Characteristics of Central American brocket deer resting sites in a tropical mountain cloud forest from eastern Mexico (#61216)

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Characteristics of Central American brocket deer resting sites in a tropical mountain cloud forest from eastern Mexico

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The Central American brocket deer is currently facing problems of overexploitation and habitat loss. It is, therefore, is essential to implement conservation strategies that consider habitat features such as resting sites. In this study, we describe the characteristics of Central American brocket deer resting sites at two different scales: landscape and microhabitat. We used a point pattern analysis to describe resting site distribution, fitted four models to explain the effects of landscape variables, and compared known resting sites to nearby random sites at the microhabitat scale. Resting sites were aggregated at distances below one km. Vegetation type and elevation affected resting site distribution at a landscape scale, and all resting sites displayed similar values of the following microhabitat variables: 1) distance to the nearest water resource, 2) quantity of footpaths, 3) slope angle, 4) concealment cover for fawns, 5) canopy closure, and 6) understory height. Our results showed that Central American brocket deer selected resting sites with specific characteristics at both landscape and microhabitat scales. While preserving the existing forest and preventing poaching are important throughout the study area, our results suggest that preserving Mexican beech forest and oak forest and protecting deer from poaching in core resting site areas are particularly crucial.

Characteristics of Central American brocket deer resting sites in a tropical mountain cloud forest, eastern Mexico

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Abstract

The Central American brocket deer is currently facing problems of overexploitation and habitat loss. It is therefore is essential to implement conservation strategies that consider habitat features such as resting sites. In this study, we describe the characteristics of Central American brocket deer resting sites at two different scales: landscape and microhabitat. We used a point pattern analysis to describe resting site distribution, fitted four models to explain the effects of landscape variables, and compared known resting sites to nearby random sites at the microhabitat scale. Resting sites were aggregated at distances below one km. Vegetation type and elevation affected resting site distribution at a landscape scale, and all resting sites displayed similar values of the following microhabitat variables: 1) distance to the nearest water resource, 2) number of footpaths, 3) slope angle, 4) concealment cover for fawns, 5) canopy closure, and 6) understory height. Our results showed that Central American brocket deer selected resting sites with specific characteristics at both landscape and microhabitat scales. While preserving existing forest and preventing poaching are important throughout the study area, our results suggest that preserving Mexican beech forest and oak forest and protecting deer from poaching in core resting site areas are particularly crucial.

Introduction

Central American brocket deer (*Mazama temama* Kerr.) currently face problems of overexploitation and habitat loss, in part because a history of hunting has led to the species being considered a hunting trophy (Villarreal et al., 2013). Furthermore, habitat loss due to agricultural activities is increasing pressure on Central American brocket deer, and several deer populations are now extinct or decreasing across their natural distribution range (Cossio et al., 2010; Gallego-

Zamorano et al., 2020). These factors make it particularly important to implement conservation strategies that consider important habitat features such as resting sites (Findlay et al., 2015).

Resting sites have important effects on survival and fitness; they provide adults and offspring with shelter from adverse weather conditions, buffer against variation in temperature and moisture, protect from predation during inactive periods and breeding, and conserve energy and getting access to escape routes, food and water (Lutermann et al., 2010; Camps, 2011; Palomares et al., 2017).

Several authors have described the characteristics of resting sites for many species, but this does not include Central American brocket deer. Research on this species has primarily considered their spatial distribution and basic ecology, leaving the habitat requirements for resting sites virtually unknown in this species (Weber, 2005; Muñoz-Vazquez & Gallina Tessaro, 2016). The aim of conducting this study was to describe the characteristics of Central American brocket deer resting sites. We did this at two different scales: landscape and microhabitat (Johnson, 1980). We tested the hypothesis that resting sites must fulfill specific criteria to provide enough protection against predators and access to food and water. This was assessed by describing the characteristics and distribution patterns of resting sites, comparing the characteristics of resting sites at two spatial scales, and designing a model that could predict resting site locations within a tropical montane cloud forest in eastern Mexico.

Material & Methods

Study area

The study was conducted in the least disturbed tropical mountain cloud forest of the Sierra Madre Oriental in Mexico (Fig-1). The climate is temperate (Cb; *sensu* García, 2004). There is high humidity (annual precipitation of 1, 200-2, 050 mm) and temperatures are mild (14.5-24.4°C; Peters, 1997). The forest contains relict-endemic and endangered tree species such as *Magnolia schiedeana*, *Fagus grandifolia* subsp. *mexicana*, *Quercus delgadoana*, *Q. trinitatis*, *Q. meavei*, *Symplocos coccinea*, *Styrax glabrescens*, *Turpinia* insignis, *Beilschmiedia mexicana*, several tree fern species, including *Cyathea fulva, Dicksonia sellowiana* var. *arachneosa* and *Alsophila firma*, inhabit steep slopes. The understory is mainly composed of *Miconia glaberrima*.

Resting sites

We carried out 32 transects of 500 m length sampled from November 2017 to March 2019, to look for resting sites. Bedding sites were identified based on the presence of recent and old fecal pellets (≥ 5 pellets), footprints in several directions, compacted litter, and signs of browsing (i.e., cut buds and shoots). The locations of all resting sites were recorded using a Global Position System. It is important to notice that Central American brocket deer ´s tracks cannot get confused with those from other species in the study area, the tracks were identified using the guide from Aranda (2012).

