Microhabitat characterization in the home range of the Mule deer (*Odocoileus hemionus*) in arid zones

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Knowing the home range of a species helps to identify the resources it needs to survive and reproduce and how this behavior is expressed spatially. Within home ranges, core areas are the sites where the main resources are abundant. The microhabitat is a spatial area composed of variables that can affect individual behavior. In this sense, the characterization of this inner part of the home range can contribute significantly to understanding the elements that these areas offer compared to the rest of the habitat of a population. This work characterized the home range and areas outside it, as well as the core areas of female mule deer on a microhabitat scale in the Chihuahuan Desert, México. The structure and composition of the vegetation were characterized according to three habitat use hierarchies: interior of the core areas and zones within and outside the home ranges of seven female mule deer. A Principal Component Analysis (PCA) was performed, and a hierarchical clustering was used to relate the variables. The variation in structure and composition in each hierarchy was evaluated by performing multivariate permutation tests. Twenty-five plant species were recorded in the transects. The PCA showed the most similar use hierarchies are the core and home range inner areas. The core area presents higher density and cover-dominance values, and the zone outside the home range showed high values of distance to the individual closest to the central point and greater variation in this parameter. The MANOVA indicated a significant variation in vegetation structure and composition in relation to use hierarchies. Significant differences in vegetation structure and composition were found at the microhabitat level between the core area of activity and the zones within and outside the home range. The core area has a greater structural complexity of vegetation, with greater plant coverage-abundance and density; this suggests that the core area is located in a more competitive and saturated environment. Outside the home range, the microhabitat has greater spatial heterogeneity of vegetation, with greater distance and variation of plant cover. Future research could address the spatial (micro-macro) and temporal scales to better understand the ecological dynamics of the species in different habitat use hierarchies.

Conocer el ámbito hogareño de una especie ayuda a comprender cuáles son los recursos que necesita para sobrevivir, reproducirse y cómo este comportamiento se expresa de forma espacial. Dentro de estos, las áreas núcleo representan los sitios donde se encuentran disponibles en mayor abundancia los recursos más importantes. El microhábitat es un área espacial compuesta por variables que pueden llegar a afectar el comportamiento individual, en este sentido, la caracterización de este al interior del ámbito hogareño puede contribuir significativamente en entender qué ofrecen estas áreas en comparación con el resto de su hábitat. En este trabajo se caracterizó el ámbito hogareño y las áreas fuera de este, así como las áreas núcleo de hembras de venado bura a una escala de microhábitat al interior del Desierto Chihuahuense, México. Se caracterizó la estructura y composición de la vegetación dentro de tres jerarquías de uso de hábitat: interior de las áreas núcleo, dentro y fuera de los ámbitos hogareños de siete hembras de venado bura. Se realizó un análisis de componentes principales (PCA) y se empleó un agrupamiento jerárquico para relacionar las variables. Para evaluar la variación en la estructura y composición en cada jerarquía se realizaron pruebas de permutación multivariadas. Se registraron 25 especies vegetales en los transectos, el PCA resolvió que las jerarquías de uso más similares son el área núcleo y dentro el ámbito hogareño. El área núcleo presenta valores más altos de densidad y de cobertura-dominancia y fuera del ámbito hogareño se presentaron valores altos de distancia al individuo más cercano al punto central, así como mayor variación en ellas. El análisis de MANOVA indicó una variación significativa en la estructura y composición de la vegetación en relación con las jerarquías de uso. Se encontraron diferencias significativas en la estructura y composición vegetal a nivel microhábitat entre el área núcleo de actividad, y dentro y fuera del ámbito hogareño. El área núcleo tiene una mayor complejidad estructural de la vegetación, con mayor cobertura-abundancia y densidad de las plantas; esto sugiere que el área núcleo se encuentra en un ambiente más competitivo y saturado. Fuera del ámbito hogareño el microhábitat tiene una mayor heterogeneidad espacial de la vegetación, con mayor distancia y variación de la cobertura. Se sugiere que futuras investigaciones puedan abordar la escala espacial (micro-macro) y temporal para obtener una comprensión más completa de las dinámicas ecológicas de la especie en diferentes jerarquías de uso del hábitat.

Keywords: Core area; habitat structure; habitat use; home range; plant composition.

Introduction

The home range is a subject that has been approached from different questions and perspectives to understand the variables that govern it and how, in turn, these relate to the individual, the family group, or other organisms (Spencer 2012). A home range is formed from daily and short-term movements within a given season and area, and this is the area normally used by an individual to feed, reproduce, raise their offspring, rest, and move (Burt 1943; Powell 2000; Mackie *et al.* 2003). Ultimately, the home range of a species involves understanding which resources it needs to survive and reproduce and how this behavior is expressed spatially (Burt 1943; Börger *et al.* 2008).

Within the home range, core areas are the sites where individuals spend most of the time and, in theory, where the most important resources for individuals of a given species are most abundant (Samuel *et al.* 1985; Asensio *et al.* 2012). Knowing and describing these areas significantly contribute to understanding the distribution and abundance patterns of species, so this information is essential for management and conservation strategies (Börger *et al.* 2006).

