Mapping Potential Habitat and Range-Wide Surveying for the Texas Kangaroo Rat

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Abstract

The Texas kangaroo rat *Dipodomys elator* is considered a species of conservation concern by state and federal agencies. There have been a limited number of sightings in only seven counties in northern Texas during the past 30 y. The apparent decline of the species has been attributed to habitat loss due to increasing conversion of natural areas into cropland. The magnitude and exact cause of the decline are difficult to determine because of insufficient data on the distribution of the species and its habitat within its relatively small geographic range. Habitat studies have focused on the microhabitat of burrows rather than a coarser-scale identification of habitat and its distribution within the species' historic range. Multiple species of *Dipodomys* have demonstrated strong associations with certain soil and land-cover types. Therefore our goal was to develop a range-wide map of potential habitat on the basis of the association of *D. elator* with specific soil and land-cover types. We used the map to guide roadside surveys and also updated the map with information on *D. elator* distribution obtained during the surveys. Over the course of two summers (2016 and 2017) we documented *D. elator* at 138 separate point locations in five counties. A geographic information system-based analysis of soil and land-cover data revealed that the species is associated with clay-loam and loam soils and mixed-grass/shortgrass prairie. We also found an unexpected association with cropland, although we do not know the exact extent to which *D. elator* actually uses cropland. The surveys provide an updated assessment of the species distribution and the maps of potential habitat indicate areas where the species may still exist.

Keywords: cropland; GIS; roadside surveying

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Introduction

The Texas kangaroo rat *Dipodomys elator* has a very restricted geographic distribution and it may have experienced population declines and range contraction in the past century (Jones et al. 1988; Martin 2002; Nelson et al. 2013). Moreover, the species is a habitat specialist, particularly with regard to preferred soil type (Dalquest and Collier 1964; Roberts and Packard 1973; Martin and Matocha 1991), and it exists in a region that has experienced widespread landscape transformation due to expanding agriculture, particularly crop farming and elimination of prairie dog colonies. To some extent, these anthropogenic activities may have resulted in the loss of habitat that exacerbated population declines. Unfortunately, there is no long-term population data for

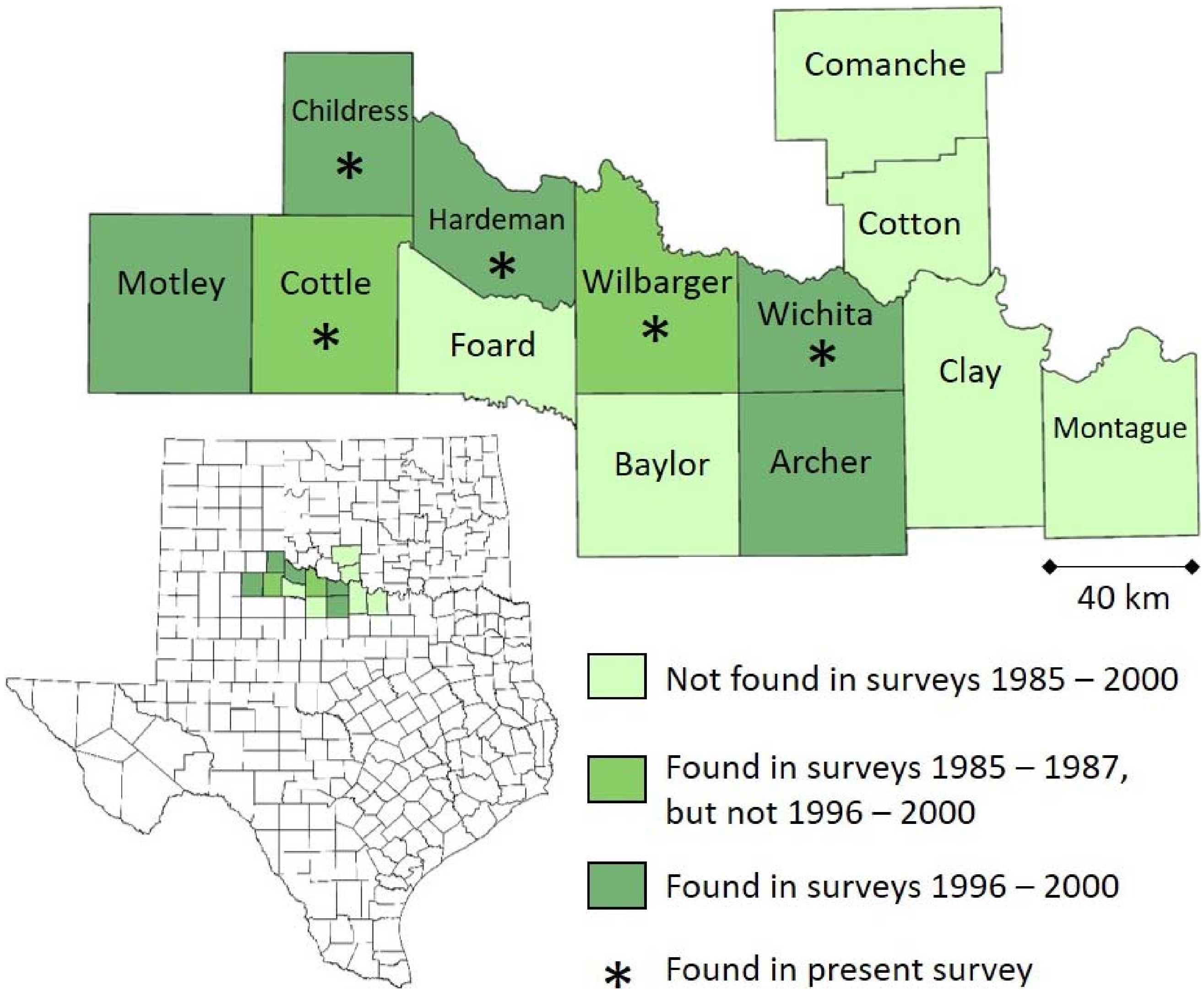

Figure 1. Thirteen counties in Texas and Oklahoma where there is at least one record (collected specimen) of *Dipodomys elator*. Lightest shading indicates counties where the species was not recorded by the 1985–1987 survey of Jones et al. (1988), 1996–2000 survey by Martin (2002), or the present survey. Darkest shading indicates counties where the species was found by Martin (2002) and by the present study if indicated by an asterisk.

D. elator, and thus this link cannot be conclusively demonstrated or refuted. Even apart from possible negative anthropogenic effects on the species, Texas kangaroo rats have always been considered a relatively uncommon species (Dalquest and Collier 1964; Martin and Matocha 1972; Jones et al. 1988). As such, the species continues to need further study, particularly with regard to understanding habitat requirements and the extent of the species distribution within its range.

