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Updated distribution of the Texas kangaroo rat (*Dipodomys elator*) and patterns of rodent species associations from county road surveys in Texas

John D. Stuhler[1]*, Michaela K. Halsey[1,2], Jim R. Goetze[3], Robert D. Bradley[2,4], David A. Ray[2], and Richard D. Stevens[1,4]

[1] Department of Natural Resources Management, Texas Tech University. Box 42125, 79409. Lubbock, Texas, U.S.A. E-mail: john.stuhler@gmail.com (JDS); michaela.k.halsey@gmail.com (MKH); and richard.stevens@ttu.edu (RDS).
[2] Department of Biological Sciences, Texas Tech University. 2901 Main Street, 79409. Lubbock, Texas, U.S.A. E-mail: david.4.ray@gmail.com (DAR); and robert.bradley@ttu.edu (RDB).
[3] Natural Sciences Department, Laredo College. West End Washington Street, 78040. Laredo, Texas, U.S.A. E-mail: goetzejimzoo@gmail.com (JRG).
[4] Natural Science Research Laboratory at the Museum of Texas Tech University. 3301 4th Street, 79415. Lubbock, Texas, U.S.A.
*Corresponding author: https://orcid.org/0000-0003-0974-2396

The Texas kangaroo rat (*Dipodomys elator*) is a rare species of conservation interest at both the state and federal level. Therefore, an updated understanding of distribution and abundance of *D. elator* is critical for initiating informed decisions about its conservation status and subsequent management strategies. We surveyed more than 850 locations along unpaved county roads across the historical range of this species in north-central Texas to identify sites of *D. elator* presence and examine patterns of rodent species associations. We determined that *D. elator* presently occurs in five counties in Texas within its historical range and was the eighth most abundant species of the 14 species that we captured. Moreover, we found that the majority of pairwise species associations, including those involving *D. elator*, were random and there was no strong evidence that pairs of rodents were aggregating or segregating with respect to each other. We did observe negative associations between *D. elator* and both *Dipodomys ordii* (Ord's kangaroo rat) and *Sigmodon hispidus* (hispid cotton rat). Nonetheless, these patterns indicate that interspecific interactions do not play a strong role in influencing the distribution of *D. elator*. However, the restricted and temporally dynamic distribution of this species suggests that a metapopulation perspective should be considered when making future conservation considerations.

La rata canguro de Texas (*Dipodomys elator*) es una especie rara, de interés para la conservación tanto a nivel estatal como federal. Por lo tanto, un conocimiento actualizado de la distribución y abundancia de *D. elator* es fundamental para tomar decisiones informadas sobre su estado de conservación y subsecuentes estrategias de manejo. Estudiamos más de 850 localidades a lo largo de carreteras rurales sin pavimentar en el área de distribución histórica de esta especie en el centro-norte de Texas para identificar los sitios con presencia de *D. elator* y examinar los patrones de asociación de especies de roedores. Determinamos que *D. elator* se encuentra actualmente en cinco condados de Texas dentro de su área de distribución histórica y que es la octava especie más abundante de las 14 que capturamos. Además, descubrimos que la mayoría de las asociaciones de especies por parejas, incluyendo las que implicaban a *D. elator*, eran aleatorias y no hay evidencia sólida de que las parejas de roedores se estuvieran agregando o segregando entre sí. Observamos asociaciones negativas entre *D. elator* y *Dipodomys ordii* (rata canguro de Ord) y *Sigmodon hispidus* (rata algodonera crespa). No obstante, estos patrones indican que las interacciones interespecíficas no juegan un papel importante en la distribución de *D. elator*. Sin embargo, la distribución restringida y temporalmente dinámica de esta especie sugiere que debe tenerse en cuenta una perspectiva meta poblacional a la hora de realizar futuras consideraciones de conservación.

Keywords: *Dipodomys elator*; distribution; road surveys; small mammal; Texas kangaroo rat.

Introduction

Accurate knowledge of species distributions is fundamental to conservation biology. Occurrence data are a valuable source of information for managers to guide and assess conservation planning. These data especially are important for rare species that pose additional logistical challenges due to low density, which may be further exacerbated by inaccessible habitat (McCain and Childs 2008; Kéry *et al.* 2010). Furthermore, many rare species may be highly temporally dynamic in terms of presence and abundance across their distribution (Hanski 1991), and continually updated information regarding species occurrences is important for promoting the most effective management strategies.

