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Habitat characteristics of the white-toothed woodrat (*Neotoma leucodon*) in the Potosino-Zacatecan plateau

Características del hábitat de la rata nopalera (*Neotoma leucodon*) del Altiplano Potosino-Zacatecano

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ABSTRACT

The white-toothed woodrat (*Neotoma leucodon*) inhabits the arid zones of north-central Mexico and it is important for rural communities for food and economic income. The objective was to characterize the habitat of the white-toothed *woodrat* in the Potosino-Zacatecano Plateau. In 44 sites with burrows and 44 random sites, the altitude, slope, slope exposure, ground cover: shrubs, grasses, rock, woody material and bare soil, as well as the density of prickly pear cactus, agave, shrubs and palms were recorded. In addition, 21 hunter-gatherers (H-G) were surveyed about woodrat habitat conditions. The *woodrat* builds its burrows in agaves (40.4 %) and 47.6 % of the H-Gs stated that the woodrat was more frequent in prickly pear cactus. Ninety % of the burrows were located on terrain with low slopes (≤ 4 %), where shrub density and cover were dominant (2085.6 ± 1825 ha $^{-1}$, 36.1 ± 17.5%, respectively). Rat burrows are associated with shrubs and cactus, as they provide them with food and protection from predators. The H-G consider that in order to conserve the woodrat it is necessary to allow them to reproduce, establish hunting seasons and maintain the vegetation.

Keywords: Soil cover, local knowledge, density, burrow.

RESUMEN

La rata nopalera (*Neotoma leucodon*) habita las zonas áridas del centro-norte de México y es importante para las comunidades rurales como alimento e ingreso económico. El objetivo fue caracterizar el hábitat de la rata nopalera en el Altiplano Potosino-Zacatecano. En 44 sitios con madrigueras y 44 aleatorios, se registró la altitud, la pendiente, exposición de la pendiente, la cobertura del suelo: arbustivas, gramíneas, roca, material leñoso y suelo desnudo, así como la densidad de nopal, maguey, arbustos y palmas. Asimismo, se encuestaron 21 cazadores-recolectores (C-R) acerca de las condiciones del hábitat de la rata. Ésta construyó sus madrigueras en maguey (40.4 %) y el 47.6 % de los C-R aseguran que la rata es

más frecuente en los nopales. El 90 % de las madrigueras se ubicaron en terrenos con pendientes bajas (≤ 4 %) donde la densidad y la cobertura de arbustivas fueron dominantes (2085.6 ± 1825 ha $^{-1}$, 36.1 ± 17.5 %, respectivamente). Las madrigueras de rata se asocian con arbustos y nopales, ya que les brindan alimento y protección contra depredadores. Los C-R consideran que para conservar la rata es necesario dejar que se reproduzcan, establecer temporadas de caza y mantener la vegetación.
Palabras clave: Cobertura de suelo, conocimiento local, densidad, madrigueras.

INTRODUCTION

Rodents are the largest group of mammals in the world; in Mexico there are about 245 known species of rodents. The genus *Neotoma* is composed of four subgenera (Teonopus, Hodomys, Teonoma and Neotoma), the latter consisting of four species (*albigula*, *floridana*, *lepida* and *mexicana*) (Hall, 1982) and more recently *N. leucodon*, which, through cytochrome-b sequencing was separated from the *N. albigula* group (Edwards *et al*., 2001).

The species distributed in the Potosino-Zacatecan high plateau are *N. leucodon* and *N. mexicana*. The distribution of *N. leucodon* ranges from southeastern Colorado, eastern New Mexico, western Oklahoma and Texas (USA). Southward through Chihuahua, Coahuila, Guanajuato, Querétaro and into central Mexico, (Ceballos, 2010a), while the distribution of *N. mexicana* starts from southeastern Utah and central Colorado, U.S.A., south to western and interior Mexico (Ceballos, 2010b).

