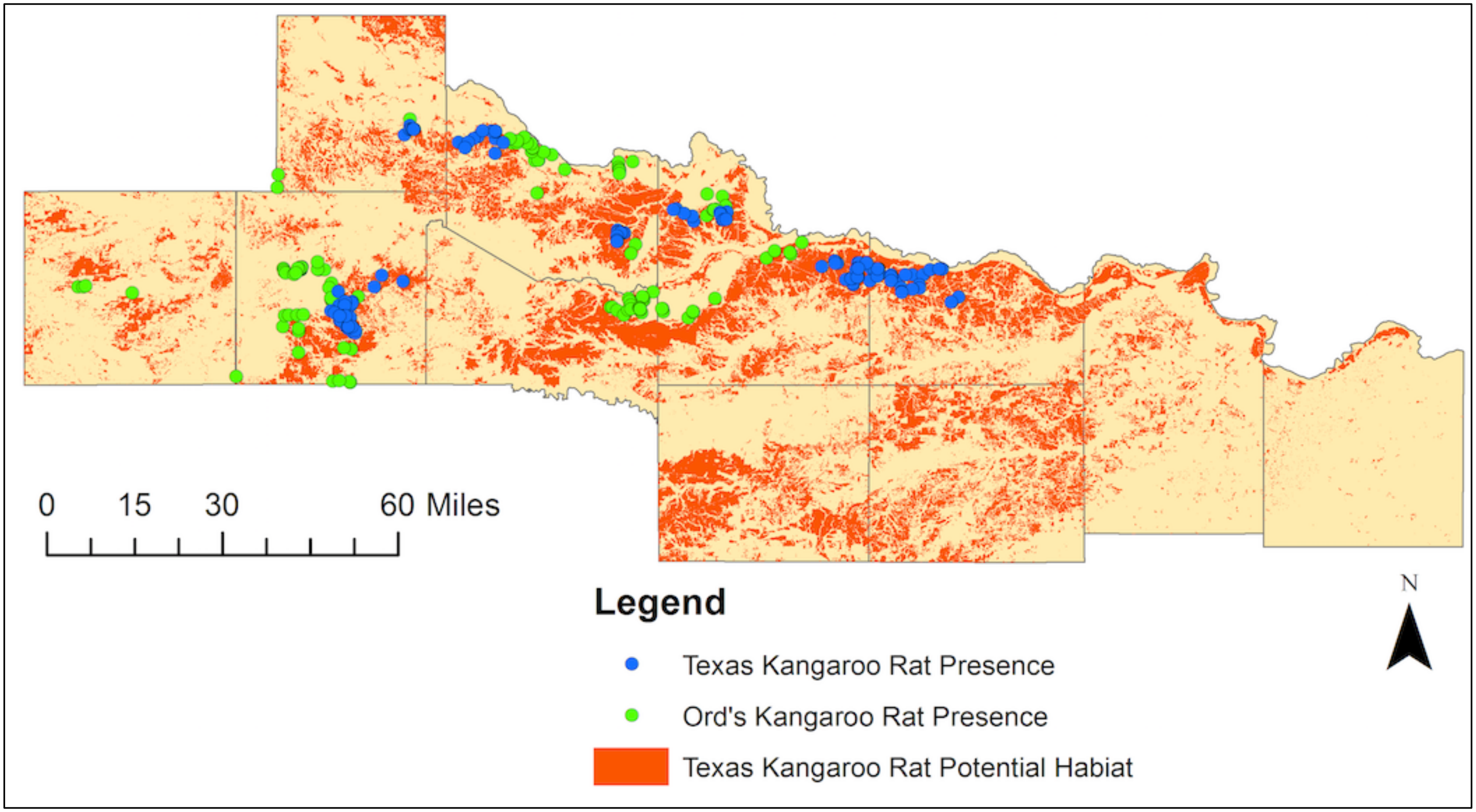


Figure 6. Viable habitat model for Texas Kangaroo Rat.



Texas and Ord’s Kangaroo Rat sightings overlying Texas Kangaroo Rat viable habitat model. Observations for 2016 and 2017 are combined for each species model. Observations for 2016 and 2017 are combined for each species.

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