Resting site distribution

We used a point pattern analysis to describe resting site distribution. First, we used the resting site locations to construct a planar point pattern (ppp), then used the Kernel-smoothed intensity to measure the mean number of occurrences per unit at a point (*u*) defined by λ (u). Finally, we performed a first-order characteristics analysis of a spatial process for a general location (*s*; Equation 1):

$$\lambda_b(s) = \frac{1}{C_b(s)} \sum_{i=1}^{n} K_{ib} (s - x_i) \qquad \textit{Equation 1}$$

where $K_b(\ )$ is a Kernel with band $b > 0$, and $C_b(\ )$ is an edge correction factor (Yang et al., 2007).

We performed a quadrat count test to determine whether there was complete spatial randomness. Once we determined that the pattern was not random, we calculated the inhomogeneous K and L functions (Equation 2):

$$\hat{K}_{inhom}(r) = \frac{1}{|W|}\sum_{i}\sum_{j \neq i}\frac{1\{\|x_i - x_j\| \leq r\}}{\hat{\lambda}(x_i)\hat{\lambda}(x_j)}e(x_i, x_j; r) \quad Equation\ 2$$

Where *e (u, v, r*) is an edge correction weight and $\hat{\lambda}(u)$ is an estimate of the intensity function $\lambda(u)$.

Landscape

We tested the effects of five landscape variables on resting site distribution:

Two variables—*Vegetation type* and *NDVI*—were derived from a Landsat 8 OLI image, with an unsupervised classification to get a vegetation type layer using an Iso cluster function. An NDVI layer using a raster calculator from Spatial Analyst toolbox was obtained using Equation 3:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \qquad Equation\ 3$$

where ρ_{NIR} corresponds to band 5 (near infrared), and ρ_{Red} to band 4 (visible red; Viña et al. 2011).

The other three variables—*Aspect*, *elevation* and *slope*—were calculated from a Digital Elevation Model (DEM) of the study site. Elevation was derived directly from the DEM, and aspect and slope were calculated with the Surface toolbox in Arc Map 10.3.

Vegetation type was treated as categorical variables with the following classes: ravines, oak-pine, oak, Mexican beech, secondary, roads, grazing and villages. Similarly, hillside aspect was treated as a categorical variable with the following classes: north, northeast, east, southeast, south, southwest, west and northwest. Elevation was divided into three categories: low (1122-1427 m), medium (1428-1731 m), and high (1732-2036 m), as well, slope was divided into low (0-29.25°), medium (29.3-58.5°), and high (58.5-87.75°).

Erdas Imagine software v.14.0 was used to reproject the Landsat and DEM images and perform atmospheric and radiometric corrections (Intergraph Corporation). All five layers were converted to ASCII files. Then, we calculated the total percentage of pixels in each class (hereafter, “availability”), and the percentage of pixels occupied by resting sites (hereafter, “usage”)

Model fitting and diagnostics

We fit four Poisson models to explain resting site distribution:

1) M0 was a null model, assuming uniform resting site distribution within the area.
2) M1 assumed that environmental variables explained resting site distribution
3) M2: environmental variables (M1) + Cartesian coordinates of resting site locations
4) M3: environmental variables (M1) + Cartesian coordinates of resting site locations + interaction of environmental variables and Cartesian coordinates

To confirm the models, we performed Lurking variable plots, and inhomogeneous second-order K functions were fitted to the models. We used Akaike’s Information Criterion (AIC) to determine which model was best supported by the data. All statistical procedures were performed in R v. 3.4.3 (http://www.r-project.org).

Microhabitat

We collected variables that describe the resting site microhabitat in terms of the basic requirements of water, food, and protection. At each resting site, we measured the distance from the resting site to the *nearest water resource* using a measuring tape. We used a manual counter (Base Mount Tally Counter) to count *deer footpaths* observed in each resting site and the *slope* from the ground was measured using a clinometer (SUUNTO®).

We measured *concealment cover* following Griffith and Youtie (1988), except that we considered that the cover closest to the ground ("first segment", 0-50 cm) provides cover for fawns while the cover in the second (50-100 cm) and third segments (100-150 cm) provide cover for adults.

We performed 20 *canopy closure* readings—five in each of the four cardinal directions—at each resting site between 9:00 am and 12:00 pm using a densiometer (Model C, Lemmon, 1957). Finally, we performed four Canfield lines along a transect of 10 m to record all understory vegetation cover ≤2 m in height. These surveys were used to calculate the *understory density*, *coverage, height, and species richness* (Canfield, 1941). These variables were then used to describe thermal cover.

We also looked at scraps, branches removed, compacted litter, and preference for bedding below a tree and/or tree fern species.

Statistical comparison

For each resting site surveyed, we established an associated control plot where we measured the same attributes. Control plots were selected in a random cardinal direction 50 m from the identified resting site. Comparisons between the resting site and control plot were made with Wilcoxon tests. All statistical procedures were performed in R v. 3.4.3 (http://www.r-project.org).

