Research Article

Classification of vegetation types in the habitat of white-tailed deer in a location of the Tehuacán-Cuicatlán Biosphere Reserve, Mexico

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Abstract

This paper classifies the vegetation types that comprise the habitat of the white-tailed deer *Odocoileus virginianus* at a location within the Tehuacan-Cuicatlan Biosphere Reserve (TCBR) in Mexico. The vegetation was sampled, identified, and mapped at 308 points distributed along 28 transects (each of 500 m in length). To determine the effect of the classified and mapped vegetation types on the white-tailed deer, we estimated population density using the PELLET procedure based on the pellet-group count method. The principal vegetation types at the study site are tropical dry forest (TDF, 63% of the area) dominated by tetecho (*Neobuxbaumia tetezo*), uña de gato (*Mimosa* spp.) and mulato (*Bursera* spp.), and crassicaule scrub dominated by mantecoso (*Parkinsonia praecox*). The TDF can be sub-classified into four spatially different clusters (vegetation types) depending on the dominance of these species. The white-tailed deer population density varied significantly depending on vegetation type. Our results contribute to the ecological knowledge of the white-tailed deer in tropical habitats and are of value for the implementation of effective conservation and management.

Key words: *Odocoileus virginianus*, tropical habitat, multivariate analysis, R, PELLET, UMA.

Resumen

En este artículo se clasifica los tipos de vegetación en el hábitat del venado cola blanca *Odocoileus virginianus* en una localidad en la Reserva de la Biosfera Tehuacán-Cuicatlán (TCBR) en México. La vegetación fue muestreada en 308 puntos a lo largo de 28 transectos (500 m). Para saber si los tipos de vegetación afectan al venado cola blanca, se estimó la densidad poblacional empleando el método de conteo de grupos fecales y el procedimiento PELLET. Los principales tipos de vegetación son bosque seco tropical (TDF, 63% de la superficie) dominado por tetecho (*Neobuxbaumia tetezo*), uña de gato (*Mimosa* spp.) y mulato (*Bursera* spp.), y el matorral crassicaule dominado por mantecoso (*Parkinsonia praecox*). El TDF se puede subdividir en cuatro diferentes grupos espacialmente diferenciados dependiendo de la dominancia de las especies. La densidad de venados varió significativamente dependiendo la clasificación de vegetación. Los resultados permiten entender la ecología del venado cola blanca en hábitats tropicales y pueden ser útiles para su conservación.

Palabras clave: *Odocoileus virginianus*, hábitat tropical, análisis multivariado, R, PELLET, UMA.

Introduction

The characterization, classification and evaluation of the habitat of the white-tailed deer *Odocoileus virginianus* are common objectives in many studies and are important for the management of populations and habitats of this species [1]. For example, such studies explain the relationships between habitat variables (vegetation, climate, topography and others) and population density and habitat use [e.g. 2-4]. Vegetation types (plant communities) have been the criteria by which to define different habitat units at landscape level [5-7], and tools such as multivariate analysis have a long tradition in ecological studies and wildlife management [8]. The objective of clustering is to recognize discontinuous subsets in an environment that is sometimes discrete but normally perceived as continuous in ecology [2]. Hierarchical clustering methods allow the predetermination of numbers of groups into dendrograms and the plotting of additional information pertaining to the clustering [9]. This information can be used to determine and map habitat and vegetation types for a given species.

The white-tailed deer is the principal game species in North America, where its management and monitoring are common practices [1]. In contrast, few data exist concerning the ecology of this species in Neotropical habitats [10, 11]. In this region, the white-tailed deer is important because it is used by indigenous and rural people to complement their diet and, in some areas, as a commercial and game trophy [12]. However, intense hunting pressure and habitat loss have negatively affected the population of this deer in the tropics [13]. Monitoring of populations, habitat, and human factors that affect this species is therefore fundamental to appropriate management and conservation strategies. At specific sites, management practices are known by different names, depending on the country; for example, "*ranchos,*" "*cotos de caza,*" and "*wildlife management units*." In Mexico, they are called Management Units for Wildlife Conservation (UMAs, by their Spanish acronym) [14].

The white-tailed deer is one of the most prized species for subsistence and trophy hunting in different regions in Mexico [15-18]. In the UMAs scheme, this deer represents one of the main species exploited in the tropical regions [19-21]. This species inhabits the Tehuacan-Cuicatlan Biosphere Reserve (TCBR) [22, 23], which is highly important for biodiversity conservation [24]. In this region, both subsistence and trophy hunting are common practice. Previously, Ramos-Robles et al. [23] analyzed habitat-density relationships in four locations in the TCBR in order to determine the habitat (vegetation and topographic) and human variables associated with deer density. In this paper, we present: 1) a classification of vegetation types using multivariate cluster analysis and a Geographic Information System; 2) a comparison of the population density of white-tailed deer based on the maps used to classify vegetation types; and 3) suggestions for the management of this species in the study area, which is one of the first UMA in the TCBR where sustainable use of white-tailed deer is practiced.