On the other hand, the conformation of the home range through time and space is part of the habitat use strategy employed by many species to intensely exploit diverse environments, as is the case of the mule deer (*Odocoileus hemionus;* Mackie *et al.* 2003), which is distributed in temperate and arid zones from southern Alaska to northern México. Throughout this distribution range, the species displays a wide variation regarding the size of its home range and the use of resources (Anderson and Wallmo 1984; Geist 1998). Some studies on its habitat have found that the species prefers sites with heterogeneous vegetation and relief, with slopes above 30 % and obstacles (Geist 1981, 1998; Gallina-Tessaro *et al.* 2019b) although, in contrast, some authors have suggested that the slope is not a habitat selection factor (Pérez-Solano *et al.* 2017). These variables facilitate the escape and protection of individuals because the mule deer typically runs upward in a straight line in hills by making large jumps, changing its trajectory instantaneously and unpredictably, unlike the white-tailed deer (*Odocoileus virginianus*), which uses fast gallop to escape their predators (Gallina-Tessaro *et al.* 2019b).

Likewise, it has been suggested that safety, rather than food, has a higher priority for the mule deer in the choice of habitat (Geist 1998; Hernández *et al.* 2005; Esparza-Carlos *et al.* 2011). Plant cover is one of the main drivers for the species, since it chooses sites with medium plant cover that facilitates visibility and provides protection against predators (Esparza-Carlos *et al.* 2011, 2016). These sites are also used to give birth and shelter the offspring and provide them with protection against temperature extremes (Fox and Krausman 1994; Tull *et al.* 2001; Alcalá-Galván y Krausman 2013; Gallina-Tessaro *et al.* 2019b).

In the Chihuahuan Desert in México, mule deer populations live in geographically isolated patches, often sur-rounded by areas relatively unsuitable for the species due to overgrazing, which negatively influences habitat availability and quality, altering the vegetation structure (Sánchez- Rojas and Gallina 2000a, b; Weber and Galindo-Leal 2005). In this region, the species uses space differentially between seasons and types of plant associations and shows variations between individuals, sexes, age groups, and physiological statuses (Pérez-Solano *et al.* 2016, 2017). Similarly, water is a resource that influences site selection; since individuals do not remain without access to it for long periods, their greatest activity occurs near this resource (Pérez-Solano *et al.* 2017).

Based on the above, it is important to mention that the habitat within the home range of the mule deer in México has not been characterized at the microhabitat level. The available information consists of approximations from assessments at a digital level or without delimiting home ranges (Gallina-Tessaro *et al.* 2019a). According to Morris (1987), the microhabitat is a spatial area composed of variables that can affect individual behavior. In this sense, its characterization within the mule deer home range would contribute to understanding what these areas offer compared to the rest of their habitat and determining the characteristics of core areas, which theoretically offer the best resources. Therefore, the objective of this work was to characterize the home range and the areas outside it, as well as the core areas of female mule deer in a central arid zone of the Chihuahuan Desert.

Materials and methods

Study Area. This study was conducted in the central area of the Mapimí Biosphere Reserve (RBM, in Spanish), located in the Chihuahuan Desert (Figure 1). The local climate is dry and extreme semi-warm, with summer rainfall; the mean annual precipitation is 271 mm. The rainy season runs from July to October, and the dry season from November to June. The mean annual temperature is 20.8 °C, with a mean minimum temperature of 3.9 °C in winter and a maximum of 36.1 °C in summer (Montaña and Breimer 1988; CONANP 2006).

The landscape within the reserve is heterogeneous. Based on the classification by Montaña (1988) and identified by Pérez-Solano *et al.* (2017), there are 11 plant associations named by the most dominant species: 1) *Larrea tridentata* and *Fouquieria splendens*. 2) *Prosopis glandulosa*, *Hilaria mutica*, and *Larrea tridentata*. 3) *Prosopis glandulosa*, *Pleuraphis mutica*, *Larrea tridentata*, and *Opuntia rastrera*. 4) *Hilaria mutica* and *Prosopis glandulosa*. 5) *Larrea tridentata*, *Opuntia rastrera,* and *Fouquieria splendens*. 6) *Opuntia rastrera*, *Agave asperrima,* and *Larrea tridentate*. 7) *Larrea tridentata*, *Opuntia microdasys*, and *Fouquieria splendens*. 8) *Larrea tridentata*, *Agave asperrima*, and *Fouquieria splendens*. 9) *Larrea tridentata* and *Opuntia rastrera*. 10) water-bank vegetation. 11) *Mogote*, *i. e.*, arch-shaped vegetation patches with a main axis perpendicular to the slope, mainly composed by *Prosopis glandulosa*, *Hilaria mutica*, and *Lar-*

rea tridentata. Mogotes are immersed within other plant associations (Montaña 1992).

Habitat Variables. Based on the home ranges and core areas estimated for seven female mule deer living in the RBM (Pérez-Solano *et al.* 2016, 2017), 24 transects were randomly traced assisted with ArcMap 10.0 (ESRI http://www.esri.com), considering a separation of at least 500 m between them. Eight transects were within the core area, eight outside the core area but within the defined home range, and eight outside the home range (Figure 1).

It should be noted that this study only considered female mule deer because only one young male was captured despite a 95-day capture effort over two years; this individual spent half the monitoring time with his mother and then separated (Pérez-Solano *et al.* 2016), so we decided not to include this information to avoid biasing the results.

