Journal of Arid Environments (2002) **50**: 513–519
doi:10.1006/jare.2001.0900, available online at http://www.idealibrary.com on IDEAL®

Presence/absence of a keystone species as an indicator of rangeland health

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(Received 7 July 2000, accepted 26 June 2001)

We examined the relationship between a Chihuahuan Desert grassland keystone species (banner tailed kangaroo rat, *Dipodomys spectabilis*) and several vegetation and soil indicators of rangeland health in order to define a threshold indicator value for irreversible change in ecosystem structure and function. The abundance of occupied and/or abandoned *D. spectabilis* burrow-mounds was assessed at 117 sites in south-central New Mexico where previous studies had reported vegetation cover and composition. The most robust indicator for presence/absence of *D. spectabilis* was shrub cover. *D. spectabilis* did not occur at sites with shrub cover >20%. It was concluded that a threshold value of 20% shrub cover could be applied to assessment and monitoring of Chihuahuan Desert rangelands because higher shrub cover results in the local extinction of this keystone species. The combination of data on the presence/absence of a keystone species with vegetation and soil indicators provides a method for identifying thresholds of degradation that may be irreversible.

Keywords: banner-tailed kangaroo rat; Chihuahuan Desert; desertification; *Dipodomys spectabilis*; environmental indicators; degradation threshold

Introduction

Desertification of the desert grasslands of the south-western United States is recognized by increased shrub cover and reduced grass cover. Soil loss by wind and water erosion is frequently coincident with the vegetation changes (Whitford, 1995). These changes in vegetation and soils resulting from degradation of desert grasslands have had minimal effects on animal biodiversity (Whitford, 1997). However, the soil

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0140-1963/02/030513+07 $35.00/0

and vegetation changes have had a negative impact on some species that are grassland specialists such as the banner-tailed kangaroo rat (*Dipodomys spectabilis*) (Schroder, 1987).

Dipodomys spectabilis has been described as a keystone species in Chihuahuan Desert grasslands. *Dipodomys spectabilis* is a major contributor to soil heterogeneity. The burrow-mounds of this species are nutrient-rich soil patches that support populations of relatively rare plants (Whitford, 1997). Radio-tracked *Dipodomys spectabilis* showed distinct preference for habitats with a low density of shrubs (Shroder, 1987). However, not all desert grasslands are suitable habitats for banner-tailed kangaroo rats. Areas of dense grass cover and/or dense, tall grass are avoided as burrow sites by *Dipodomys spectabilis* (Anderson & Kay, 1999).

When desertification of Chihuahuan Desert grasslands has proceeded past some threshold, elimination of the environmental stress that is driving the change will not result in recovery of the ecosystem to the pre-stressed state. When ecosystem degradation has moved past that threshold, restoration may also be nearly impossible (Whitford, 1995). Such ecosystems are considered irreversibly degraded (Eve *et al.*, 1999). The identification of the irreversible degradation threshold is essential for land management strategies designed to halt or reverse desertification.

The presence or absence of a keystone species such as *Dipodomys spectabilis* could be a useful indicator of the status of an ecosystem with respect to the irreversible degradation threshold. The presence of active burrow-mounds provides an index of population size of this species (Cross & Waser, 2000). Abandoned banner-tailed kangaroo rat mounds may remain as identifiable landscape elements long after the ecosystem has passed the irreversible degradation threshold (Chew & Whitford, 1992). Thus, it is essential to determine if banner-tailed kangaroo rat mounds are used by *Dipodomys spectabilis* and not by other species if burrow-mounds are to be used as an indicator for identifying degradation thresholds for desert grasslands.

Methods

The desertification status of desert grasslands in south-central New Mexico was evaluated by remote sensing classification by Eve *et al.* (1999). The vegetation cover, bare ground cover and plant species composition of 117 sites in the region was reported by Johnson *et al.* (2000). We recorded the abundance of occupied and abandoned banner-tailed kangaroo rat mounds at the sites described by Johnson *et al.* (2000) in order to identify the vegetation and soil characteristics of sites above the irreversible degradation threshold as indicated by the presence of a keystone species. We then used these data to evaluate percentage of land area irreversibly degraded using the keystone species indicator.