The Texas kangaroo rat (*Dipodomys elator*) is a rare, semi-fossorial rodent that has historically been documented in 11 counties in north-central Texas and two counties in southern Oklahoma, United States (Carter *et al.* 1985; Martin 2002; Schmidly and Bradley 2016). However, this species has not been observed in Oklahoma in over a century, except for one questionable record immediately north of the border with Texas, and is believed to be extirpated from that part of its historical range (Bailey 1905; Baumgardner 1987; Braun *et al.* 2021). The present distribution of *D. elator* within Texas is uncertain, in part because new records that expand the distribution of this species continue to be identified (*e. g.,* Martin 2002), while resurveys of previously inhabited sites have often failed to document the continuous presence of any *D. elator* individuals (*e. g.,* Nelson *et al.* 2013).

Because *D. elator* can be easily observed on unpaved roads at night (Martin and Matocha 1972), surveying county roads may be an effective means of discovering sites of occurrence. Prior to this study, *D. elator* had been known from six Texas counties: Clay (Merriam 1894; Bailey 1905), Wilbarger (Blair 1949; Dalquest and Collier 1964), Archer (Dalquest and Collier 1964), Foard (Packard and Judd 1968), Wichita (Packard and Judd 1968), and Baylor (Baccus 1971) (Figure 1). Martin and Matocha (1972), based on county road surveys, documented *D. elator* again in Archer, Foard, Wichita, and Wilbarger, as well as in two new counties: Hardeman and Motley, both to the west of the prior geographic range. Jones *et al.* (1988), also based on county road surveys, surveyed a total of 14 counties in Texas and documented *D. elator* in only four: Cottle (*i. e.*, a new county record), Hardeman, Wichita, and Wilbarger. More recently, Martin (2002) visited all of the counties in the historical range of *D. elator* and documented the species in five: Archer, Childress, Hardeman, Motley, and Wichita (Figure 1).

Although there appears to be consensus as to the general geographic range of *D. elator*, the results of previous surveys suggest a dynamic distribution, in that (1) hotspots of abundance were found in different portions of its geographic range at different time periods and (2) across many of these locations *D. elator* was encountered only sporadically through time. This, coupled with a decade-and-a-half long hiatus since the last range-wide survey, suggests that an update is paramount to understanding the present-day status of *D. elator*. Such an update via county road surveys would provide an important comparison to earlier studies. Furthermore, although interspecific interactions can have an important influence on distribution and abundance of rodent species (*e. g.*, Brown and Munger 1985), relatively little research has been conducted on patterns of rodent species associations with *D. elator* or their potential influence on distribution of this species.

Materials and methods

Between June 2015 – August 2017, we surveyed 808 locations along dirt and gravel roads within the 11 counties in Texas where *D. elator* has been documented (Figure 2). An additional 60 sites were surveyed in Hall County between 24 – 26 March 2017 (Figure 2). While *D. elator* has never been documented in Hall County, Martin (2002) recommended additional surveys at the periphery of the historical range, particularly to the west, and Hall County is located directly to the northwest of the historical geographic range of *D. elator* (Figure 2). Although *D. elator* is believed to be active year-round (Dalquest and Collier 1964), we completed our surveys primarily during the spring, summer, and fall to avoid logistical challenges and potential mortality events associated with trapping rodents in below-freezing temperatures. We selected survey locations based primarily on vegetation preferences described for *D. elator*, which includes short, sparse grasses (Goetze *et al.* 2007; Sikes et al. 2016; Nelson *et al.* 2013), as well as sites in which burrows were present. At each site we placed a Sherman live trap (7.6 × 7.6 × 25 cm; H.B. Sherman Traps, Inc., Tallahassee, Florida) every 10 m along the side of the road over a total distance of 100 m. Traps were baited with rolled oats for one night and checked the following morning, for a total of 11 trap nights per site. Given the primary objective of this study, we opted for one night at each site in order to maximize the spatial coverage of our survey efforts. All transects were separated by a minimum of 200 m. Rodent handling adhered to Texas Tech