For the tracing of transects, the home ranges and core areas of each of the seven females were superimposed in such a way that a single polygon could be generated to represent all the home ranges and one for all the core areas because there was an overlap of these areas between the females studied (Pérez-Solano *et al.* 2017). The transects were located at a minimum distance of 500 m from each other and separated at least 1 km between each use hierar-

chy (*i. e.*, core area, home range, and outside zone); only one transect within the core area (T8CA) was located less than 500 m away from another (T5CA) due to terrain conditions (Figure 1). Transects outside the home range were traced based on logistics and access to the area, seeking to represent the site heterogeneity.

To evaluate the microhabitat of the mule deer, we evaluated the vegetation composition and structure in each 800 m transect using point-centered quarters and the nearest-neighbor method (Mueller-Dombois and Ellenberg 1974) at points marked every 100 m. We recorded the distance (m) of the individual closest to the central point, its height (m), and the largest and smallest diameters of the treetop (m). The species was identified based on a previously created photographic catalog (Grajales-Tam, pers. comm.); only organisms measuring 50 cm in height minimum were considered. Additionally, vertical cover was measured using a 2 m ruler placed perpendicularly at 15 m from the point on the transect. With this rule, visible 20 cm sections were counted between the 0 to 50 cm, 50 to 100 cm, 100 to 150 cm, and 150 to 200 cm ranges to estimate the percentage of visibility. To this end, the rule was divided into 10 sections painted alternately black and white (Griffith and Youtie 1988).
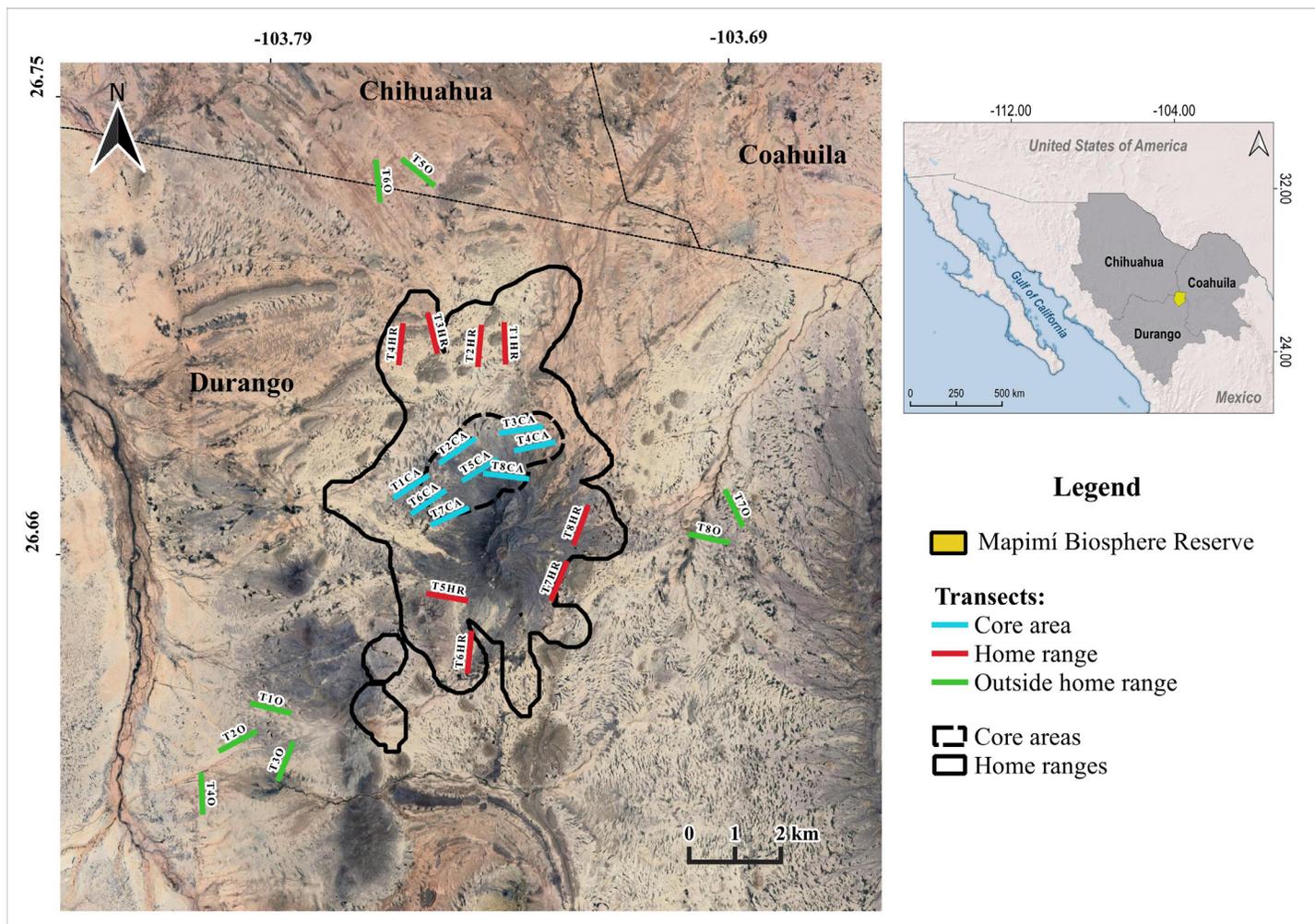
Figure 1. Location of the transects sampled in the core area and the areas within and outside the home range of seven female mule deer in the Mapimi Biosphere Reserve.

