Research Article

Habitat and human factors associated with white-tailed deer density in the tropical dry forest of Tehuacán-Cuicatlán Biosphere Reserve, Mexico

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Abstract

The main objective of this study was to analyze the relationship between population densities of the white-tailed deer *Odocoileus virginianus* and certain habitat and human characteristics in the tropical dry forest of the Tehuacan-Cuicatlan Biosphere Reserve (TCBR), Mexico. To estimate population density and characterize the habitat, we established 32 strip transects (500 x 2 m) at four different locations in the TCBR from May to June during the dry season of 2010. Principal component analyses were used to order the 32 transects using habitat/human impact variables and tree species composition. Estimated average density was 1.7 deer/km^2, ranging from 0.1 to 2.9 deer/km^2. The variables associated with white-tailed deer density were: basal area, distance to roads, distance to the area with largest human population, slope, aspect and presence of cattle; the principal plant species were Zapotillo (*Lantana camara*), Chintoborrego (*Vallesia glabra*), Nanche (*Bunchosia biocellata*), Cuachalalate (*Amphipterigyum adstringens*) and Cuajiote Amarillo (*Bursera aptera*). Compared to other tropical dry forests, estimated white-tailed deer densities in the TCBR were lower. We discuss the possible effect of these variables on deer density and suggest management actions.

Key Word: *Odocoileus virginianus*, pellet-groups count, human influence, management.

Resumen

El objetivo principal de este estudio fue analizar la relación entre la densidad poblacional del venado cola blanca *Odocoileus virginianus* con algunas características del hábitat en el bosque tropical seco de la Reserva de la Biosfera de Tehuacán-Cuicatlán (TCBR), México. Para estimar la densidad y caracterizar el hábitat, se colocaron 32 transectos de franja (500 x 2 m) en cuatro diferentes localidades de la TCRB de mayo a junio de 2010. Se llevaron a cabo análisis de componentes principales para ordenar los 32 transectos conforme a las variables del hábitat, impacto humano y su composición vegetal. La densidad promedio fue de 1.7 venados/km^2, con una variación entre de 0.1 a 2.9 venados/km^2. Las variables relacionadas con la densidad del venado fueron el área basal, la distancia a caminos, la distancia a la localidad con mayor número de habitantes, la orientación y la presencia de ganado. En las localidades con mayor densidad de venados las plantas dominantes fueron Zapotillo (*Lantana camara*) Chintoborrego (*Vallesia glabra*), Nanche (*Bunchosia biocellata,* Cuachalalate (*Amphipterigyum adstringens*) y Cuajiote Amarillo (*Bursera aptera*). Comparado con otros bosques tropicales, las densidades estimadas en la TCBR fueron menores. Se discute el posible efecto de estas variables sobre la densidad del venado y se sugieren algunas acciones de manejo.

Palabras clave: *Odocoileus virginianus*, conteo de grupos fecales, influencia humana, manejo.

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Introduction

The wide geographic distribution of the white-tailed deer *Odocoileus virginianus* is largely due to its ability to adapt to different environmental conditions [1]. This species is one of the most studied in Mexico [2-4]; it has the ability to modify vegetation structure [5, 6], is a main prey for larger carnivores [7] and is one of the most utilized animals for subsistence and game hunting [8, 9]. In the Neotropical region, white-tailed deer inhabit various ecosystem types, including tropical dry forest [3, 4]. The marked seasonality of this forest affects the availability of food, water and cover [10, 11]. Because cover and tree density provide protection against extreme temperatures and potential predators, transformation of these factors can have an effect on deer population density [12, 13]. In addition, anthropic pressure factors such as settlements, roads, agricultural activity and hunting, among others, are likely to have a negative effect on deer populations [14].

Studies that have evaluated the effect of environmental variables on deer densities in tropical ecosystems have focused on the structural attributes of vegetation and landscape [15-17]. In contrast, little information exists regarding the effects of human pressure on deer population densities [18-20]. This pressure occurs mainly in ecosystems that are undergoing serious fragmentation, such as the tropical dry forest [21]. The role played by protected areas, including the large Biosphere Reserves, in the generation of biological knowledge and conservation of white-tailed deer is of great importance [22-24]. The Tehuacan-Cuicatlan Biosphere Reserve (TCBR) is an area of high biodiversity and endemism of species in central Mexico [25]. Three species of native ungulates inhabit this site, all of which are important in subsistence hunting: white-tailed deer, red brocket deer (*Mazama temama)* and the collared peccary (*Pecari tajacu)*. In the TCBR at present, there is great interest in the sustainable use of white-tailed deer in Management Units for the Conservation of Wildlife (UMAs by their Spanish acronym). The objective of this study was therefore to characterize habitat and human attributes in order to identify the most important variables associated with white-tailed population density, and to use these findings to suggest possible management actions.