Methods

Study area
The study was conducted on the communal lands of San Gabriel Casa Blanca in the municipality of San Antonio Nanahuatipam in the state of Oaxaca, Mexico (17° 39' - 18° 53' N, 96° 55' - 97° 44' W; Fig. 1a). The site is located within the region La Cañada on its border with the Oaxacan Mixteca. The community of approximately 5,700 ha forms part of the Tehuacan-Cuicatlan Biosphere Reserve (TCBR), which covers an area of 490,187 ha in the southeast of the state of Puebla and northeast of Oaxaca [24]. The community features a semi-desert climate with an average temperature of 24° C. Rainfall occurs in summer, and average annual precipitation is 438 mm. The municipality of San Antonio Nanahuatipam belongs to the Papaloapan region; the Salado and Calapa rivers are the largest watercourses, providing a permanent supply of water for the community and wildlife. The area has three permanent water channels, which are utilized for domestic use and irrigation. The site consists of rough terrain between canyons, hills, and mountains such as Nanahualtepec, Cihualtepec, and Petlanco. Land use in the municipality is composed of 8% agriculture, 1% urban, 63% tropical dry forest, and 28% crassicaule scrub. The land is distributed among small common and private property; 80% of the population is mainly engaged in cultivating sugar cane, tomatoes, corn, beans and melons, and raising cattle and goats [25].

According to the Forest Series III inventory by INEGI [26], San Gabriel Casa Blanca has two main vegetation types: tropical dry forest and crassicaule scrub. Tropical dry forest is characterized by the dominance of woody plants of 8 to 10 m in height, with the dominant trees losing their foliage during the dry season (Fig. 1b). The most characteristic species are: tetcho (*Neobuxbaumia* spp.), mulato/copal (*Bursera morelensis, B. aptera, B. arida* and *B. schlectendalii*). Other species are uña de gato (*Mimosa Luisana*), cubata (*Acacia cochliacantha*), jiotillo (*Escontria chiotilla)*, pochote (*Ceiba parviflora*), oreganillo (*Lippia graveolens*) and mala mujer (*Cnidosculus tehuacanensis*). The crassicaule scrub plant community is characterized by large numbers of thick-stemmed succulents and succulent-stemmed, succulent, large-sized and chandelier-shaped plants. This vegetation type mainly

develops on undulating terrain with outcrops of granitic material in alluvium of diverse origin. The most representative species are: nopal (*Opuntia* spp.), cardonal (*Pachycereus pringlei, Pachycormus discolor*), viejitos (*Cephalocereus columna-trajani*), xoconostle (*Stenocereus stellatus*), mezquite (*Prosopis leavigata*, and lechuguilla (*Hechtia podantha*) [27].
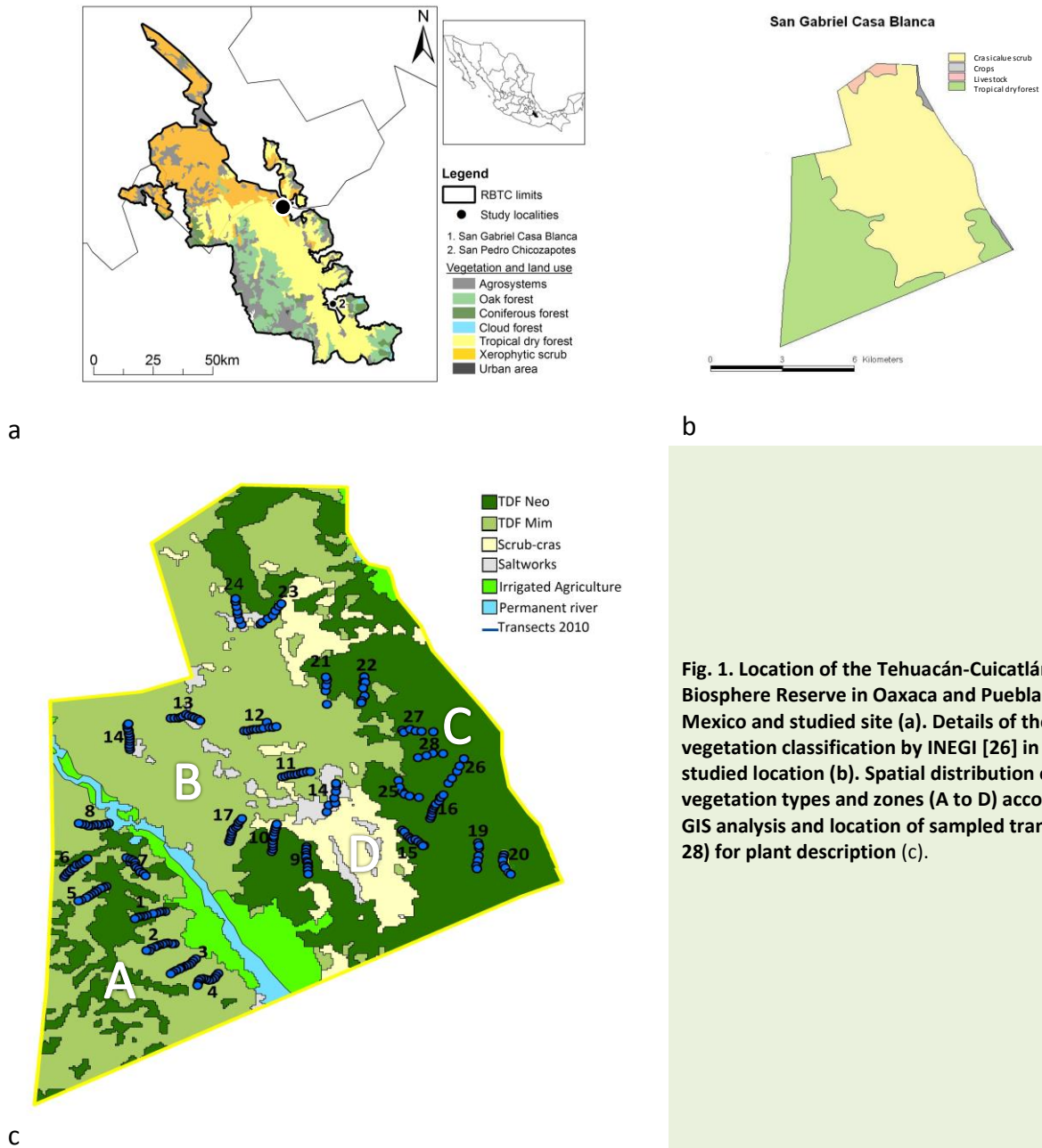