Results

Resting site distribution

We found and characterized 43 resting sites and their corresponding control plots. The highest density of resting sites occurred in two "hotspots" located at the core of the study area (Fig-2A). K and L function graphs showed that the empirical curve was higher than the theoretical curve at distances up to 900 m (Fig-2B). Therefore, we determined that the resting sites had an aggregated spatial pattern from 0 to 900 m, but their distribution was completely random at longer distances.

Landscape variables

Most of the resting sites were found within oak and Mexican beech forest, and the usage of these vegetation types was far higher than their availability. Most resting sites were found at sites with NDVI values greater than 0.75, on hills oriented northwest followed by north and northeast, with elevations from 1732 to 2036 m asl and in places with slopes less than 29° (Fig-3; Table-1).

Model fitting and diagnostics

The best-supported model by AIC and Lurking variable plots was the one that also included the interaction of resting site coordinates and environmental variables (M3, Fig-4; Table-2).

Mexican beech and oak forests displayed the strongest positive effect followed by secondary vegetation and ravines. The next most important positive effect was displayed by elevation, particularly medium and high elevations. (Table-1).

Microhabitat

We found that all resting sites were near a water resource, most within 20 m. The number of deer footpaths ranged from two to six in each resting site, and the slope angle was flat or nearly flat in all resting sites. Concealment cover for fawns (0-50 cm) was complete at every resting site, as was concealment cover for adults at the first segment. There was more variation in the degree of cover from 50-100 cm, ranging from 0 to 100 % of coverage. The canopy closure at resting sites was total or near-total (Fig-5).

The understory density in resting sites ranged from 0 ind./m^2 to 0.9 ind./m^2, with an average of 0.5 ind./m^2, and understory coverage varied from none to complete coverage, with an average of 56.2%. Understory height ranged from 0 to 1.9 m, with an average of 0.9 m. Finally, species richness ranged from 0 to 9 species, with an average of 4.6 species at resting sites (Fig-5).

We identified six dominant species in the tree stratum (*Fagus grandifolia subsp. mexicana, Quercus trinitatis, Q. delgadoana, Q. meavei, Dicksonia sellowiana var. arachneosa,* and *Alsophila firma*). The understory contained 12 species; the most dominant were *Miconia glaberrima* and *M. oligotricha*. Fifty percent of the resting sites located next to oak trees, 30% under fallen trees, 14% next to Mexican beech trees, and 6% next to tree ferns. There were signs of scraping at 10 resting sites.

Statistical comparison

There were significant differences (p = 0.05) between resting sites and random sites. Resting sites 1) were closer to the nearest water resource, 2) had a larger number of footpaths, 3) had flatter slope, 4) had a greater concealment cover for fawns, 5) had closer canopy, and 6) taller understory (Fig-6).

Discussion

Over the course of a year, we found 43 resting sites in the study area. That could be considered a low number of sites compared to those found for other deer species such as roe deer, white-tailed deer and Indian muntjac (Dahlgren & Gladfelter, 1986; Teng et al., 2004; Christen et al., 2018). On the other hand, a similar number of resting sites were found for Texan white tailed deer and sika deer, although the survey in sika deer lasted only three months (Gallina et al., 2010; Li & Liu, 2017). This could be due to the low abundances of Central American brocket deer in addition to their solitary habits and low reproductive rates (Reyna-Hurtado & Schipper, 2016)

We found that Central American brocket deer were selective with respect to resting site location. Resting sites were only found in the core areas of the habitat, in accordance with results across southeastern Mexico that show that the species restricts its distribution to core areas with occasional excursions to the forest edges (Bello-Gutiérrez et al., 2004; Weber, 2005). The current study thus supports previous findings showing that Central American brocket deer are habitat specialists (Weber, 2008).

Our results showed that vegetation type was the most important variable in resting site distribution. Similarly, Garcia-Marmolejo et al. (2013) found that landscape composition was the single most important variable contributing to potential distribution of Central American brocket deer in the Huasteca region of San Luis Potosí, Mexico. Despite the availability of different vegetation types, a relatively high percentage of resting sites were found in Mexican beech forest habitats. This shift might indicate disturbances in at least some parts of the habitat that made this forest more desirable for resting sites (Christen et al., 2018). Remnants of Mexican beech forests are considered hotspots with high connectivity and low disturbance in our study area (Rodríguez-Ramírez et al., 2016). Additionally, secondary vegetation clearly played an important role in resting sites, coinciding with other studies where deer are distributed in secondary vegetation near well-preserved forests (Bello-Gutiérrez et al., 2004). Ravines were also important sites for Central American brocket deer resting sites, reflecting this elusive species' strategy of avoiding predators, including humans (Camps, 2011).

In contrast with our results, in Campeche, the presence of evergreen forest was a determinant factor for the Central American brocket deer presence, while our results suggest that the species avoids this vegetation type (Contreras-Moreno et al., 2016). This may be related to the overexploitation and human presence in the evergreen forest in our study area; there are only small fragments remaining, and they are frequently visited by local hunters (Muñoz-Vazquez, 2013). The more frequent presence of local hunters in lowlands may be promoting that Central American brocket deer prefer the highlands in spite of the species displays wide elevational shifts (Bello et al., 2016). This may be because much of the lowland area that was previously evergreen forests has been converted to crops and grazing land, and the remaining lowland evergreen forest remnants are frequently visited by local hunters; this may push deer into higher elevations, which still have larger tracts of forest (in this case, tropical mountain cloud forest) and poaching pressure is less intense. Nevertheless, elevation seems to be a very important factor that limits the distribution of many ungulates (Li et al., 2020).