The geographic range of *D. elator* is very restricted. Since its initial discovery in 1894 in Clay County, Texas (Merriam 1894), *D. elator* has been documented in only 11 counties in north-central Texas and 2 in southwestern Oklahoma (Bailey 1905; Blair 1949; Packard and Judd 1968; Baccus 1971; Martin and Matocha 1972; Cokendolpher et al. 1979; Figure 1). However, there have been no reports of *D. elator* in Oklahoma since 1969 despite several surveys, and all Oklahoma populations are believed to be extirpated (Moss and Mehlhop-Cifelli 1990; Martin 2002). In the most recent range-wide surveys, conducted in Texas during 1985–1987 (Jones et al. 1988) and 1996–2000 (Martin 2002), *D. elator* was found in only four and five counties respectively (Figure 1) at 27 and 23 unique locations respectively. These studies involved visual surveying while traveling rural roads at night. From 2011 to 2012, Nelson et al. (2013) also conducted a range-wide survey by trapping at Martin's (2002) known locations of *D. elator*. They found that the species was apparently absent from 33 of 48 sites where it had been previously recorded by Martin (2002). The remaining 15 sites could not be resurveyed because of lack of landowner permission for access. The infrequent sightings during the surveys of Jones et al. (1988), Martin (2002), and Nelson et al. (2013) may be indicative of a species experiencing population declines and a contracting range. In addition, the apparent rarity of *D. elator* might also be due in part to it being a habitat specialist.

Compared with the habitat preferences of other kangaroo rat species, *D. elator* is atypical in its use of clay-based soils (rather than sand and sandy loam) for burrowing, although it also will use a few loamy soils (Dalquest and Collier 1964; Roberts and Packard 1973; Martin and Matocha 1991). Initial accounts and studies of the species indicated an association with mesquite *Prosopis glandulosa* shrubs (Bailey 1905), particularly with regard to burrows being dug at the base of shrubs (Dalquest and Collier 1964). However, studies conducted since then have revealed that *D. elator* does not have any particular need for mesquite (Stangl et al. 1992; Goetze et al. 2007; Nelson et al. 2009; Stasey et al. 2010). Texas kangaroo rats actually avoid areas of dense woody growth and are likely displaced from an area as natural succession or excess precipitation leads to substantial woody and herbaceous plant growth (Stangl et al. 1992; Goetze et al. 2007, 2015; Nelson et al. 2009, 2011). Most kangaroo rat species, including *D. elator*, are primarily granivorous and forage for seeds on the ground surface. As the name suggests, kangaroo rats have long hind legs and feet, with a long tail that stabilizes the body when jumping. Unlike other rodents, they do not scurry or crawl. Even when moving slowly for a short duration, they use a short hopping motion. Given the saltatorial form of locomotion, most kangaroo rat species require a substantial amount of bare ground to facilitate foraging and predator escape (Thompson 1982; Price and Heinz 1984). Previous studies have documented mean values of approximately 50% bare ground at small spatial scales (1-m^2 quadrats centered on burrows or 5-m line transects near to burrows), although percent bare ground at individual burrows can range from 0 to 94% (Martin and Matocha 1991; Goetze et al. 2007, 2015, 2016; Stasey et al. 2010; Nelson et al. 2011, 2013). These relatively narrow habitat requirements suggest that *D. elator* has a restricted distribution (or spatial dispersion) within its overall geographic range. That is, its range fill (or area of range that is occupied) is much less than 100% and thus the map of its geographic range (e.g., Linzey et al. 2008) overestimates the amount of area potentially occupied by populations.

The lack of information on range fill, apparent rarity of the species, small historical range size, and possibility of continuing habitat loss have brought attention to the conservation status of *D. elator*. Currently, the U.S. Fish and Wildlife Service (USFWS) is conducting a species status assessment to determine if listing *D. elator* as endangered is warranted under the U.S. Endangered Species Act (ESA 1973, as amended). The USFWS was previously petitioned to list *D. elator* (USFWS 2011). The state of Texas currently categorizes *D. elator* as "threatened" (Texas Parks and Wildlife Department 2012) and the International Union for the Conservation of Nature categorizes it as "vulnerable" (Linzey et al. 2008). In this study, our objectives were to develop a map of potential habitat within the historic range of *D. elator* and conduct a range-wide survey to document extent of occurrence. We define potential habitat as areas where *D. elator* individuals could presumably exist given the environmental conditions in the area.

Methods

Development of a potential habitat map

We used ArcGIS (ESRI 2013) to create a map of potential habitat. This map identified areas having suitable soil and land cover for *D. elator*. We obtained information on suitable soil and land-cover types from previous field studies of the species (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). We included any land-cover type that was predominately grassland or shrubland (i.e., land-cover types without a complete woody canopy) and any soil type composed of clay, clay loam, or loam of a sufficient depth (at least 50-cm depth to a restrictive feature) for burrowing and not prone to flooding. The Natural Resources Conservation Service defines "restrictive feature" as a layer that impedes water penetration and root growth, and we assume also impedes digging by kangaroo rats. Soil type and land-cover type were separate geographic information system (GIS) data layers and hence mapping consisted of overlaying the two layers. We obtained spatially referenced soil data from the Natural Resources Conservation Service Web Soil Survey (USDA 2017) and land-cover data from the Texas Parks and Wildlife Department's (TPWD) Ecological Mapping System (TPWD 2017). Data from each source have a resolution of 10×10 m. Potential habitat was mapped at this resolution for the entire 11-county region. The map consisted of pixels where the appropriate soil types and land-cover types overlapped. The map of potential habitat was used to guide our surveying efforts.

Range-wide survey for kangaroo rats

We conducted road-cruising surveys for *D. elator* from May through August 2016 and June through July 2017 within an 11-county region encompassing the Texas portion of the historic range. These surveys were intended to document presence of *D. elator*, not abundance or density. Because kangaroo rats are nocturnal, surveying consisted of driving unpaved (dirt or gravel) county-maintained roads at night at slow speed ($<$ 25 kph) while using the vehicle headlights and handheld spotlights to visually scan the road surface and the roadside verge. This method was also used in previous studies and surveys for *D. elator* (Martin and Matocha 1972; Jones et al. 1988; Martin 2002). Jones et al. (1988) drove a total of 12,397 km of rural roads in 14 Texas counties and 3 Oklahoma counties during surveys conducted from 1985 to 1987. Martin (2002) drove 3,300 km of rural roads in 12 Texas counties from 1996 to 2000. The surveyed region of both studies overlaps that of the present study, although exact survey routes might differ somewhat. Martin and Matocha (1972) did not report survey effort. In our survey, we drove less total distance (see Results) because our effort was guided by the map of potential habitat, whereas the previous surveys did not use any type of habitat map.