a

b

c

Fig. 1. Location of the Tehuacán-Cuicatlán Biosphere Reserve in Oaxaca and Puebla states, Mexico and studied site (a). Details of the vegetation classification by INEGI [26] in the studied location (b). Spatial distribution of the vegetation types and zones (A to D) according to GIS analysis and location of sampled transects (1-28) for plant description (c).

Geographic Information System analysis

According to studies of land use and vegetation cover [24, 26], there are two vegetation types in the study area, but according to our objectives and field observations this information is inadequate. We therefore evaluated the patterns of land use with Landsat 8 images in the GIS Idrisi v. 16 using the modules *segmentation*, *segtrain, maxlike* and *segclass* [28]. Following the teledetection process, we used Cartalinx 1.1 software to correct possible classification problems. These analyses were used to map vegetation types, including other landscape elements such as terrain, slope, watercourses, hills, and roads.

Vegetation sampling

During the dry season (March to May) of 2010, we established 28 transects (500 m) for vegetation characterization following the general procedures used in other studies of this deer species [23, 29-32]. Eleven sampling units were established every 50 m along each transect for a total of 308 sampling points. At each point, we sampled the trees using the point-centered quarter method to estimate: 1) tree variables (species composition, richness, Shannon diversity index, basal area, height and density) and 2) understory variables (species richness, and protection cover at 0-50 cm and 51-100 cm). We sampled in circular plots of radius 2 m in order to determine the number of species [31].

Multivariate analysis

To determine different vegetation types in the study area, we used hierarchical agglomerative clustering methods on the species abundance data per transect through multivariate cluster analyses. The original matrix was 28 transects per 58 tree species; however, for the purposes of the cluster analysis, we eliminated those species with fewer than 10 individuals and grouped the species of the genus *Bursera.* The analyzed matrix was therefore 28 transects x 21 "species," and the data were normalized prior to analysis. We used the procedures described in Bocard et al. [9], which include the packages in the program R: *ade4, vegan, gclus, cluster*, *ape, RColorBrewer, labdsv, mvpart* and *MVPARTwrap.* Specifically, we computed the matrix of Euclidian distances followed by four clustering methods using the function *hclust* of the *stats* package in R. The methods employed were single linkage, complete-linkage, average agglomerative (UPGMA) and Ward's minimum variance.

To interpret and compare the hierarchical clustering results, we used the cophenetic correlation, Shepard-like diagrams and Gower´s distance index [9]. To identify interpretable clusters (k-groups), we decided at what level to cut the dendograms by plotting the fusion level values for each clustering method. In addition, we explored the silhouette width graphs as a measure of the degree of membership of each transect to its cluster, using the function *silhouette* of the package *cluster*. Finally, to examine the species content of the clusters according to the group memberships, we used the function *vegemite* of the package *vegan*.

Statistical analysis

We present the results and graphs of the clustering that we considered the most ecologically interpretable according to the previous criteria. However, in some cases, two clustering methods and different dendrogram cutting values produced relatively different numbers of groups. The spatial plot of the clustering results was therefore superimposed on the vegetation type map obtained by GIS, in order to compare the k-groups (clusters) obtained with multivariate analysis. To test differences in vegetation variables (tree density, tree height, tree basal area, tree richness, understory cover and understory richness) among vegetation types (clusters), we used one-way analysis of variance [33]. We tested ANOVA assumptions using the Saphiro-test to confirm normality of the residuals and the Bartlett-test to determine the homogeneity of variances. Where these tests were rejected, we used the non-parametric Kruskal-Wallis test. All analyses were run in R version 2.15.3 [34].

Deer population density

To estimate the spatial and temporal variation in population density of white-tailed deer, we used the indirect method of counting pellet-groups [35]. We surveyed 28 strip-transects (500 x 2 m) during the dry season of 2010. Pellet-groups could be collected following the fecal standing crop (FSC) or re-sampling the same plots two or more times (FAR, Fecal Accumulation Rate). Previously, Camargo-Sanabria & Mandujano [35] discussed the advantages and limitations of the FAR and FSC for census pellets in other tropical dry forests. In this study, we used the FSC method, visiting each sampling plot only once and counting the total standing crop of fecal material accumulated during the dry season. According to previous studies in tropical dry forests [19, 20, 23, 30, 32, 35], fecal loss is minimal during the dry season, whereas in the rainy season, the fecal decay rate is almost 100% from June to December. Moreover, visibility is low in the rainy season, as understory plants are at their most dense and the probability of detection of feces is therefore lower. Surveys were carried out by two or three persons.