We surveyed the abundance of occupied and abandoned banner-tailed kangaroo rat mounds on 117 sites identified by global positioning system (GPS) co-ordinates at which vegetation composition and cover had been measured (Dappen, 1999; Johnson *et al.*, 2000) (Fig. 1). Study sites were re-located with a GPS unit (Trimble Geoexplorer II, accuracy $\pm$ 50 m). All *Dipodomys spectabilis* mounds within a 1-ha plot centered on the GPS co-ordinates were located and classified as abandoned or occupied. Fresh signs of activity were used to identify occupied mounds (fresh digging, soil, seed husks, plant fragments kicked out of mound entrances, foot prints and tail-drag marks, entrances free of debris or spider webs). Occupied *Dipodomys spectabilis* mounds assessed by these activity signs provided population size estimates equal to those based on saturation trapping (Cross & Waser, 2000). Mounds occupied by other species, usually wood-rats (*Neotoma* spp.) or smaller kangaroo rats (*Dipodomys* spp.) had some entrances covered with sticks, dried dung, etc. or with

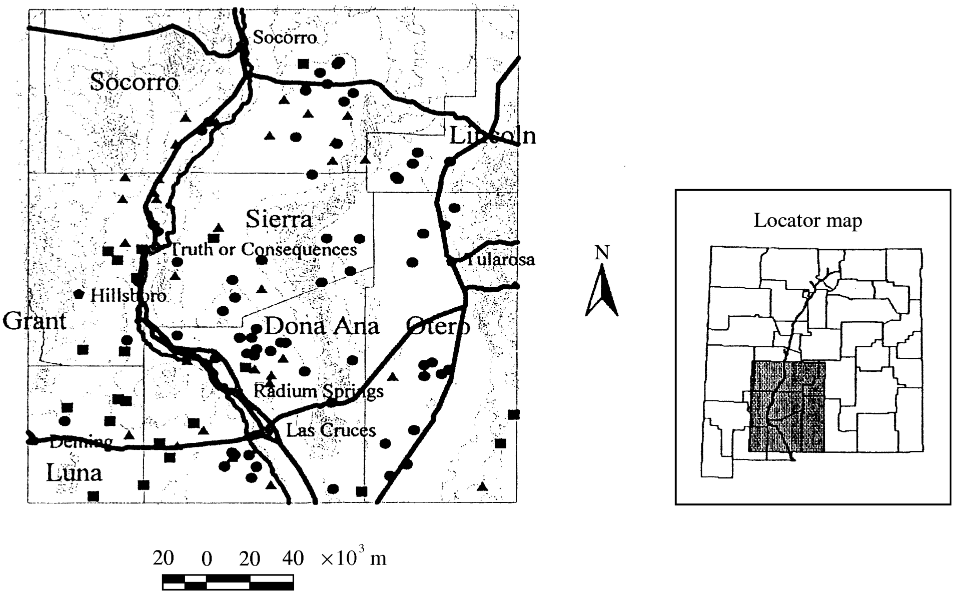

Figure 1. Map of the study sites indicating those sites with occupied banner-tailed kangaroo rat (*Dipodomys spectabilis*) mounds, sites with abandoned mounds, and sites with no mounds present. ■, Occupied; ▲, Abandoned; ●, No mounds; ⬟, Cities; , Roads; , Rio Grande; , 200-ft contours; , county boundaries.

spider webs and there were no seed husks or grass fragments near the burrow entrances. Soil depth to indurated calcified layers or to the maximum depth of *Dipodomys spectabilis* mounds (100 cm) was measured by driving a smooth steel rod into the soil until the rod transit was stopped by cemented calcrete as evidenced by white calcium carbonate adhering to the rod tip. In rocky soils, several measurements were attempted at 1 spacing. If neither 100 cm depth nor calcrete was reached, the maximum depth reached was recorded. Soil-depth measurement locations were chosen by selecting a random azimuth between 0° and 120° from a random numbers table. A depth measurement was made at 4·5 m from the perimeter of a mound on that azimuth. Two additional soil-depth measurements were made at 120° from the random azimuth. In plots with no *Dipodomys spectabilis* mounds, three soil depth measurements were made at 70 m spacing along a diagonal across the plot.

Data were analysed by multiple regression and by logistic regression (Neter *et al.*, 1989). Data were also subjected to the Wilcoxon Rank Sum test (McGrew & Monroe, 1993; Downing & Clarke, 1997). Median soil depths at sites with no mounds, occupied mounds, and abandoned mounds were examined by Kruskal-Wallis (McGrew & Monroe, 1993).

Results

Multiple regression of the number of occupied mounds per hectare as the dependent variables with shrub cover, grass cover and mean size of bare ground patches as independent variables showed that shrub cover was the most important variable (r^2=0·42). Twenty-one sites had active *Dipodomys spectabilis* mounds, 31 sites had abandoned mounds, and 65 sites had no mounds. There were no occupied mounds