Methods

Study area

The Tehuacan-Cuicatlan Biosphere Reserve, comprising an area of almost 5,000 km² (Fig.1), is located in the southern part of Puebla state and the northern part of Oaxaca state (17° 39' - 18° 53' N and 96° 55'- 97° 44' W) and is considered a biological province of the Mexican xerophytic region [26]. It contains a complex physiographic mosaic with internal valleys separated by numerous mountains. Altitude ranges from 600 to 2,950 m asl, while annual mean temperature varies from 18 to 22 °C and annual precipitation from 250 to 500 mm [27, 28]. The vegetation types are tropical dry forest (33%), semi-arid shrub land (30%) and temperate pine-oak forest (20%). The most common species in tropical dry forest are: *Bursera* spp., *Acacia cochliacantha*, *Mimosa* spp., *Prosopis laevigata*, *Parkinsonia praecox*, *Marginatocereus marginatus*, *Opuntia pubescens* and *O. decumbens* which are associated with the columnar cacti *Pachycereus weberi, Neobuxbaumia tetezo* and *Cephalocereus columna-trajani* [29]. The incidence of deforestation and fragmentation in the TCBR is considerably lower than in other tropical dry forests in Mexico [21].

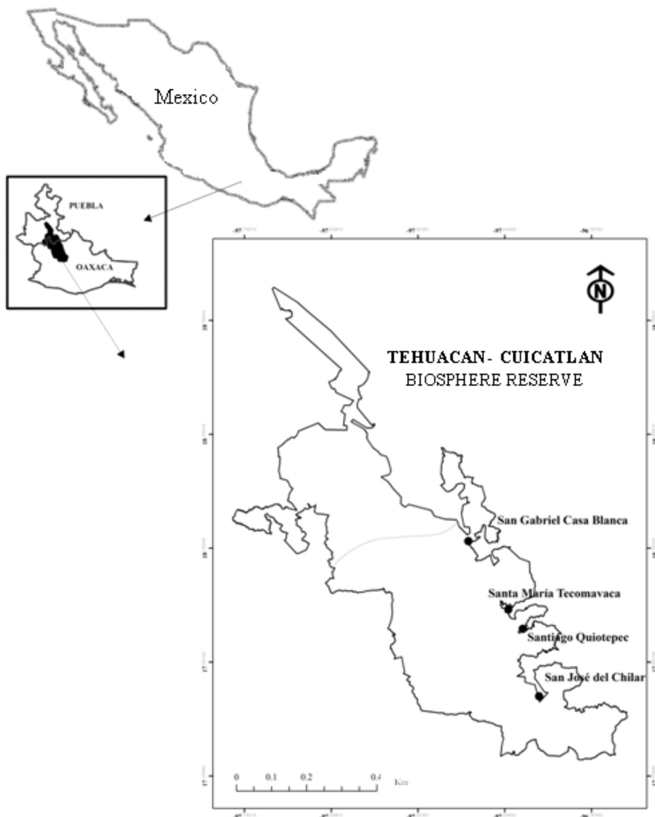

Fig. 1. Location of the four studied communities in the Tehuacan-Cuicatlan Biosphere Reserve, Mexico.

Density estimation

To estimate white-tailed deer density, four locations were chosen (San Gabriel Casa Blanca, San Juan Quiotepec, Santa Maria Tecomavaca and San Jose del Chilar) within the region known as La Cañada, which is dominated by tropical dry forest (Fig. 1). These locations were chosen because of the interest among the inhabitants in establishment of an UMA for developing the sustainable use of white-tailed deer [30]. To estimate population density, we used the indirect method of counting pellet-groups [31]. We established 32 transects (eight per location), which were surveyed from May to June 2010 during the dry season. Transects were 500 x 2 m wide, a width that was considered adequate to census complete pellet-groups in dense vegetation understory [32]. Fecal groups were collected following the Fecal Standing Crop (FSC) method [33, 34], which consists of visiting each sampling plot once and counting the total standing crop of feces accumulated during the dry season. According to a previous study in other tropical dry forests [17, 32, 35], fecal loss is minimal during the dry season, while in the rainy season the fecal decay rate is almost 100% from June to December because of the action of rain and insects. Additionally, visibility is low in the rainy season because of dense understory plants and therefore the detection probability of feces is lower. Due to the fact that we sampled each location only once, our analysis does not take possible seasonal changes in habitat use into account.

