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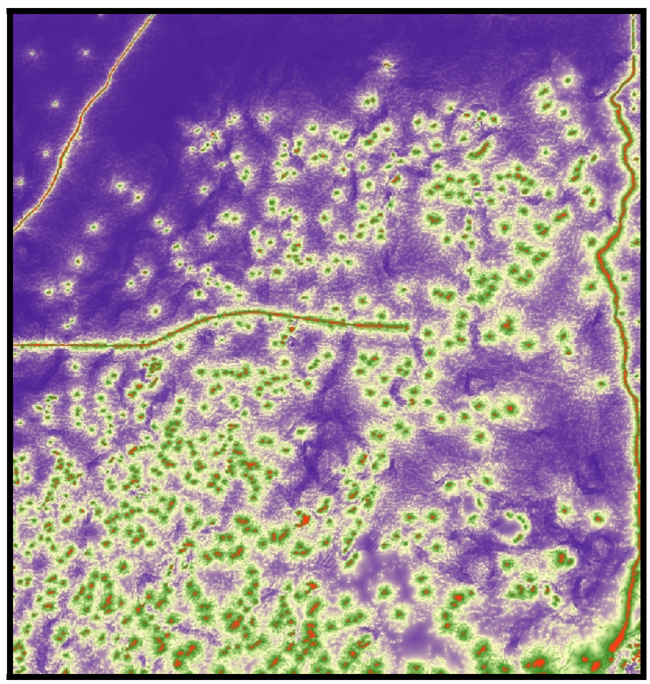
An Occurrence-based Habitat Model for the Ord's Kangaroo Rat (*Dipodomys ordii*) in Alberta



Alberta Species at Risk Report No. 136

Government of Alberta

An Occurrence-based Habitat Model for the Ord's Kangaroo Rat (*Dipodomys ordii*) in Alberta

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EXECUTIVE SUMMARY

Ord's kangaroo rat (*Dipodomys ordii*) is a small, nocturnal rodent adapted to arid environments. It is the only species of kangaroo rat to occur in Canada, and its distribution in Alberta is limited to a small number of active sand dune habitats, particularly within and adjacent to the Middle Sand Hills north of Medicine Hat. The Ord's kangaroo rat is considered an endangered species provincially in the Alberta Wildlife Act and federally in the Species at Risk Act due to its limited geographic distribution, small population size, extreme population fluctuations, and declines in natural habitat. The Recovery Plan identifies a number of activities necessary to recover this species in Alberta, including identification of distribution, habitat requirements, and essential habitat. These needs are addressed in this report which presents information about the current distribution and habitat requirements for the species across its range in the province. We used a statistical modelling approach to identify key habitat features based on Ord's kangaroo rat occurrence records. Our goal was to produce a habitat model that could estimate the distribution of kangaroo rat habitat across its range and predict the occurrence of the species in Alberta. A secondary goal of the study was to validate the model using population monitoring data obtained in subsequent years and report on the predictive ability of the model.

The statistical model that was produced to predict Ord's kangaroo rat distribution appeared to be influenced by all of the variables we considered: elevation, slope, and proximity to eolian sand deposits, exposed soil, sparsely vegetated soil, and river valleys. The model selection process determined that a model including all of these variables was more explanatory than models containing only a subset of variables, suggesting that each was important to predict kangaroo rat occurrence. The resulting model was then mapped to create a relative probability of occurrence map. Interpretation of this predicted occurrence map revealed that kangaroo rats were most highly associated with exposed or sparsely vegetated soils of eolian deposits, particularly sand dunes and sandy roads/fireguards. Exposed slopes along the South Saskatchewan and Red Deer River Valleys were also identified by the model, although this habitat type may have been overemphasized in the model.

We used independent data to validate the model and demonstrate that the model performed well and was highly predictive. Evaluation of the areas predicted to be most used by kangaroo rats revealed that the vast majority of the study area is likely non-suitable habitat for the species. In fact, the model estimates that 2% of the landscape supports about 70% of the kangaroo rats in Alberta, meaning that kangaroo rats are highly selective when locating habitat. Thus, the habitat model performs exceptionally well for identifying precise locations of habitats that are believed essential for the Ord's kangaroo rat in Alberta. However, we caution that the habitat map produced in this study is insufficient for identifying critical habitat for the species because it does not discriminate high quality, low-quality, and sink habitats. We suggest other ways in which the products of this research might be useful for conservation and management of Ord's kangaroo rats in Alberta.

ACKNOWLEDGEMENTS

This work was supported by funding and in-kind support from Alberta Sustainable Resource Development (ASRD), Canadian Forces Base Suffield, Royal Alberta Museum, Parks Canada Western and Northern Service Centre, and the University of Calgary. The authors wish to thank Dr. Arlen Todd for his guidance and improvements to this report.

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1. INTRODUCTION

Ord's kangaroo rat (*Dipodomys ordii* Woodhouse, 1853) is a small (~60 g), nocturnal, granivorous rodent adapted to arid environments. It is the only species of kangaroo rat to occur in Canada. In Alberta, kangaroo rats are limited in distribution to a small number of active sand dune habitats, particularly within the Middle Sand Hills north of Medicine Hat, Alberta and a number of smaller, outlying sand dune complexes (Figure 1). The Ord's kangaroo rat is considered an endangered species provincially in the Alberta Wildlife Act and federally in Canada's Species at Risk Act. The primary reasons for endangerment include its limited geographic distribution, small population size, extreme population fluctuations, and declines in natural habitat (Gummer 1997b, COSEWIC 2006).