White-toothed woodrats, in addition to playing an important role in community dynamics, are prey for some birds and mammals, including humans. In the Potosino-Zacatecan high plateau, this species is used by the rural population as a source of food and for local trade (Márquez-Olivas, 2002). Inhabitants of this area attribute various nutritional properties to this species and consider it to be a safe food, since their diet is based on plant consumption. However, its habitat preferences are unknown.

White-toothed woodrat is territorial, and like other rodents is ecologically important, as it disperses seeds (Schupp *et al.,* 2010) and enhances the regeneration of plant communities (Nathan & Muller-Landau, 2000); likewise, plant communities allow the establishment of diverse rodent populations (Riojas-López, 2012). In addition, rat burrows enhance water infiltration, allow for nitrogen mineralization, and they are refugia for arthropods (Whitford & Steinberger, 2010). *N. albigula* is a generalist and feeds on *Opuntia* spp, *Yucca* spp, *Prosopis* spp and *Agave* spp. (92%), cactus fruits and insects (Sorensen *et al*., 2005); however, little is known about the vegetation influence on the settlement of its populations (Edwards & Bradley, 2002).

N. leucodon is associated with desert scrub (Edwards *et al*., 2001); however, another study showed that *N. leucodon* and *N*. *mexicana* do not prefer any specific vegetation type (Villanueva-Hernández *et al*., 2017). Unlike other species of the same genus such as, *N. lepida*, which requires rocky habitats for thermoregulation (Murray & Smith, 2012). Given such differences, it is required to complement the knowledge related to the vegetation selection by wildlife species. The objectives of this work were: 1) to characterize the white-toothed woodrat habitat (*Neotoma leucodon*) in sites with burrows and random sites; 2) to determine the habitat variables with which the presence of the white-toothed woodrat is mostly associated and 3) to complement the information on habitat characteristics with local knowledge. This study contributes to the knowledge of the genus *Neotoma*, and its results can be considered to improve habitat conditions and establish management plans for this species.

MATERIAL AND METHODS

Study area. This study was conducted during the period from September to December 2017 in the Potosino-Zacatecan high plateau in San Luis Potosí, Zacatecas and Guanajuato states (Figure 1). The Potosino-Zacatecan high plateau is located in the central plain physiographic region of the Mexican high plateau, within the high plateau of central and southern San Luis Potosí and southeastern Zacatecas and includes Aguascalientes and adjacent regions of Guanajuato and Jalisco. The study area is located at coordinates 21°30' to 23°30' NL and 100°45'to 102°45' WL. This zone is characterized by the presence of mountain ranges, hills and plains, with altitudes ranging from 1,000 to 2,600 m. The climate is predominantly dry and temperate. The climate is predominantly dry temperate (BS_0 kw) with rainfall in the summer and winter precipitation between 5 and 10.2% of the annual total, with average temperatures in the warmest month between 12 and 18 °C and the coldest month between -3 and 18 °C (INEGI, 2021). In the plant communities it is common to find succulent, rosetophyllous and microphyllous scrub.

The predominant plant species in the succulent scrub are of the *Opuntia* genus, including: *O. leucotricha*, *O. streptacantha*, and shrub species such as: *Dalea tuberculata*, *Jatropha dioica*, *Mimosa aculeaticarpa*. In the microphyllous desert scrub, *Larrea tridentata*, *Parthenium incanum*, *Prosopis laevigata*, *Zinnia acerosa*. The rosetophyllous scrub is dominated by *Agave lechuguilla*, *Dasylirion acotriche*, *Yucca carnerosana*, Y*. filifera*, and *Salvia ballotaeflora* (Giménez & González, 2011).