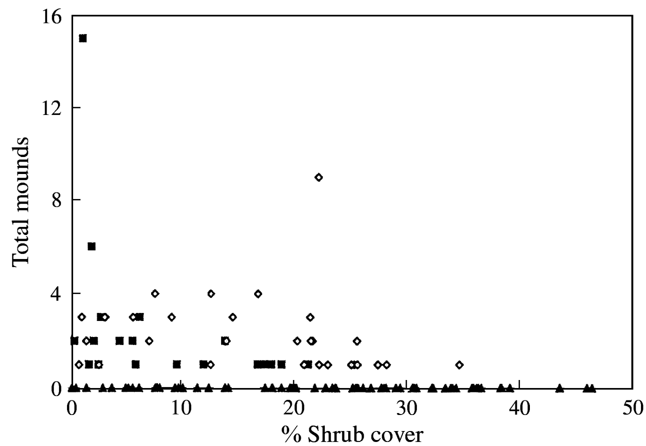

Figure 2. The number of occupied, and abandoned banner-tailed kangaroo rat (*Dipodomys spectabilis*) mounds on sites with varying percentage of shrub cover: ■, Occupied; ◇, abandoned; ▲, none.

on sites with more than 21% shrub cover. The threshold vegetation cover value for sites with occupied mounds was therefore considered to be around 20% shrub cover (Fig. 2). The density of occupied mounds ranged from 1 to 15 ha^{-1}. The highest densities of occupied mounds were at sites with very low shrub cover and very low total vegetation cover.

Non-linear logistic regression with presence/absence of occupied mounds as the dependent variable and vegetation cover as the independent variable showed that the best predictor for the presence of active *Dipodomys spectabilis* mounds at a site was shrub cover. According to this model, the probability of finding occupied *Dipodomys spectabilis* mounds at sites with shrub cover >20% is 0·1 (Fig. 3). This supports the conclusion that 20% shrub cover is a reasonable estimate of the threshold for irreversible degradation.

There were marginal differences in soil depth among sites with occupied mounds, sites with abandoned mounds, and sites without banner-tailed kangaroo rat mounds ($p<0{\cdot}06$). Therefore, soil depth cannot be considered a significant variable affecting the presence or absence of banner-tailed kangaroo rats.

None of the 28 sites classified as mesquite (*Prosopis glandulosa*) coppice dunes had banner-tailed kangaroo rat mounds. Nearly half of the sites classified as creosotebush (*Larrea tridentata*) shrubland had occupied and/or abandoned *Dipodomys spectabilis* mounds. With the exception of alkali sacaton (*Sporobolus airoides*) grasslands, most of the grassland sites had banner-tailed kangaroo rat mounds (Table 1). Sites with little or no perennial plant cover also had *Dipodomys spectabilis* mounds. Sites in ephemeral flood zones dominated by little-leaf sumac shrubs (*Rhus microphyllum*) had no mounds (Table 1).

Discussion

Linking the minimum habitat requirements for a keystone species with vegetation parameters that can be easily measured in assessment or monitoring provides an indicator of the threshold for irreversible degradation. Because a keystone species such as *Dipodomys spectabilis*, affects soil nutrient heterogeneity and soil texture (profile

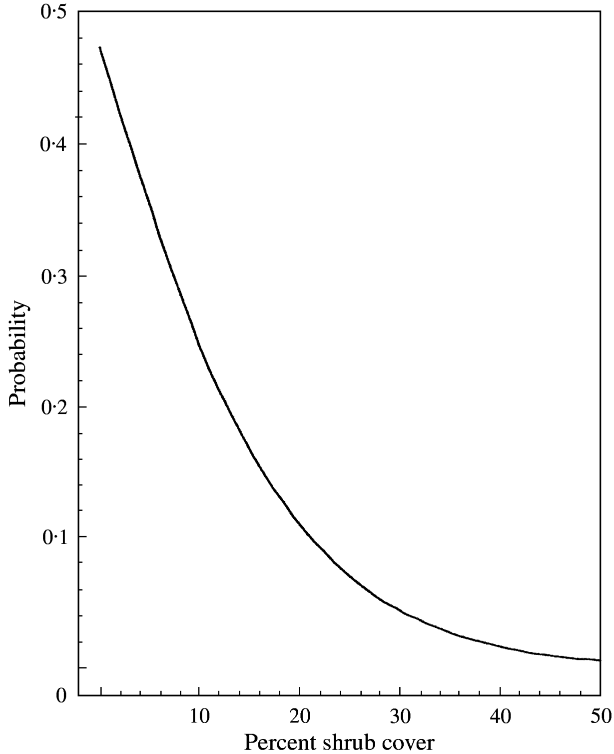

Figure 3. The relationship between percent shrub cover and the probability of the presence of banner-tailed kangaroo rats (*Dipodomys spectabilis*) at a site.