The Recovery Plan for Ord's Kangaroo Rat in Alberta identifies a number of activities necessary to recover this species in Alberta, including identification of distribution, habitat requirements, and essential habitat (Alberta Ord's Kangaroo Rat Recovery Team 2005). These needs are addressed in this report which presents information about the current distribution and habitat requirements for the species across Alberta. We used a statistical modelling approach to identify key habitat features from Ord's kangaroo rat occurrences observed in the first two complete years of standardized population monitoring (see Bender et al. 2007). Using this information, our goal was to produce a habitat model that could estimate the distribution of kangaroo rat habitat across its range and predict the occurrence of the species in Alberta. A secondary goal of the study was to validate the model using population monitoring data obtained in subsequent years and report on the predictive capacity of the model. We also interpret the findings of the model and suggest ways in which the products of this research might be useful for conservation and management of Ord's kangaroo rats in Alberta.

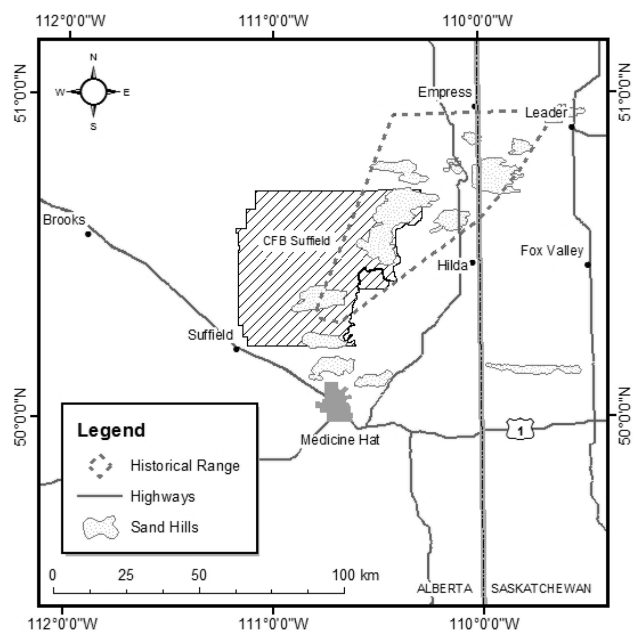

Figure 1. Historical range of the Ord's kangaroo rat in Alberta.

2. SPECIES DESCRIPTION AND STUDY AREA

2.1 Species Description

Kangaroo rats belong to the family Heteromyidae, a group of rodents which consists primarily of kangaroo rats and pocket mice. Kangaroo rats have enlarged hind limbs and are named for their saltatory, kangaroo-like mode of travel (Gummer 1997b). They dig underground burrows for shelter and food storage, emerging primarily on warm (>1° C), dark nights for activities such as foraging, collection of nest material, and mating. Their diet consists mostly of seeds, which they carry in their external, fur-lined cheek pouches while foraging (Best and Hoditschek 1982). Kangaroo rats are well adapted to arid environments with little standing water. Water conservation is enhanced by their highly concentrated milk (Kooyman 1963) and urine (Fairbanks et al. 1983). Convoluted nasal passages also reduce water loss from respiration (Collins et al. 1971). Almost all of the animal's water needs are obtained from the seeds they eat (Gummer 1997b). These seeds are cached in their burrows to provide sustenance throughout winter. During winter months, above-ground activity of the species declines. Alberta kangaroo rats use shallow hibernation to conserve metabolic resources during the long and cold winter period (Gummer 2005).

Ord's kangaroo rats are relatively opportunistic foragers and will collect available seeds from vegetation near their burrow. A diet analysis for Alberta kangaroo rats (Gummer et al. 2005) revealed that kangaroo rats collect seeds from a wide variety of plant species, depending on what is locally available to them and including seeds of a number of invasive alien plants. Kangaroo rats appear to select habitats that provide open, sparsely vegetated and sandy soiled substrates that facilitate their hopping style of locomotion and extensive burrowing activities (Bartholomew and Caswell 1951, Armstrong 1979, Hallett 1982, Kenny 1989, Gummer 1999).

Kangaroo rats reproduce from about March to September each year and typically have 2 to 4 offspring per litter (Gummer 1997a, b). Sexual maturity is reached within about 50 – 60 days of birth, and an adult kangaroo rat may have up to four litters in one year. Given these high reproductive rates, Alberta kangaroo rats are capable of increasing their population size and expanding their distribution rapidly under ideal conditions. However, the species exists at the northern extent of its range and often suffers exceptionally high over-winter mortality (up to 90%, see Gummer 1997a). Thus, the population often exhibits 'boom-and-bust' population cycles from high abundance and wide distribution at the end of each summer to low abundance and scattered distribution each spring. For this reason, it is important to consider multiple years of survey data when building habitat models for these species that exhibit such spatial dynamics in distribution and abundance.

2.2 Study Area

We assessed the distribution and habitat of the species across its entire current range in Alberta. Most of the natural habitat for the species (i.e. active sand dunes) occurs within the Middle Sand Hills, much of which falls within the CFB Suffield National Wildlife Area (Figure 2). Portions of the historical range, such as the sand dunes north of Hilda, AB (Figure 1), were not surveyed directly, although the modeling approach allows for extrapolation into these or other nearby areas with similar habitat characteristics.