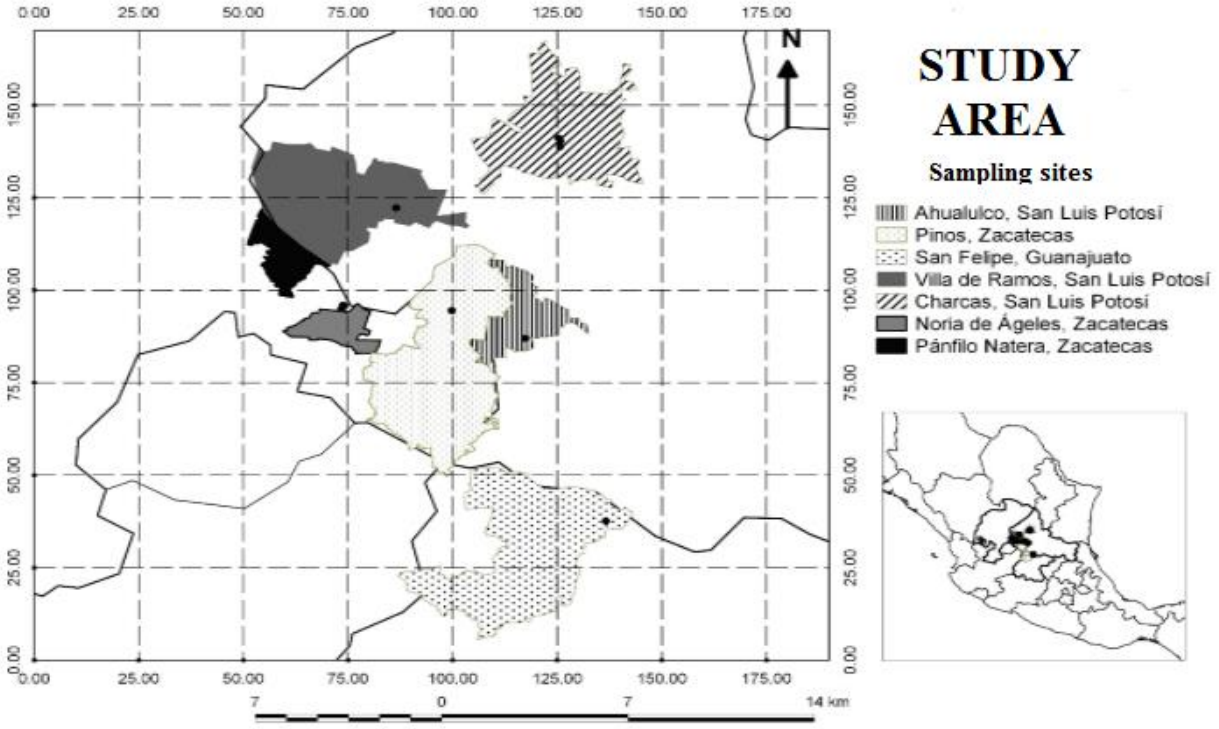

Figure 1. States and municipalities in which the habitat of the white-toothed woodrat (*Neotoma leucodon*) was characterized in the Potosino-Zacatecan high plateau

Habitat characterization. The white-toothed woodrat habitat was characterized in circular plots of 20 m diameter (Solís & Gutiérrez, 1990), considering active burrows as the center and in random sites. Burrows were located with the support of local hunters by means of field trips and active burrows were considered to be those where the construction material was found arranged, with corridors free of vegetation, presence of cactus and gnawed maguey. The sampling of active burrows consisted of selecting those that maintained a distance of at least 50 m between one burrow and another. A random plot was evaluated for each plot established in the active burrows, these were established at 50, 100, 150 or 200 m and in a north, south, east and west direction, considering the home range, whose greatest distance was 50 m for *N. magister* (Hornsby, 2005) and the activity area of *N. fuscipes*, which according to Innes *et al*. (2009) is restricted to the central area of its burrow. Likewise, Cranford (1977) reported that the home range of males and females of *N*. fuscipes was 2 289 m^2 and 1 924 m^2, respectively.