Road-based surveying allows for large areas to be surveyed relatively quickly and often it is the only alternative in regions where there is very little public land to survey and access to private land is difficult to obtain. We initiated surveys 30 min after sunset and terminated surveys because of inclement weather, hazardous road conditions, sunrise, or surveyor fatigue. Typically, survey periods were 3–8 h (mean = 5 h) along a preplanned route. To eliminate error that could arise from having routes surveyed by different observers, we used a single observer for all surveying. In addition, a singl observer was always accompanied by either of just two assistants. Road-cruising surveys allowed for a large expanse of the 11-county region to be searched in a relatively short time frame of several months during each of the 2 y. Given the goal of documenting extent of species occurrence within the overall region, we focused our survey efforts in areas most likely to be occupied by *D. elator*, i.e., areas of potential habitat as revealed by the map. However, we also intentionally surveyed areas outside of potential (predicted) habitat so as to test whether *D. elator* might associate with land cover and soil types not included in the map. In 2017 we focused our surveying effort within potential habitat revealed by a slightly different map updated with information gained from surveys conducted in 2016. In addition, we planned the 2017 survey routes so that we resurveyed every point location where *D. elator* was detected in 2016. Although two repeat surveys is not sufficient for calculating a detection probability, the resurveying did allow us to verify whether kangaroo rat locations of 2016 still had kangaroo rats in 2017.

Once we sighted a kangaroo rat during a survey, we made every effort to identify the kangaroo rat in the spotlight beam at < 20 m. We were able to confidently distinguish between *D. elator* and the sympatric Ord's kangaroo rat *D. ordii* in that the former has a white-tipped tail that is very prominent when seen in a spotlight beam. On occasion, kangaroo rats will lose the tip of the tail; however, shortened tails were never observed and thus this was not an issue in spotlight identification of the two species. *Dipodomys elator* and *D. ordii* can also be distinguished in that the former has four toes on the hind feet and the latter has five, although identification in this way requires close examination in hand. Once we definitively identified the kangaroo rat to species, we recorded global positioning system (GPS) coordinates (latitude and longitude) 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, we recorded them as being at the same GPS point. When a definitive species identification was not possible, we recorded the GPS coordinates for the point and attempted a positive species identification by placing a motion-sensitive camera at the location the following morning. The camera was placed within a natural opening in the roadside vegetation or at a burrow opening, if one was found. A birdseed-and-oats mixture was used as an attractant in the camera's field of view. We deployed cameras for 1–3 d, after which all photographs taken by the camera were examined; *D. elator* and *D. ordii* were easily distinguished in the photographs. Camera verification was needed at $< 5\%$ of the initial kangaroo rat sightings.

In addition to roadside surveys, we also intended to conduct surveys and trapping on private land throughout the 11-county range of *D. elator*. We sent a letter of inquiry to 80 landowners whose properties contained potential habitat; however, only 12 responded positively to our written request for access and each of these 12 properties had minimal amounts of habitat. We visited each but did not find any sign (e.g., burrow openings) of *D. elator* and hence we decided not to investigate further.

Analysis of habitat at a landscape scale

As a way of possibly refining the habitat map, we conducted an analysis of the soil and land-cover types associated with the locations of *D. elator* obtained during the 2016 survey season ($N = 75$). Again, we used soil data from the Natural Resources Conservation Service Web Soil Survey and land-cover data from the TPWD Ecological Mapping System. In ArcGIS we created a circular buffer (radius = 150 m) centered on the latitudinal and longitudinal coordinates of each *D. elator* location. The typical maximum distance that a kangaroo rat would move from its burrow during a nightly foraging bout is likely contained within a buffer of this size (Jones 1989; Price et al. 1994; J. A. Veech, Texas State University, unpublished data). Within each buffered area, we calculated percent composition of all soil and land-cover types. 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. These layers are often different (e.g., loam above clay loam) and distinguishing between them recognizes that kangaroo rats might be selective for each. The top layer is the substrate that a kangaroo rat will initially encounter while foraging, dispersing, and initiating a burrow. The bottom layer is encountered when a kangaroo rat invests time and energy in digging a deep burrow that will presumably be a relatively permanent den. Our analysis used eight different land-cover types, some of which represented a combination of two or more cover classes from the TPWD Ecological Mapping System database. These cover types were 1) mixed-grass/shortgrass prairie, 2) mixed-grass sandy prairie, 3) savanna grassland, 4) gypsum-breaks grassland, 5) restored grassland in the Conservation Reserve Program, 6) mesquite shrubland/woodland, 7) juniper shrubland/woodland, and 8) row crops. By name, these categories may seem to overlap; however, the names follow naming conventions in the

Table 1. Survey effort and number of *Dipodomys elator* locations recorded during the surveys of 2016 and 2017. Survey effort is shown as total road length (km) surveyed in each county during each season and the percentage of the total survey effort (both years) dedicated to each county.

	Survey effort				*Dipodomys elator* locations		
County	Length 2016	Length 2017 new	Length 2017 repeat	Percent	2016	2017	Both
Archer	214	98	5	8.5	0	0	0
Baylor	154	91	0	6.6	0	0	0
Childress	248	54	55	9.6	3	5	2
Clay	141	56	1	5.3	0	0	0
Cottle	223	49	84	9.6	17	15	5
Foard	139	92	22	6.8	0	0	0
Hardeman	299	116	91	13.6	11	11	3
Montague	100	53	1	4.1	0	0	0
Motley	142	49	63	6.8	0	0	0
Wichita	273	105	75	12.2	26	4	3
Wilbarger	439	95	93	16.9	18	28	6
Total	2,371	857	491	100	75	63	19

TPWD Ecological Mapping System database. Detailed descriptions of these cover types can be found at https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst. This set of eight categories was not exhaustive of all the land cover in all the buffers, with remaining cover types such as urban/suburban, riparian, floodplain, and marsh not included in analyses. When these cover types did occur in a buffer they were minor components.