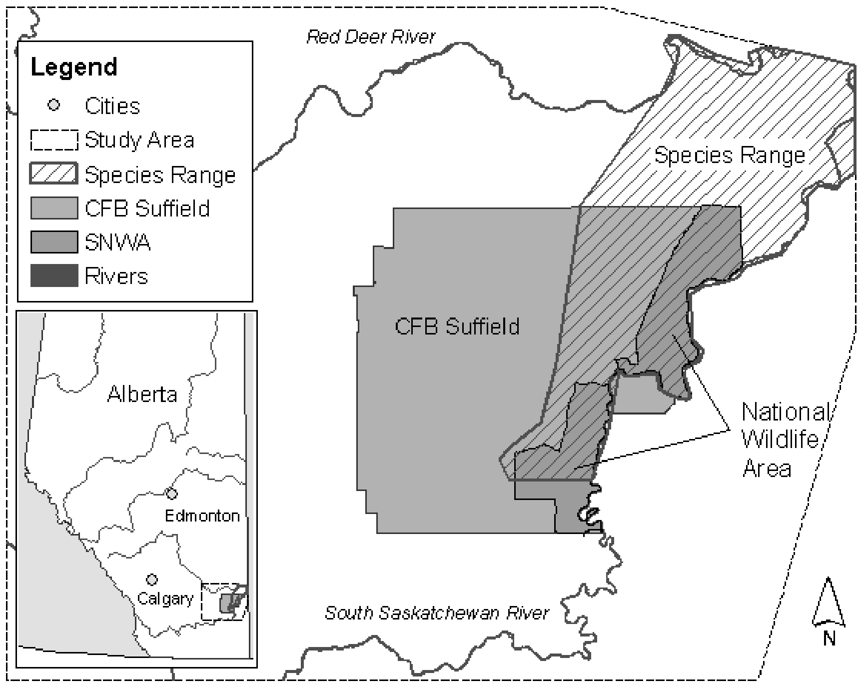

Figure 2. Current extent of occurrence for the Ord's kangaroo rat in Alberta (adapted from Podgurny 2004).

The study area occurs within the dry mixed-grass prairie ecoregion which is characterized by some of the lowest summer precipitation (about 150 mm/year; Strong 1992) in the province. Dominant vegetation in the broader region includes *Stipa comata*, *Bouteloua gracilis*, and *Agropyron* spp. However, natural habitats for the Ord's kangaroo rat are almost exclusively confined to the sandy soils within choppy sandhills sites (although anthropogenic habitats may extend outwards along the network of adjacent sandy roads, trails and fireguards). The soils within the choppy sandhills are predominantly eolian sand deposits that are exceptionally well drained and easily eroded. The xeric soils within the choppy sandhills favour vegetation communities with *Psoralea lanceolata*, *Calamovilfa longifolia*, *Agropyron dasystachyum*, and *Artemesia cana*.

2.3 Habitat Requirements

Ord's kangaroo rat has very specific habitat requirements in Alberta. The species requires open, sparsely vegetated, sandy habitats for its hopping style of locomotion and burrowing (Bartholomew and Caswell 1951, Armstrong 1979, Hallett 1982, Kenny 1989, Gummer 1999). In Alberta, natural habitats are associated with sandy features such as actively eroding sand dunes or blowouts, and sometimes semi-stabilized sand dunes. To a lesser extent, kangaroo rats may occasionally occupy stabilized sand dunes or eroded sandy slopes, particularly along the

South Saskatchewan River valley. Kangaroo rats are also found in areas where sand is exposed by human activities (Nero and Fyfe 1956, Smith and Hampson 1969, Kaufman and Kaufman 1982, Stangl et al. 1992, Gummer 1997a, Gummer 1999, Bender et al. 2005). Examples of such anthropogenic habitats include roads, trails, ploughed fireguards, the margins of cultivated agricultural lands, and bare ground associated with oil or natural gas fixtures (COSEWIC 2006).

It is believed that anthropogenic sites occupied by kangaroo rats represent low-quality habitats and are not good substitutes for natural habitats. Teucher (2007) studied a number of differences between natural and anthropogenic habitats in Alberta. He demonstrated that at anthropogenic sites, soil compaction was higher (presumably impeding burrow construction and maintenance), winter-time burrow temperatures were lower (posing thermoregulation challenges to kangaroo rats), and exposure to predators was greater (possibly leading to higher predator avoidance or mortality). Gummer et al. (2005) also demonstrated that a significantly greater proportion of kangaroo rat food items in anthropogenic habitats included seeds of invasive alien plants, which are believed to represent poor forage quality. Finally, simulation models by Heinrichs et al. (unpublished data) have demonstrated that low-quality anthropogenic habitats may actually function as demographic sinks, leading to increased risk of population extinction. Thus, in this report we distinguish two types of habitat for the Ord's kangaroo rat: natural habitats (active sand dunes, blow-outs, semi-stable dunes, or other naturally eroding sandy features) and anthropogenic habitats (sandy roads, trails, fireguards, etc.).

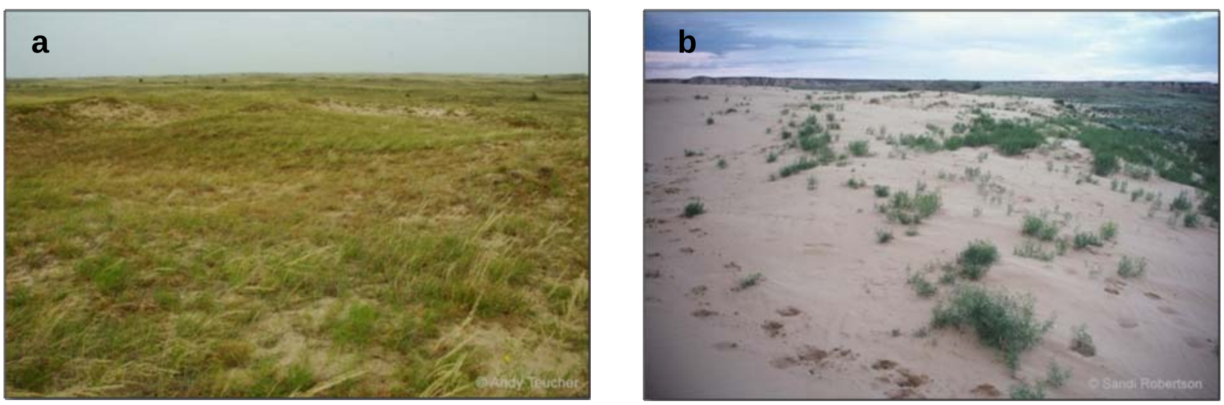

Figure 3. Examples of (a) sparsely vegetated sandy soils and (b) bare soil on semi-stabilized and active sand dunes, respectively. (Photo credits: Andrew Teucher and Sandi Robertson.)

