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Habitat characterization of *Athene cunicularia hypugaea* (Bonaparte, 1825) in Central-Northern Mexico

Caracterización del hábitat de *Athene cunicularia hypugaea* (Bonaparte,1825) en el Centro-Norte de México

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ABSTRACT

The objectives were to characterize the habitat of the burrowing owl (*Athene cunicularia hypugaea*) and to know the variables related to the presence of the species in Coahuila, Durango, San Luis Potosi and Zacatecas, Mexico. The search for the owl took place from May to October 2018. Localized burrows were geo-referenced and measured. The sites with burrows were characterized, in plots of 20x20 m, from September to December 2018, taking as center the burrows, was measured: slope, aspect, cover of the soil, density of plants, among others. To identify any possible habitat selection by this species; for each active burrow, two randomly established plots were evaluated. The sites with presence were three in Coahuila, one in Durango, four in San Luis Potosí and two in Zacatecas. Based on the results of the Poisson regression analysis, the variables associated with the burrows were: A) height of the burrow entrance, b) height of the burrow mound, c) width of the entry, d) cover of grasslands and e) woody material. The information generated in this study can be used to complement a management plan for the conservation of the species in central-northern Mexico.
Keywords: Burrow, conservation, grasslands, raptors.

RESUMEN

Los objetivos fueron caracterizar el hábitat de la lechuza llanera (*Athene cunicularia hypugaea*) y conocer las variables relacionadas con la presencia de la especie en Coahuila, Durango, San Luis Potosí y Zacatecas, México. La búsqueda de la lechuza se realizó de mayo a octubre de 2018. Las madrigueras localizadas se georreferenciaron y se midieron. Los sitios con madrigueras se caracterizaron, en parcelas de 20x20 m, de septiembre a diciembre de 2018, tomando como centro las madrigueras, se midió: pendiente, orientación, cobertura del suelo, densidad de plantas, entre otras. Para identificar alguna posible selección de hábitat por esta especie; por cada madriguera activa, se evaluaron dos parcelas establecidas al azar. Los sitios con presencia fueron: tres en Coahuila, una en Durango, cuatro en San Luis Potosí y dos

en Zacatecas. Con base a los resultados del Análisis de Regresión Poisson las variables asociadas con las madrigueras fueron: a) altura de la entrada de la madriguera, b) altura del montículo de la madriguera, c) ancho de la entrada, d) cobertura de pastos y e) material leñoso. La información generada en este estudio puede ser utilizada para complementar un plan de manejo para la conservación de la especie en el centro-norte de México.
Palabras clave: Conservación, madriguera, pastizales, rapaces.

INTRODUCTION

The burrowing owl (*Athene cunicularia*) is a species of the order Strigiforme; in North America there are three subspecies; *A. c. floridana*, which is distributed on the east coast of the United States of America; *A. c. rostrata*, endemic to the Revillagigedo Archipelago, Colima, Mexico; and *A. c. hypugaea*, distributed from southern Canada to western Panama (Clark, 1997). In Mexico, *A. c. hypugaea* occurred in 27 States (Enríquez-Rocha *et al.*, 1993). This species has diurnal and fossorial habits; for protection, it uses burrows abandoned by badger (*Taxidea taxus*, Schreber, 1778), desert tortoise (*Goopherus agassizii*, Cooper, 1861) and ground squirrels (*Citellus tereticaudus* Elliot, 1904; *Spermophilus beecheyi* Richardson, 1829; *S. townsendii* Bachman, 1839) (Rich, 1986).