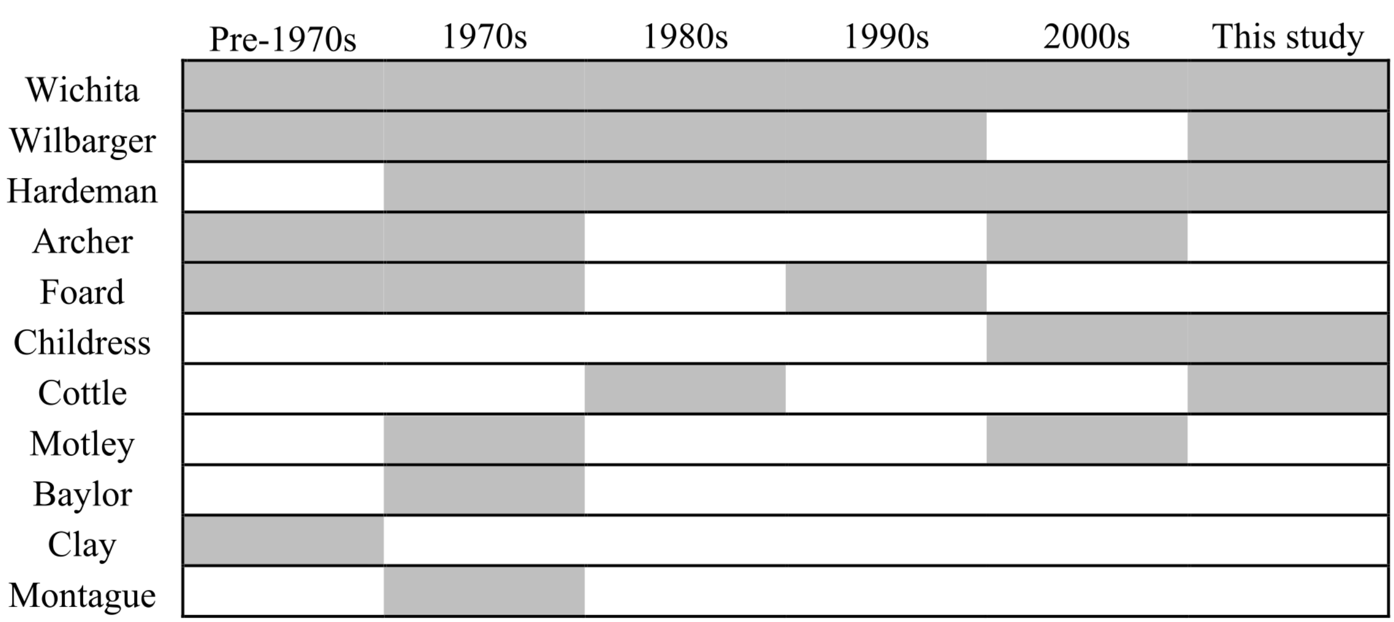

Figure 1. Summary of the county-level distribution of *D. elator* in Texas organized by decade, determined by the results of status surveys and other publications. Darker cells indicate detections of *D. elator* within a given county. Counties are arranged in order of the number of times *D. elator* has been detected.