Our study shows that Central American brocket deer tend to locate their resting sites on north- or northeast-facing slopes. Whether this is a result of actively choosing sites that are less exposed to solar radiation or simply a result of choosing Mexican beech forests that grow in this orientation is unclear, although the first this is a very common behavior for many deer species (Pérez-Solano et al., 2016).

The vegetation characteristics were similar among Central American brocket deer resting sites and differed from the vegetation structure found in surrounding areas. In general, deer chose resting sites located closer to streams and rills and with more thermal and concealment cover than expected at random. Evidence shows that water availability influences the location of resting sites for many mammals (Kirby et al., 2017; Delgado-Martínez et al., 2018; Lira et al., 2018). Particularly, Gallina et al. (2010) found a strong relationship between the presence of water bodies and the probability of deer survival.

Central American brocket deer also tended to prefer flat spots (≈180°) to rest, likely so that they do not slide off the bedding site. This was despite resting sites being located in areas of steep overall terrain, which could be interpreted as a sign of comfort behavior (Mysterud & Ostbye, 1995; Erdtmann & Keuling, 2020).

Our results support the importance of thermal and concealment cover. This tendency has also been reported for other deer species, such as fawn and adults of white-tailed deer (Huegel et al., 1986; Gallina et al., 2010). Landscapes that offer more concealment and dense vegetation contribute to the avoidance of predators. In our study area, we detected the presence of the main natural predator of brocket deer, *Puma concolor* (Foster et al., 2010; Huerta-Valdez, 2017; Christen et al., 2018). The results of our study show that Central American brocket deer tend to select resting site locations with high canopy coverage. As a forest specialist, it is not surprising that this species prefers forest habitat to rest (Weber, 2008).

When comparing our findings with the study about general habitat preferences of Central American brocket deer in the same area, we notice that canopy closure was complete in almost all resting sites, while in general habitat was 60%. Second, the concealment cover for fawns and adults was denser and taller at resting sites than in general habitat (Gallina-Tessaro et al., 2019). The greater cover provides better concealment and thermal insulation, which may provide advantages to the Central American deer while resting (Tilman & Karieva, 1997).

This is the first study to quantify the characteristics of Central American brocket deer resting sites. The species inhabits dense vegetation environments, and they are elusive and shy, which makes them difficult to observe directly in the wild. Thus, tracks provided an important reference for identifying resting sites. We performed an exhaustive search of resting sites throughout the study area and test the effects of landscape and microhabitat.

Conclusions

Significant variations between resting and random sites characteristics were evident, suggesting that Central American brocket deer select places with specific characteristics to rest, at both the landscape and microhabitat scales. In the area, there are only a few forest patches that meet Central American brocket deer resting site requirements; the rest of the habitat is unsuitable for this behavior due to disturbances that include intense agricultural and livestock activities in the area. This scenario has been observed in the majority of the studies of this species, and Central American brocket deer habitat is frequently highly fragmented (Garcia-Marmolejo et al., 2013). Therefore, we suggest preserving the existing forests, with a special interest in Mexican beech forest and oak forest. Moreover, we recommend avoiding poaching in the entire study area, but especially in the core areas where we observed the highest density of resting sites. Preserving enough habitat for Central American brocket deer would both improve their conservation status and alleviate decrease potential human-wildlife conflicts.

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Conflict of interest

No conflict of interest declared by the authors

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Figure 1

Figure 1.

Geographical location of the San Bartolo Tropical Montane Cloud Forest of the Sierra Madre Oriental in eastern Mexico, where we analyzed the distribution and characteristics of Central American brocket deer resting sites from 2017 to 2019.