Every animal selects the site that allows it to survive, with food availability, a high possibility of finding a mate and a low risk of predation (Mayor *et al*., 2009). In this regard, the burrowing owl selects open areas with isolated, low-growing shrubs, with visibility to detect predators and prey (Howell & Webb, 1995). It tolerates some level of human disturbance, locating its burrows in agricultural areas, due to the presence of insects (Stuber *et al*., 2018); however, it is exposed to agrochemicals that affect its fertility, laying fewer eggs (Bennett *et al*. 1991) and thin-shelled eggs (Gervais, 2000).
The burrowing owl depends on the grassland ecosystem, and presents drastic declines in its populations (Stanton *et al*., 2018) and distribution (Valencia-Maldonado *et al.,* 2016), mainly due to habitat loss or due to the use of strychnine and carbofuran for rodent control in some Jurisdictions in the United States of America has decreased its population (James & Espie, 1997). In North America, in the last decades the distribution area of the Burrowing Owl has decreased, due to fragmentation, modification of its breeding habitat, decrease of prey and predation (Valencia-Maldonado *et al*., 2016). In addition, the significant population decline has also been reported in several US States and even its extirpation from British Columbia and Manitoba with loss of 73 % of the population and 53 % of the distribution area of the species in the whole USA (Lincer *et al.,* 2018). In northeastern Mexico, in the last 30 years, more than 74 % of medium open grassland has been transformed (Scott-Morales *et al*., 2004), due to the expansion of agriculture, desertification, introduction of exotic species and the growth of urban sprawl (Panjabi *et al*., 2010).

The recovery of species at risk, such as *A. cunicularia hypugaea*, which is subject to special protection in Mexico (SEMARNAT, 2010), requires knowledge of their essential needs for survival. In the United States of America and Canada, the distribution of *Athene cunicularia* (Macías-Duarte & Conway, 2015), population density (Klute *et al*., 2003) food habits (Herse, 2017), genetics (Faircloth *et al*., 2010), health (Franson, 2017; Justice-Allen & Loyd, 2017) and habitat (Rich, 1986; Crowe & Longshore, 2013) have been studied. In Mexico, the population density by land use type of Hermosillo urban area has been analyzed, finding average density of 0.43 owls/km^2 (Valencia-Maldonado *et al.,* 2016). For the southeastern Chihuahuan Desert the diet of the burrowing owl 56.6 % consisted of vertebrates (Ruiz-Aymá *et al*., 2019); for the Mapimí Biosphere Reserve, Durango, Rodríguez-Estrella (1997) found a correlation between grassland associated with *Prosopis-Hilaria* and the reproductive success of this species, but not with the type of burrow, distance to the nearest nest, soil texture or number of perches.

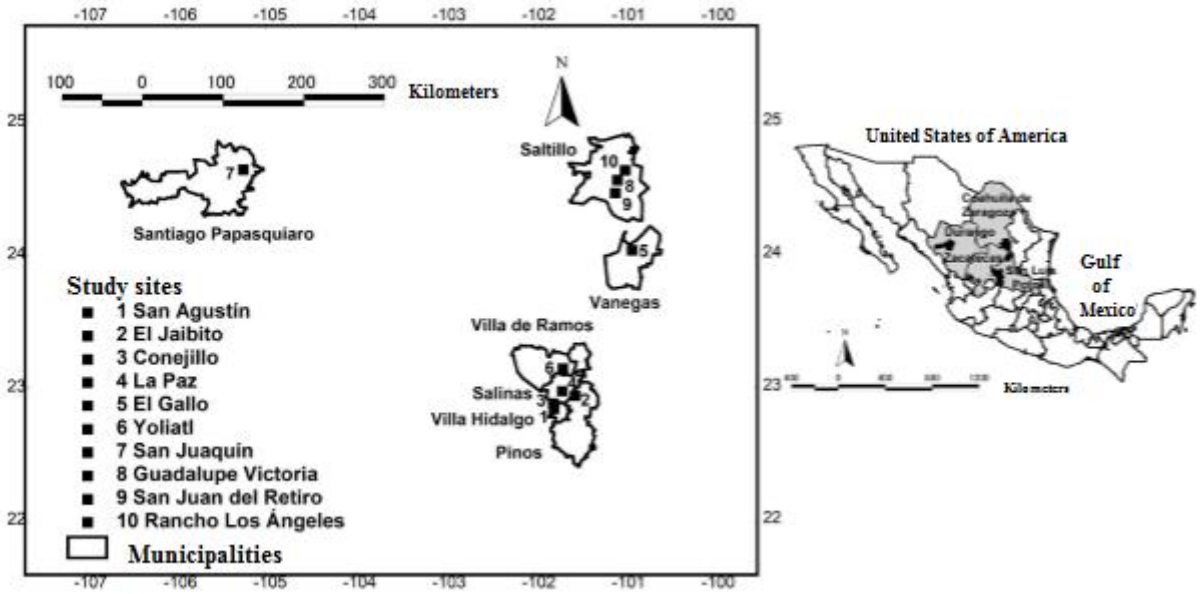

Figure 1. Location of the study sites, own elaboration with data of municipal division and topography scale 1:250,000 from INEGI https://www.inegi.org.mx/datos/