3. METHODS

We used a statistical modeling approach to identify habitat characteristics that were associated with occurrences of kangaroo rats, based on population surveys conducted in years 2006 – 2007 by the long-term population monitoring program for the Ord's kangaroo rat (see Bender et al. 2007). To identify and map used habitat resources, we used a Resource Selection Function (RSF) approach (Boyce and McDonald 1999, Boyce et al. 2002, Manly 2002) to model the predicted occurrence of the species in Alberta. Species occurrence data and landscape variables were incorporated into a geographic information system (GIS), and logistic regression (Hosmer and Lemeshow 2000) was used to identify the landscape attributes associated with occurrence locations. The resulting habitat availability map predicted the relative probability of kangaroo rat occurrence throughout the species range.

3.1 Species Occurrence Data

Ord's kangaroo rat occurrence records were collected using standardized survey methods between 21 April and 29 August 2006, and between 10 May and 26 August 2007. Survey locations included active and stabilized sand dunes, eroded slopes, and anthropogenic habitats within the species range in Alberta. Details of the survey methods can be found in Bender et al. (2007). We used only one record per individual (most recent date of capture) in the analysis to avoid pseudoreplication (Hurlbert 1984). In total, 701 capture records from 2006 to 2007 were used as presence points to develop the RSF model. An additional 523 capture records from subsequent years (2008 – 2009) of standardized population monitoring were used as a validation dataset to evaluate model performance.

We employed a use-available design (Boyce et al. 2002) to compare habitat attributes of used locations to those of an equal number of randomly selected "available" locations across our study area. A mask restricted the random points to the species range so that only areas of potential habitat were considered. Within the species range, the following features were also excluded since they do not represent suitable habitat for kangaroo rats: bodies of water (including dry lakebeds), human settlements (e.g. towns or ranches), paved roads and railroads, cultivated fields, and uninhabitable exposed soil areas (e.g. gravel pits). Areas obscured by cloud on the satellite imagery could not be interpreted and were also removed from the statistical analysis.

3.2 Landscape Variables

The habitat variables incorporated into the model were chosen on the basis of biological relevance and data availability. Spatial data derived from satellite imagery and regional databases were incorporated into a GIS in order to provide geographic context and a visual representation of the model. Geospatial data sources included high spatial resolution (5 m) IRS-1C panchromatic imagery of the kangaroo rat range (dated 1999) and IR-enhanced panchromatic SPOT imagery (2.5 m resolution; dated 2005). A 30m resolution digital elevation model (DEM) was used to derive slope and aspect. All layers were projected to UTM Zone 12N (WGS 1984). A summary of layers used in the model appear in Table 1 and are described in detail below.

3.2.1 Topographic Variables: Slope and Elevation

Kangaroo rats frequently locate their residences at sites with rolling or rugged terrain, such as on the tops of sand dunes or along the sandy slopes of the South Saskatchewan River valley (Gummer 1997b). In particular, south facing slopes and steeper slopes receive higher solar insolation (Christopherson 2002), which may moderate the cold winter microclimate and benefit kangaroo rat survival. Teucher (2007) tested for these effects and showed that kangaroo rats tend to avoid flat areas when locating a burrow and prefer southerly facing slopes. Thus, we incorporated slope as a variable in our RSF model. However, it was not possible to obtain precise estimates of aspect from the coarse resolution elevation data, particularly for sand dunes, and therefore we did not include aspect in the analysis. Raw elevation was included as a variable to help distinguish sandy soils in upland sites vs. exposed sandy soils along the valley bottom of the South Saskatchewan River valley.

Table 1. Summary of the independent variables used in the habitat model.

Variable	**Source**
Slope	Digital elevation model
Elevation	Digital elevation model
Log distance to rivers	Digitized river layer from IRS-1C and SPOT-5 imagery
Log distance to eolian sand	Digitized eolian sand deposits layer from IRS-1C and SPOT-5 imagery
Log distance to exposed soil	Supervised classification of IRS-1C imagery
Log distance to sparsely vegetated soil	Supervised classification of IRS-1C imagery

3.2.2 Proximity to Rivers

Although kangaroo rats are not typically associated with rivers or valley bottoms, many of the highest occupancy habitats (both anthropogenic and natural) in Alberta occur near the South Saskatchewan River or Red Deer River valleys. Eolian sands have historically drifted eastward and accumulated on the slopes of the river valley, providing substantive amounts of open, and sparsely vegetated sandy habitats. Because of the steep valley slopes, vegetation encroachment appears to be less prevalent in these sites. A proximity layer was created for the river valleys and expressed as log-distance to rivers.

3.2.3 Proximity to Eolian Sand Deposits

At the landscape scale, kangaroo rats require loose, open sand which is plentiful in the eolian sand deposits associated with the sand dune fields of the Middle Sand Hills, and smaller nearby fields of Dune Point along the Red Deer River and the Empress dunes on a meander of the South Saskatchewan River. The boundaries of the sand dune fields were interpreted and hand digitized from high resolution imagery. Distance to eolian sand deposits (using a log Euclidean distance function) were generated in ArcGIS 9 (ESRI Inc., Redlands, CA) and used as a variable in the logistic regression analysis.

3.2.4 Proximity to Open and Sparsely Vegetated Areas

Kangaroo rats are closely associated with areas of exposed sandy soil, as well as with sparsely vegetated areas which provide forage. Two layers were used to describe the degree of exposed soil:

i) sparsely vegetated sandy soil: areas with limited vegetation cover (< 30%) and visible bare ground detectable as high brightness in the panchromatic IRS imagery (Figure 3a), and
ii) exposed sandy soil: areas with negligible (< 5%) vegetation cover (Figure 3b).

A supervised classification of IRS-1C imagery was used to characterize vegetation cover and extent of bare ground. Using the Focus tool in Geomatica 9.1 (PCI Geomatics, Richmond Hill, ON), training sites were created from known points within the masked study area. Four thematic classes were used to describe the landscape: shrublands, grasslands, sparsely vegetated soil, and exposed soils. The sparsely vegetated and exposed soil classes were extracted as individual layers. Since kangaroo rats occupy sites in close proximity to these habitat features, we created two layers to represent the distance to each feature in ArcGIS 9. We used the log Euclidean distance to each feature for generating distance layers representing proximity to exposed soil and sparsely vegetated soil that were used in subsequent logistic regression analysis.