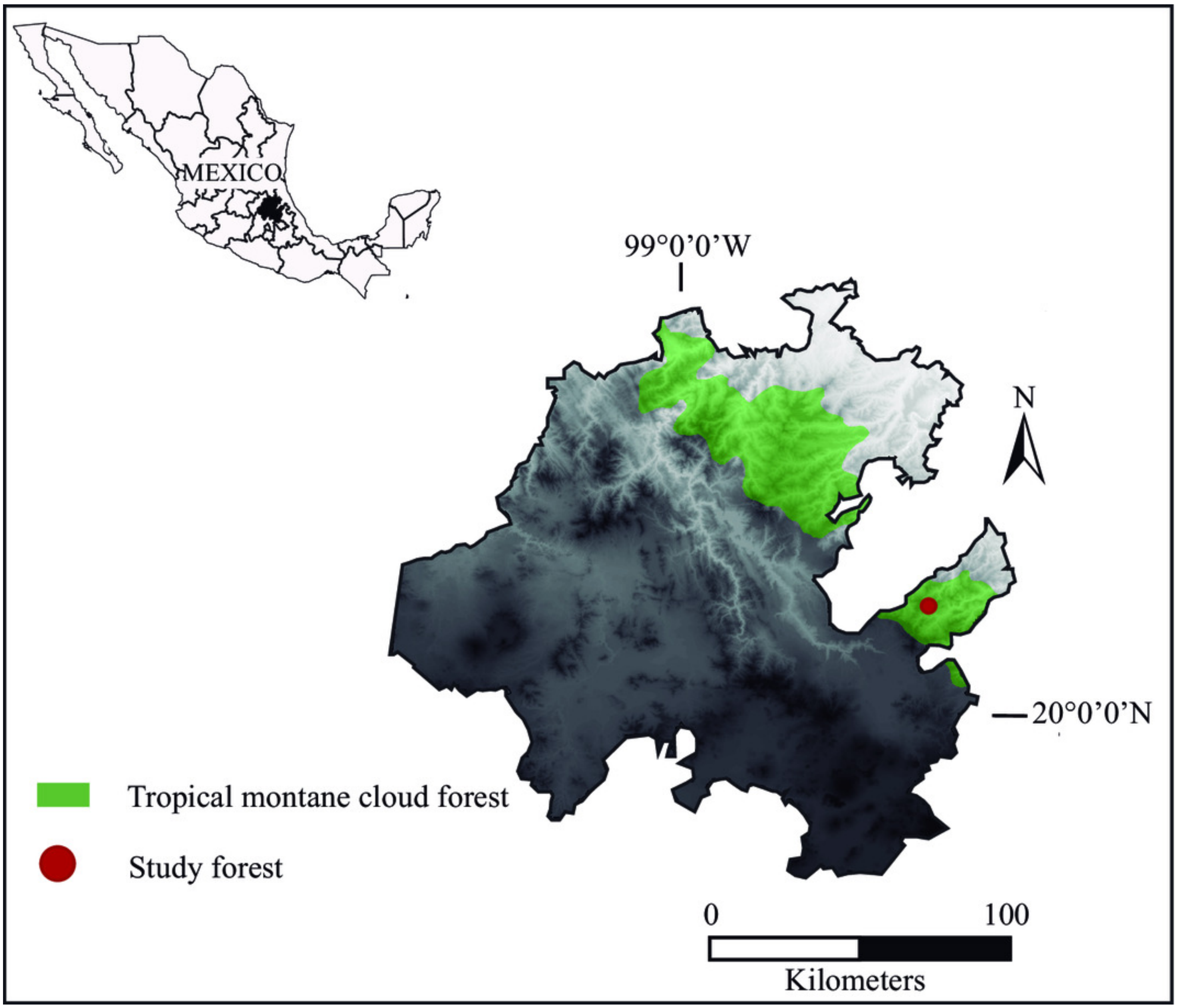

Figure 2

Figure 2

Spatial point pattern analysis of Central American brocket deer resting site distribution. A) Kernel-smoothed intensity. B) Generalized *K* and C) *L* functions for the spatial pattern. The shaded area shows envelopes from 99 simulations of each model, while the *solid black line* represents the empirical function from the fitted model and the *dotted line* shows the mean of the function from the fitted model.