Therefore, the objectives were: a) Characterize the habitat of the burrowing owl and b) Identify the variables that explain the presence of the species in the municipalities of Saltillo, Coahuila; Santiago Papasquiaro, Durango; Salinas, Villa de Ramos, Vanegas, San Luis Potosí, San Agustín, and Pinos, Zacatecas, Mexico. The results of this research contribute to the knowledge of the ecology of the burrowing owl in north-central Mexico and may be useful to manage its habitat in an adequate manner.

MATERIAL AND METHODS

Study area

The research was conducted in ten localities in four states: Conejillo and La Paz, Salinas municipality. Yoliátl, municipality of Villa de Ramos; El Gallo, Vanegas municipality, San Luis Potosí; El Jaibito, Pinos municipality, San Agustín, Villa Hidalgo municipality, Zacatecas; San Julián, Santiago Papasquiaro municipality, Durango; Guadalupe Victoria, San Juan del Retiro and Rancho Los Ángeles, Saltillo municipality, Coahuila (Figure 1). These localities were selected based on unpublished reports of Burrowing Owl presence in those places and discussions with other researchers; in those places there is also land use change and extensive cattle ranching, so they were considered representative of the areas with presence of this species.

In the study areas, or sites, the predominant soil is that with a high calcium carbonate content (Calcisol). The average altitude is 2011 m, with a maximum of 2136 m at Rancho Los Angeles and a minimum of 1715 m at El Gallo. In terms of climate, both arid temperate and semi-arid temperate climates are present in the same number of localities. The dominant precipitation is 300 to 400 mm, with the highest in San Julián; the temperature is mainly temperate and semi-warm; with respect to topography, the terrain is flat (plains) to slightly undulating, which is consistent with the name "llanera" of the owl (Table 1).

Location of burrows

Burrows were located from May to October 2018, through walks in open areas with low vegetation (with height less than one meter) and abandoned burrows, consultation with villagers about sightings, showing them photographs of the species. The search and identification was carried out using SWIFT® binoculars with 12x50 focal coverage. The burrows, georeferenced (decimal coordinates and Datum WGS84) with Garmin Etrex 10® GPS, were recognized by the presence of pellets, remnants of prey, cattle droppings or grass (Haug et al., 1993).

Statistical analysis

Descriptive statistics were obtained with the data of the variables evaluated. Likewise, a Poisson Regression Analysis (PRA) was performed to determine the habitat characteristic variables that are significant in the selection of burrows by the burrowing owl, using a Generalized Linear Model (GLM), the z value was used to calculate the p value of each of the variables used in the model and a $p < 0.5$ was considered. In this model, the variables were selected using the Steepwise (backward steps) method. The link function is used to model data that do not fit a normal curve, thus mapping a nonlinear relationship to a linear one. To compare models, the AIC value was used, which provides a simple

and objective method to select the model that best fits the experimental data (Martínez et al., 2009), and the best Poisson regression model had an AIC of 42.5.

Table 1. Characteristics of the studied areas (elaborated with information from INEGI scale 1:250000 referring to the edaphological, topographical, physiographic, climatic, and land use and vegetation charts series VI, https://www.inegi.org.mx/datos/)

Study area	Main soil	Vegetation and land use	Altitude, m	Topoform	Climate	Rainfalls mm	Temperature
San Agustín	Calcisol	MDM, At	2116	Plain	Árt	300-400	T
El Jaibito	Calcisol	MDM	2116	Descent	St	400-500	T
Conejillo	Calcisol	MDM, At	2097	Plain	Árt	300-400	T
La Paz	Calcisol	MDM, P	2084	Descent	St	400-500	T
El Gallo	Calcisol	P, MDM	1715	Plain	Árt	300-400	S
Yoliátl	Calcisol	MDM, P	2064	Descent	St	400-500	T
San Julián	Phaeozem	P, At	2047	Plain	St	500-600	T
Guadalupe Victoria	Calcisol	MDM, P	1943	Descent	Árt	300-400	T
San Juan del Retiro	Calcisol	MDM, At	1794	Plain	Árt	300-400	S
Rancho Los Ángeles	Leptosol	P	2136	Descent	St	400-500	T