3.3 Statistical Analysis

We followed procedures advocated by Boyce et al. (2002) for constructing and interpreting a use-available RSF model using logistic regression techniques. We developed a number of candidate models based on plausible subsets of the variables listed in Table 1 and compared them to the performance of the global model (i.e. all variables) using Akaike's Information Criterion (AIC) for model selection (Burnham and Anderson 1998). We compared the AIC weights of all models to determine the most appropriate model to predict occurrence.

Once the top model was selected, we used the coefficients from the logistic regression to predict the relative probability of occurrence. This equation was then applied with the input layers (Table 1) using the Map Algebra functions in ArcGIS Spatial Analyst to create a predictive surface of kangaroo rat occurrence.

We also adopted methods for RSF model validation advocated by Boyce et al. (2002). We used a separate validation dataset comprised of 2008-2009 capture locations to test the predictive ability of our model. We classified model results (i.e. the values estimated from the logistic function) into equal-interval bins and cross-validated them with our validation data set. When a model performs well, it should correctly predict occurrence data in the validation set. Following Boyce et al. (2002), we used a Spearman rank correlation test to determine if the observed frequencies of occurrence (adjusted for area of each bin) in the validation set were correlated with the RSF scores of the model. A significant rank-order correlation indicates that increasing RSF scores correctly predict increasing numbers of validation points. To avoid issues with unequal numbers of validation points in each bin, we replicated the validation test using equal numbers of validation points (every 10^{th} percentile) and calculated area-adjusted frequencies for each resulting bin prior to performing the Spearman correlation test.

In addition to quantitative validation, we also qualitatively investigated the types of features identified in the model to be predictive of occurrence and we describe both the quantitative and qualitative predictors of kangaroo rat occurrence.

4. RESULTS

We evaluated the candidate models and found strong support for the global model, but relatively little support for the other (subset) models (Table 2). The AIC weight for the global model (all variables) exceeded 0.99, clearly indicating that it was the top model. Given this result, we chose not to interpret any other candidate models. The overall fit for the top (global) model was high (likelihood ratio χ^2=1183.37, df = 6, $p < 0.001$).

Table 2. Candidate models and AIC model selection results for RSF models.

Model	-2LL	K	AIC	Δ_i	w_i	Rank
ES, SV, AE, RI, EL, SP	760.22	8	776.22	0.00	0.9970	1
ES, AE, RI, EL, SP	773.98	7	787.98	11.76	0.0028	2
ES, SV, AE, RI, SP	779.22	7	793.22	17.01	0.0002	3
ES, SV, RI, EL, SP	789.66	7	803.66	27.45	1.09E-06	4
ES, SV, AE, EL, SP	846.21	7	860.21	84.00	5.73E-19	5
ES, SV, AE, RI	856.28	6	868.28	92.06	1.02E-20	6
ES, AE, EL, SP	862.04	6	874.04	97.82	5.71E-22	7
ES, AE, RI	868.08	5	878.08	101.87	7.55E-23	8
ES, AE	891.61	4	899.61	123.40	1.60E-27	9
ES, SV, EL, SP	902.83	6	914.83	138.61	7.93E-31	10
ES	949.19	3	955.19	178.97	1.36E-39	11
SV, AE, RI, EL, SP	1304.36	7	1318.36	542.15	1.87E-118	12
AE, RI, EL, SP	1430.74	6	1442.74	666.52	1.84E-145	13
RI, EL, SP	1594.00	5	1604.00	827.79	1.77E-180	14

Model variables: ES=log distance to exposed soil, SV=log distance to sparsely vegetated soil, AE=log distance to eolian sand, RI=log distance to river, EL=elevation, SP=slope

All of the regression coefficients for each variable in the global model were highly significant (Table 3), suggesting that each variable influenced habitat selection by kangaroo rats. Kangaroo rats selected habitats with relatively low slope and high elevation that were close in proximity to exposed soil, sparsely vegetated soils, eolian sand, and river valleys (Table 3).

Table 3. Estimated coefficients and standard errors for the RSF model.

Variable	β_i	SE	*P*
log distance to exposed soils	-2.7583	0.1704	< 0.001
log distance to sparsely vegetated soil	-0.6492	0.1763	< 0.001
log distance to eolian sand	-0.3246	0.0602	< 0.001
log distance to river	-2.1374	0.2448	< 0.001
elevation	0.0130	0.0030	< 0.001
slope	-0.2819	0.0368	< 0.001

Validation of area-adjusted frequencies were correlated with RSF predictions ($r_S = 0.988$, $p < 0.001$; Figure 4), indicating that the model performed well and was highly predictive. Also note from Figure 4 that the majority of validation points fell within the top two bins, indicating the strong discriminating capability of the model; however, unequal sample sizes in the bins may bias the test, so we re-ran the test using re-scaled intervals so that each bin contained approximately equal numbers of validation points (Figure 5). The resulting Spearman correlation was also highly significant ($r_S = 0.988$, $p < 0.001$). The model was highly discriminating of kangaroo rat habitat, correctly predicting 70% of kangaroo rats to occur within about 2% of the study area, and fully 90% of correct occurrences to fall within only 11.7% of the study area (Table 4).

We then applied the logistic equation back to the input layers to derive a predicted occurrence map (Figure 6). Inspection of the predicted occurrence map reveals that much of the species range is predicted to have a low probability of occurrence. These areas are not expected to be important habitat for Ord's kangaroo rats. In fact, about 93% of the landscape was rated with an RSF score of 0.5 or less, indicating that kangaroo rats are highly selective and use only a small proportion of the landscape.

An inspection of the resulting predicted occurrence map reveals that particular features appear to be strongly selected by kangaroo rats. At finer scales of visualization, a fine patchwork of high probability (dark green) areas is evident within the Middle Sand Hills (visible in Figure 7) indicating the more highly selected habitats, which tend to be active and semi-stable sand dunes. Two other features are prominently selected in the model as well: anthropogenic features, particularly the road network and linear fireguards, and eroding slopes along the South Saskatchewan and Red Deer River valleys.