To estimate population density, we employed PELLET version 2.1, which is a semi-automatized procedure in Excel ® [36]. PELLET approaches density calculation by assuming that density has a probabilistic distribution depending on variation in the parameters of defecation rate, time of persistence of the fecal pellet-groups, and the pattern or spatial distribution of the fecal pellet-groups. For statistical analysis, the density estimated in each transect was grouped according to criteria: the vegetation types defined by the INEGI [18] and the clusters obtained by multivariate analysis and SIG analysis. For each case, we compared the density using one-way ANOVA and the post-hoc Tukey HSD test in the program R.

Results

Vegetation map

Identification and mapping of different vegetation types were achieved through SIG considering the spatial distribution of the principal tree species, slopes, watercourses, human activities and other landscape elements (Fig. 1c). According to this SIG and the distribution of the principal trees, we defined the following vegetation types: tropical dry

forest (TDF), dominated by *Neobuxbaumia* (Neo) and *Bursera* (Bur) (zone A, Fig. 2a), TDF dominated by Bur, *Parkinsonia* (Par) and *Opuntia* (Opu) (zone B, Fig.2b), TDF dominated by Neo (zone C), crassicaule scrub (zone D), human salt works and irrigated agriculture along the course of the river. This map differs from the vegetation types presented in Fig. 1b.

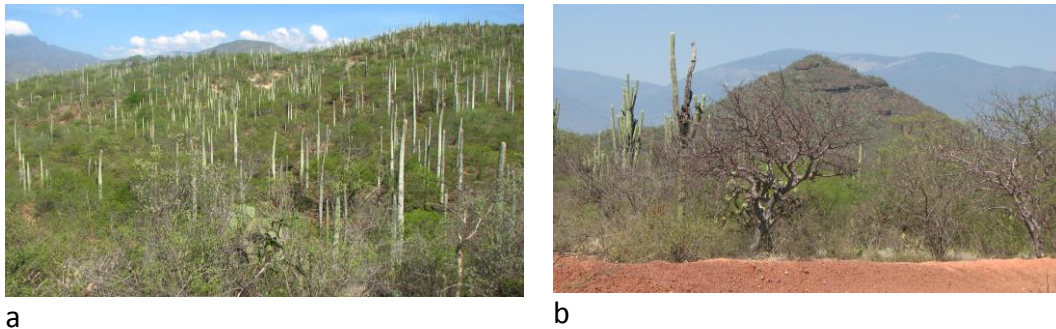a   b

Fig. 2. Landscape photographs of typical forest dominated by the columnar cactus tetecho (*Neobuxbaumia*) (a), and the tropical dry forest dominated by mulato (*Bursera*), nopal (*Opuntia*) and uña de gato (*Mimosa*) species (b).

Vegetation characterization

We counted a total of 1,232 trees of 58 species belonging to 20 plant families. The most frequently represented families were Cactaceae (12 spp.) and Burseraceae (10 spp.). Six families had two to four species, while 12 families were represented by a single species. The genera and species with the highest numbers of individuals were *Neobuxbaumia tetezo*, *Bursera* spp., *Mimosa* sp., *Parkinsonia praecox*, and *Opuntia* with 246, 216, 112, 88, and 65 individuals, respectively, representing 61.1% of the total number of trees counted. The spatial distribution of these tree species showed a particular pattern: *Neobuxbaumia* is found on hillsides with steeper slopes, while *Bursera* grows on shallow slopes (Fig. 3).

Vegetation classification

The four clustering methods (single linkage, complete-linkage, UPGMA and Ward) produced slightly different dendrograms. Calculation of the cophenetic distance coefficient suggests that UPGMA was the optimum clustering method for the matrix data. According to the final dendrogram, which produced four groups or clusters of transects (Fig. 4), the heat map of the double ordered matrix (Fig. 5), the spatial distribution of the 28 transects classified in the four groups (Fig. 6), the SIG analysis (Fig. 1c), and the abundance distribution of the principal genus (Fig. 3), the following is a general description of each cluster: *Cluster 1*: corresponds to tropical dry forest (TDF) dominated by *Neobuxbaumia* in hillside mountains in the zone C of the studied locality. *Cluster 2*: corresponds to transects dominated by *Mimosa* particularly in shallow slopes, but this cluster did not present clear spatial boundaries. *Cluster 3*: co-dominated by *Bursera* and also patches of crassicaule scrub dominated by *Parkinsonia*; this cluster is present in zone B. *Cluster 4*: dominated by *Neobuxbaumia* and *Bursera* in hillside mountains of Zone A. No transect was classified as
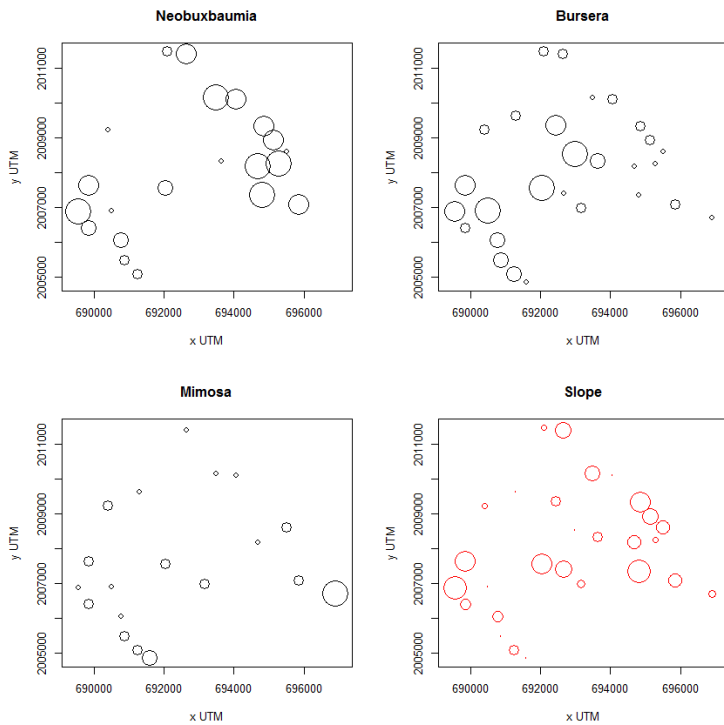
crassicaule scrub (Zone D).