To statistically test whether soil and land-cover types at *D. elator* locations were different from presumably unoccupied locations, we created a data set of 300 null points located along the routes driven during the 2016 survey. We randomly selected null points to be at least 1 km from recorded *D. elator* locations, but without regard for, or reference to, the habitat map. A total of 300 points appeared to be sufficient for characterizing land cover and soil composition along roads within the study region. A preliminary analysis indicated that estimated percentages of each land-cover and soil type did not change appreciably as more points were added to the null set. We created buffers for the null points and characterized habitat as described above for the *D. elator* locations. We then conducted a two-group randomization test on each of the three data categories: land-cover type, soil top-layer class, and soil bottom-layer type. The two-group randomization test involved randomly assigning the data of each buffer to either a group of size $N = 75$ or a group of size $N = 300$, representing the "presence" data and "absence" data respectively. The assignment was done irrespective of the group to which the observed data belonged. Essentially the randomization test randomly reassigned the data to the two groups while maintaining the sample sizes. The difference in mean cover percentage (D) for each soil type and land-cover type was then determined between these two groups as $D = \bar{X}_{75} - \bar{X}_{300}$. For example, if $\bar{X}_{75} = 30\%$ and $\bar{X}_{300} = 20\%$, then $D = 10\%$, which is the percentage point difference, not the percent difference, which would be calculated as $([30 - 20]/20) \times 100 = 50\%$. The randomization process was repeated 1,000 times to produce a null distribution of differences in mean percent cover for each variable. For each soil and land-cover variable, the observed (actual) difference in mean percent cover was then compared with the respective distribution to determine if the observed difference was significant as indicated by the proportion of the null distribution that had 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 (Veech 2012). To conduct these tests, we used computer code written in the TrueBASIC computing language. We did not use the 2017 *D. elator* locations in this analysis because some of the survey routes overlapped 2016 survey routes and many of the 2017 *D. elator* locations were repeats from 2016. In this way we thereby avoided spatial pseudoreplication in our habitat analysis.

Results

During the surveys of 2016 and 2017, we drove 2,371 km and 1,348 km of rural roads, respectively. Survey effort was distributed relatively equally among the counties (Table 1) although counties with fewer roads received less effort, as did the two easternmost counties (Clay and Montague, see Figure 2), given that *D. elator* had not been recorded from those two counties in well over 50 y. In 2016 we recorded 75 *D. elator* locations distributed within 5 of the 11 counties surveyed (Table 1). These 75 locations represented 96 individuals with a maximum of four individuals at a single location. In 2017 we recorded 63 *D. elator* locations and 78 individuals (Table 1), with a maximum of three individuals at a single location. The 2017 sightings came from the same five counties as in 2016 despite surveying new routes throughout the 11-county survey region in 2017 (Figure 2). During the 2017 resurveying of the 2016 locations, we reconfirmed *D. elator* at 19 locations, i.e., sightings of individuals within 150 m of a location from the 2016 survey (Table 1). The 44 "new" locations of *D. elator* found in 2017 were in proximity to those of 2016; the

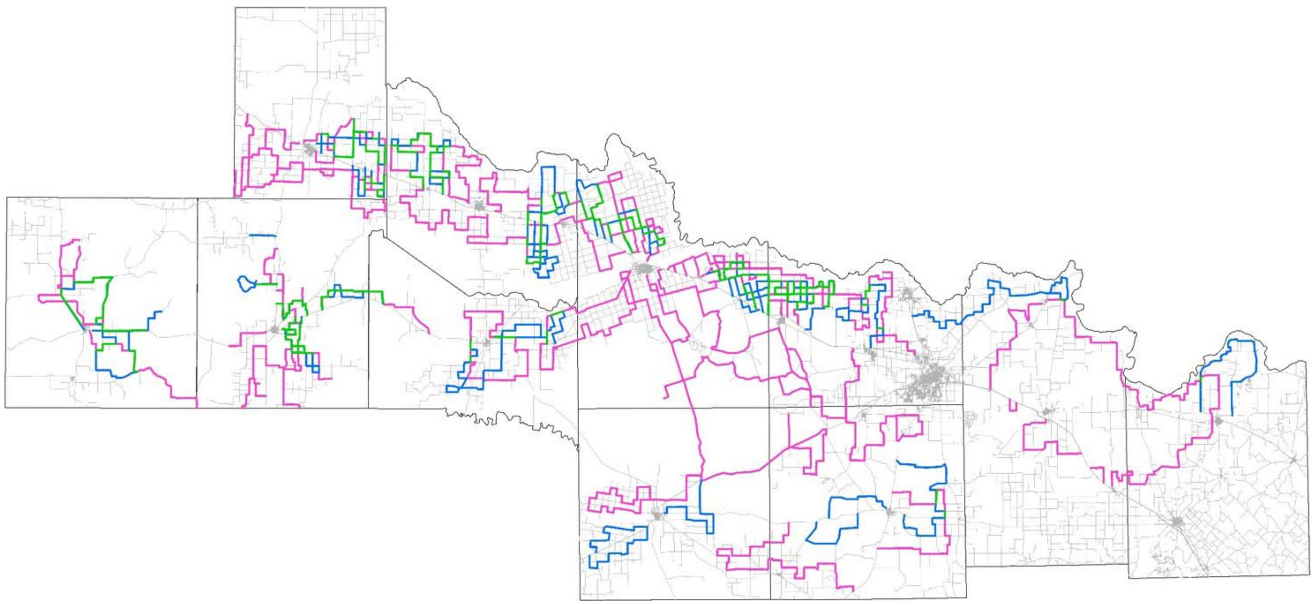

Figure 2. Roads surveyed for *Dipodomys elator* within the 11-county study region in 2016 (pink), 2017 (blue), and both years (green).

greatest distance between a new location from 2017 and a 2016 location was 5.1 km.

Our habitat analysis revealed some differences between the 150-m radius buffers surrounding *D. elator* locations and buffers surrounding random points along the survey routes. On average, the *D. elator* locations had significantly more mixed-grass/shortgrass prairie ($P = 0.081$) and cropland ($P \leq 0.001$) but less mixed-grass sandy prairie ($P \leq 0.001$), mesquite shrubland/woodland ($P \leq 0.001$), savanna grassland ($P = 0.069$), and Conservation Reserve Program grassland ($P \leq 0.001$) (Figure 3). We note that two of these differences are marginally significant ($0.05 < P < 0.1$). The other two cover types, gypsum-breaks grassland and juniper shrubland/woodland, were not significantly different ($P > 0.1$) between the *D. elator* and random locations. With