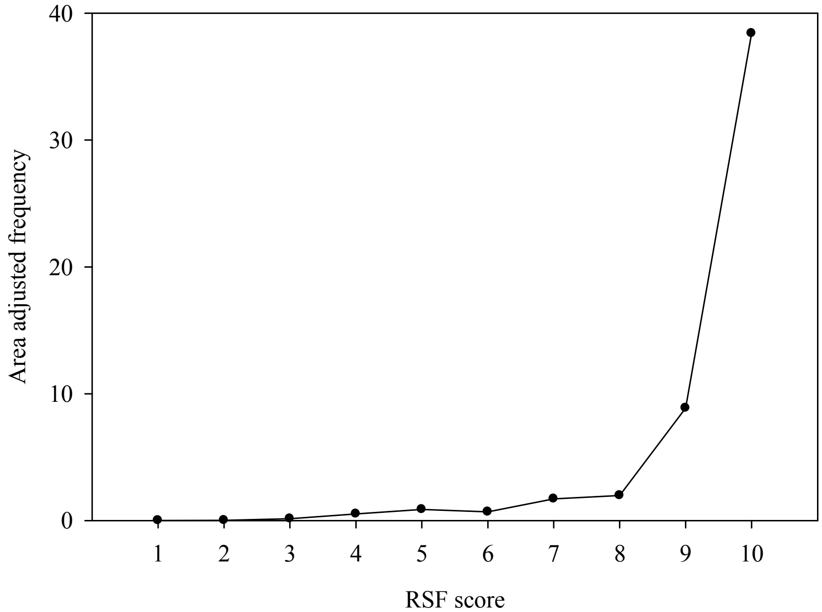

Figure 4. Area-adjusted frequency of categories of RSF scores based on a withheld validation dataset. RSF scores were derived as 10 equal interval bins.

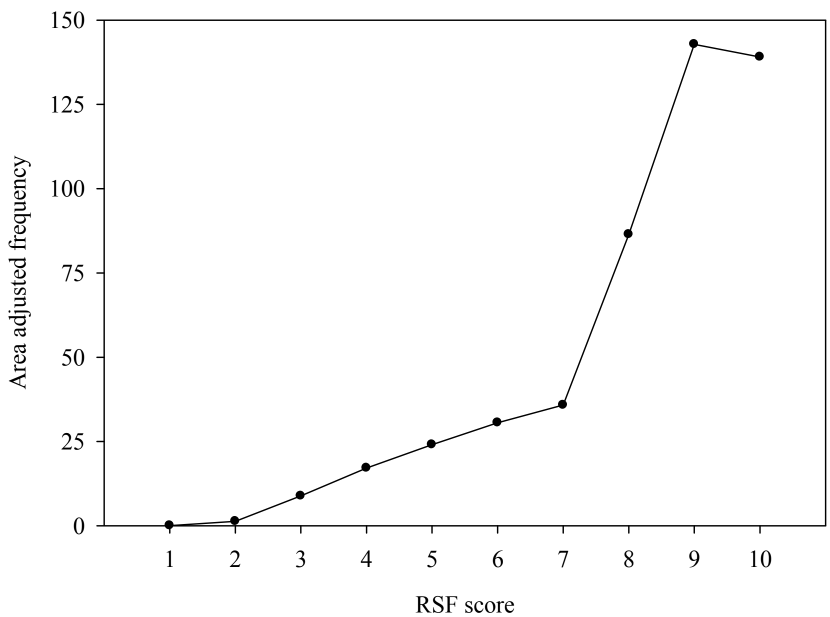

Figure 5. Area-adjusted frequency of categories of RSF scores based on a withheld validation dataset. RSF scores were derived as bins containing approximately equal proportions of validation records (each 10th percentile).