Fig. 3. Spatial distribution of the tree genus with the highest abundance (61.1% from 1,232 trees) in the 28 sampled transects, and slope variation in the studied site (right-down graphic). The size of the circle is proportional to the number of individuals of each species and slope (in red).
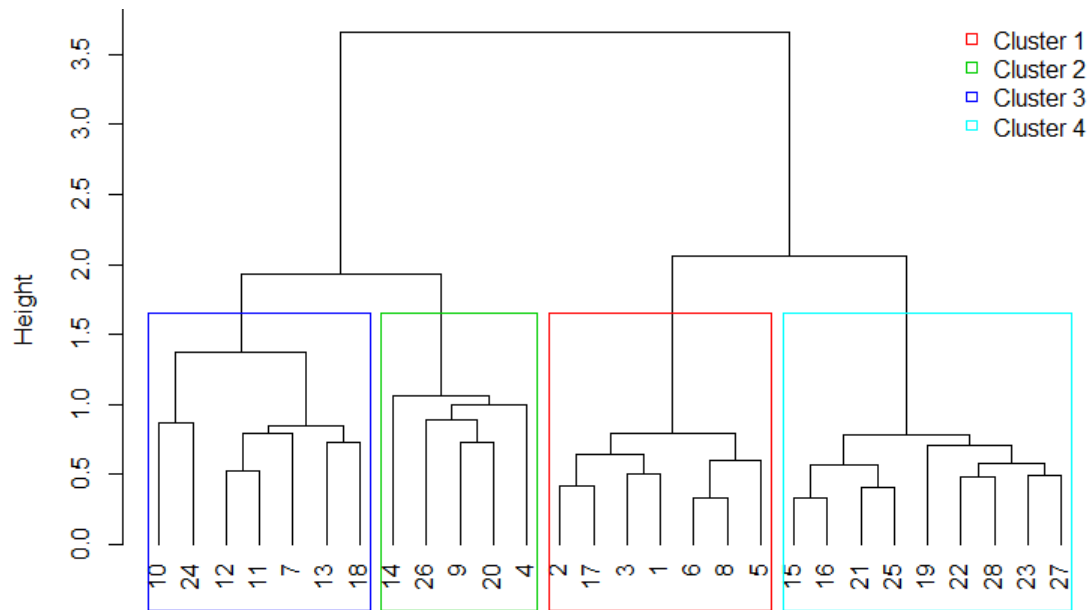

Fig. 4. Final dendrogram with the boxes around the four classified groups of transects using the UPGMA average agglomerative clustering method.
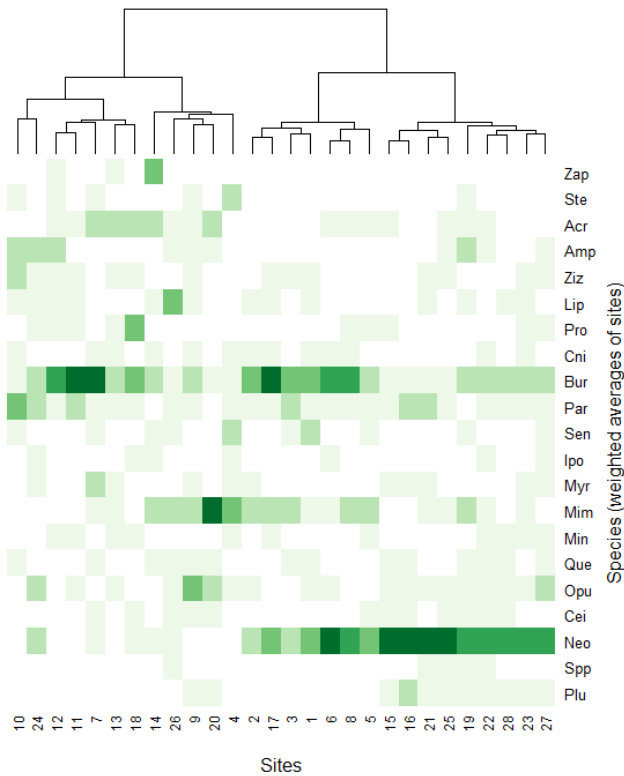
Fig. 5. Heat map of the double ordered matrix (28 sites x 21 species). Dark green represents higher abundance while light green lower. Abbreviations: escobillo *Zapoteca formosa* (Zap), xoconstle *Stenocereus stellatus* (Ste), coyolito *Acrocomia mexicana* (Acr), cuachalala *Amphipterigyum adstringens* (Amp), cholulo *Ziziphus amole* (Ziz), oreganillo *Lippia graveolens* (Lip), mezquite *Prosopis laevigata* (Pro), mala mujer *Cnidoscolus tehuacanensis* (Cni), mulato/copal *Buresera* (Bur), mantecosos *Parkinsonia praecox* (Par), tecuahue *Senna* (Sen), cazahuate *Ipomea murucoides* (Ipo), garambullo *Myrtillocactus* (Myr), uña de gato *Mimosa* 1 (Mim), *Mimosa* 2 (Min), encino *Quercus* (Que), nopal *Opuntia* (Opu), pochote *Ceiba parviflora* (Cei), tetecho *Neobuxbaumia* (Neo), unknown species (Spp) and cacaloxochilt *Plumeria rubra* (Plu).
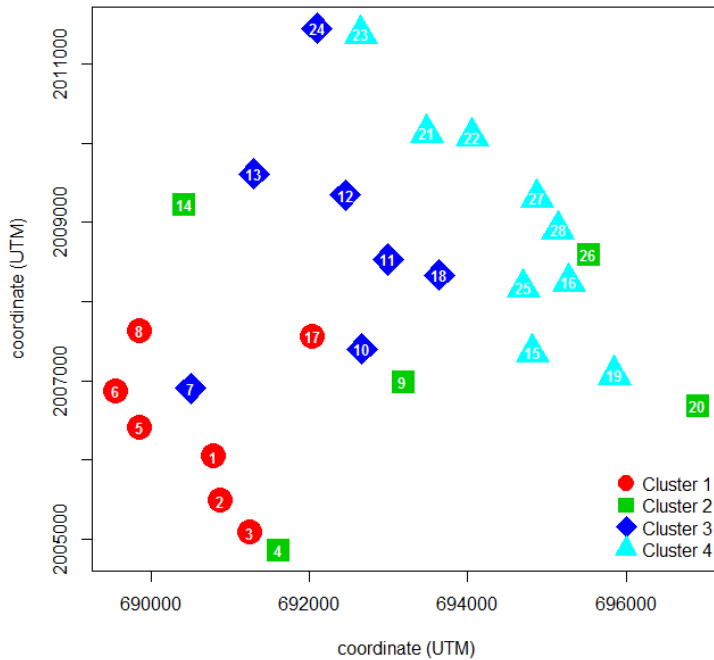