Data Analysis. From the variables of vegetation structure, we estimated the following parameters, which were included in the analyses as variables: plant cover (m²; total value, mean, and standard deviation), which was obtained by estimating the ellipse ($C = \pi \times 0.25 \times major\ diameter \times minor\ diameter$); volume (m³; mean and standard deviation), estimated for each individual depending on its shape, either cylindrical (*e. g.*, *Opuntia rastrera*; $Vol_{cyl} = \pi \times r^2 \times h$) or inverted cone (*e. g.*, *Larrea tridentata*; $Vol_{cone} = [\pi \times r^2 \times h] / 3$); vegetation absolute density (ind./100 m²); species richness (number of species per transect), and species dominance by modifying the Braun- Blanquet cover-abundance index (IBB = density x mean cover; Wikum and Shanholtzer 1978).

Similarly, the distance (m) of the individual closest to the central point and the plant height (m) (mean and standard deviation in both cases), as well as the four vertical cover categories (%; mean of each category), were considered variables in the analyses.

Using the 16 variables described above, a Principal Component Analysis (PCA) was performed to represent the set of study units (transects), whose relationships were quantified according to their similarity in structure and composition (Gower 1966; Härdle and Hlávka 2007). The data structure was also visualized with a graphical representation of the groups obtained through the PCA. This approach allowed exploring the clustering of transects at different levels of habitat use hierarchy in the space defined by the first two main components (Wiegleb 1980; Bezuidenhout *et al.* 2012).

We also sought to identify clustering patterns, which provide an understanding of the relationship between habitat use levels (Clarke 1993; Mérigot *et al.* 2010). To this end, we used hierarchical clustering to analyze the characteristics of the microhabitat in the 24 transects, focusing on aspects related to the vegetation structure (height,

cover, density, and volume) and composition (species richness and cover-abundance index; McGarigal *et al.* 2000). Euclidean distances between transects were used to calculate similarities, and a dendrogram was created with the UPGMA method using the base package and dendextend in R (Galili 2015; R Core Team 2023).

The variation in microhabitat structure and composition between the different levels of the habitat use hierarchy was evaluated with multivariate permutation tests (999 permutations; MANOVA) using the *vegan* package in R (Oksanen *et al.* 2022). The complexity of the data was assessed through a dimensionality reduction using the first five Principal Components (which explained more than 90 % of data variance). Furthermore, paired comparisons were carried out as a *post hoc* test between specific pairs of levels, allowing us to examine in detail the differences in the composition of use levels using the pairwiseAdonis package in R (Martinez 2020). This analysis, supported by the use of the PCA, provided a deeper perspective on multivariate variation in the structure of biological communities in relation to the use hierarchy.

Results

Sixteen variables of vegetation structure and composition were measured for subsequent evaluation. These included total, mean, and standard deviation values, summarized in Table 1. The core area was the one that had the highest absolute density (4.6 ± 2.2 ind./m²), and the total plant cover (m²) was highest in transects outside the home range (102.6 ± 17), followed by the core area (76.6 ± 18.9). The mean vertical cover (%) in the four height categories was higher within and outside the home range (Table 1). Core areas attained higher cover-abundance index (10.3 ± 6.5) and species richness (8.5 ± 1.9; Table 2).

Table 1. Description of the variables used in the PCA. Mean values and standard deviations (±) of the transects for each hierarchy of use in relation to the home range of deer are reported.

Variable	Core area	Home range	Outside of the home range
Total cover (m²)	76.6 (± 18.9)	61.7 (± 12.3)	102.6 (± 17)
Mean cover	2.1 (± 0.5)	1.7 (± 0.3)	2.9 (± 0.5)
Standard deviation of cover	1.6 (± 0.4)	1.3 (± 0.3)	2.5 (± 1)
Mean volume (m³)	1.3 (± 0.3)	0.8 (± 0.3)	1.5 (± 0.5)
Standard deviation of volume	1.4 (± 0.4)	0.9 (± 0.4)	1.6 (± 0.9)
Absolute density (ind./m²)	4.6 (± 2.2)	2.9 (± 2.2)	1.2 (± 0.8)
Species richness	8.5 (± 1.9)	7.0 (± 1.7)	5.1 (± 2.3)
Cover-abundance index	10.3 (± 6.5)	5.3 (± 4.5)	3.8 (± 3.2)
Mean distance (m) of the individual closest to the center point	3.1 (± 1.1)	4.5 (± 1.8)	6.9 (± 3.2)
Standard deviation of the distance of the individual closest to the center point	2.2 (± 1.2)	4.0 (± 2.3)	4.7 (± 3.0)
Mean height (m)	1.0 (± 0.1)	0.9 (± 0.1)	1.1 (± 0.1)
Standard deviation of height	0.4 (± 0.1)	0.4 (± 0.2)	0.3 (± 0.1)
Mean cover, 0 cm–50 cm (%)	16.9 (± 7.8)	28.2 (± 8.1)	32.0 (± 7.8)
Mean cover, 50 cm–100 cm (%)	31.3 (± 7.3)	38.3 (± 5.5)	37.7 (± 7.4)
Mean cover, 100 cm–150 cm (%)	43.1 (± 5.0)	45.5 (± 2.1)	45.5 (± 3.7)
Mean cover, 150 cm–200 cm (%)	46.4 (± 4.1)	48.8 (± 1.2)	48.0 (± 2.7)

We recorded 25 species of plants in the transects, considering all hierarchies together; one species could not be identified (Table 2). The core area showed a species richness of 19 species, where the most dominant were *Larrea tridentata* (6.0 ± 5.2) and *Cordia parvifolia* (1.5 ± 0.8). The species richness in the home range was 17 species, the most dominant again being *L. tridentata* (2.5 ± 3.0) and *Opuntia rastrera* (1.0 ± 1.3). Twelve plant species were recorded outside the home range, with a greater dominance of *L. tridentata* (1.9 ± 2.6) and *Prosopis glandulosa* (1.9 ± 1.6).