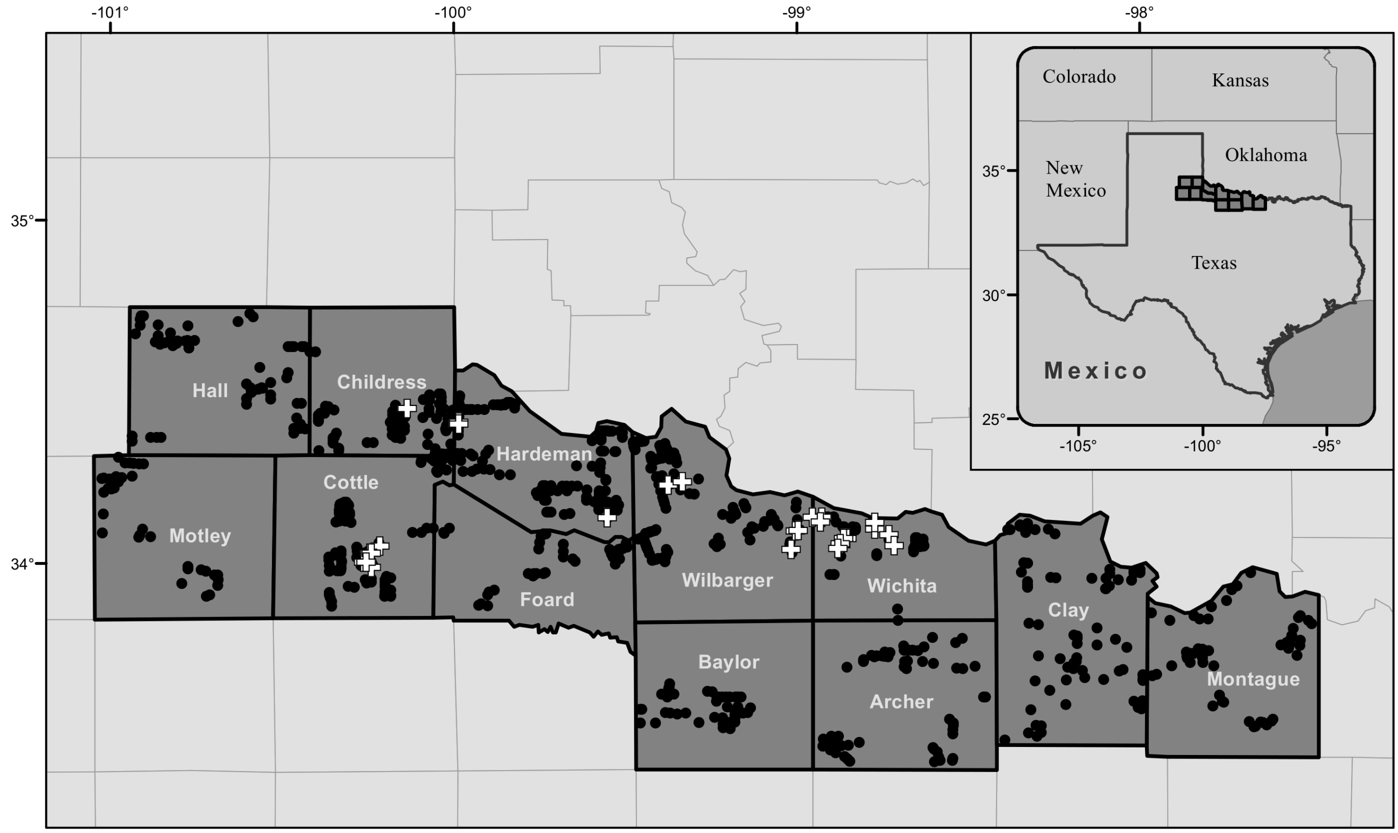

Figure 2. Results of county road surveys (n = 868 sites) across the historical distribution of *D. elator*, including Hall County, between 2015 – 2018. Dark circles indicate areas where traps were deployed but the species was not captured (*i. e.*, "absence" sites), whereas light crosses indicate areas where *D. elator* was captured (*n* = 26 localities).

University Institutional Animal Care and Use Committee Protocol 18013-02 based on guidelines approved by the American Society of Mammalogists (Sikes *et al.* 2016). We identified captured individuals to species (Schmidly and Bradley 2016) and collected and deposited voucher specimens in the collection at the Natural Sciences Research Laboratory (NSRL), Museum of Texas Tech University.

We examined spatial structure of rodent species composition based on a Canonical Correspondence Analysis (CCA; Ter Braak 1986). Geographic coordinates of latitude and longitude formed the independent matrix, and rodent species presence or absence across sites formed the dependent matrix. We examined the final solution of the CCA to determine if it accounted for more variation than expected by chance based on 10,000 permutations of the original data. If the amount of variation accounted for by the CCA based on the real data was greater than in 95 % of the applications to permuted data this was considered significant.

We analyzed patterns of species associations based on a site-by-species presence/absence matrix, excluding sites at which no species was detected, as well as the results from Hall County because we were primarily interested in species associations within the known geographic range of *D. elator*. After filtering, 481 sites were used for the species association analysis. We used the package *cooccur* (Griffith *et al.* 2016) in R (R Core Team 2020), which is based on the probabilistic model of species co-occurrence (Veech 2013). The probabilistic model determines the probability that the observed frequency of co-occurrence is significantly large and greater than expected (*i. e.,* a positive association), significantly small and less than expected (*i. e.,* a negative association), or not significantly different and approximately equal to expected (*i. e.*, a random association; Griffith *et al.* 2016). The expected co-occurrence of any two species is the product of the two species' probability of occurrence multiplied by the number of sampling sites (Griffith *et al.* 2016).

Results

We captured 35 *D. elator* at 26 (3 %) of 868 surveyed sites (Figure 2) in five counties: one site in Childress, six sites in Cottle, three sites in Hardeman, ten sites in Wichita, and six sites in Wilbarger. Seven of these sites had more than one *D. elator* individual (maximum: three individuals), and 16 of these sites had other species (*i. e.*, 1-2) present. We captured fourteen rodent species in total (Figure 3). The five most abundant and widely distributed species were *Sigmodon hispidus*, *Dipodomys ordii*, *Chaetodipus hispidus*, *Peromyscus maniculatus*, and *Peromyscus leucopus*, respectively (Figure 3, Table 1). *Dipodomys elator* occurred at the eighth most sites (Table 2) and was the eighth most abundant species (Figure 3, Table 1). Furthermore, *D. elator* shared six sites each with *P. leucopus* and *P. maniculatus*, four sites each with *C. hispidus* and *S. hispidus*, and one site each with *D. ordii*, *P. laceianus*, and *R. fulvescens* (Table 1). The *D. ordii* individual that occurred at the same site as *D. elator* was a juvenile that we believe was dispersing.

Table 1. Species list from the road surveys indicating the total number of individuals captured, number of sites each species was captured at, and the number of sites at which a particular species co-occurred with *D. elator*.