Fig. 6. Map of the spatial distribution of the 28 transects classified in the four groups. Colors are according to the boxes in the Fig. 4.
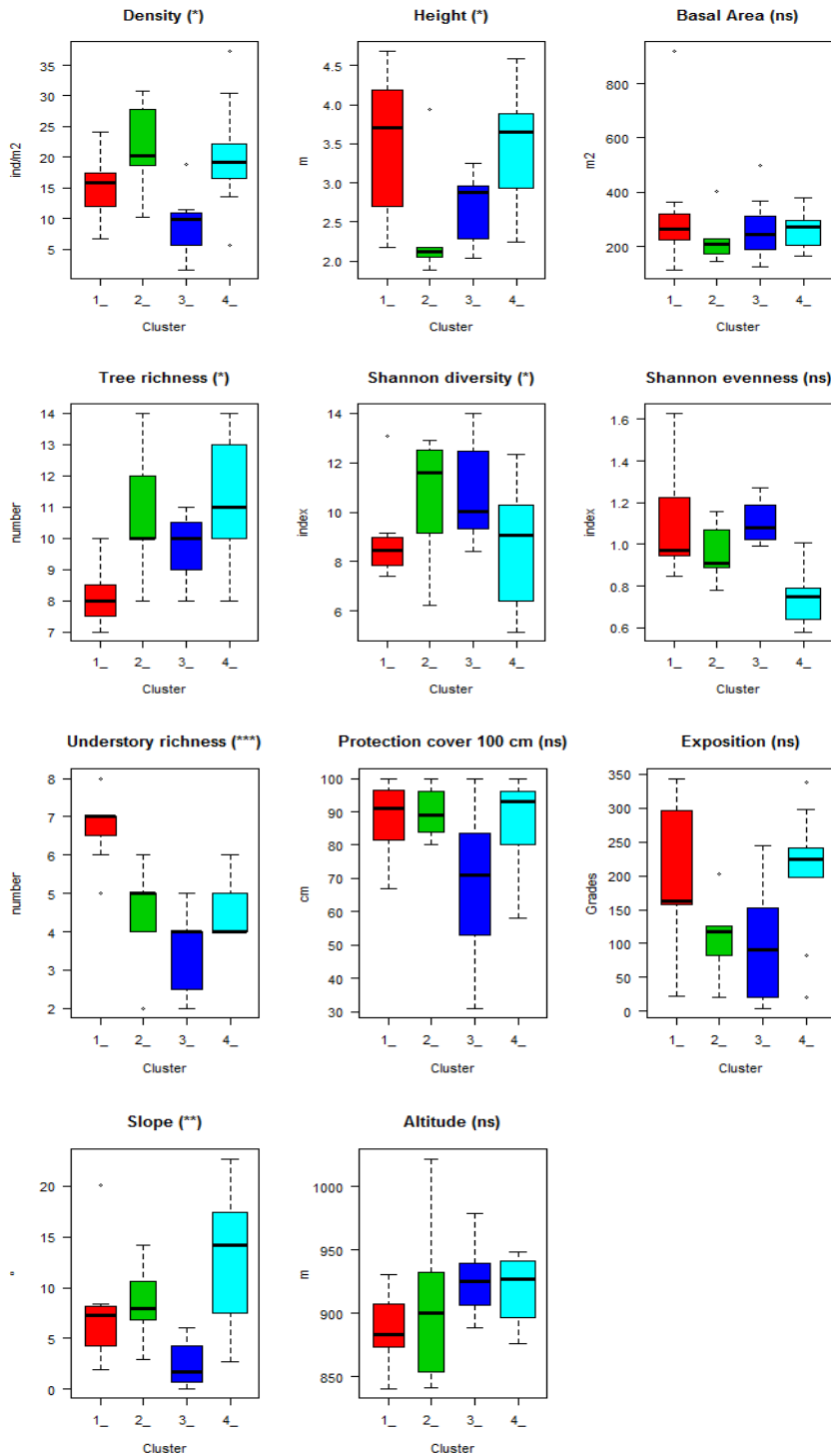
Fig. 7. Histograms of the evaluated variables in the clusters. Colors are according to the groups in previous figures. Statistical differences (ns, *, *).**