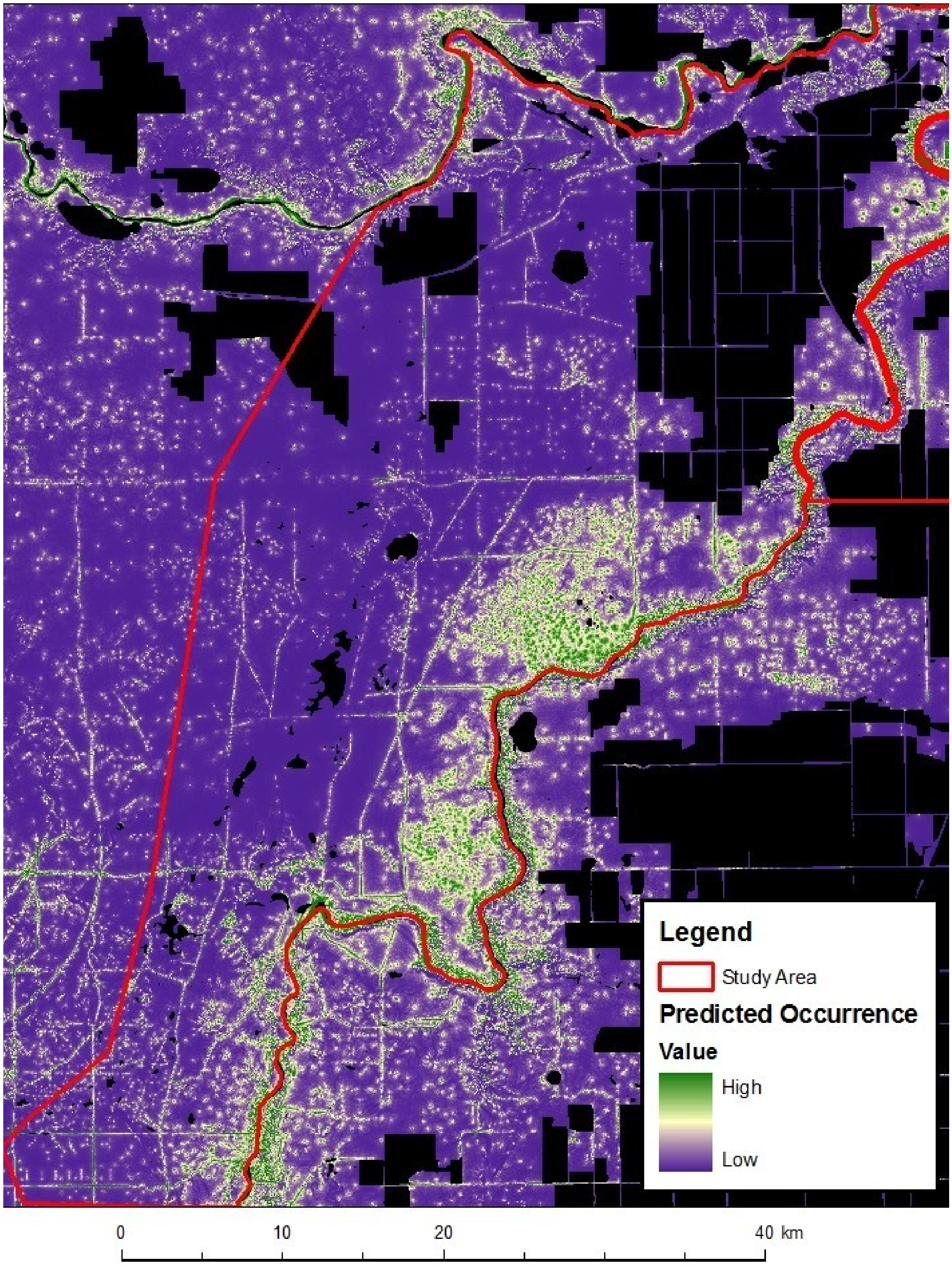

Figure 6. Map of predicted occurrence generated from the RSF model. Black areas indicate regions of non-habitat (e.g., cultivated croplands) that were not considered in the model.

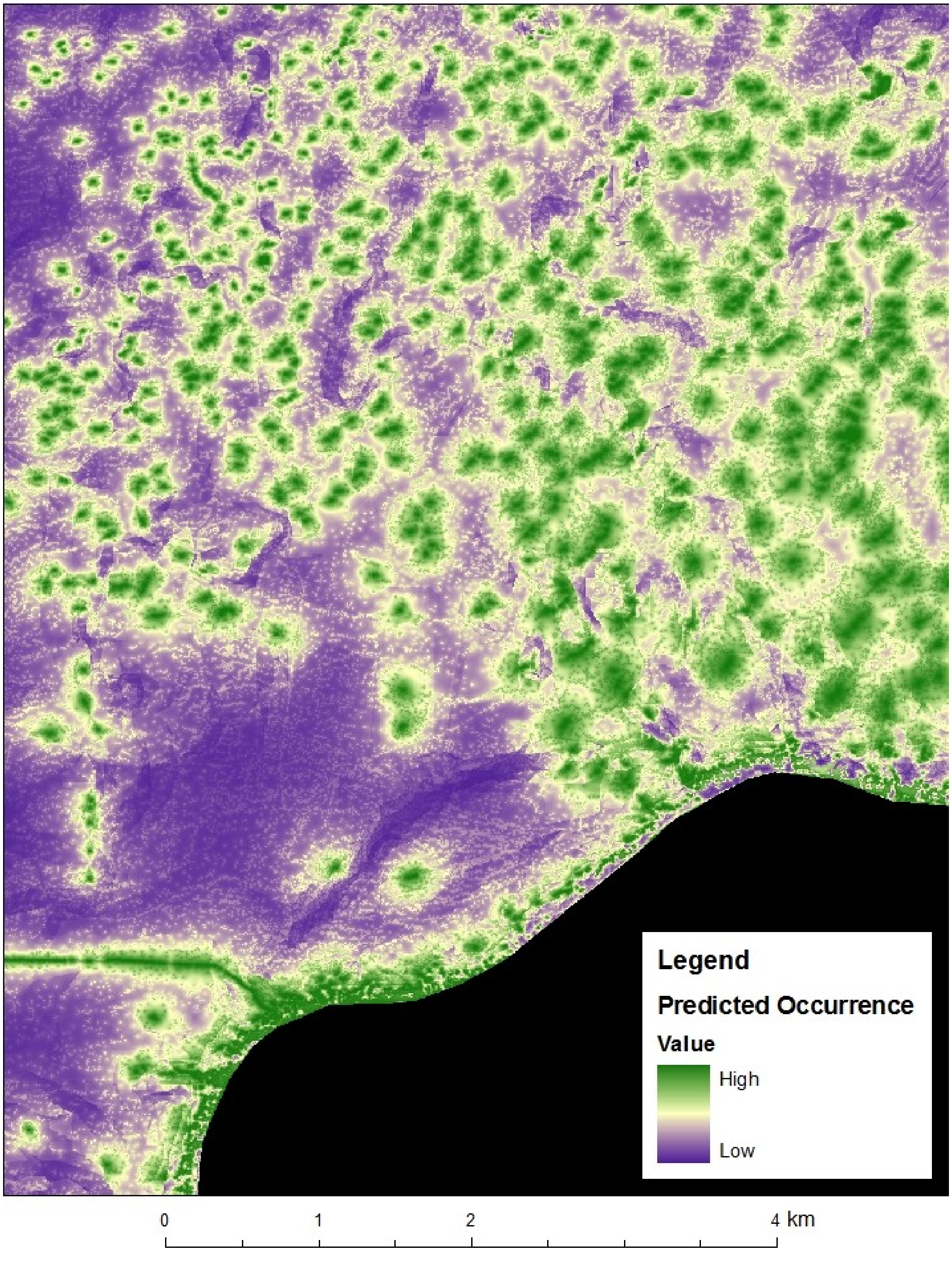

Figure 7. Predicted occurrence map for a portion of the Alberta range of Ord's kangaroo rats illustrating the fine scale detail of the model. Dark green patches generally indicate active and semi-stable sand dunes that represent the most highly selected habitat.