To estimate population density (D, individuals/km^2), we applied the equation proposed by Eberhardt and Van Etten [36] as: $D = (NP \times D_{pg})/(T \times dR)$, where NP = number of strip transects per square kilometer, D_{pg} = mean pellet groups per transect; T = mean decay time; and dR = defecation rate. To estimate mean pellet-groups, we used the equation: $D_{pg} = n/2Lw$, where n = number of fecal groups, w = transect width (1 m) and L = total transect length sampled. Variance of density was estimated according to Plumptre [37] as: $Var(D) = [(NP \times D_{pg})/(T \times dR)]^2 \times [(CV\ (D_{pg}))^2 + (CV(dR))^2 + (CV(T))^2]$. Estimations of $CV(D_{pg})$ were calculated following a negative binomial distribution to estimate standard error (Se) as: $Se = \surd\ (x + x^2 / k) / n$, where k = parameter of the binomial negative and n = number of transects; in particular $k = D_{pg}^2 / (S^2 - D_{pg})$, and S^2 = variance. $CV(dR)$ was calculated according to an estimated defecation rate for tame deer, as a mean of 17 ± 4 (Se) fecal groups/deer/day [38]. Estimation of $CV(T)$ was considering a mean of 123 ± 2.4 days [32].

Habitat description

Habitat characterization was obtained by sampling every 50 m in the same transects used for the pellet-groups count. We chose this distance because of the heterogeneity conferred by the irregular topography in the studied region. We thus obtained data of 352 sampled points (88 per location). Data included vegetation variables (tree diversity, tree density, basal area, protection cover and understory richness), physical variables (altitude, slope, orientation and distance to the nearest permanent water body) and human-impact variables (distance to roads and locations, distance to the area with largest population and livestock presence) (Appendix 1). To obtain vegetation data, we applied the point-centered quarter method [39], which consists of sampling the four nearest trees in each quarter for each point along the transect. Each tree was identified and diameter at breast height (dbh) measured. With this information, we estimated Shannon diversity index using PAST software [40], as well as tree density and basal area. Vertical protection cover was measured using a rule of 200 x 5 cm divided into 10 sections of 20 cm alternately painted in black and white. The rule was placed vertically on a point and the number of sections visible at a distance of 25 m was counted. Difference in the total number of sections was expressed as a percentage of protection cover [41]. Understory plant richness was estimated using circular plots of radius 2 m. Terrain variables such as elevation, slope and aspect were generated from a digital elevation model of 90 m from INEGI [42]. Distance to permanent rivers was obtained from the average of three points away from each transect. The variables of human influence with a negative effect on deer populations (distance to roads, to locations and the area with largest population) were estimated using a Geographical Information System in Arc View 3.2 [43]. Finally, in order to test whether a relationship existed between the presence of deer and cattle, we also counted the cattle dung deposited in the transects. It should be noted that, while hunting is an important variable of anthropic pressure, it was not evaluated in this study, although we assume it to be similar across the whole study area. We recognize, however, the importance of quantifying hunting in future studies.

Statistical analysis

A nonparametric Kruskall-Wallis test was applied, along with a Mann-Whitney contrast, to test if deer density varied significantly between studied sites. To determine differences in habitat factors among locations, we used a one-way ANOVA test and an *a posteriori* multiple comparison Tukey test. Data were normalized using log-transformation [log and log (x + 1)]. Where variables were not transformed, a non-parametric Kruskal-Wallis test and multiple comparisons Mann-Whitney test were used. For this analysis, we used the statistical software JMP 3.2.1 [44]. To identify the relationships of each variable with deer density, we used simple linear regressions. To determine the relationships between white-tailed deer density and habitat variables, we used principal component analysis (PCA). In the first PCA, the density was ordered considering habitat and human pressure variables using the correlation matrix, while in the second PCA, ordination of density was conducted using tree species composition (presence/absence). The statistical software MVSP 3.2 [45] was used for this analysis.

Results

We counted a total of 174 pellet-groups in 24 out of the 32 transects in the four studied locations. Mean population density was 1.7 ind/km², but this value varied significantly among sites ($P < 0.05$). Highest densities, 2.9 and 2.6 ind/km², were estimated for Chilar and Casa Blanca, respectively; in Tecomavaca, density was 1.1 ind/km², while in Quiotepec it was 0.1 ind/km² (Appendix 1). Habitat structure varied among sites, but Tecomavaca and Casa Blanca were quite similar while Quiotepec showed the most contrasting result.