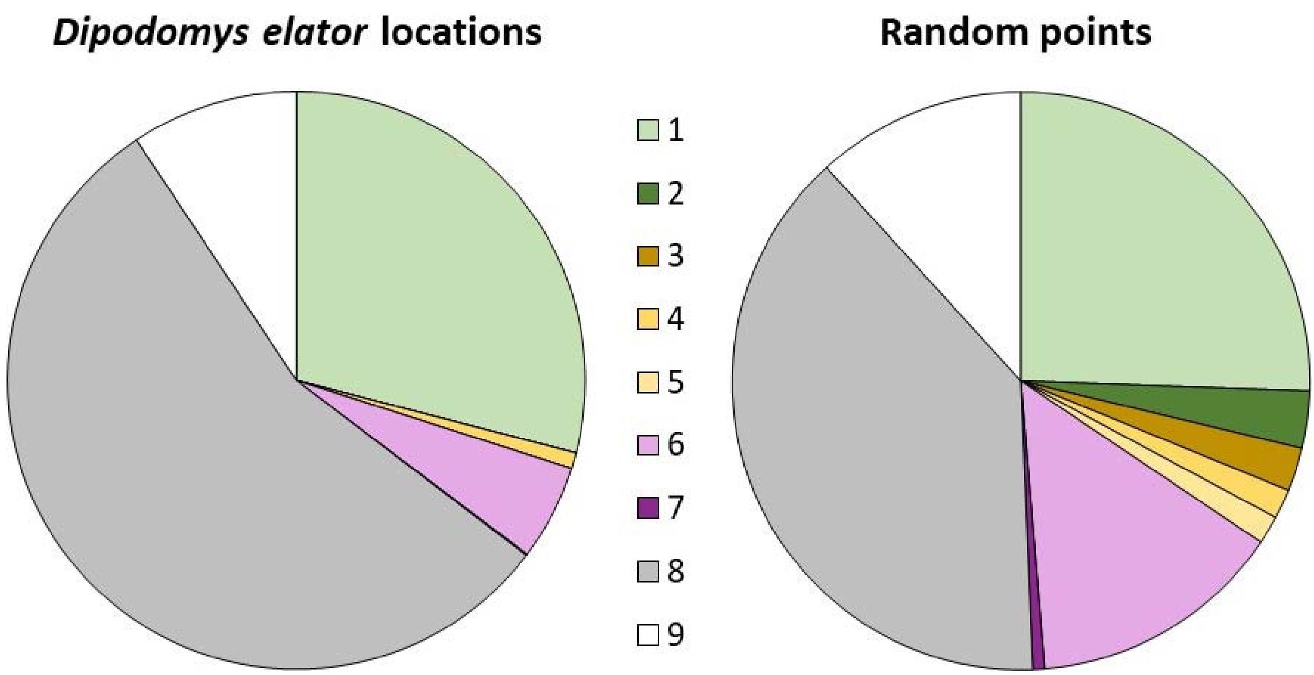

Figure 3. Land-cover composition within 150-m radius buffers centered on *Dipodomys elator* locations (2016 survey only) and random points. Land-cover types are labeled as follows: 1: mixed-grass/shortgrass prairie; 2: mixed-grass sandy prairie; 3: savanna grassland; 4: gypsum-breaks grassland; 5: Conservation Reserve Program (restored grassland); 6: mesquite shrubland/forest; 7: juniper shrubland/woodland; 8: row crops; and 9: other. Green and yellow shading represent prairie and grassland cover types. Purple shading represents shrubland, woodland, or forest cover types.

Table 2. Mean difference in percent cover between the 150-m radius buffers centered on *Dipodomys elator* locations and random points for different soil types. *P*-values were obtained from the two-group randomization test applied to the survey data from 2016. Significant *P*-values ($P < 0.05$) for a positive mean difference indicate that the soil type composed a greater percent cover at the *D. elator* locations than at random points and hence a positive association of *D. elator* with that soil type. Significantly negative mean differences indicate negative associations.

Soil type	Layer	Mean difference in percent cover	*P*	Association
Clay loam	Top	28.8	0.01	Positive
	Bottom	−15.7	0.11	Neutral
Loam	Top	36.7	0.01	Positive
	Bottom	−53.1	0.14	Neutral
Sandy loam	Top	−16.9	0.25	Neutral
	Bottom	−61.1	0.03	Negative
Sand	Top	−99.9	< 0.01	Negative
	Bottom	−74.5	0.63	Neutral
Silt loam	Top	−40.0	0.12	Neutral
	Bottom	−96.0	0.64	Neutral
Clay	Top	−75.1	0.11	Neutral
	Bottom	37.1	< 0.01	Positive
Soil w/restrictive feature		−54.9	0.04	Negative

regard to soil type, the *D. elator* locations had a significantly greater ($P \leq 0.01$) percent cover of clay loam and loam in the top soil layer and clay in the bottom soil layer compared with random locations (Table 2). There was significantly less ($P < 0.05$) and hence an apparent avoidance of sand in the top layer, sandy loam in the bottom layer, and any soil types with a restrictive feature in the top 50 cm (Table 2).

On the basis of the above results, the final map of potential habitat included mixed-grass/shortgrass prairie and cropland combined into a single land-cover category overlaying either clay loam or loam in the top soil layer with clay in the bottom soil layer (Figure 4). Because the type of soil in the bottom layer may be irrelevant to burrowing kangaroo rats (if their burrows do not often penetrate deeper than 30 cm), we also developed a more inclusive version of the habitat map that ignored the bottom soil layer (Figure 5). The restrictive version of the map (Figure 4) revealed potential habitat accounting for 7.6% of the total area of the 11-county region and the inclusive version (Figure 5) had potential habitat as 11.8% of the region. Habitat as defined in the restrictive map accounted for 37.3% of the total buffered area of *D. elator* locations in 2016 and 46.6% in 2017. Habitat defined more inclusively accounted for 67.1% and 83.2% of buffered *D. elator* locations respectively in 2016 and 2017.