Vegetation and land use: At=Temporary agriculture, MDM=Microphilous desert scrub, P=Natural grassland; Climates: Árt=temperate arid, St=temperate semiarid; Temperature: T=Temperate, S=Semi-warm

Showing graphically the association between *A. c. hypugaea* burrows and significant variables in the PRA, a Simple Correspondence Analysis (SCA, in Statistica 10) was performed. For this analysis, it was necessary that ordinal variables were converted to nominal and were categorized, considering the maximum and minimum values, in centimeters or in percentage, for each variable (Table 2). These variables were used because they characterize burrowing owl habitat and are used by other authors (Pulido *et al*., 2021). To determine possible differences between species density and ground cover, between burrowed and random sites, the Kruskal-Wallis non-parametric test was performed with a significance of α=0.05, in the R studio® software.

Table 2. Keys and intervals of the variables used in the Simple Correspondence Analysis (SCA)

Variable	Key	Interval
Height of burrow entrance (cm)		
Low	AEb	1-15
Medium	AEm	16-24.4
High	AEa	≥ 24.25
Width of burrow entrance (cm)		
Small	ANc	1-14
Medium	ANm	15-22.87
Large	ANg	≥ 23
Size of mound (cm)		
Low	AMb	1- 7.25
Medium	AMm	7.26-12.7
High	AMa	≥ 12.8
Pasture cover (%)		
Low	CGb	1- 3.75
Medium	CGm	3.76-34.7
High	CGa	≥ 34.8
Woody material cover (%)		
Low	CMLb	1-1.25
Medium	CMLm	1.26-5.26
High	CMLa	≥ 5.27

Where: a=High, b=low, m=Medium, c=Small, g=Large. Entrance height

RESULTS AND DISCUSSION

In the burrows (n=32) used by *A. c. hypugaea* (13 in San Luis Potosí, 8 in Coahuila, 8 in Durango and 3 in Zacatecas, Table 3) 41 individuals were recorded. Most of them were located in southern and southeastern exposure (Table 4). This preference may be associated with thermal regulation; when the temperature in the burrow exceeds the acceptable range for owls, they seek cooler places or allocate more energy to maintain homeostasis (Bryan & Bryant, 1999). On the other hand, Mexican spotted owls (*Strix occidentalis lucida*) prefer to roost in sites with northern and northeastern exposure because they present cooler environments (Silva-Piña *et al*., 2018).

30 burrows corresponded to cavities built and abandoned by wild mammals, the others were located in rock formations (Table 4), the use of the latter may be due to scarcity of abandoned burrows (Rich, 1986). The burrows were located at an average altitude of 1972m (Table 4), higher than those reported (1000 m and 1350 m) by Rodríguez-Estrella & Ortega Rubio (1993) for Durango, Mexico, for New Mexico (1358 m) by Berlardelli *et al*.

(2010), for Montana (749 m) in the USA (Restani *et al*., 2001). In Peru they are found from sea level to 4000 m (Pulido et al., 2021).

Table 3. Location of *A. c. hypugaea* burrows in Central-Northern Mexico

State	Municipality	Locality	No burrow	No individuals
S.L.P.	Salinas	La Paz	1	1
		Conejillo	8	11
	Villa de Ramos	Yoliátl	1	1
	Vanegas	El Gallo	3	3
Coahuila	Saltillo	San Juan del Retiro	6	8
		Guadalupe Victoria	1	1
		Rancho Los Ángeles	1	1
Durango	Santiago Papasquiaro	San Julián	8	12
Zacatecas	Pinos	El Jaibito	1	1
	Villa Hidalgo	San Agustín	2	2

Table 4. Mean and standard deviation of the variables evaluated in burrows of Burrowing Owls (*A. c. hypugaea*) in Coahuila, Durango, San Luis Potosí and Zacatecas