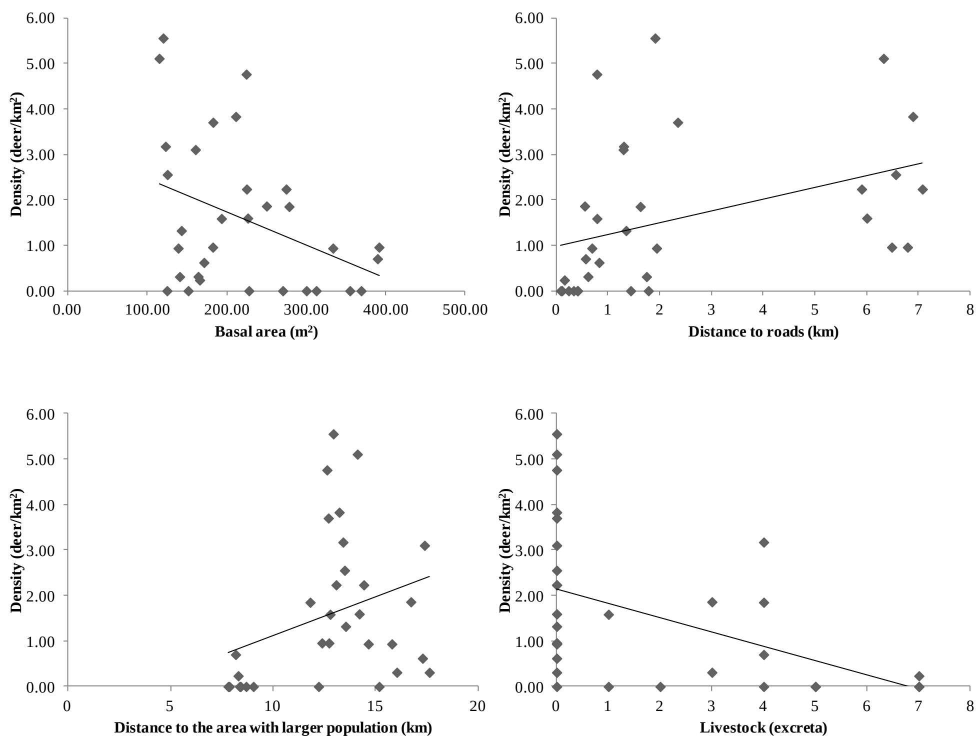

Fig. 2. Correlations of the deer density and habitat variables in different studied sites of the Tehuacan-Cuicatlan Biosphere Reserve, Mexico.

Regression analysis showed that the habitat variables that had a negative relationship with density were basal area (r = -0.355, P = 0.045) and cattle presence (r = -0.563, P = <0.05). On the other hand, distance from roads (r = 0.613, P = 0.002), and from the town with the highest population density (r = 0.363, P = 0.04), were both positively related to deer density (Fig. 2).

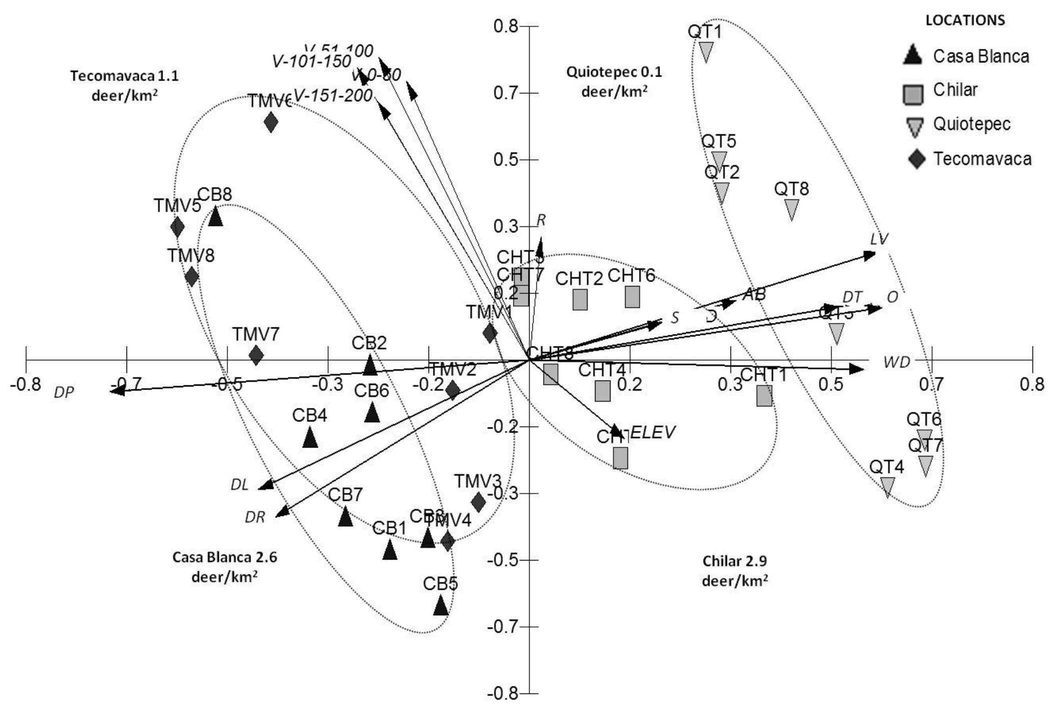

Fig. 3. Principal component analysis ordination of 32 transects based on 15 habitat variables: basal area (AB), tree density (DT), richness (R), protection cover 0-50 cm (V-0-50), protection cover 51-100 cm (V-51-100) protection cover 101-150 (V-101-150), protection cover of 151-200 (V-151-200), distance to roads (DR), distance to locations (DL), distance to water bodies (WD), distance to largest human community (DP), altitude (ELEV), slope (S), orientation (O) and presence of livestock (LV). Locations: CB = Casa Blanca, CH = Chilar, QT = Quiotepec, TCMV = Tecomavaca.