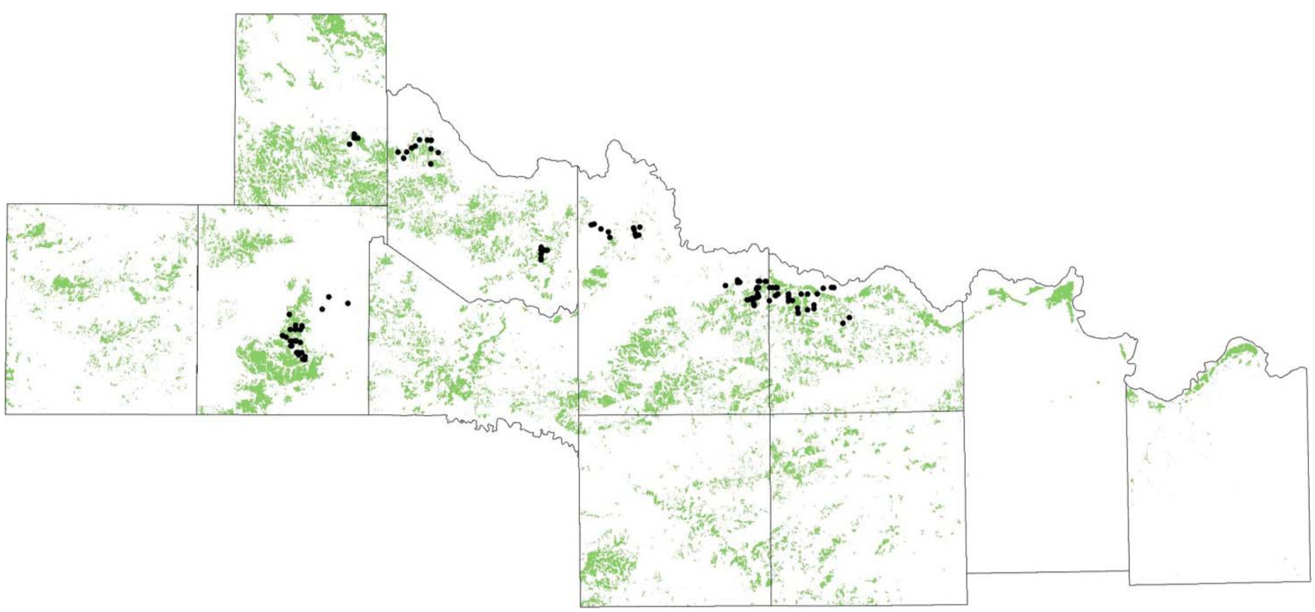

Figure 4. Restrictive version of the map of potential habitat and known locations (2016 and 2017 surveys) for *Dipodomys elator* in the 11-county study region. In this map, habitat is defined as cropland and mixed-grass/shortgrass prairie overlaying either clay-loam or loam soil types in the top layer (30 cm) and clay in the bottom layer of the soil horizon.

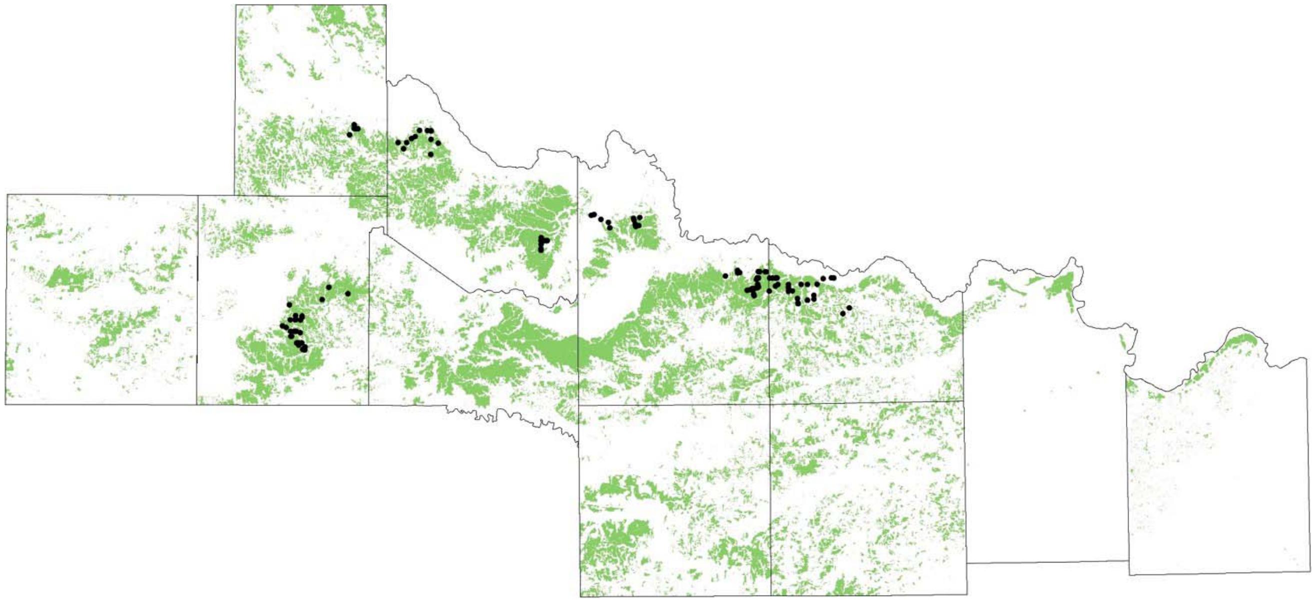

Figure 5. Inclusive version of the map of potential habitat and known locations (2016 and 2017 surveys) for *Dipodomys elator* in the 11-county study region. In this map, habitat is defined as cropland and mixed-grass/shortgrass prairie overlaying either clay-loam or loam soil types in the top layer (30 cm) of the soil horizon without regard for deeper soil layers.

Discussion

Over the past 50 y, several researchers have speculated on the apparent scarcity of *D. elator*, and several assessments of its distribution have been conducted. In general, its distribution is thought to have become more restricted and abundance to have declined. Suggested causes have included factors such as mesquite encroachment leading to closed canopy vegetation, loss of the natural fire and grazing regimes leading to excessive grass growth, infrastructure development related to agriculture and road building, and conversion of prairie to monoculture cropland (Dalquest and Collier 1964; Martin and Matocha 1972; Hamilton et al. 1987; Stangl et al. 1992; Martin 2002; Nelson et al. 2009; Goetze et al. 2016). All of these factors can be summarized as loss of the species' natural habitat that consists of sparsely vegetated grassland (or prairie).

Our habitat analysis provided evidence that *D. elator* selects for mixed-grass and shortgrass prairie, as would be expected on the basis of previous habitat association studies. However, mixed-grass sandy prairie, gypsum-breaks grassland, restored grassland (Conservation Reserve Program), and savanna grassland appear not to be selected by *D. elator* even though these habitat types are relatively open with little or no canopy. Mixed-grass sandy prairie and gypsum-breaks grassland likely are not selected because the underlying soils consist of sand or have restrictive features near the surface. Conservation Reserve Program grassland and savanna grassland might be avoided, even when they overlay clay loam and loam soils, if the ground-level vegetation is too dense. Texas kangaroo rats also appeared to have a significant avoidance of mesquite shrubland/forest and only a random association with juniper shrubland/woodland most likely because these land-cover types have a substantial amount of woody canopy. We note that juniper shrubland/woodland was a very minor component of the 150-m radius buffers centered on *D. elator* locations and random points (Figure 3).