Variable	Mean and SD
Elevation (m a.s.l)	1972 ± 160
Slope exposure (%)	South (180°) and Southeast (135°), 25
Slope (%)	1.3 ± 0.4
Animal origin of burrow (%)	93.7
Burrow entrance width (cm)	24.2 ± 8.1
Burrow entrance height (cm)	24.9 ± 10.4
Burrow entrance diameter (cm)	24.6 ± 7.3
Mound height (cm)	16 ± 7
Interior temperature (°C)	18.2 ± 3.7

The average slope was 1.33 ± 0.4 % (Table 4), lower than that recorded in Montana (2.6 %) (Restani *et al*., 2001). These results confirm that the burrowing owl prefers flat or slightly sloping areas (Dechant *et al*., 1999). Similarly, it has been documented that *Cynomys ludovicianus*, whose abandoned burrows are often used by burrowing owls, are established on slopes of less than 10 % (Roe & Roe, 2003). The best Poisson regression model had an AIC=42.05 and 5 variables (Table 5) were significantly associated with burrows of burrowing owls.

Table 5. Results of the Poisson Regression Analysis to identify the association between habitat variables and the presence of *A. c. hypugaea* in Coahuila, Durango, San Luis Potosí and Zacatecas Mexico

Variable	Estimate	Standard error	Z value	Pr(>|z|)
Intercept	4.84655	2.46876	1.963	0.04963*
Burrow entrance height	-0.18494	0.08255	-2.240	0.02506*
Entrance width	0.08655	0.03734	2.318	0.02044*
Mound height	-0.31823	0.12864	-2.474	0.01337*
Grass cover	0.05414	0.01798	3.011	0.00260**
Woody material cover	0.12984	0.04003	3.244	0.00118**

Statistically significant variables (*) and highly significant variables (**)

The average height and width of burrow entrances were 24.9 ± 10 cm and 24.2 ± 8 cm, respectively, greater than those reported in Idaho, USA (14.8 ± 0.7 and 20.2 ± 0.5) (Belthoff & King, 2002). The average diameter (24.6 cm) was similar to that reported by Williford *et al*. (2007) for south Texas (22 ± 1.5 cm). It does not agree with Smith & Belthoff, (2001) that Burrowing Owls prefer burrows with an average diameter of 10 cm. Large burrow entrances can facilitate access to predators such as the coyote (*Canis latrans*, Say,1823), northern fox (*Vulpes velox*, Say,1823) and tlalcoyote (*Taxidea taxus* Schreber,1778).

The average height of the mound was 13.2 cm, higher than that reported by Belthoff & King (2002) (8.4 cm), but lower than that of Poulin *et al*., (2005) (17.3 cm), the higher the mound, the more protection against flooding (Belthoff & King, 2002). Likewise, a large mound is indicative of a burrow with a long tunnel that hinders access to predators (Smith & Belthoff, 2001) and protects owls (Butts & Lewis, 1982). In this regard, *Cynomys* spp and *Spermophillus lateralis*, during breeding, use larger burrows to reduce the risk of predation (Bihr & Smith, 1998).

Grass and bare ground cover (Table 6) were similar (38.9 and 36.0 %, respectively); however, bare ground was not significant in PRA. Cruz-Nieto (2006) for Nuevo León reported 80 % bare soil, 3.4 % grasses and 16.6 % herbs and shrubs. Agricultural activity has been the cause of the degradation of burrowing owl habitat (Scott-Morales *et al*., 2004; Estrada-Castillón *et al*., 2010).

The PRA identified the cover of woody material associated with the selection of burrows, which coincides with the finding of burrowing owls roosting in downed shrubs. This woody material is a source of nutrients (Sánchez *et al*., 2008) for the soil and for detritivorous organisms, which are consumed by the barn owl. Ground cover components, such as those evaluated in this study, influence prey availability for raptors, such as for *Strix occidentalis lucida* (Silva-Piña *et al*., 2018).