Ordination of transects based on habitat and human attributes defined three distinct groups: Casa Blanca-Tecomavaca, Chilar and Quiotepec (Fig. 3). The first component was positively associated with tree density, aspect, distance to rivers and presence of livestock, and negatively associated with the distance from the largest human community (Appendix 2). Meanwhile, the second component was associated positively with cover variables, and negatively with distance to the nearest road.

In the second ordination of transects according to tree composition, it was found that Quiotepec and Chilar had similar plant composition; in contrast, Tecomavaca and Casa Blanca showed different plant associations (Fig. 4, Appendix 3). In sites with higher white-tailed deer density, the main plant species were *Lantana camara, Vallesia glabra, Bunchosia biocellata, Amphipterigyum* *adstringens* and *Bursera aptera*, while sites with lower deer density were associated with *Neobuxaumia* sp., *Bursera schlectendalii* and *Acacia* sp.

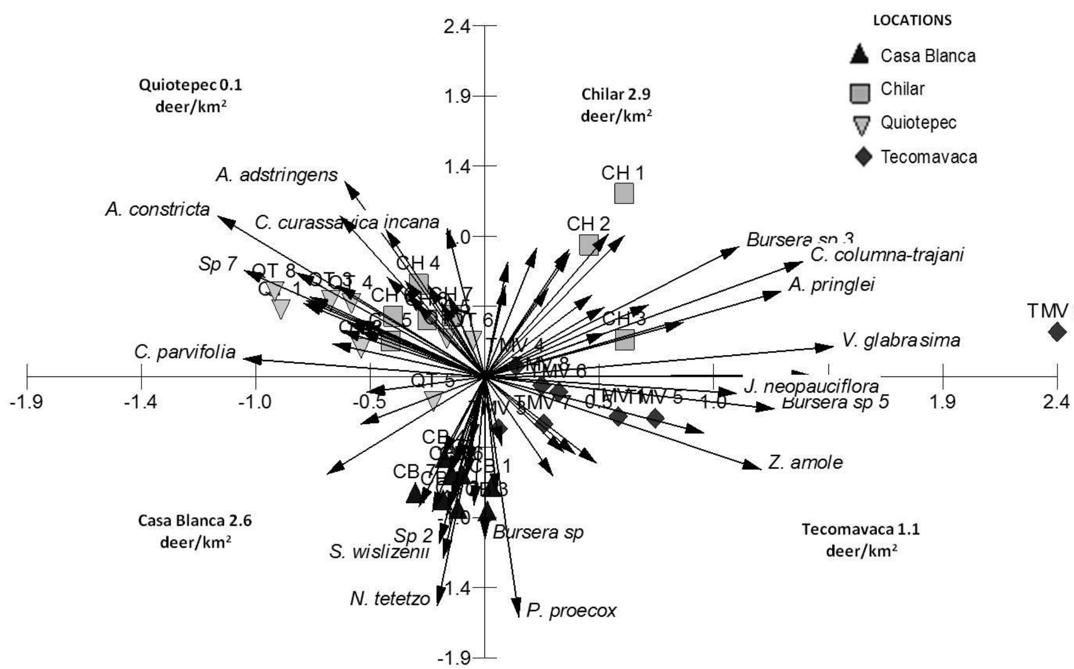

Fig. 4. Principal component analysis ordination of 32 transects based on tree species composition.

Discussion

Our results suggest that white-tailed deer population density was low in the study sites, at 0.1 to 2.9 deer/km^2. This finding is very similar to densities reported in other tropical dry forests in the Mixteca Poblana using the same indirect method of feces counts [46, 47]. However, higher densities have been reported in some other tropical dry forests (from 6 to 12 deer/km^2) [35]. Density estimations were obtained in a systematic way at all four sites using the fecal standing crop method [33, 34], and for the estimation of population density we applied the equation proposed by Eberhardt and Van Etten [36] following the recommendations by Camargo-Sanabria and Mandujano [32]. We used this method because it was considered the most appropriate for the topography and vegetation characteristics of the region with its conditions similar to other sites, including the presence of tropical dry forest [16,17, 20, 48,49]. However, we recognized that pellet-group counts could produce biased estimates, especially where defecation rate is unknown [38]. We tried to diminish this bias using the mean and coefficient of variation of the defecation rate obtained from tame deer near the study site [38]. Previously, Mandujano and Gallina [35] showed that this method produced similar results, with respect to relative density estimated with both direct counts in transect lines and track counts, and it can be used as an index to detect population changes over time. Therefore, even if our population densities estimates are biased, they were used as a density index with which to compare sites, and therefore we consider that they are valid in terms of their relationships with habitat and human variables.