Species	Total Individuals	Number of sites	Co-occurrences w/ *D. elator*
Baiomys taylori	7	6	0
Chaetodipus hispidus	182	134	4
Dipodomys elator	35	26	--
Dipodomys ordii	210	119	1
Neotoma leucodon	9	8	0
Neotoma micropus	8	7	0
Onychomys leucogaster	37	27	0
Perognathus merriami	38	32	0
Peromyscus attwaterii	3	3	0
Peromyscus laceianus	2	2	1
Peromyscus leucopus	116	85	6
Peromyscus maniculatus	159	99	6
Reithrodontomys fulvescens	13	13	1
Sigmodon hispidus	318	154	4

Although weak, significant spatial structure was exhibited by species within the study area. The first two canonical axes accounted for only 2.66 percent of the variation among sites in presence/absence of species but this was significantly greater than expected by chance alone. *Dipodomys elator* exhibited essentially no spatial structure across its geographic range (Figure 4). All other species exhibited varying degrees of spatial structure. *Baiomys taylori*, *Peromyscus attwateri*, and *P. laceianus* exhibited the greatest spatial structure with the former two species more common in the eastern portion of the study area and the latter more common to the west (Figure 4).

Out of 91 possible species pairwise combinations characterizing the rodent community, 28 pairs (30.8 %) were removed from the analysis because the expected co-occurrences of these pairs was less than one site, indicating that many species were too rare to meaningfully use in analyses. Of the remaining 63 pairs, 35 of the associations were random, one was positive, and 27 were negative. For *D. elator* specifically, there were no positive associations with other species but significant negative associations with *D. ordii* and *S. hispidus* (Figure 5). This means that the species occurred at the same sites as these species less often than expected based on their overall presence across all sites (*D. ordii*: expected number of sites: 7.4, observed number of sites: 1; *S. hispidus*: expected number of sites: 10.1, observed number of sites: 4). In contrast, *D. ordii* displayed significant negative associations with eight other species and one significant positive association with *Onychomys leucogaster* (Figure 5).