Vegetation types differences

Vegetation variables varied significantly among the clusters (Fig. 7). Tree density was higher in clusters 2 and 4 (F = 3.857, df = 3, 24, P = 0.02). Tree height was higher in clusters 1 and 4 due to the presence of the columnar cactus as *Neobuxbaumia* (F = 3.019, df = 3, 24, P = 0.04). Basal area was similar among clusters (F = 0.535, df = 3, 24, P = 0.66). Tree richness was higher in clusters 2 and 4 (F = 4.589, df = 3, 24, P = 0.01). Shannon diversity was higher in clusters 2 and 3 (F = 3.165, df = 3, 24, P = 0.04); while evenness was similar among clusters (F = 1.456, df = 3, 24, P = 0.25). Understory richness was higher in cluster 1 (F= 12.091, df = 3, 24, P = 0.0001), while protection cover at 100 cm of height was similar (F = 2.824, df = 3, 24, P= 0.06). Regarding topographic variables, the slope varied among clusters (F = 5.075, df = 3, 24, P= 0.007), while exposition (F = 2.621, df = 3, 24, P= 0.07) and altitude (F = 1.273, df = 3, 24, P= 0.31) were similar.

Deer population density

We counted 285 pellet-groups in 86% of the 28 transects sampled. Mean (±SE) density was 3.5 ± 0.6 ind/km^2. When transects were classified according to the INEGI´s classification, the densities were 4.1 and 2.7 ind/km^2 for crassicaule scrub and tropical dry forest, respectively; these differences were significant (Fig. 8a; F = 17.62, df = 2, 26, P = 0.0001). Considering the hierarchical agglomerative clustering method, the densities were 2.7, 4.2, 1.2 and 5.5 ind/km^2 for clusters 1, 2, 3, and 4 respectively, and these differences were statistically significant (Fig. 8b; F = 13.05, df = 4, 24, P = 0.0001). Post-hoc Tukey HSD test suggests that Clusters 3 and 1 were similar; while Clusters 3, 2, and 4 did not differ.

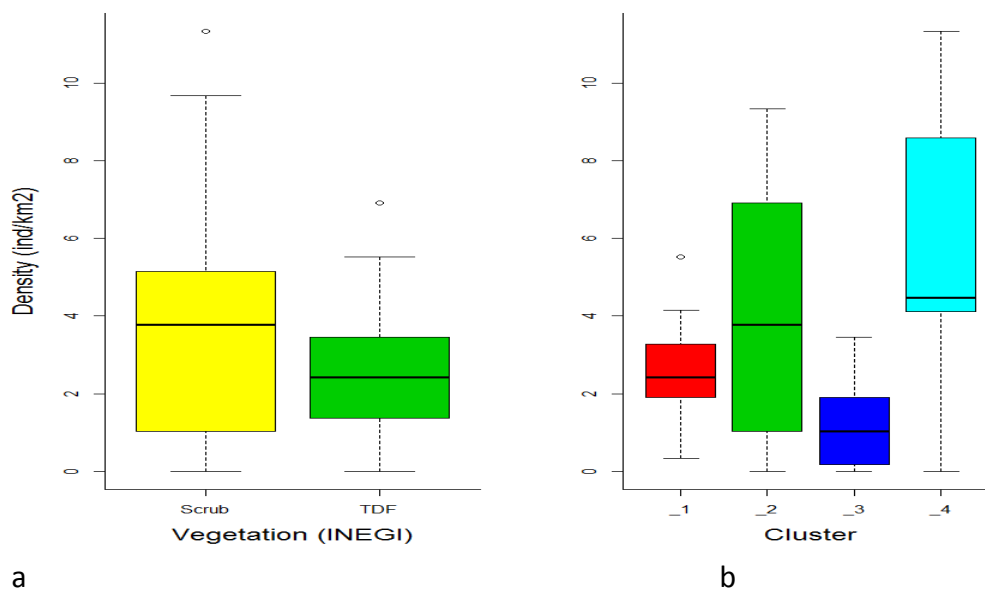a   b

Fig. 8. Population density (ind/km^2) of white-tailed deer grouping transects by vegetation according to the INEGI classification (a) and clusters obtained in multivariate analysis (b). The boxplot shows the quartiles and medians. Colors are according to the groups in previous figures. See the different maps of vegetation classification in the Fig. 1.