Specific characteristics of the habitat can explain differences between densities. For example, rainfall season length is shorter and annual average rainfall is lower in our study site (553 mm), which could affect temporal food availability for the deer and the carrying capacity of the site [24, 47, 50]; however we did not evaluate this latter variable in our study. Another possible fact that could explain the relatively low densities in this study is that these wild populations are currently under anthropogenic pressures such as habitat loss, competition with cattle for food and space, and poaching, which is one of the most important causes of wild fauna decline [8, 48]. Despite the fact that hunting was not evaluated within the study area, we suppose that it was constant and uniform among the four sites. In a study by Reyna-Hurtado and Tanner [51] in southeastern Mexico, relative abundance of the white-tailed deer was found to be significantly higher in hunting areas than in those with lower hunting pressure and these authors therefore concluded that deer can tolerate a certain amount of hunting pressure. However, hunting could have a greater effect on the deer in different habitat types, and it is therefore necessary that this variable be quantified in a future study. Within the region, vigilance committees have been established because of the interest of these communities in this resource. The efforts of these committees will surely reduce the incidence of poaching. In addition, the four study sites are relatively close to a principal highway (Tehuacan to Oaxaca city), but recently Yañez-Arenas *et al*. [49] modeling abundance distribution of white-tailed deer with a niche modeling approach, showed that higher deer densities could be expected in sites with irregular topography and lower human activities, which in the TCBR are mainly in the eastern mountainous region. Thus, the distribution of abundance is heterogeneous among locations within the TCBR.

Our results suggest that the studied locations have different habitat conditions for white-tailed deer. In general, Casa Blanca and Tecomavaca were more similar, while Chilar and Quiotepec were the most contrasting locations. However, this ordination of locations was not consistent with deer densities. Significantly higher densities were found in sites with more suitable habitat conditions, while lower densities were found in sites with a higher incidence of human activity. In addition, the multivariate analysis showed that even if some habitat and human variables were associated with deer abundance, the explained variance was low, suggesting that other factors we did not measure could be affecting deer density. Similarly, some of the habitat characteristics, such as vegetation structure and land and human pressure, were significantly different among locations, which could influence the variance in density values among them.

It has been proved that there is a relationship between habitat structure characteristics, such as cover protection, and the presence of this species, owing to the protection offered against high temperatures and predators [52, 53]. Basal area related negatively to density, probably because Quiotepec, the location with the lowest deer density**,** had trees and columnar cacti with the largest basal area. On the other hand, the northern slopes had more deer presence, as has been reported in other dry forests [54]. This is a very important habitat attribute for the species [55], because northern slopes are less exposed to solar radiation, which reduces the likelihood of dehydration. Although the importance of water access for wild species is well known [13], it did not influence the presence of deer, as the communities where the highest density was found were those located at a longer distance from water sources, and there were no significant differences between this community and another with lower density. Studies of habitat quality for white-tailed deer define distances from water sources of 0.3 km as high quality and 1.4 km as low quality. In fact, this was the average distance range in the locations we studied. It has also been reported that distances in excess of 1.6 km are considered inadequate for the species [19]. However, it is important to take water availability into account when evaluating whether habitat is appropriate for the species [13,18], particularly in places where the dry season is as marked as it is in the tropical dry forest of the TCBR. During periods of water shortage, it has been found that the white-tailed deer complements its water intake by ingesting certain wild plants and fruits [56,57]. In this regard, other studies [11,58] report that the most important species for the maintenance of deer populations are *Ceiba parvifolia, Pachisereus weberi, Ficus* spp*., Ficus contifolia, Acacia farnesiana* and *Opuntia* spp. In the communities we studied, these species were found to coincide with higher deer density.

Lower densities were related to the presence of livestock; however, with the adaptability of deer, they can also be associated with agricultural areas [3]. Nevertheless, higher deer densities are associated with temperate and tropical deciduous forests, and scrublands. Livestock production affects deer directly in terms of competition for food and space and indirectly by modifying habitat quality, and this is reflected in deer population densities [16, 59-61]. Other human pressure variables, such as proximity of settlements and roads, have an effect on the presence of white-tailed deer. It is known that noise and habitat fragmentation negatively affect populations of wild species, and also the easy access provided by roads increases poaching, which can affect distributions and deplete deer populations [14,18,62]. While poaching was not evaluated in this study, it has been reported as an important factor in the presence of this and other wild species [26,63,64].