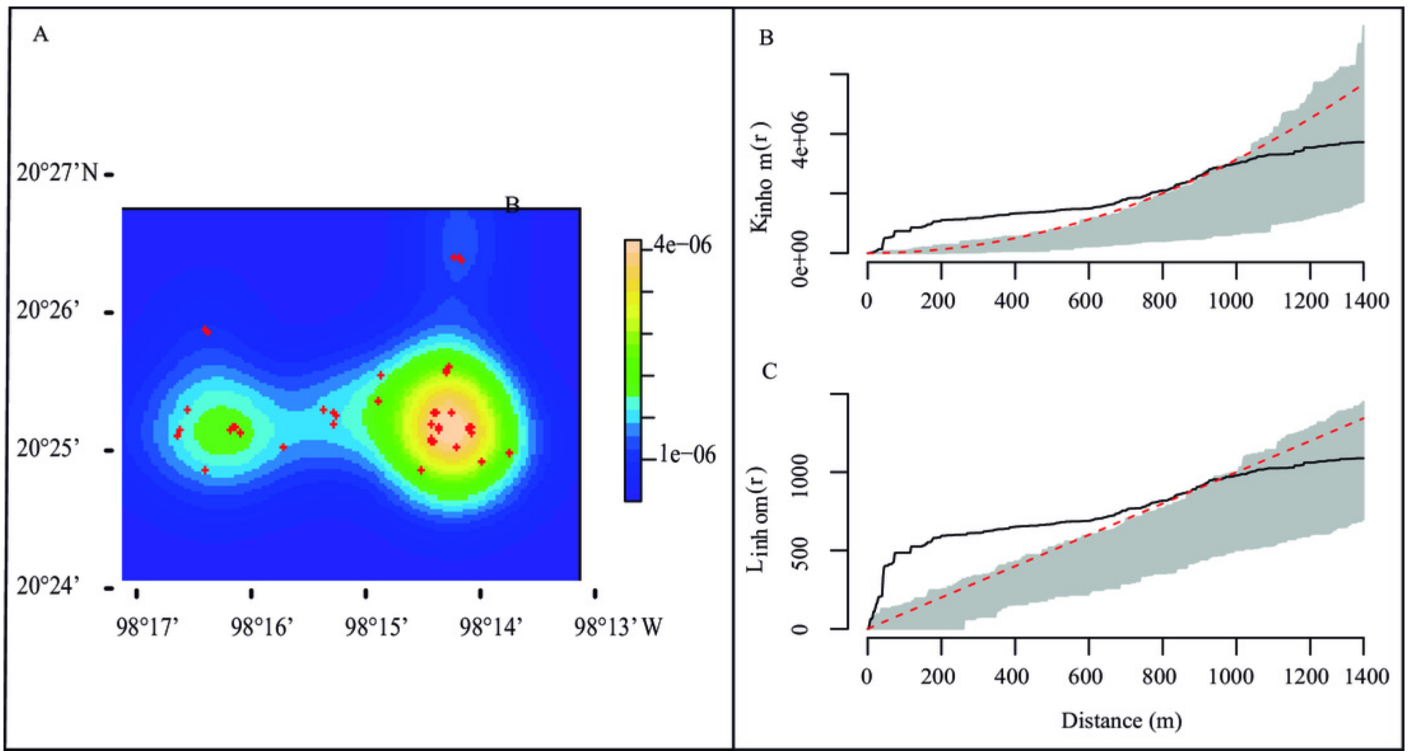

Figure 3

Figure 3

Landscape variables: A) Vegetation type, B) Hillside aspect, C) Elevation, D) NDVI, and E) Slope.

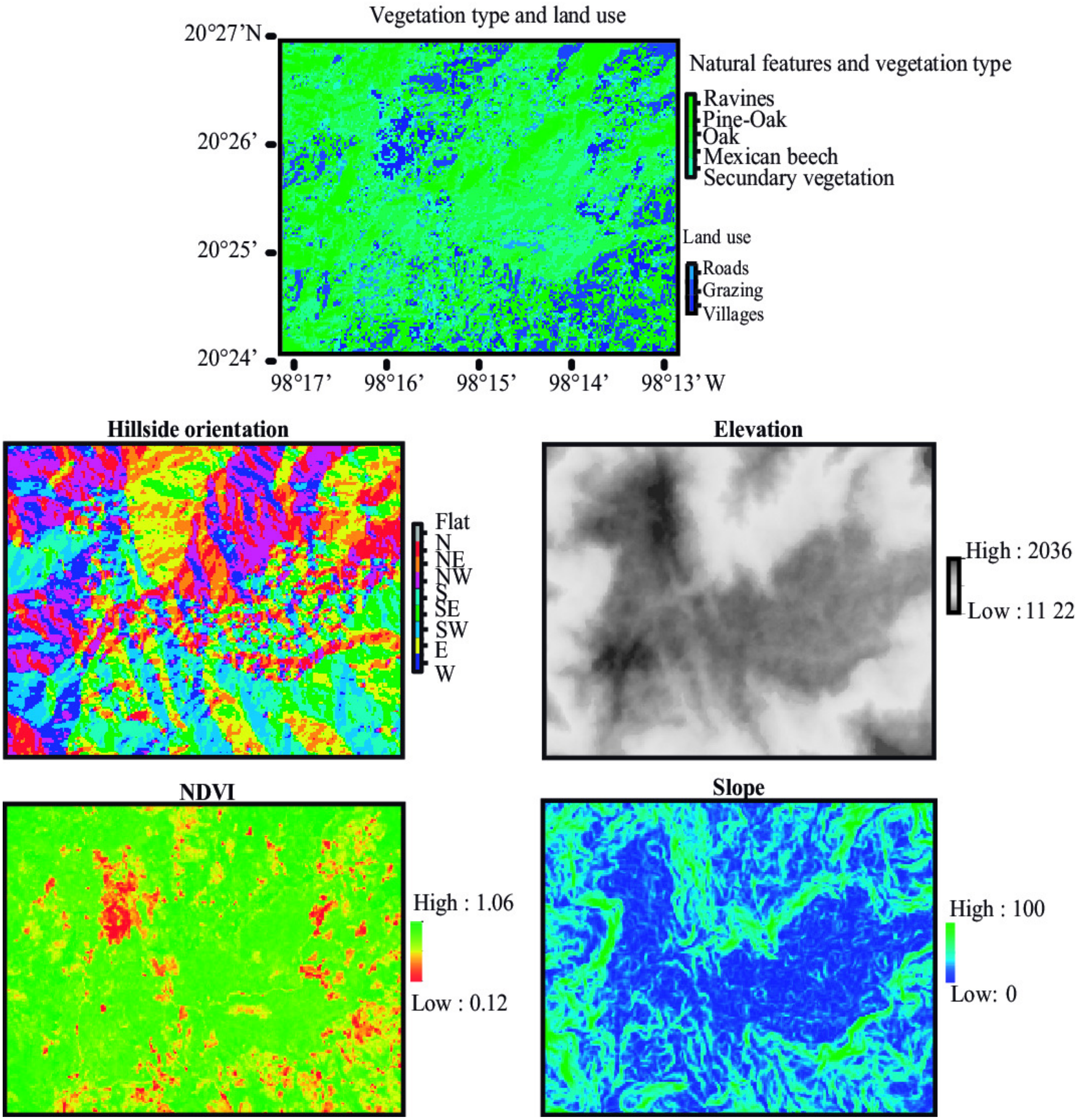
Vegetation type and land use
20°27'N
20°26'
20°25'
20°24'
98°17'
98°16'
98°15'
98°14'
98°13' W
Natural features and vegetation type
Ravines
Pine-Oak
Oak
Mexican beech
Secundary vegetation
Land use
Roads
Grazing
Villages
Hillside orientation
Flat
N
NE
NW
S
SE
SW
E
W
Elevation
High : 2036
Low : 11 22
NDVI
High : 1.06
Low : 0.12
Slope
High : 100
Low: 0

Figure 4

Figure 4

Lurking variable plots from a model including continuous landscape variables only (M1; A, B, and C) and a model including landscape variables and coordinates (M2; D, E and F) applied to Central American brocket deer resting site spatial pattern.