Texas kangaroo rats appeared to be positively associated with cropland along roadsides (Figure 3); we did not expect this result. Sixty-seven of the 75 *D. elator* locations (89%) from the 2016 survey had cropland within the 150-m buffer, 45 locations had $>$ 50% cropland, and 15 had $>$ 95% cropland. These latter locations represent *D. elator* inhabiting a landscape that consists almost exclusively of cropland except for the long narrow strip of grassy vegetation in the roadside verge, which essentially is the habitat. Most of the cropland in the 11-county study region consists of cotton or wheat and fields are sometimes left fallow even during the summer or spring growing seasons. Martin and Matocha (1972) also reported *D. elator* along roadsides bordering milo, cotton, and wheat fields. They further mention that their evidence suggests that kangaroo rats do not use the interior of crop fields. Goetze et al. (2008) used night-vision equipment to directly observe the behavior of Texas kangaroo rats. They noted that kangaroo rats never entered into a wheat field either before or after grain harvest even though there were burrows about 2 m from the edge of the field. A study of Stephen's kangaroo rat *D. stephensi* in California reported the use of crop field edges for foraging and occasional burrowing, but no use of the interior crop field particularly when crops were standing (Price and Endo 1989). Residual or spillage seeds from grain crops (e.g., wheat, sorghum) might provide a reliable food source for *D. elator*, facilitating survival along roadsides that otherwise might not provide enough habitat. We are currently conducting research

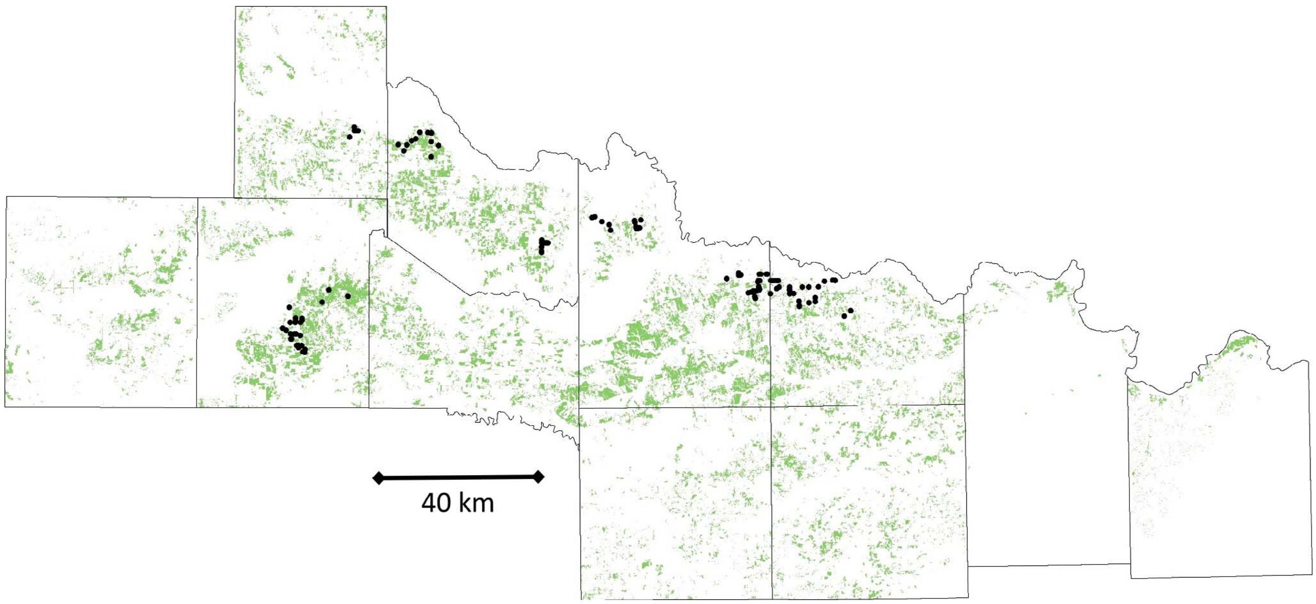

Figure 6. Inclusive version of the map of potential habitat with cropland removed. Map also shows known locations (2016 and 2017 surveys) for *Dipodomys elator*. See Figure 5 for more details.

to determine if individual kangaroo rats enter into crop fields or use them in any way.

We suspect that cropland is not truly habitat in any sense. Even in landscapes composed of a high percentage of cropland, burrows are always dug in the roadside verge of natural vegetation. To date, our research has not revealed permanent residency well within crop fields such as kangaroo rats digging burrows more than 10 m from the edge of a fallow field. We have not seen burrows or other activity within standing crops. Kangaroo rats likely only use the margins of fields when the fields are fallow or when the field is weedy and not well maintained. Thus our maps of potential habitat (Figures 4 and 5) may be overestimating the actual amount of useable habitat. We emphasize "potential"—the maps are best viewed as showing areas that have the appropriate type of soil and minimal or no canopy cover. If abandoned, then perhaps a crop field could become occupied habitat relatively quickly. Although with time and through a natural process of succession, abandoned cropland could eventually become overgrown with dense vegetation again, making the land unsuitable for kangaroo rats unless some type of active control of the vegetation is implemented. *Dipodomys elator* use of fallow and undermaintained crop fields needs to be thoroughly studied before any strong inference is made, particularly given the substantial cropland coverage in the 11-county study region. In our maps, cropland composes 46.0% of the potential habitat in the inclusive version and 61.1% of the restrictive version. The overall amount and distribution of potential habitat is substantially reduced if cropland is removed (Figure 6).

With regard to natural land-cover types, we found *D. elator* to be associated with only one cover type, mixed-grass/shortgrass prairie. This cover type generally describes vegetation consisting of a variety of grasses with only a negligible amount or no woody vegetation (Elliott 2014). As with any natural cover type, the actual standing vegetative biomass in areas of mixed-grass/shortgrass prairie can vary greatly depending on local precipitation and human land-use practices such as livestock grazing and clearing of shrubs. This variation has both a spatial and temporal component, and most important, variation in the extent and thickness of ground-level vegetation determines the amount of bare ground at the finest scale (1–10 m^2). For *D. elator*, the ideal amount of bare ground is about 50% interspersed with primarily grassy vegetation in a mosaic of fine-scale patches (see previous citations in the Introduction). Therefore, identifying "mixed-grass/shortgrass prairie" as the habitat of *D. elator* overlooks the fact that its habitat requirements are more specific than simply an association with a particular vegetation type. Related to this, even the map showing the least amount of potential habitat (Figure 6) may be overestimating the amount that is actually suitable at the present time, given the fine-scale habitat requirements of *D. elator*. In our study region, we observed that the mixed-grass/shortgrass prairie tended to have much less than 50% bare ground in many locations. Further ground truthing would be needed to determine if any particular area fulfills the fine-scale habitat requirements of *D. elator*. Moreover, although *D. elator* does not have any major seasonal change in habitat use, seasonal effects such as precipitation could temporarily alter habitat on a relatively local scale such as increasing the thickness of ground-level vegetation.