Implications for conservation

Our results suggest complex relationships between the habitat and human activities affecting white-tailed deer populations in the studied locations in La Cañada region, where tropical dry forest is the dominant vegetation type. Long-term climatic trends, vegetation changes and human impact determine herbivore population dynamics [14,65]. Current deer population density is the result of these interactions, so that habitat-density relationships analysis, a common approach in studies with this deer species [17,20,48,66,67], does not necessarily explain the causal effects. From a management perspective, however, it was found that these relationships help to define habitat and population actions [68] and this could be useful for the protection and sustainable use of this game hunting species in the TCBR.

Temporal corn-crops, sugarcane production, logging in the mountain region that dominates the landscape, and extensive livestock production are the main economic activities in this region [69, 70]. Subsistence hunting of wildlife, mainly white-tailed deer, for local consumption is a common traditional practice in the Tehuacan-Cuicatlan Valley [71]. In common with other tropical dry forests [46,72,73], we propose that Management Units for the Conservation of Wildlife (UMAs by their Spanish acronym) could be adopted as an alternative management system in the localities of Chilar and Casa Blanca, where the highest densities of deer were found. This system of management will enable the sustainable use of the deer at that site. At Casa Blanca, there have been estimates of deer density carried out for the last three years, and the results are similar to those found in this study (S. Mandujano, pers. comm.). In the particular case of Tecomavaca and Quiotepec, the sites with lowest deer densities, it is necessary to leave the populations to recover so that a system of sustainable use can be put in place at a later date. It should be noted that an UMA already exists at the latter site for the military macaw (*Ara militaris*), and it has served to protect this species. Current management policy of the TCBR includes the sustainable use of white-tailed deer as a game trophy within the extensive UMA model [74]. Factors such as population density and habitat quality/quantity must be considered in order to estimate carrying capacity and potential production of white-tailed deer for human use [75].

In places where cattle production is practiced, it is recommended to implement appropriate management, so that it has a reduced impact on wild species. For instance, switching from extensive to semi-extensive cattle production could reduce the impact of livestock on a particular site, and the negative impact on the white-tailed deer population. It is necessary to generate information regarding poaching, so that future studies can accurately evaluate the impact it has on this deer population. It is strongly recommended to increase vigilance in the studied communities in order to prevent illicit hunting, as well as enforce the established harvest rates. Besides fieldwork, it is also necessary to create habitat suitability index models that will allow us to extend our knowledge concerning the optimal habitat for this species, and to identify conservation and exploitation areas.

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Appendix 1. Habitat description of four sites in the study area. We report average values and standard deviation (±) for each locality. Values with different letters are statistically different by ANOVA (a) and Kruskall Wallis (k), P <0.05). The most important plant species are presented with regard to their relative importance value for each location. * Lists of the plants that are eaten by deer in the dry season.

Variables	Chilar	Casa Blanca	Tecomavaca	Quiotepec	*P*
Deer density (deer/km^2)	2.9^a	2.6^a	1.1^b	0.1^c	<0.05 ^{k}
range (deer/km^2)	2.2 – 4.4	2.0 – 3.9	0.8 – 1.7	0.1 – 0.3	
Coefficient of variation	38.1	31.7	43.2	64.3	
Vegetation structure					
Basal area (m^2)	173.6 ± 57.2 ^{a}	219 ± 88.0 ^{a}	188.8 ± 68.4 ^{a}	299 ± 75.8 ^{b}	0.02 ^{k}
Density of trees (ind/100 m^2)	18.4 ± 4.2 ^{ab}	14 ± 5.9 ^{a}	3.8 ± 6.0 ^{c}	21.8 ± 7.2 ^{b}	<0.05 ^{a}
Understory richness	15.4 ± 3.4 ^{b}	12 ± 2.5 ^{a}	17.3 ± 1.2 ^{bc}	14.9 ± 4.2 ^{abc}	0.01^a
Protecion cover 0-50 (%)	7.8 ± 8.1	9.8 ± 11.6	10.9 ± 11.4	11.1 ± 12.4	0.97 ^{k}
Protection cover 51-100 (%)	15.1 ± 8.7	11.4 ± 12.2	19.3 ± 17.1	15.7 ± 14.8	0.76 ^{k}
Protection cover 101-150 (%)	19.9 ± 10.3	17.5 ± 14.8	21.2 ± 14.3	18.7 ± 17.5	0.96 ^{a}
Protection cover 151-200 (%)	29.7 ± 9.9	24 ± 23.2	28.4 ± 18.5	26.0 ± 21.4	0.93 ^{a}
Physionomic structure					
Altitud (msl)	937.7 ± 90.5 ^{b}	879.5 ± 29.3 ^{ab}	825.7 ± 84.5 ^{a}	849.9 ± 75.3 ^{a}	0.03 ^{a}
Slope (°)	10.2 ± 1.1 ^{b}	4.7 ± 1.1 ^{a}	8.8 ± 6.4 ^{ab}	8.6 ± 4.0 ^{b}	0.04 ^{a}
Orientation (°)	98.8 ± 32.4 ^{a}	68.5 ± 18.9 ^{a}	124 ± 113.6 ^{a}	271 ± 27.9 ^{b}	<0.05 ^{k}
Distance to water bodies (km)	1.4 ± 0.4	0.6 ± 0.3	0.3 ± 0.2	1.2 ± 0.4	<0.05 ^{a}
Human influence					
Distance to roads (km)	1.5 ± 0.5 ^{b}	6.5 ± 0.4 ^{a}	1.1 ± 0.5 ^{b}	0.3 ± 0.2 ^{c}	<0.05 ^{k}
Distance to locations (km)	2.5 ± 0.5 ^{b}	6.8 ± 0.5 ^{a}	5.9 ± 1.3 ^{a}	3.7 ± 0.7 ^{c}	<0.05^k
Distance to the area with largest population (km)	51.3 ± 0.6	13.5 ± 0.7	24.4 ± 1.6	31 ± 0.6	<0.05^k
Livestock (feces per transect)	1.1 ± 1.8 ^{a}	0 ^{a}	1 ± 1.4 ^{a}	5 ± 2.1 ^{b}	<0.05^k
Plant communities					
Number of plant Families	27	19	31	34	
Number of plant species	123	119	138	96	
Relative importance value					
Lantana camara		103.4			
*Bursera sp 2**		57.7			
*Bursera linanoe**		48.1			
Agonandra sp		47.8			
*Randia thurberi**		40.3			
Neobuxbaumia tetetzo				554.0	
*Bursera schlectendalii**				313.7	
Mimosa sp				311.1	
Parkinsonia proecox				207.4	
*Bursera sp**				147.6	
Vallesia glabra			52.0		
Acacia pringlei			43.8		
*Bursera sp 3**			39.7		
Parkinsonia proecox			31.8		
*Randia thurberi**			28.8		
Bunchosia biocellata	40.1				
Amphipterigyum adstringens	39.1				
*Bursera aptera**	37.8				
Lippia alba	35.8				
*Bursera sp 3**	32.4				
*Opuntia sp**	32.4				
Cyrtocarpa procera	30.6				
Asclepias curassavica	30.3				
Stenocereus stellatus	30.2				