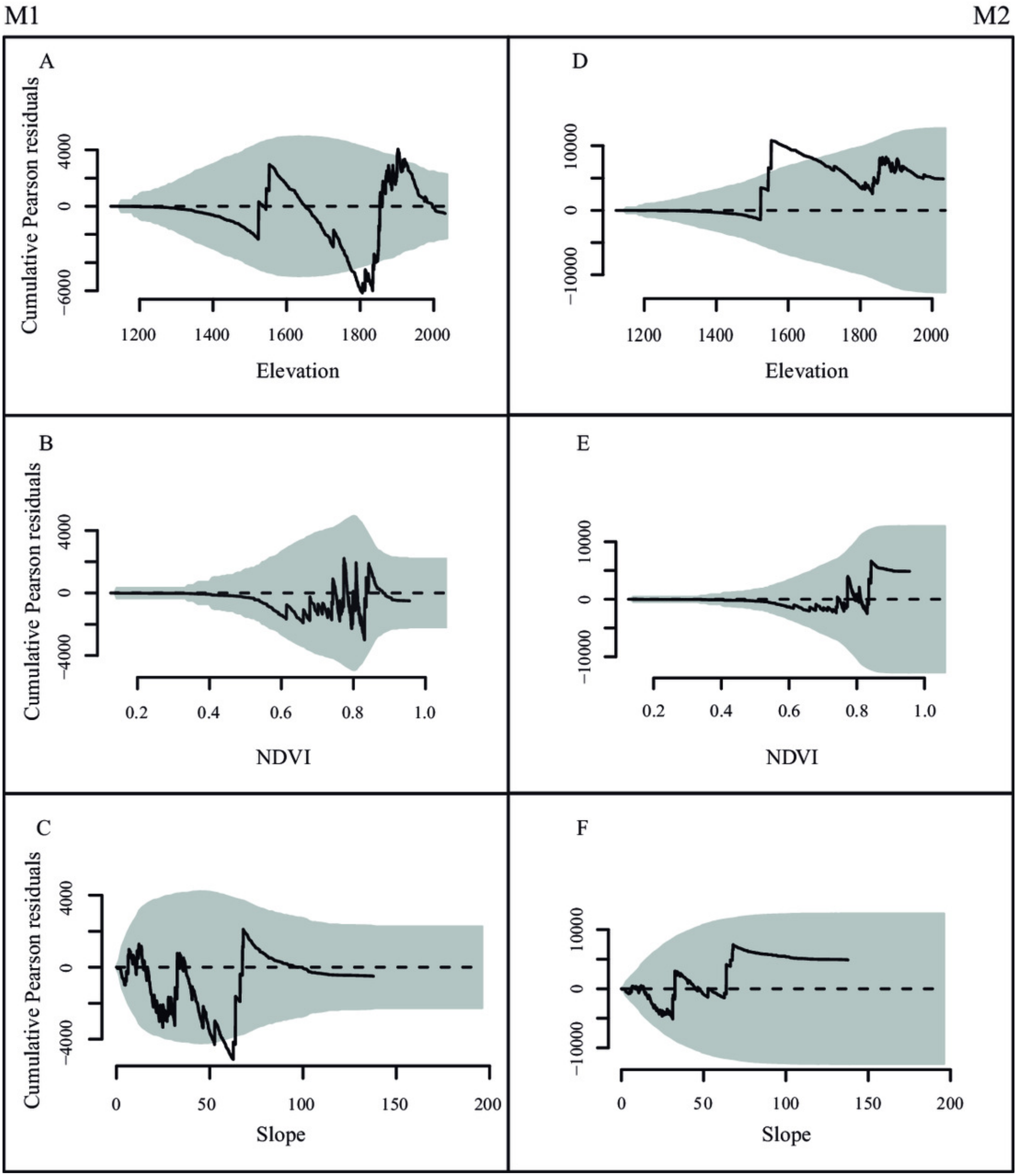
M1
M2
A
B
C
D
E
F
Cumulative Pearson residuals
Elevation
NDVI
Slope
4000
0
−6000
−4000
10000
0
−10000
1200
1400
1600
1800
2000
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200

Figure 5

Figure 5

Inhomogeneous second order K functions for: A) model including landscape variables M1. B) model including landscape variables and coordinates. And C) model including landscape variables, Cartesian coordinates and their interaction (M3). All applied on Central American brocket deer resting site spatial pattern.