Table 1. *Numbers of sites in different plant communities with occupied, abandoned, or no banner-tailed kangaroo rat (Dipodomys spectabilis) mounds in south-central New Mexico, U. S. A. Sites with one or more active Dipodomys spectabilis mounds were recorded as occupied*

Plant community	Occupied	Abandoned	None
Black-grama (*Bouteloua eriopoda*) grassland	6	7	1
Tobosa (*Pleuraphis* (*Hilaria*) *mutica*) grassland	4	2	2
Bunch grass (*Sporobolus* spp. – *Aristida* spp.) grassland	2	1	3
Alkali sacaton (*Sporobolus* airoides)	0	1	6
Mixed grama grassland (*B. eriopoda*/ *B. gracilis*)	2	1	1
Creosotebush (*Larrea tridentata*) shrubland	3	14	18
Mesquite (*Prosopis glandulosa*) coppice dunes	0	0	28
Mesquite (*P. glandulosa*) grass savanna	0	2	0
Barren – sparse herbaceous plants and small shrub	3	3	1
Tarbush (*Flourensia cernua*) burro-grass (*Scleropogon brevifolia*) mosaic	1	0	3
Little-leaf sumac (*Rhus microphylla*) ephemeral flood areas	0	0	2

characteristics) heterogeneity, local extinction of such a species aects favorable germination sites, and long-term water availability–nutrient availability patterns, and plant community structure (Chew & Whitford, 1992; Guo, 1996; Hawkins, 1996). Also, because of their feeding behavior (cutting tillers bearing ripening seeds) (Schroder, 1979), *Dipodomys spectabilis* affects grass seed dispersal and the physiological status of grasses. These are not the only ecosystem patterns and processes aected by this species. The loss of *Dipodomys spectabilis* from the system obviously compromises the resilience of the system, which can allow further degradation. Since the threshold value for habitat suitability for *Dipodomys spectabilis* is 20% shrub cover, increasing shrub cover past this value will probably lead to irreversible degradation of Chihuahuan Desert grasslands. In studies of indicators of rangeland health, those indicators that were sensitive to degradation provided a continuous range of values on sites ranging from healthy to severely degraded. There was no obvious way to establish a threshold value for irreversibility on any of the indicators (Whitford *et al.*, 1998). The data from this study provide the rationale for setting that threshold for shrub cover at 20%.

Shrub encroachment into the desert grasslands of the Chihuahuan Desert is still occurring (Grover & Musick, 1990). Shrub encroachment is recognized as the main feature of desertification in this region. Shrub encroachment is not always accompanied by soil erosion as can be seen from the soil depth data in this study. More than one-half of the sites without *Dipodomys spectabilis* mounds had shrub cover $>20\%$. The deeper soil depths in the areas with no mounds were attributable to random points on dunes in coppice dune areas where shrub cover was $>20\%$. Many of the occupied mounds had calcrete nodules on the surface of the mounds indicating that *Dipodomys spectabilis* had dug into the calcium carbonate layer during burrow-mound construction. These data suggest that soil stability rather than soil depth is the important soil variable aecting the presence or absence of banner-tailed kangaroo rats. On the Jornada Experimental Range, which is in the study region, mesquite savanna grasslands with active *Dipodomys spectabilis* mounds adjoin mesquite coppice dunes on the same soil series as the grassland. *Dipodomys spectabilis* occupied the coppice dune sites before vegetation change rendered the sites uninhabitable. Aeolian sand accumulation in the mesquite coppices has left calcrete lag in some of the interdune spaces. The calcrete lag is similar in size to the calcrete fragments on the surfaces of the *Dipodomys spectabilis* mounds in the adjoining grassland. The instability of the soils in the coppice dune areas is one of the variables that excludes banner-tailed kangaroo rats from these areas.

Not all desert grasslands are suitable habitats for banner-tailed kangaroo rats. Only one of the alkali sacaton (*Sporobolus airoides*) sites had *Dipodomys spectabilis* mounds, while the remaining six did not. *S. airoides* is a dominant grass on fine-textured, alkaline soils. *Dipodomys spectabilis* do not use grasslands or sparse shrublands on fine-textured soil as sites to build burrow-mounds (Anderson & Kay, 1999).

Shrub encroachment into the desert grasslands of the Chihuahuan Desert is still occurring (Grover & Musick, 1990) and is recognized as the main feature of desertification in the region. The populations of *Dipodomys spectabilis* are becoming more fragmented with time as more of the landscape is desertified. Eve *et al.* (1999) classified 27·5% of the land area examined in this study as severely degraded. If this trend is not stopped or reversed, banner-tailed kangaroo rats could easily become extinct sometime in the next century. Loss of this keystone species could then render these landscapes irreversibly degraded and resistant to restoration to desert grassland.

This research was supported in part by the U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Las Vegas, NV. The manuscript has not been reviewed by the US-EPA. We thank Patty Dappen, Alan Johnson and

Sandra Turner for providing the GPS locations of the sites used in this study and for allowing us to use the vegetation cover data from those sites.

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