Appendix 2. Habitat variables in the first two principal component analyses and the percentage of variance explained for each axis and the cumulative percentage. Larger scores are shown in bold.

Variables	PC I	PC II
Eigenvalues	4.02	3.55
Variance explained	26.8	23.7
Cumulative variance	26.8	50.5
Vegetation structure		
Basal area (m^2)	**0.215**	0.093
Density of trees (ind/100 m^2)	**0.321**	0.083
Richness (num. ind)	0.012	0.193
Protection cover 0-50 (%)	-0.127	**0.437**
Protection cover 51-100 (%)	-0.156	**0.474**
Protection cover 101-150 (%)	-0.179	**0.458**
Protection cover 151-200 (%)	-0.157	**0.405**
Physionomic structure		
Altitud (msl)	0.099	-0.123
Slope (°)	0.138	0.059
Orientation (°)	**0.366**	0.082
Distance to water bodies (km)	**0.347**	-0.014
Human pressure		
Distance to roads (km)	**-0.265**	**-0.246**
Distance locations (km)	**-0.281**	**-0.203**
Distance to the largest human community (km)	**-0.435**	-0.049
Livestock presence	**0.362**	0.169

Appendix 3. Tree species that contributed with larger scores in the first two principal component analyses, with the percentage of variance explained for each axis and the cumulative percentage. Larger scores are shown in bold.

Variables	PC I	PC II
Eigenvalues	10.713	9.714
Variance explained	10.503	9.523
Cumulative variance	10.503	20.026
Plant Species		
Acacia constricta	-0.173	0.169
Acacia pringlei	0.192	0.09
Amphipterigyum adstringens	-0.091	**0.206**
Bursera sp	0	-0.171
Bursera sp *3*	0.164	0.137
Bursera sp *5*	0.187	-0.034
Capparis incana	-0.024	0.156
Castela tortuosa	**0.225**	0.032
Ceiba parvifolia	-0.156	0.019
Ceiba sp	**0.225**	0.032
Cephalocereus columna-trajani	0.206	0.121
Cordia curassavica	-0.064	0.155
Ficus sp	**0.225**	0.032
Jatropha neopauciflora	0.163	-0.017
Montanoa mollissima	**0.225**	0.032
Neobuxbaumia tetetzo	-0.031	**-0.241**
Parkinsonia proecox	0.022	**-0.253**
Salix sp	**0.225**	0.032
Senna wislizenii	-0.027	-0.191
Sp 13	**0.225**	0.032
Sp 2	-0.029	-0.175
Sp 7	-0.156	0.112
Vallesia glabra	**0.225**	0.032
Ziziphus amole	0.179	-0.098