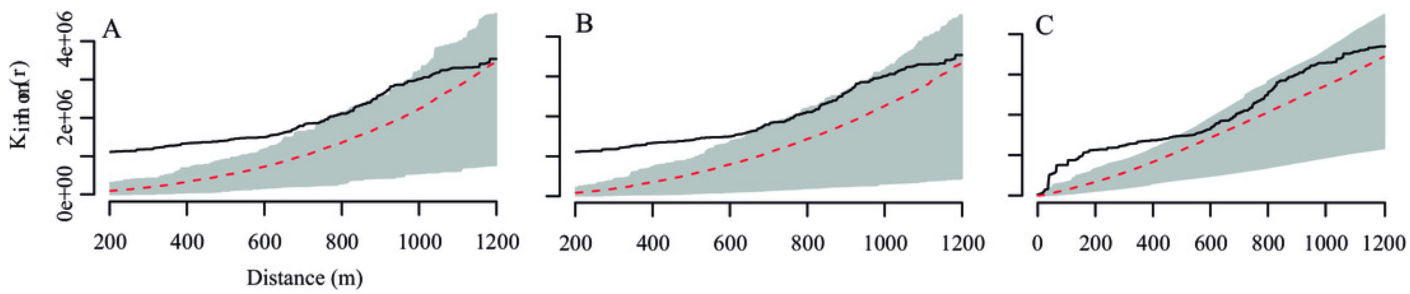

Figure 6

Figure 6

Violin plots of the microhabitat variables in Central American brocket deer resting sites and random sites. A) Distance to nearest water resource, B) Number of deer trails, C) Slope angle, D) Concealment cover for fawns, E) Concealment cover for adults, F) Canopy coverage, G) Undergrowth density, H) Undergrowth coverage, I) Undergrowth height, J) Undergrowth species richness.

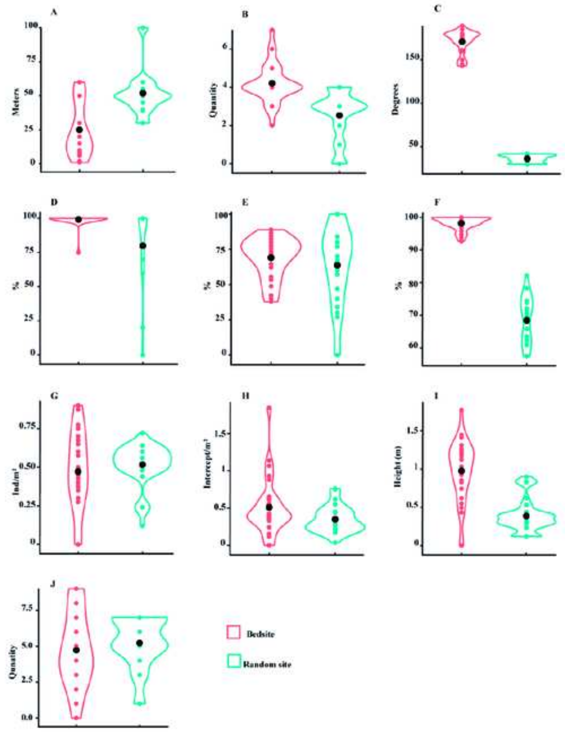
A
B
C
D
E
F
G
H
I
J
Meters
Quantity
Degrees
%
Ind/m²
Intercept/m²
Height (m)
Qunatity
Bedsite
Random site

Table 1(on next page)

Table 1

Use and availability of second order selection process covariates and coefficients from the model including covariates effects, coordinates and area interaction (M3).

Covariate	Use (%)	Availability (%)	M3 Value
Intercept			-1721566.0
X			-0.1
Y			1.6
I(x^2)			0
I(x * y)			0
I(y^2)			0
Vegetation			
Ravines	4.7	9.9	12.4
Oak-pine	11.6	16.6	0.4
Oak	25.6	15.0	13.7
Mexican beech	39.5	9.6	13.9
Secondary	9.3	11.9	12.9
Roads	0	7.1	0.2
Grazing	0	8.0	0.7
Villages	0	4.1	0.8
NDVI			0.8
Low (0.12-0.44)	0	3.3	N/A
medium (0.45-0.75)	20.9	38.9	1.0
High (0.75-1.06)	79.1	57.8	0.8
Hillside aspect			
North	16.3	9.7	-0.4
Northeast	16.3	10.5	0.2
East	7.0	11.8	-0.2
Southeast	7.0	7.2	0.2
South	14.0	12.2	0.6
Southwest	7.0	19.8	-0.4
West	11.6	20.4	0.4
Northwest	18.6	8.4	-0.2
Elevation			0
Low (1122-1427)	0	8.4	N/A
medium (1428-1731)	9.3	41.7	10.8
High (1732-2036)	90.7	50	10.9
Slope (degrees)			0
Low (0-29.25)	88.4	49.3	
medium (29.3-58.5)	11.6	46.3	1.1
High (58.5-87.75)	0	4.4	-0.1

1

Table 2(on next page)

Table 2

Evaluation of second order selection process spatial models fitted to bedsite point pattern.

Model	AIC	Pars	Model formula
Null model	1270.218	1	1
M1. Model including landscape variables only	1232.774	6	$C_1 + C_2 + C_3 + C_4 + C_5$
M2. Model including landscape variables and Cartesian coordinates	1218.876	11	$p(x, y, 2) + C_1 + C_2 + C_3 + C_4 + C_5$
M3. Model including landscape variables, Cartesian coordinates and interaction	1080.068	13	$p(x, y, 2) + C_1 + C_2 + C_3 + C_4 + C_5 + int$