Burrowed and random sites were georeferenced with a Global Positioning System (GPS Garmin Etrex 10) and the following variables were evaluated: a) elevation, b) slope (%) (Suunto PM-5/360 PC clinometer), c) slope exposure (Brunton 5007 compass), d) substrate (plant where the burrow is built), e) number of prickly pear cactus (*Opuntia* spp.), cardenches (*Cylindropuntia* spp.), magueys (*Agave* spp.), palms (*Yucca* spp.) and shrubs, as well as ground cover. To quantify ground cover in the categories of shrubs, grasses, herbaceous, bare soil, woody material and rock, two 20 m Canfield lines were used, each divided into 40 intersecting sections (every 50 cm).

Local knowledge about the white-toothed woodrat. In order to know the perception of hunter-gatherers (H-G) about the use of the habitat by the white-toothed woodrat, its food and some actions that they consider taking to conserve their populations, surveys were applied using the snowball methodology, which consists of asking each person who has been surveyed to recommend other people to be interviewed (Ledesma *et al*., 2002).

Statistical analysis. Descriptive statistics (mean and standard deviations) were obtained for the white-toothed woodrat habitat variables (ground cover and vegetation density). Also, to compare variables´ information of burrowed and random sites, a Kruskal-Wallis nonparametric test was performed in JMP v.13.10 software (2016). To decrease the variance in the set of independent variables (Ground cover categories, plant density, elevation, slope, slope exposure) a Principal Component Analysis (PCA) was performed in R software v. 3.4.3 (R Core Team, 2013). The graphical association of the presence of burrows with the variables that resulted from the PCA was obtained with a Simple Correspondence Analysis (SCA) (Ledesma, 2008) in Statistica v. 13.3 software (2017); for this, ordinal variables were converted to nominal variables and categorized. In all cases, a 95 % confidence interval and $\alpha = 0.05$ were considered. Finally, frequencies and percentages of the variables included in surveys were obtained in Microsoft Excel (2016).

RESULTS

The white-toothed woodrat burrows were located at an average altitude of 2105 ± 87.38 m on low slopes (4 %) and only one was located on a site with a slope of 11 %. Slope exposure did not represent a key habitat component for burrow establishment by *N. leucodon*, as there was no preference for any exposure; however, 12 and 10 burrows were found on northeast (NE) and northwest (NW) exposures, respectively.

In the field it was identified that most of the burrows were built at maguey base (40.9 %) and prickly pear cactus (36.4 %), while 47.6 % of the H-G mentioned that white-toothed woodrats build their burrows in the prickly pear cactus and 33.3 % of them mentioned that in the maguey. However, 42.8% of the H-G said that the rats are bigger when they are in the maguey. The white-toothed woodrat burrows were found where there was a higher density of shrubs and maguey (Table 1).

Table 1. Means and standard deviations of plant density (individual ha^{-1}) in burrowed and random sites in the white-toothed woodrat (*Neotoma leucodon*) habitat of the Potosino-Zacatecan high plateau

	Site	
	Burrow (n = 44)	Ramdom (n = 44)
Maguey	740.1 ± 899	263.3 ± 362.3
Prickly pear cactus	590.3 ± 473.1	413 ± 563.1
Cardenche	102 ± 133.9	122.2 ± 154.7
Shrubs	2085.6 ± 1825	2156.6 ± 2004.9
Palms	28.9 ± 67.9	20.3 ± 47.1

In the burrowed and random sites, the plant density and ground cover variables did not show significant differences (α = 0.05), even though in the burrowed sites a higher density of maguey and prickly pear cactus was found, as well as higher percentages of cover by shrubs and woody material, while random sites were more likely to contain rock, herbaceous and grasses (Table 2). The PCA suggests that, of the 14 variables evaluated, six explain in greater proportion the phenomenon under study (Table 3).