Table 6. Means, standard deviations of ground cover, plant density (individuals ha^{-1}) and results of the Kruskal-Wallis analysis (all with 1 degree of freedom) in burrowing and random sites of burrowing owls in Coahuila, Durango, San Luis Potosí and Zacatecas

Cover	Place		χ^2	Prob> χ^2
	Burrow	Random		
Gramineae (%)	38.9 ± 29	44.9 ± 29	0.6719	0.4124
Herbaceous (%)	14.03 ± 16	12.89 ± 14.9	0.2818	0.5955
Woody material (%)	9.8 ±16.3	7.44 ± 14.7	0.0311	0.8599
Rocks (%)	1.60 ± 5.2	0.21 ± 0.77	0.0142	0.9049
Bare soil (%)	36 ± 21	34.5 ± 24	0.1733	0.6771
Plant density (ha^{-1})	245 ± 429	453 ± 786	4.2873	0.0384*

* Statistically significant variable

SCA analysis found an association between the significant variables in the PRA and the evaluation sites. The dimensions explain 54.1 % of the total inertia and show the formation of three groups or sets (Figure 2). The first set included seven sites and it is related to the categorical variables: a) high burrow mound (AMa), b) average width of the burrow entrance (ANm), c) high burrow entrance (AEa), d) percentage of high and medium grasses (CGa, CGm) and e) cover of high and low woody material (CMLa, CMLb). The second set grouped two sites related to: a) average burrow entrance height (AEm) and b) large burrow entrance width (ANg). The third set included a site with average width of burrow entrance (ANm) and average percent cover of woody material (CMLm).

The Kruskal-Wallis analysis (Table 6) identified significant differences in plant density between sites with and without burrows (245 and 453 plants ha^{-1}, respectively), which coincides with that reported by Plumpton & Scott (1993), who mention that owls use areas with sparse vegetation. Some studies mention that shrub species affect grassland birds Coppedge *et al.,* 2008); for example, *Ammodramus savannarum* and *A. henslowii*, avoid nesting in sites close to patches of woody vegetation because in these sites the risk of predation is higher (Cully & Michaels, 2000). Likewise, Thiele (2013) mentions that owls, during the selection of their burrows, avoid areas with the presence of trees, because these constitute perching sites for the raptors that prey on them. Unlike other species of the order Strigiformes, which depend on their sense of hearing for hunting, the barn owl, due to the hunting techniques it uses (running or flying after prey, hovering in the air, observing from a perch), depends on its eyesight (Johnsgard, 2002). In this sense, its hunting success decreases in sites with dense, closed vegetation and presence of tall shrub species, so it prefers open areas to hunt and evade predators (Green & Anthony, 1989). In this research, Burrowing Owl burrows were located in sites with an average visibility of 92.0 % and a low species density, which allows them to monitor their environment. Therefore, invasion of burrowing owl habitat by shrub species should be

avoided and in areas where shrubs predominate, management and habitat restoration actions should be implemented.