The known association of *D. elator* with clay-loam and loam soil types was confirmed in our study. We also found that *D. elator* was randomly associated with surface clay but positively associated with clay soils appearing in the bottom layer. Perhaps the relatively firm compaction of surface clay inhibits initiation of a burrow, but when clay is encountered at lower depths (below clay loam or loam on the surface), burrow construction continues because of the kangaroo rat already making an initial investment and the clay providing good structural support for the burrow. Texas kangaroo rats can burrow to a depth of at least 45 cm (Roberts and Packard 1973). Regardless of the mechanics and energetics of burrowing, the presence of clay-loam or loam soils and the lack of a restrictive feature are very good indicators of where *D. elator* might exist. We successfully used the habitat maps to guide our survey efforts and likely encountered kangaroo rats at a much higher rate than we would have otherwise.

During the 2017 survey, all locations of *D. elator* were within the habitat revealed in the inclusive version of the habitat map. Further, all of the 2017 locations were within 5 km of a location from the 2016 survey even though some of the 2017 survey routes covered areas (e.g., Archer and Baylor counties, northern portions of Clay and Montague counties) substantially distant from the 2016 known locations of *D. elator* (Figure 2). This result suggests that *D. elator* may be absent over much of the 11-county region. As with our survey, the 1996–2000 survey by Martin (2002) did not find *D. elator* in Baylor, Clay, Foard, or Montague counties. Our survey results differ from those of Martin (2002) in that he found *D. elator* in Archer and Motley counties but not in Cottle County. More recently, Nelson et al. (2013) resurveyed many of the *D. elator* locations revealed in the Martin (2002) survey but did not find the species in either Archer or Motley counties. Overall, we found a greater number of individuals and documented more locations than had the two previous road surveys of Jones et al. (1988) and Martin (2002), despite our survey covering fewer kilometers. Although we believe our survey was relatively thorough, areas that could be surveyed further include eastern Foard County, southwestern and central Wilbarger County, and southwestern Baylor County. These are areas that have a substantial amount of potential habitat and yet no *D. elator* individuals were found.

The maps of potential habitat provide an assessment of where *D. elator* could hypothetically exist if its fine-scale habitat requirements were met. The maps also indicate the possible historical extent of its distribution before the region being settled and transformed by human settlers practicing agriculture. The region was a Comanche stronghold and thus Anglo settlers did not arrive until the late 1870s (Handbook of Texas Online 2018). *Dipodomys elator* was likely never highly abundant given that it has fairly specific habitat requirements and its habitat appears to be naturally very discontinuous and fragmented even when viewed on a coarse scale (Figure 4). Moreover, the ecological processes that created the requisite bare ground are not exactly known, although fire, bison grazing, and prairie dog towns may have been sources of bare ground and suppression of excess grass growth (Stangl et al. 1992; Martin 2002; Nelson et al. 2009). More important, with regard to conservation, *D. elator* is likely even less common today than it was 140 y ago. No one has ever recorded more than 20 *D. elator* individuals from a single location at a single time. Roberts and Packard (1973) captured 18 individuals at a site in Wichita County in May 1966. Martin (2002) reported live-trapping 19 individuals from a 2-ha property in Hardeman County in 1987 (unreported month). More recently, 18 individuals were captured from a 15-ha property in Wichita County between May and July 2005 (Goetze et al. 2007, Nelson et al. 2009). In a study of the diet of *D. elator*, Chapman (1972) captured 213 individuals over a 1-y period (July 1969–July 1970) in the "vicinity of a ranch" near Quanah in Hardeman County. On the basis of our survey results, we doubt this number of individuals could be presently caught in a similar time period from a relatively confined area of any county.

A complete assessment of *D. elator* populations should incorporate additional surveys on private lands. Unfortunately, surveying for "species of conservation concern" such as the Texas kangaroo rat is a sensitive topic with private landowners in Texas. Our attempts to secure access for surveys on private lands met with little success. Nelson et al. (2013) also had difficulty in accessing private properties to survey for *D. elator*.

Given its geographically limited distribution of habitat and apparently small population size, *D. elator* would benefit from active habitat management. Several studies have found that grazed pastures provide better habitat than adjacent nongrazed pastures (Stangl et al. 1992; Goetze et al. 2007; Nelson et al. 2009; Stasey et al. 2010) and thus cattle grazing would seem to be an obvious management tool. In addition, control of shrub encroachment into the grassland habitat might be necessary in some areas. We encountered many areas of mixed-grass/shortgrass prairie that had small mesquite shrubs. Given time and lack of brush control, these areas will transition into mesquite shrubland and eventually mesquite woodland. The maps of potential habitat can definitely aid in the conservation of *D. elator*. They indicate areas that could be further surveyed to possibly find additional populations and areas that might be appropriate for habitat management including possible reintroduction efforts.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Reference S1. Elliott L. 2014. Descriptions of systems, mapping subsystems, and vegetation types for Texas. Unpublished paper.

Found at DOI: https://doi.org/10.3996/122018-JFWM-113.S1 (1.28 MB PDF); also available at https://tpwd.texas.gov/gis/programs/landscape-ecology/supporting-documents.

Reference S2. Martin RE. 2002. Status and long-term survival estimates for the Texas kangaroo rat, *Dipodomys* *elator*, Section 6, Project 70. Texas Parks and Wildlife Department, Austin, Texas.

Found at DOI: https://doi.org/10.3996/122018-JFWM-113.S2 (949 KB PDF); also available at https://tpwd.texas.gov/business/grants/wildlife/section-6/projects/mammals.

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Found at DOI: https://doi.org/10.3996/122018-JFWM-113.S3 (535 KB PDF); also available at https://tpwd.texas.gov/business/grants/wildlife/section-6/projects/mammals.

Reference S4. [TPWD] Texas Parks and Wildlife Department. 2012. Texas Conservation Action Plan 2012-2016: Overview. Editor, W Connally, Texas Conservation Action Plan Coordinator. Austin, Texas.

Found at DOI: https://doi.org/10.3996/122018-JFWM-113.S4 (872 KB PDF); also available at https://tpwd.texas.gov/landwater/land/tcap/.

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