Table 4. Summary of model performance for the kangaroo rat occurrence model, indicating the cumulative proportion of occurrences correctly predicted within each RSF bin (see text) for an independent validation dataset (n = 523).

RSF values	RSF score	Area (%)	Cumulative area (%)	Cumulative # of occurrences (%)
0.997 - 1.000	10	0.08	0.08	10
0.994 - 0.997	9	0.07	0.15	20
0.988 - 0.994	8	0.13	0.27	30
0.977 - 0.988	7	0.26	0.53	40
0.962 - 0.977	6	0.34	0.87	50
0.934 - 0.962	5	0.48	1.35	60
0.889 - 0.934	4	0.66	2.01	70
0.820 - 0.889	3	1.02	3.03	80
0.442 - 0.820	2	8.68	11.71	90
0.000 - 0.442	1	88.29	100.00	100

5. DISCUSSION

The RSF modeling approach provided a clear and easily interpretable predicted occurrence map that reflects selection of habitat by Ord's kangaroo rats in Alberta. The model identifies a number of key habitat features that are selected by kangaroo rats, including active sand dunes, semi-stable dunes, roads or other anthropogenic features, and eroding slopes along the river valleys. Population monitoring over the last 15 years in Alberta has demonstrated that active sand dunes and some sandy roads are consistent places to observe kangaroo rats, supporting their importance in the model. However, the role of semi-stable dunes and river valley slopes has not been extensively studied. There are observations of kangaroo rats occupying both semi-stable sand dunes and exposed soils along the river valleys, but such records are sparse. However, the majority of monitoring efforts are directed at sites with high densities of rats, so it may not be surprising that we have few records in the semi-stable dunes and river valleys despite the relatively high importance in the model. Future research may be needed to determine the extent to which kangaroo rats actually occupy these habitat types, or whether they are superficially similar to other habitats (active dunes, roads) and are simply over-emphasized in our model. We suspect the latter is true, particularly for exposed river valley slopes, because limited surveys conducted on stabilized dunes and eroding slopes along the river valleys have failed to locate significant numbers of kangaroo rats (Gummer and Bender, unpublished data).

An interesting feature of the predicted occurrence map (Figure 6) is that the model emphasizes habitat along the road network. Despite the large amount of roadside habitat, there are surprisingly few occupants in these areas, especially in the spring period following the winter-mortality bottleneck. During the summer period, particularly at the annual population peak near the end of the summer, much of this roadside habitat may become occupied, which is likely driving its importance in the model. A seasonal-occurrence model may be required to discriminate seasonal occupancy and habitat selection.

The model was exceptionally efficient at detecting active sand dune habitats, which are the primary natural habitat for the species. Based on observations from the last five years of standardized population monitoring (Bender et al., unpublished data) these sites tend to support the highest densities of rats, they exhibit the most consistent patterns of occupancy from year to year, and they are most likely to remain occupied after the winter-mortality bottleneck. However, these sites represent an exceptionally small proportion of the landscape (less than 0.5%), despite the fact that they may contain the majority of kangaroo rats contributing to inter-annual population persistence. Thus, we recommend caution when interpreting the predicted occurrence model (Figure 6) because (1) not all habitats identified by this occurrence model are likely to be of equal quality and support large numbers of kangaroo rats, and (2) the total amount of productive habitat may appear greater than actually exists.

Overall, our predictive occurrence model for Ord's kangaroo rats was highly discriminating of kangaroo rat habitats and strongly predictive for an independent validation dataset. The habitat model and resulting spatial map have many applications for kangaroo rat conservation and management. In particular the spatial habitat map is likely to provide a useful basis for identifying and prioritizing areas for: (i) spatially explicit population viability analysis (PVA); (ii) research on effects of habitat characteristics on kangaroo rat behaviour, survival and population dynamics; (iii) additional population monitoring surveys; (iv) monitoring of habitat condition through time; (v) potential restoration of natural habitats; and (vi) potential translocations of kangaroo rats to suitable habitats where kangaroo rats were previously extirpated.

Another common application of predicted occurrence models is to delineate patches of habitat for protection, particularly species at risk of extinction. It is technically possible to choose a threshold RSF value and identify all locations in the landscape that exceed that value. In our model, if a relatively high RSF threshold is chosen, it will identify a small amount of habitat that accounts for a large proportion of the population (e.g., an RSF threshold value of 0.9 would account for less than 2% of the species range and approximately 70% of the population). When such a threshold is applied to the habitat map, a set of relatively discrete patches of natural habitat and discrete network of roadside habitats become apparent, which may be useful for delineating habitat boundaries. If the RSF threshold is lowered, the habitat boundaries expand and the number of rats occurring within increases, although the additional habitat that is included is less certain to be occupied by kangaroo rats overall. Table 4 can be used to predict how the choice of threshold implicates a certain proportion of the study area and proportion of kangaroo rats within it. One note of caution that we wish to emphasize is that regardless of the RSF threshold value chosen, the quality of habitat implicated is always uncertain. For example, some of the highest RSF values obtained in the model are located along roadside habitats. So while these areas have a high probability of being occupied at some point during each year, field research has determined that persistence at these sites may be very low and kangaroo rats inhabiting these areas may not contribute substantively to long-term population persistence. In fact, Teucher (2007) suggests that many roadside habitats in Alberta may act as attractive sinks to kangaroo rats, and these habitats may actually be detrimental to long-term persistence. Thus, occurrence-based habitat models, such as the one presented here for the Ord's kangaroo rat, should not be used as the basis for identifying essential or critical habitats because they cannot discriminate high quality habitats that contribute to population persistence from sink habitats that contribute to population decline. Future research is needed to determine the quality and role of habitats identified by this model before the model can be used as a basis for identifying or protecting critical habitats for the species.

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