The first two principal components accounted for 68.8 % of the explained variance, 38.3 % corresponding to PC1 and 30.4 % to PC2 (Table 3). The three levels of use hierarchy showed a different distribution in the plane defined by PC1 and PC2. The most similar use hierarchies were the core area and the zone within the home range. The core area showed higher density and cover-dominance values, and the zone outside the home range showed high values of distance to the individual closest to the central point and greater variation (Figure 2).

According to the hierarchical clustering, seven transects placed outside the home range (T1O–T6O and T8O) were grouped in one cluster, while the 16 transects in the home range were mixed in two groups (Figure 3). Transect T7O outside the home range and T8CA of the core area were not grouped with the rest of the transects corresponding to the sampled use hierarchy.

The MANOVA analysis indicated a significant variation in vegetation structure and composition in relation to use hierarchies ($F = 5.202$, $P = 0.001$; Table 4). Statistically significant differences were observed between the core area and the zone outside the home range ($F = 5.684$, $p = 0.001$) and between the zones within and outside the home range ($F = 6.217$, $P = 0.001$), highlighting the differential influence of these levels on the composition of transects. Likewise, the comparison of the core area vs. the zone within the home range revealed a significant difference ($F = 3.564$, $P = 0.03$), providing greater perspectives on the differences in vegetation composition between habitat use hierarchies.

Discussion

The fauna that inhabits arid ecosystems, including mule deer, has adapted morphologically and physiologically to these sites; these adaptations, together with their behavioral strategies, have allowed them to succeed in habitats with extreme conditions (Ward 2018). One of these behavioral strategies is the movement patterns that define the home range and the core areas of activity within these, which theoretically represent the best combination of habitat variable conditions (Samuel *et al.* 1985). This study

Table 2. Species recorded in the core area, home range, and zone outside the home range. The mean values and standard deviations (±) of the number of individuals (*n*) and the cover- abundance index (IBB) recorded by transect are reported.