Table 2. Means and standard deviations of ground cover percentages of burrowed and random sites in the white-toothed woodrat (*Neotoma leucodon*) habitat of the Potosino-Zacatecan high plateau

Ground cover (%)	Site	
	Burrow (n = 44)	Ramdom (n = 44)
Shrubs	36.1 ± 17.5	23.1 ± 16
Bare soil	18.6 ± 16.1	19.3 ± 19
Rock	13.6 ± 13.2	23.2 ± 22.4
Woody material	8.4 ± 5.6	1.5 ± 2.6
Grasses	13.4 ± 13.7	18.6 ± 18
Herbaceous	9.9 ± 15	14.2 ± 19.3

Table 3. PCA results for habitat variables of burrowing (44 sites) and random (44 sites) sites in the habitat of the white-toothed woodrat (*Neotoma leucodon*) in the Potosino-Zacatecan high plateau

Variable	Comp. 1	Comp. 2	Comp. 3
ALTITUDE	0.3044	0.2360	- 0.1649
SHR COVER	0.0639	*- 0.5350*	0.2142
GR COVER	- 0.0031	0.2899	0.4895
WOODMC	0.0610	-0.3566	- 0.294
FOR COV	- 0.0846	0.2016	*- 0.5663*
ROCK COV.	*- 0.4076*	0.2375	0.0086
BS COV	*0.4437*	- 0.0717	- 0.0969
SHR DENS	*0.4095*	- 0.0596	- 0.1404
CARDE DENS	0.3586	0.1626	0.1045
MAGUEY DENS	- 0.2506	- 0.3536	- 0.0717
PPEAR DENS	- 0.0257	*- 0.3696*	0.3121
PALMS DENS.	- 0.1699	- 0.2079	- 0.3700
SLOPE	- 0.3746	0.0977	- 0.0047
Importance of components			
	Comp. 1	Comp. 2	Comp. 3
Standard deviation	1.7429231	1.5177777	1.2400455
Proportion of variance	0.2336755	0.1772038	0.1182856
Cumulative proportion	0.2336755	0.4108792	0.5291649

SH COVER= Shrub cover (%), GRA COVER = Grass cover (%), WOODMC = Woody material cover (%), FOR COVER. = forage cover (%), ROCK COV. = Rock cover (%), BS COV = Bare soil cover (%), SHR DENS = Density of shrubs ha $^{-1}$, CARDE DENS = Density of cardenches ha $^{-1}$, MAGUEY DENS = Density of maguey ha $^{-1}$, PPEAR DENS = Density of prickly pear cactus ha $^{-1}$, PALMS DENS = Density of palms ha^{-1}.

The simple correspondence analysis showed a graphic association of variables that resulted from the PCA with the presence of white-toothed woodrat burrows in the study area, which identified the conformation of three groups that are related with an inertia that explains 37.5% (Figure 2). Groups one and three show that the white-toothed woodrat a preference for prickly pear cactus density, shrub cover and density, rock cover, grass cover and bare ground.

66.7 % of respondents mentioned that the white-toothed woodrat bases its diet on the intake of creeping cactus (*O. rastrera*), cardon cactus (*O. streptacantha*) and maguey (*Agave* spp.); therefore, it is considered as a healthy food free of contaminants. Thirty-six percent of the H-Gs stated that the rat can be hunted throughout the year; however, this activity has decimated its populations, as 42.8 % of the H-Gs stated, 38% mentioned that its abundance has remained the same and only 23.8% mentioned that it has increased. However, the abundance of this rat in the Potosino-Zacatecan high plateau is still unknown, as well as its level of consumption and rate of utilization by the local population.