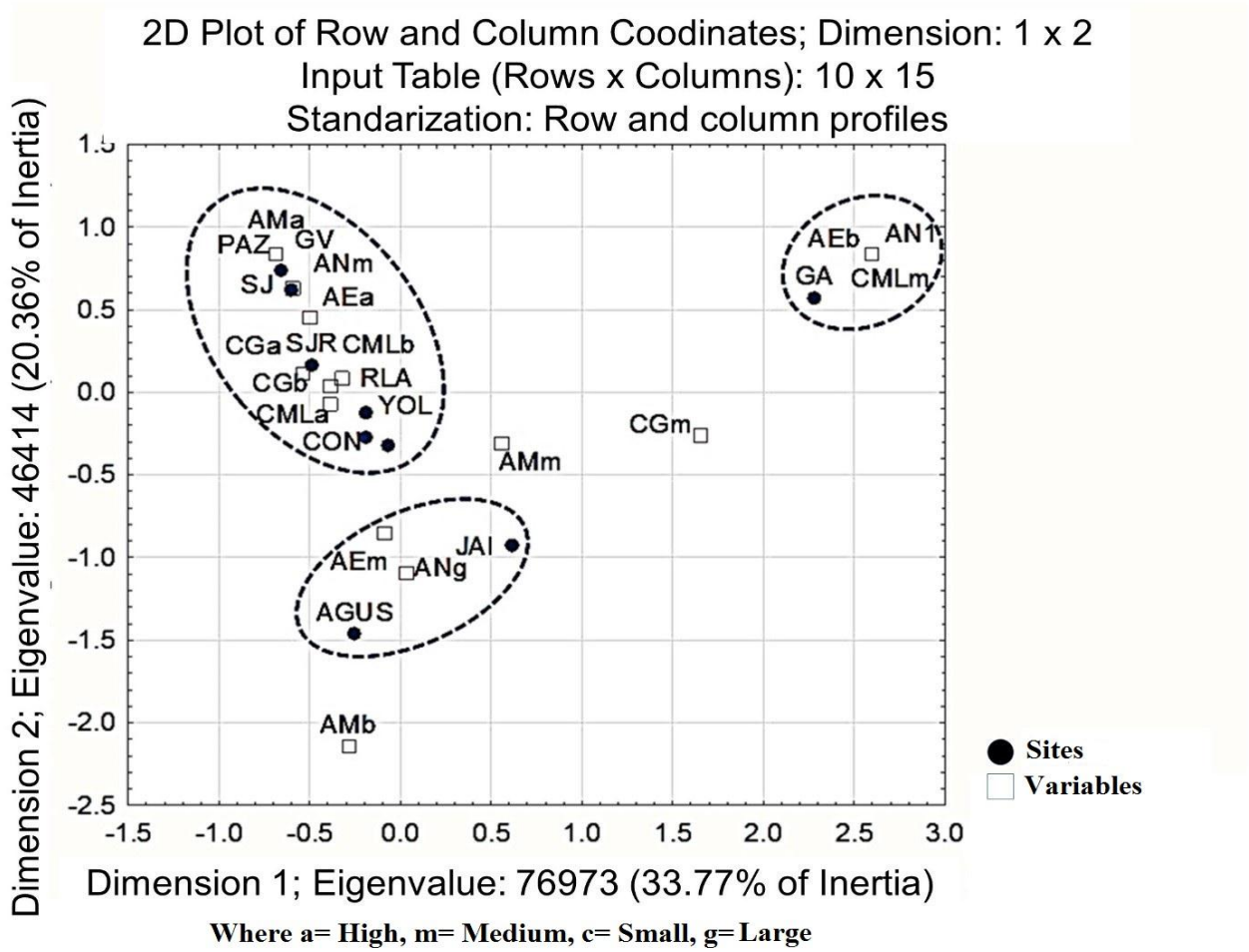

Figure 1. Graphical representation of the Simple Correspondence Analysis of the significant variables in the Poisson Regression Analysis

In the burrowing owl's habitat (burrowing and random sites), 56 plant species grouped into 53 genera and 12 families were identified. In this regard, Cruz-Nieto (2006), reports 33 species for Nuevo León, Mexico, mainly herbaceous and grasses. In the burrow sites, the most frequent plant families were Asteraceae, Solanaceae and Lamiaceae, while in the random sites, Solanaceae, Fabaceae and Asteraceae. At both sites, Asteraceae and Solanaceae families were the most abundant.

Birds are related to the composition and structure of the vegetation, because it provides them with food, where to nest and evade predators, as well as protection in extreme weather conditions, frequent in arid areas (Ruiz-Ayma, 2014). In this sense, MacCraken

et al. (1985) mention that chick rearing coincides with the growth of herbaceous plants, which, during their first flight attempts, provide the chicks with protection against predators.

STUDY LIMITATIONS/IMPLICATIONS

This study contributes important information to the knowledge of the habitat of *A. c. hypugaea* in the southern Chihuahuan Desert. However, it was necessary to study other areas of its distribution to corroborate this information and to understand better its habitat, including its status, which was not possible to address in this study, and the species associated with *A. c. hypugaea*, which will contribute to the management and conservation of this species in the long term.

CONCLUSIONS

The most important burrowing owl habitat variables in the area studied were origin of the cavity, visibility, height and width of the burrow, cover of woody material and rocks. The variables that were associated with owls were burrow entrance height and width, mound height, grass and woody material cover. In order to maintain viable habitats for the burrowing owl and the grassland bird species with which it coexists, it is necessary to adequately manage the pasture, conserve native grasses, and promote their regeneration.

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Errata Erratum

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