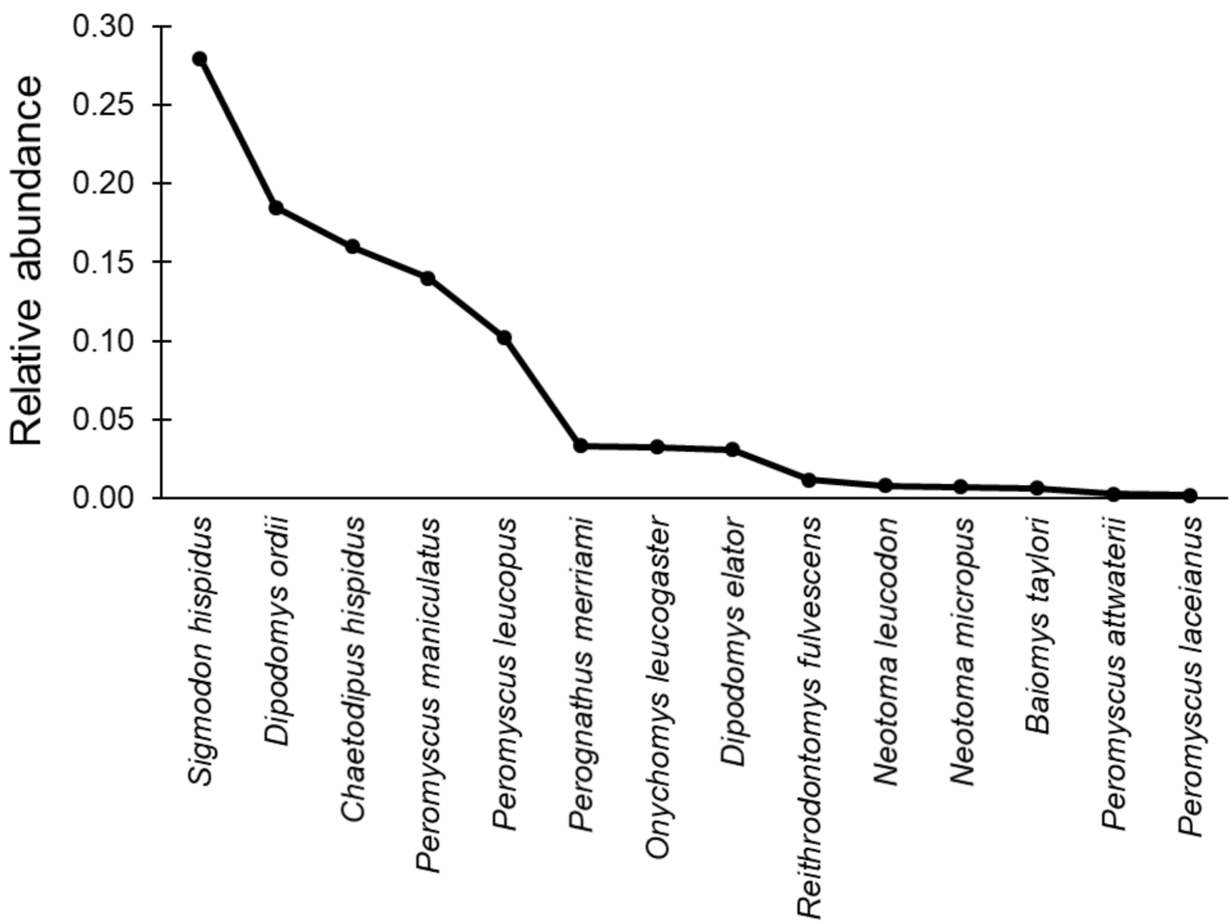

Figure 3. Rank-abundance curve for the rodent community (*n* = 14 species) based on the county road surveys. The y-axis denotes the proportional abundance of every species (along the x-axis) within the overall species pool.

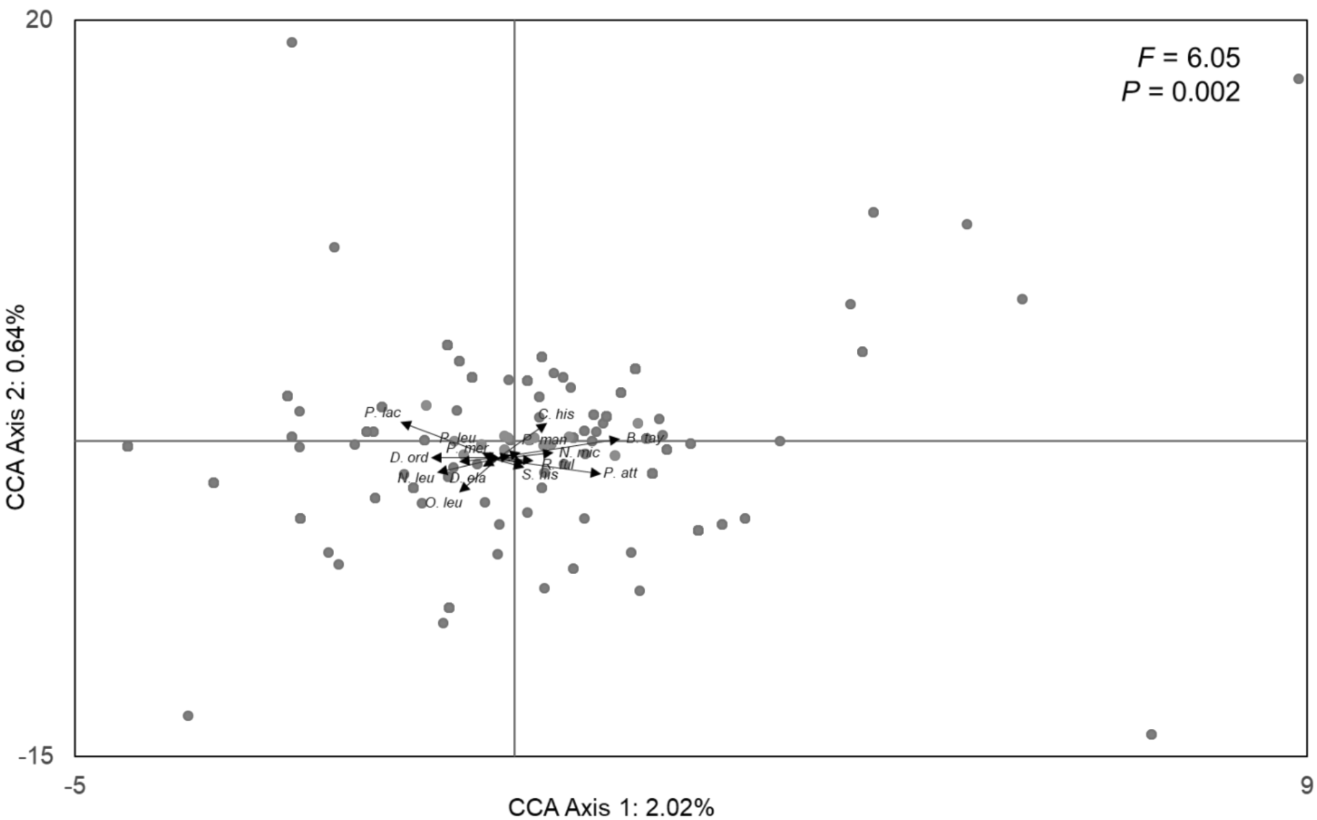

Figure 4. Results from canonical correspondence analysis (CCA) depicting the amount of spatial structure in the distribution of rodent species occurring in the geographic range of *D. elator*. CCA Axis 1 corresponds to a west to east (small to large values) gradient whereas CCA Axis 2 corresponds to a south to north axis (small to large values). Length and orientation of arrows indicated how correlated species are to a particular axis. A long arrow that is parallel to a particular CCA axis indicates a strong correlation.