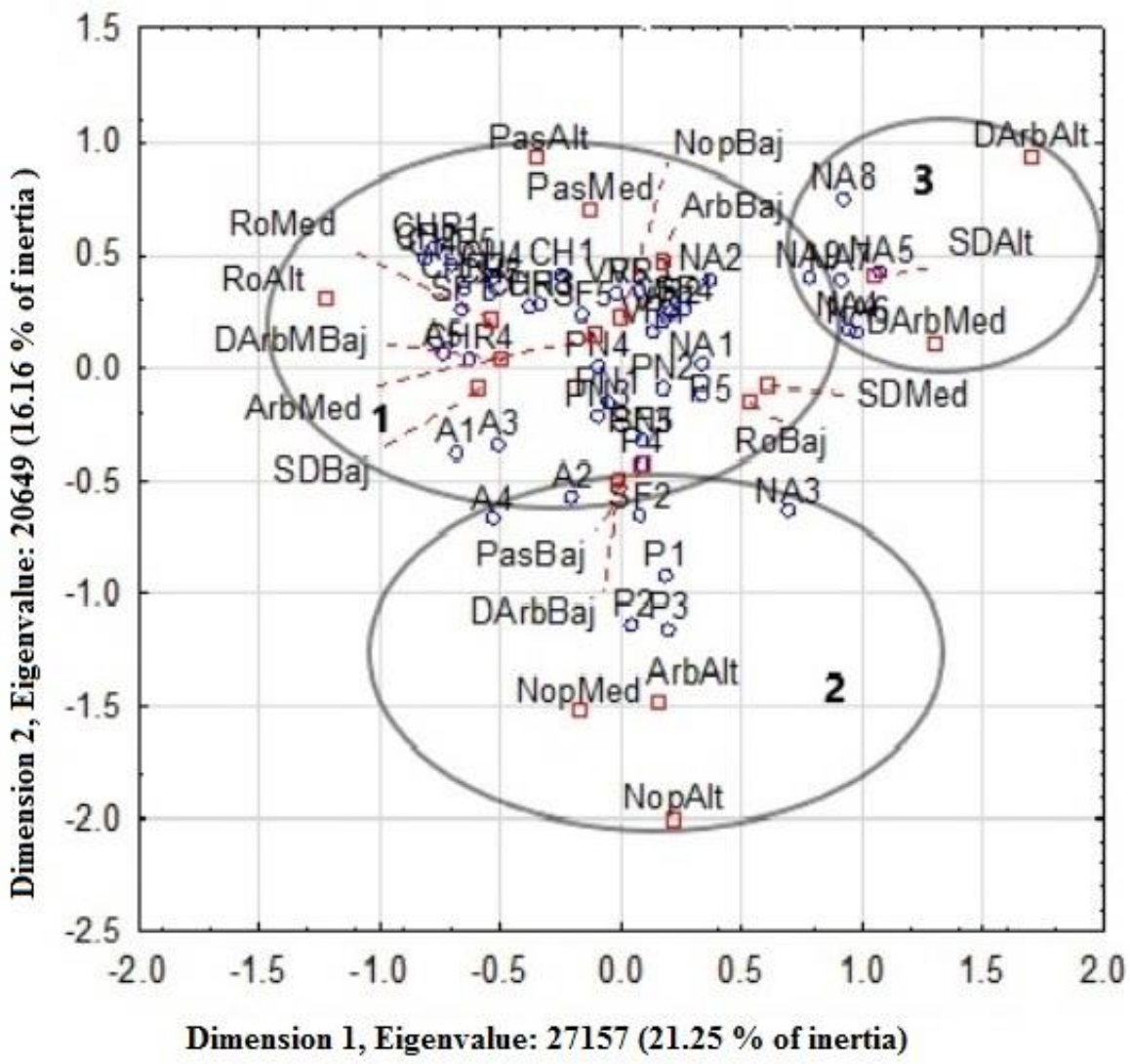

Figure 2. Dimensional representation of the SCA for white-toothed woodrat (*Neotoma leucodon*) presence and categorical habitat variables in the Potosino-Zacatecan high plateau. ° Sites with burrows and ▫ habitat variables; DArbMB= shrub density ha^{-1} very low, DArbBaj= shrub density ha^{-1} low, DArbMed= shrub density ha^{-1} medium, DArbAlt= shrub density ha^{-1}high, ArbMed= shrub cover medium, ArbBaj= shrub cover low, ArbAlt= shrub cover high, RoBaj= rock cover low, RoMed= rock cover medium, RoAlt= high rock cover, PasBaj= low grass cover, PasMed= medium grass cover, PasAlt= high grass cover, NopBaj= low cactus density ha^{-1}, NopMed= medium cactus density ha^{-1} ,SDBaj= low bare soil cover, SDMed= medium bare soil cover, SDAlt= high bare soil cover.