Discussion

A primary goal of vegetation classification is to arrange vegetation patterns into an ecologically meaningful set of types, and a secondary goal is its ability to serve as a guide for mapping [7]. Multivariate vegetation classification separated a large heterogeneous region into smaller and more homogeneous entities, in terms of land use [2]. According to the INEGI forest classification [26], the study area mainly presents crassicaule scrub while the tropical dry forest (TDF) is located in the hills of a portion of this site (see Fig. 1b). However, our results based on SIG and multivariate analysis of the field data suggest a completely different scenario (see Fig. 1c). The main finding is that crassicaule scrub is in fact limited to small patches, while the TDF dominated the study area and can be sub-classified into three or four types according to tree species composition and dominance, principally of the genera *Neobuxbaumia*, *Bursera, Mimosa* and *Parkinsonia.* The distribution and abundance of these species, as well as some topographic variables such as slope, ensured that vegetation types are well defined spatially. These vegetation types differ in structural variables such as tree height, density, richness, and diversity. For white-tailed deer, interpretation of how vegetation types affect population density therefore differs depending on the particular classification map used.

To understand these results, it is important to compare these defined clusters with other community descriptions found in similar locations and how they are associated with the habitat and resources used by the white-tailed deer in tropical dry forests. According to the data, the 28 sampled transects were classified into four clusters depending on tree dominance. Clusters 1 and 4 correspond to vegetation dominated by *Neobuxbaumia* on hillsides in zones C and A, respectively. Specifically, *Bursera* is co-dominant in Zone A. Vegetation dominated by *Neobuxbaumia* is known locally as "tetechera" and is common in the arid and semi-arid regions of the Tehuacán Valley [27, 37]. This vegetation is found in the mountainous portion of the studied area. Irregular topography provides greater protection against both predators and solar radiation [38]. In particular, some species such as *B. simaruba* and others in the TDF offer palatability and chemical composition that are suitable for the white-tailed deer [39].

Cluster 2 is dominated by *Mimosa* on shallow slopes in Zone B. Most of the *Mimosa* species occur in the arid tropical scrub and TDF, which are considered the most endangered vegetation types of the Tehuacán Valley [40]. *Mimosa* species are multipurpose shrubs/trees of the agrosilvopastoral system of this region and are used for fodder, fuel, living fences, construction material and medicine [41]. In the study site, the white-tailed deer consume a small proportion of *Mimosa polyantha* during the dry season [42]. This foraging pattern has also been reported in other regions [43].

In contrast, Cluster 3 is co-dominated by *Bursera* and *Opuntia* and also features patches of crassicaule scrub dominated by *Parkinsonia praecox* in Zone B. Several of the tree and scrub species in this site have been reported as plant resources for the human communities in the Tehuacán-Cuicatlán Valley [27, 44]. Our findings indicate that while most plant distribution

patterns are restricted to local conditions, thus forming mosaics of vegetation, human disturbance may also drastically affect the structure of plant communities [40].

The TDF dominated by *Neobuxbaumia, Bursera* and *Mimosa* is therefore the vegetation type that offers better habitat conditions and important food resources for the white-tailed deer in this location [43, 45, 46]. In a previous study in four locations of the Tehuacán-Cuicatlán Biosphere Reserve, including San Gabriel Casa Blanca, the variables associated with white-tailed deer density were: basal area, distances to roads and to the area with largest human population, slope, aspect, and presence of cattle [23]. In this study we find that vegetation types offer different degrees of cover to hide from predators and hunters, contain different availability of water for deer, and differ in distance from areas with human activity. Particularly, the associations dominated by tropical dry forest (clusters 1,2, and 4) offer better conditions, while Cluster 3, dominated by crausicaule vegetation, had less cover and species diversity, with constant presence of human activities. This can explain the higher white-tailed deer densities estimated in Zones A and C (clusters 1, 2, and 4), while density was lowest in Zone B (cluster 3).

Importantly, because we sampled only during the dry season it is possible that the deer-habitat association could change during the rainy season. Pellet-group count is not appropriate for use during the rainy season due to the decomposition rate of feces [35]. However, preliminary analysis of both site occupation and activity patterns using camera-traps during the dry and rainy seasons suggests that deer use the same sites year-around [Mandujano et al. in preparation, 47]. Future studies using radio-tracking could give specific data of deer movements and changes in habitat use [see 48].

In comparison with other locations in the TCBR, the study site presents a relatively higher density of white-tailed deer [49]. However, comparison between the mean estimated density (3.5 ± 0.6 ind/km^2) and data obtained in other tropical dry forests in the Central and Pacific region of Mexico [30, 32, 50] suggests that the TDF of the studied region in fact supports lower densities of white-tailed deer. The influence of the relatively low precipitation in the lower elevations of the TCBR could explain this pattern, as has been suggested in a large-scale geographical analysis by Mandujano and Naranjo [51]. Another possibility is that the actual density in the studied location could be lower than the carrying capacity (K) [50]. Therefore, it is necessary to evaluate biomass production and quality of the principal plant species consumed by this deer species [52].

Implications for conservation

The TDF is the dominant vegetation type that offers better habitat conditions and important food resources for the white-tailed deer in this location. Activities for the protection of deer have been conducted in the study site for several years, certainly benefitting both population and habitat. However, habitat management practices as water availability and food supplement in the critique period during the dry season, could be necessary to increase the habitat carrying capacity [53]. Our analysis of vegetation classification and the

variation of white-tailed deer densities suggests that the study area could be a suitable site for practicing legal hunting, through the extensive model UMA [54].

Acknowledgements

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