Discussion

We conducted roadside surveys for *D. elator* across its historical geographic range (Figure 1). Our results suggest that this species (1) presently occupies less than half of the Texas counties from which it was previously documented and (2) occurs sporadically in both space and time throughout its distribution. Furthermore, a majority of possible pairwise species associations were random, including for *D. elator*, suggesting that interspecific interactions do not strongly structure rodent communities within the distribution of the Texas kangaroo rat.

The spatial distribution of *D. elator* described by the current study was similar to that reported by recent surveys (Martin 2002; Ott *et al.* 2019). Importantly, *D. elator* was encountered in the same five counties as Ott *et al.* (2019), a study that was conducted over a time period corresponding to our study, and four of the same five counties as Martin's earlier study (2002). This suggests that the regional distribution of *D. elator* has remained relatively stable over the last two decades, although site-level persistence may be much more variable (*e. g.*, Nelson *et al.* 2013). Martin (2002) suggested that *D. elator* may be shifting its distribution to the periphery of its historical geographic range, and in particular to the west, but we did not find support for this hypothesis. Although *D. elator* was not captured in Clay or Montague Counties, where the species has not been detected for several decades (*e. g.*, Martin 2002), Wichita County had the highest number of *D. elator* capture sites (Figure 2). Similarly, Wilbarger County also had several sites of presence (Figure 2). In contrast, *D. elator* was only captured on the eastern edge of Childress County, near the border with Hardeman County, and no Texas kangaroo rats were captured in Motley County or during ancillary surveys in Hall County (Figure 1). Based on these results, there is no indication that the species is shifting to the western portion of its range. Because much of the research on *D. elator* has been conducted at small scales (*e. g.*, Martin and Matocha 1991; Stangl *et al.* 1992; Nelson *et al.* 2009, 2011; Goetze *et al.* 2007, 2016), future investigations should incorporate comparisons of habitat and population characteristics across the entire region (*e. g.*, Nelson *et al.* 2013). Such an approach would identify differences between the eastern and western portions of the species' range and persistence of *D. elator* in these areas.

There was no evidence that interspecific interactions are strongly influencing *D. elator* distribution patterns. As with most other species, a majority of the interspecies associations with *D. elator* were random, and only two were negative (*i. e., D. ordii* and *S. hispidus*; Figure 4). Although anecdotal accounts suggest that *D. elator* may be a relatively docile, unaggressive species (Goetze *et al.* 2008), and that *D. ordii* is comparably more aggressive (*e. g.*, Perri and Randall 1999), it is more likely that the negative associa-