Especie	Core area		Home range		Outside home range	
	n	I_{BB}	n	I_{BB}	n	I_{BB}
Agave asperrima	3.0 (± 1.6)	0.3 (± 0.2)	4.2 (± 2.9)	0.6 (± 0.6)	1.3 (± 0.6)	0.04 (± 0.04)
Atriplex canescens	-	-	-	-	16.5 (± 17.7)	0.8 (± 1.0)
Castela erecta	1.8 (± 1.0)	0.3 (± 0.3)	2.2 (± 2.0)	0.4 (± 0.4)	3.0 (± 2.1)	0.1 (± 0.1)
Cordia parvifolia	2.0 (± 1.4)	1.5 (± 0.8)	4.2 (± 2.9)	0.6 (± 0.6)	-	-
Cylindropuntia imbricata	2	0.1	1	0.1	-	-
Echinocereus enneacanthus	1	0.03	-	-	-	-
Euphorbia antisyphilitica	0.1 (± 0)	0.2 (± 0.2)	7	1.2	-	-
Flourencia cernua	1.6 (± 1.3)	0.4 (± 0.4)	1.6 (± 0.5)	0.1 (± 0.1)	3.0 (± 1.4)	0.4 (± 0.2)
Fouquieria splendens	1.5 (± 0.5)	0.5 (± 0.5)	2.3 (± 1.3)	0.6 (± 0.4)	-	-
Haplopappus sp.	-	-	1.5 (± 0.7)	0.1 (± 0.01)	1	0.2
Jatropha dioica	2.8 (± 1.0)	0.8 (± 0.8)	2.0 (± 0.9)	0.4 (± 0.5)	-	-
Krameria grayi	1	0.1	-	-	3.5 (± 0.7)	0.2 (± 0.1)
Larrea tridentata	16.3 (± 7.8)	6.0 (± 5.2)	17.8 (± 8.6)	2.5 (± 3.0)	11.7 (± 9.5)	1.9 (± 2.6)
Lippia graveolens	0.1 (± 0)	0.2 ± 0.2)	-	-	-	-
Opuntia leptocaulis	0.1 (± 0)	0.2 (± 0.2)	0.1 (± 0)	0.1 (± 0.1)	2.0 (± 0.8)	0.2 (± 0.2)
Opuntia macrocentra	-	-	1	0.02	1.0 (± 0)	0.1 (± 0.1)
Opuntia microdasys	1.5 (± 0.7)	0.9 (± 0.3)	-	-	-	-
Opuntia rastrera	6.5 (± 3.0)	1.2 (± 0.6)	3.6 (± 3.0)	1.0 (± 1.3)	2	0.2
Prosopis glandulosa	3.3 (± 1.5)	1 (± 0.5)	6.0 (± 5.0)	0.9 (± 0.8)	15.8 (± 9.5)	1.9 (± 1.6)
Sarcomphalus obtusifolius	-	-	2.5 (± 2.0)	0.3 (± 0.4)	-	-
Vachellia farnesiana	-	-	4.7 (± 5)	0.3 (± 0.2)	4.5 (± 4.9)	0.5 (± 0.7)
Vachellia vernicosa	1	0.2	-	-	-	-
Parthenium incanum	2.0 (± 1.0)	0.2 (± 0.1)	-	-	-	-
Chrysactinia mexicana	4	0.2	-	-	-	-
Sp1	-	-	3	0.19	-	-
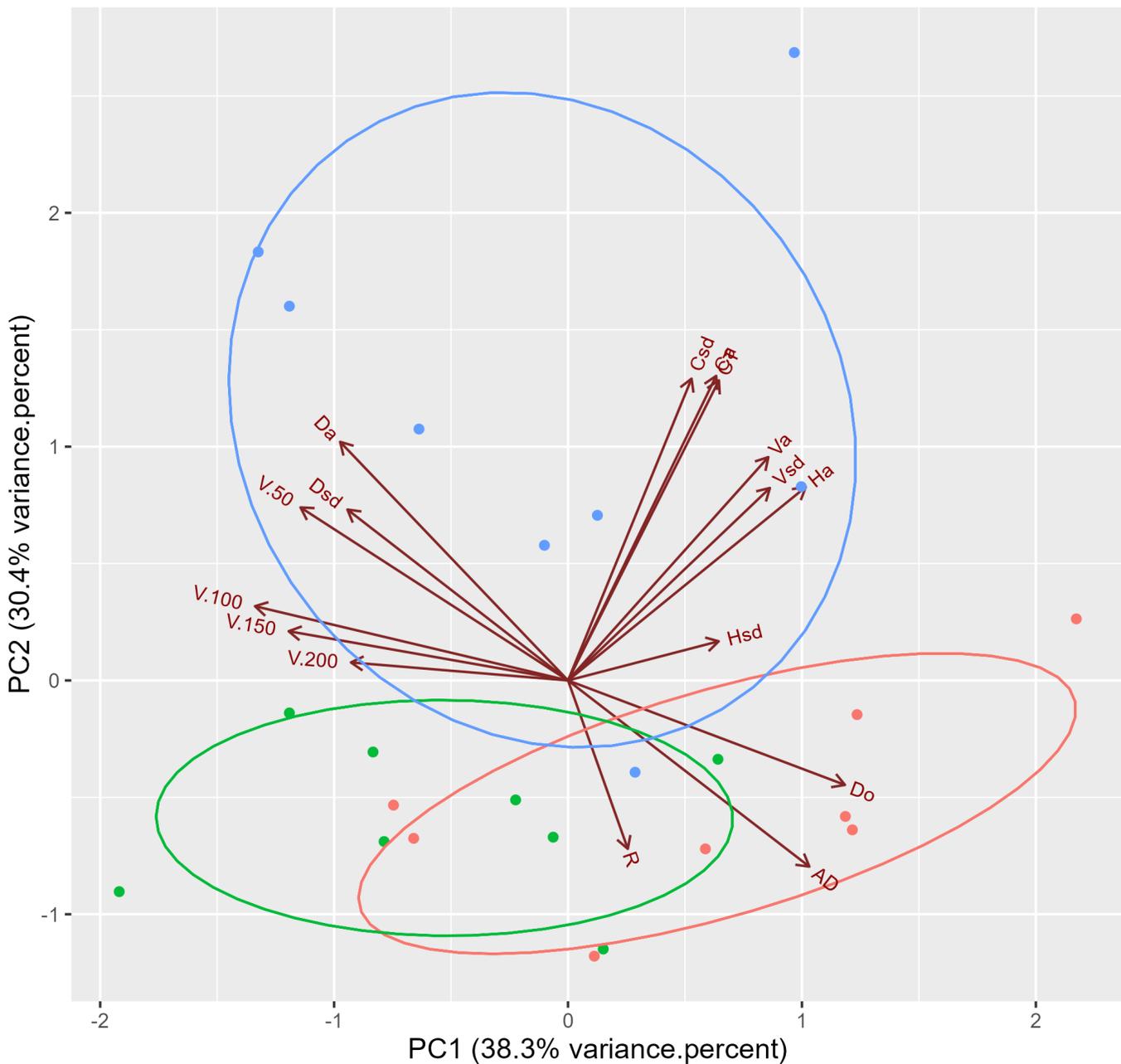
Figure 2. Principal Component Analysis of the vegetation structure and composition variables in the core area and the areas outside and within the home range of seven female mule deer. The red color represents the core area, green represents the home range, and blue represents outside the home range. Total cover (CT), Mean cover (Ca), Standard deviation of cover (Csd), Mean volume (Va), Standard deviation of volume (Vsd), Absolute density (AD), Species richness (R), cover-abundance index (Do), Mean distance (Da), Standard deviation of distance (Dsd), Mean Height (Ha), Standard deviation of height (Hsd), mean vertical cover, 0 to 50 cm (V-50), mean vertical cover, 50 to 100 cm (V-100), mean vertical cover 100 to 150 cm (V-150), mean vertical cover, 150 to 200 cm (V-200).

found statistically significant differences in vegetation structure and composition between the areas of each use hierarchy (core areas, within the home range, and outside the home range), indicating differences in microhabitat within each of them. This finding could explain why female mule deer spend most of their time resting and displaying movement patterns within delimited areas such as home ranges (Pérez-Solano *et al.* 2017, 2019).