71.4% of the H-G mentioned that there is one rat per burrow and the rest mentioned that when females are lactating this number increases. Therefore, the H-G mentioned that, in order to maintain an adequate abundance over time, it is important to let them reproduce, maintain the vegetation and establish hunting seasons (Figure 3).

It is important to mention that the H-G consider that hunting the white-toothed woodrat is not a sport; they do it out of necessity and because they consider it for medicinal use. The H-G mention that, even though the rats can be used throughout the year, they extract them when they order them for a sick person or when they wish to consume them.

In some places, rat hunting causes damage to vegetation; this happens when the rats are much hidden and it is necessary to dig deep to find them. However, hunters, aware of the impact of this activity, when they cut the cactus stalks to search for and collect rats, make sure to cover them with soil, which they consider to be reforestation. Likewise, in the field visits that were conducted, most of burrows were located in dry maguey where it is easier to obtain them. On the other hand, the H-G do not destroy the burrow completely, since another rat will nest in it; therefore, most of the time they hunt the rats in their local common lands.

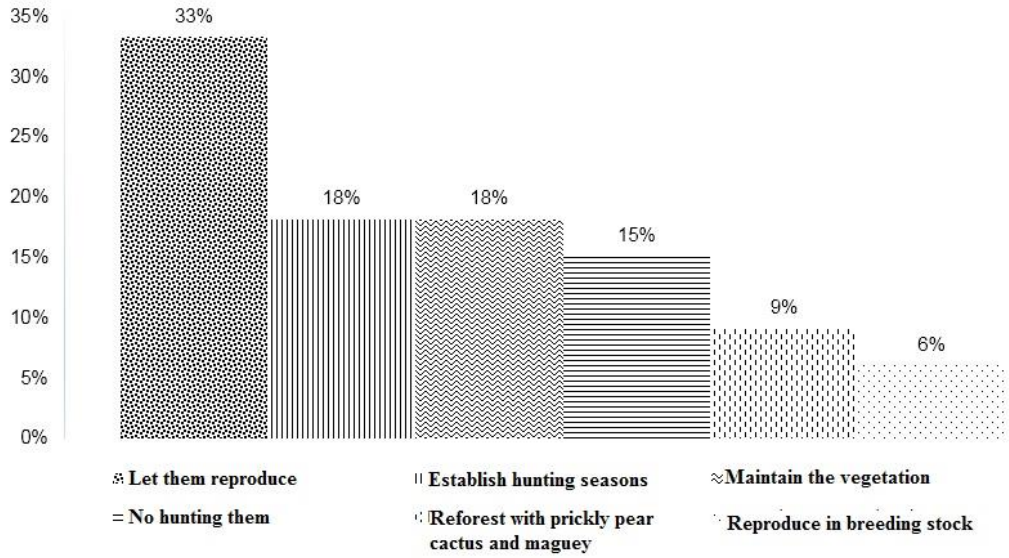

Figure 3. Aspects considered important by the local population to conserve populations of the white-toothed woodrat (*Neotoma leucodon*) in the Potosino-Zacatecan high plateau

DISCUSSION

The construction of burrows at the base of its main food sources (Opuntia spp. and Agave spp.) guarantees proximity to its food and avoids antagonistic intraspecific encounters (De Haro & Martínez-Gutiérrez, 2017); in addition, it provides protection during foraging and the energy expenditure for displacement is lower (Atsatt & Ingram, 1983). Another survival strategy of this species is to protect the entrance of their burrows, as they nest, rest, store food and serve as shelter for other invertebrate species (Innes *et al*., 2007; Whitford & Steinberger, 2010). Protection of the burrow entrance consists of forming mounds of dry plant material, shrub branches and cacti with spines, which allows them to keep predators away, this behavior is also characteristic of *N. lepida* (Murray & Smith, 2012). *N. magister*, *N. lepida* and *N. cinerea*, select rocky outcrops to build their burrows, as it involves less work to protect their burrow and provides them with various forms of escape (Lombardi *et al*., 2017).