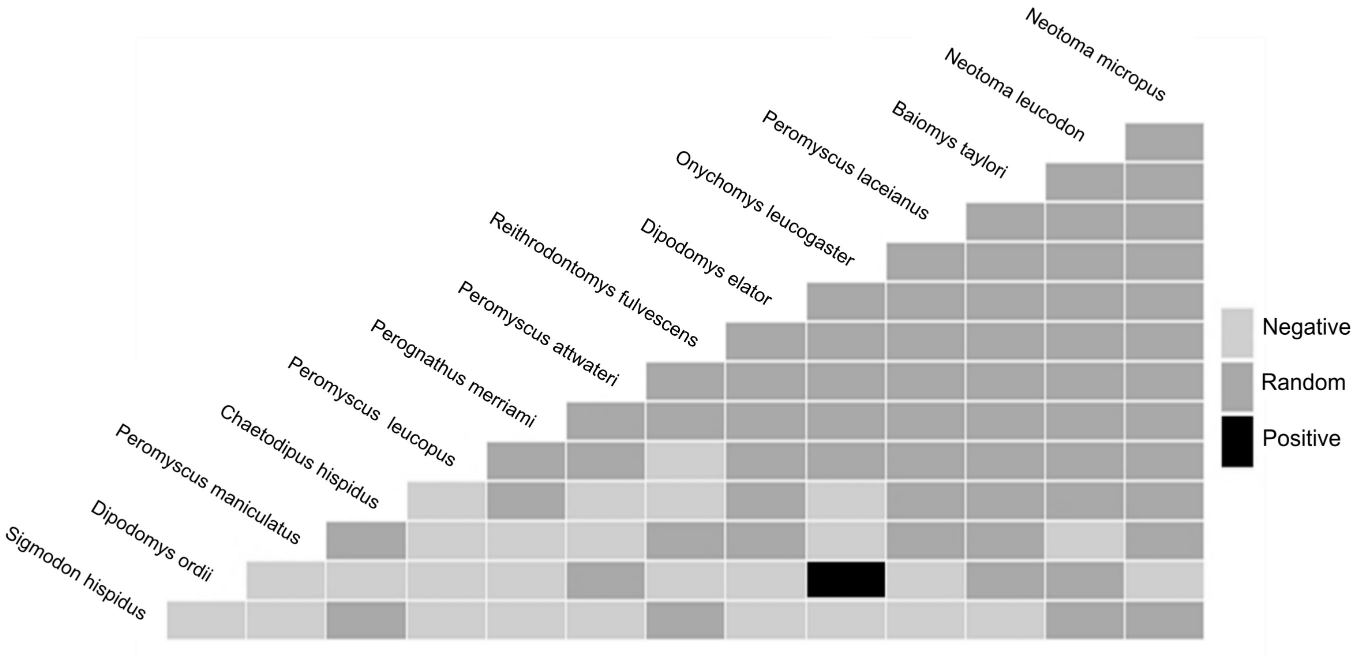

Figure 5. Species co-occurrence matrix from the road survey sites, excluding Hall County, for which there were significant positive, negative, or random associations based on the probabilistic model of species co-occurrence. Note that associations for which there was not sufficient data to detect are also categorized as random.

tions documented herein are a product of differences in habitat associations between *D. elator* and both *D. ordii* and *S. hispidus*. In particular, *D. elator* is often associated with clay-loam soils (Roberts and Packard 1973; Goetze *et al.* 2007), whereas *D. ordii* is associated with habitats with sandy soils (Garrison and Best 1990; Schmidly and Bradley 2016). Moreover, while *D. elator* is typically found in sparse, short grassland habitat (Roberts and Packard 1973; Stangl *et al.* 1992; Nelson *et al.* 2009), *S. hispidus* utilizes grass-dominated habitats (Cameron and Spencer 1981). This is notable because *S. hispidus* and *D. ordii* were the two most abundant species in this region (Figure 3) and occurred at the highest and third highest number of sites, respectively (Table 1). The pervasiveness of these two species in the rodent community, given their different habitat associations in relation to *D. elator*, suggests a lack of suitable habitat for *D. elator* along roadsides and in adjacent pastures across this region (Goetze *et al.* 2016). Such unsuitable habitat conditions along roadsides and within pastures could have consequences to dispersal patterns because *D. elator* likely uses roadsides and pasture margins as movement and/or dispersal corridors (Roberts and Packard 1973; Stangl *et al.* 1992).

Most of the earlier surveys for *D. elator* were performed along roads to verify presence within its current range (*e. g.*, Jones *et al.* 1988; Martin 2002). However, Goetze *et al.* (2016) found more frequent use of pastureland relative to adjacent roadsides, likely because dense concentrations of introduced grasses along roadsides negatively affected *D. elator* (*e. g.*, impeding burrow construction and/or movements). Nelson *et al.* (2013) suggested that, despite not documenting *D. elator* at any of the same sites as Martin (2002), there were large amounts of potential habitat on private land. Greater effort should therefore be given to accessing private land to obtain complementary estimates of *D. elator* distribution and abundance. Nevertheless, access to private land remains difficult and there is little public land in this portion of Texas, such that county roads remain the best available option for both studying and managing this species in a range-wide context. More focus should therefore be given to understanding how *D. elator* utilizes different road types for movement, foraging, etc. (*e. g.*, Roberts and Packard 1973; Brock and Kelt 2004) as well as the suitability of roadsides as habitat for *D. elator* (Goetze *et al.* 2016). Such information will be critical for developing management strategies.

A number of range-wide surveys for *D. elator* have been performed over the last four decades (*e. g.*, Martin and Matocha 1972; Jones *et al.* 1988; Martin 2002; Nelson *et al.* 2013; Ott *et al.* 2019). Although these surveys have provided updates as to the distribution of *D. elator*, and despite indications that the distribution is changing (*e. g.*, Martin and Matocha 1991; Martin 2002), no study has evaluated these changes. This is significant because these changes suggest that *D. elator* forms a metapopulation that exhibits local extinction and recolonization dynamics (Hanski 1991). Directly incorporating a metapopulation perspective when investigating distribution and abundance of threatened and endangered species can improve our understanding of such dynamics and our ability to manage these species (Hanski 1991). Thus, future studies should examine *D. elator* within a metapopulation framework to better understand the importance of different characteristics to *D. elator* persistence across the landscape (Halsey *et al.* 2022).

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