The Principal Component Analysis and hierarchical grouping revealed the spatial and structural differences between the deer use hierarchies. The first two principal components showed a clear separation between the core

areas, zones within the home range, and zones outside the home range, suggesting the existence of specific factors that determine the plant composition of each area; this approach allowed us to get a deeper insight of the spatial organization of the vegetation. PC1 represents a gradient of vegetation structural complexity, where high values indicated greater cover-abundance, density, height, and mean volume, and low values showed a higher variation coefficient for height at different levels. The core area had high values in PC1, which reveals greater structural complexity of vegetation, with higher plant cover- abundance and density; this suggests that the core area is in a more

Table 3. Microhabitat variables in the first five principal components and percentage of variance explained by each axis.

Variable	PC1	PC2	PC3	PC4	PC5
Eigenvalues	6.14	4.87	1.49	1.14	0.78
Proportion of variance	0.38	0.30	0.09	0.07	0.05
Cumulative proportion	0.38	0.69	0.78	0.85	0.90
Total cover (m²)	0.17	0.39	0.13	0.13	0.06
Mean cover	0.17	0.39	0.11	0.10	0.03
Standard deviation of cover	0.14	0.39	-0.05	-0.14	-0.16
Mean volume (m³)	0.23	0.29	0.22	-0.19	-0.16
Standard deviation of volume	0.23	0.25	0.13	-0.42	-0.24
Absolute density (ind./m²)	0.28	-0.24	0.29	0.05	0.13
Species richness	0.07	-0.22	-0.27	-0.64	-0.23
Cover-abundance index	0.32	-0.14	0.29	0.13	0.24
Mean distance (m) of the individual closest to the center point	-0.26	0.31	-0.07	0.09	-0.06
Standard deviation of the distance of the individual closest to the center point	-0.25	0.22	-0.30	0.04	-0.09
Mean height (m)	0.27	0.25	-0.16	0.04	0.29
Standard deviation of height	0.17	0.05	-0.42	-0.31	0.70
Mean cover, 0 to 50 cm (%)	-0.31	0.22	-0.06	0.08	0.19
Mean cover, 50 to 100 cm (%)	-0.36	0.10	0.07	-0.11	0.17
Mean cover, 100 to 150 cm (%)	-0.32	0.06	0.38	-0.27	0.12
Mean cover, 150 to 200 cm (%)	-0.25	0.02	0.46	-0.34	0.31

competitive and saturated environment, with more interactions between species (Powell and Mitchell 2012; Ward et al. 2018).

On the other hand, PC2 represents a gradient of vegetation spatial heterogeneity, where high values indicate greater plant cover, distance, and standard deviation of plant cover, and low values indicate higher density, species richness, and cover-abundance. Outside the home range, the microhabitat showed a greater spatial heterogeneity of vegetation, with greater distance and variation in plant cover. These findings suggest a more heterogeneous and dispersed environment outside the home range, with fewer resources and competition (Threlfall et al. 2016).

The MANOVA confirmed the significant variation in vegetation structure and composition between use hierarchies, indicating that the use of space by mule deer is a response to the available resources (Gallina-Tessaro et al. 2019b). The variability in the measured variables reflects not only the variation in plant species richness and cover-abundance between areas but also key aspects of vegetation structure, such as density and vertical cover. The formation of different clusters for core areas, zones within the home range, and zones outside the home range suggests the existence of specific dynamics that may be associated with factors

such as the intrinsic characteristics of each area or potential disturbances.

The vegetation variables that most influenced core areas are absolute density and the cover-abundance index, which showed high and medium total cover values. These reflect what has previously been reported for the mule deer, *i. e.*, its association with areas that have medium vegetation cover (*e. g.*, between 15 % and 50 % vertical cover), which provides them with shelter against extreme temperatures and suitable spaces to give birth and shelter for fawns (Fox and Krausman 1994; Tull *et al.* 2001; Alcalá-Galván and Krausman 2013) without losing adequate visibility to detect predators (Sánchez-Rojas and Gallina 2000a; Esparza-Carlos *et al.* 2011, 2016). Likewise, the core areas had high values of species richness, which plays a central role in habitat selection by mule deer (Sánchez-Rojas and Gallina 2000a). In contrast, this variable has sometimes not been statistically significant in determining habitat use. This is attributed to the fact that deer constantly move as a strategy of protection against predation and have a varied diet adapted to the habitat, in particular the rosettophyllous scrub with plants such as agaves and prickly-pear cactus associated with steep-slope areas (Geist 1981; Cossio-Bayúgar *et al.* 2015), plant associations, and closeness to water bodies (Pérez-Solano *et al.* 2017).

On the other hand, plant density has been shown to be positively correlated with habitat use by mule deer (Lozano-Cavazos *et al.* 2018). For example, in years with scarce precipitation, the species concentrates its activities in areas with greater forage availability, including candelilla (*Euphorbia antisyphilitica*; Esparza-Carlos *et al.* 2011), which was recorded only in the core area and in the rest of the home range. However, although the distribution of mule deer in the landscape is not uniform, it has been reported to be strongly influenced by water availability, relief heterogeneity (Sánchez-Rojas and Gallina 2000a, b), and precipitation, which is inversely related to population size (Hernández-Silva 2018). This could explain why the time delay in the sampling does not alter the results obtained regarding mule deer presence and habitat use in the RBM.