The density of shrubs and prickly pear cactus in the desert scrub proved to be an important component of white-toothed woodrat habitat. The prickly pear cactus is a source of food and water for the white-toothed woodrat, while shrubs provide it with building material and a diversity of food. In Arizona, *N. albigula* reached its highest populations at sites where prickly pear cactus is abundant, even when there was no shrub cover and even in open grasslands (Eldridge *et al*., 2009). Unlike *N. leucodon*, *N. albigula* does not associate with prickly pear cactus, but does associate with shrubs (Turkowski & Watkins, 1976) as does *N. fuscipes riparia*, which correlates positively with plant density, as it builds its burrows under shrub cover (Schooley *et al*., 2018). In contrast, in California it has been reported that even though shrub density is an important component of microhabitat, it does not determine the location of *N. fuscipes* (Innes *et al*., 2007).

Shrub, grasses, rock covers, and the presence of bare ground were important components of white-toothed woodrat habitat. Shrub cover not only provides protection from predation, but also improves moisture and temperature conditions for species survival (Slowik, 2015). Similarly, *N. cinerea* is associated with cover from conifers and aboveground logs (Lehmkuhl *et al*., 2006) unlike other studies that mention that *Neotoma leucodon* does not show an association with plant cover (Markovchick-Nicholls *et al*., 2008). However, to determine the habitat preference of the white-toothed woodrat, it is necessary to increase the sampling effort, identify shrub and prickly pear cactus species, and determine their importance value index. The cover of grasses is important, because when food is scarce, they function as a food substitute for the white-toothed woodrat (Eldridge *et al*., 2009). Bare ground cover may not be closely related to the presence of

white-toothed woodrat in the habitat; however, this variable could be an indicator of human disturbances such as livestock grazing and erosive effects caused by wind and rain. It is very likely that the association of the white-toothed woodrat with grass and shrub cover is a strategy to avoid antagonistic encounters and competition in its niche.

A significant reduction of white-toothed woodrat was reported in north-central Mexico, where overharvesting reduced its populations to such a degree that local people believed it to be extinct (Martínez-Calderas *et al*., 2015). However, in the Potosino-Zacatecan high plateau, the abundance of rat is still unknown and there is no information on the exploitation level by the local population. Although internationally, *N. leucodon* and *N. mexicana* are in the category of Least Concern, due to their wide distribution and presumed large population (IUCN, 2016a; 2016b), in Mexico these species are not listed in NOM-059-SEMARNAT-2001 (SEMARNAT, 2010).

Even though the white-toothed woodrat is not under any protection status, in order to avoid overexploitation, it is necessary to establish management plans for sustainable harvesting, establish the harvesting season, and standardize hunting methods. In reference to the recommendations of the H-G to maintain white-toothed woodrats, a System of Management Units for the Conservation of Wildlife and reproduction and breeding centers should be established for reintroduction purposes in habitats such as those reported in the present study.

CONCLUSIONS

Local knowledge of the white-toothed woodrat habitat conditions and field research show that the presence of prickly pear cactus and shrubs (huizaches, gobernadora and rama blanca) are a key component of the white-toothed woodrat habitat, as it depends on them for food. Likewise, the prickly pear cactus provides the substrate for the construction of its burrow and the shrubs provide the material, as well as protection against predators and high temperatures. Although in this research maguey was the main substrate where white-toothed woodrats built their burrows, it was not an important component according to the PCA and SCA.

Undoubtedly, the survival success of the white-toothed woodrat is due to its food range, its adaptability to diverse ecosystems and the ability to build its burrows with the materials available in its habitat. The results of this research and considerations of hunter-gatherers suggest maintaining the vegetation in the white-toothed woodrat habitat, as well as elaborating management plans for a sustainable use of the species in the Potosino-Zacatecan high plateau.

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