The cover-abundance of plant species was two-fold within the core area relative to the rest of the home range. *L. tridentata* was the dominant species with the highest cover and abundance in both hierarchies. This result was expected because this species has a broad distribution in the region (Montaña and Breimer 1988) and is present in all plant associations considered (Pérez-Solano *et al.* 2017).

Table 4. Results of the MANOVA that compared the variation in microhabitat structure and composition between the core area, home range, and outside the home range (use hierarchy) of female mule deer.

	DF	Sum of squares	R2	F	Pr(>F)
Use hierarchy	2	109.85	0.3313	5.2022	0.001
Residual	21	221.73	0.6687		
Total	23	331.58	1		
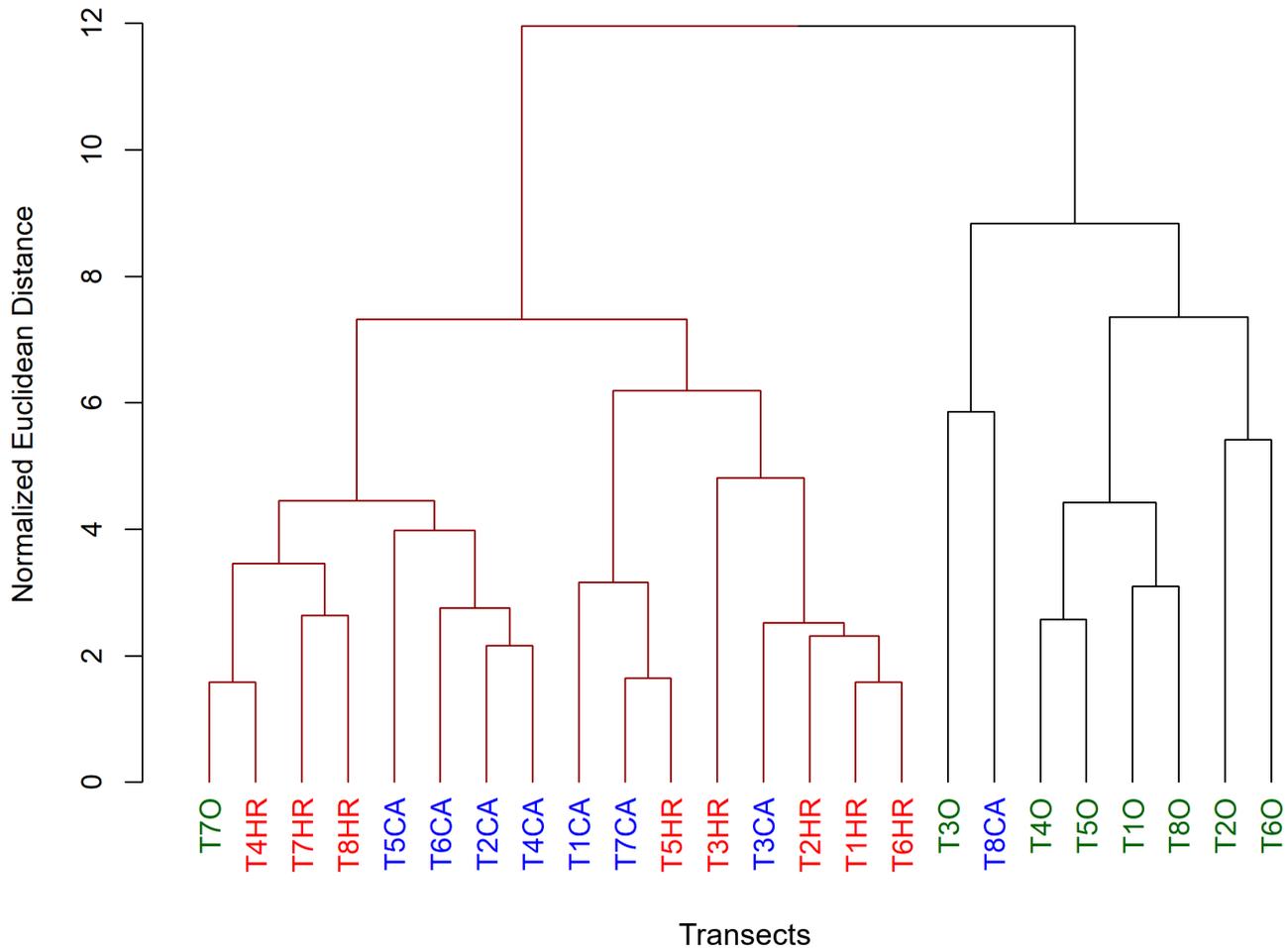
Figure 3. Dendrogram of the vegetation structure and composition variables in the core area and the areas outside and within the home range of seven female mule deer. The black branch marks the clustering of most transects sampled outside the home range. The red branch shows the transects within the home range and core area combined.

Additionally, *L. tridentata* has leaves all year round and can reach a sufficient size to cover a deer, providing them with protection against extreme temperatures and predators.

Finally, this study aimed to offer a detailed view of the structure and composition of the vegetation in different mule deer habitat use hierarchies, specifically the core areas and those within and outside the home range. Despite these revealing findings, this study has some limitations, such as the time scale, since vegetation phenology (Gallina *et al.* 2017) and precipitation patterns have been detected to influence habitat use by mule deer (Hernández-Silva 2018). Future research can address these limitations to better understand the characteristics of vegetation in different habitat use hierarchies. Overall, the results reported here contribute significantly to understanding the ecology of mule deer in arid zones, particularly in México.

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