THERYA, 2024, Vol. 15(1):91-102 DOI:10.12933/therya-24-5753 ISSN 2007-3364

Biogeographic analysis of population density of White-tailed deer in Mexico: importance of the protected natural areas and wildlife management units

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The white-tailed deer *Odocoileus virginianus* is the wildlife species with the greatest geographic distribution and economic importance in Mexico. This article presents a biogeographic analysis of the population density of this deer species by federal states, vegetation types, biogeographic provinces, and field methods, based on 200 selected studies. Estimates are highly variable and potentially biased due to the different field designs and statistical analyses. The national average density was estimated at 6.9 deer/km^2 (SD = 5.1); specifically, 75.5 % of the estimates were less than 10 deer/km^2, and only 5.5 % were greater than 15 deer/km^2. The highest densities were obtained in the northern region by applying the strip transect counts; while estimations using the fecal group count method were more variable and were the most used method in temperate and tropical dry forest regions. The states with the highest densities were Coahuila, Tamaulipas, Jalisco, Morelos, Michoacán, and Durango. The highest densities were estimated in the xerophilous scrublands of the northeast, intermediate for temperate, tropical dry, and sub-deciduous forests; and the lowest in the tropical wet forest. The highest densities were reported for the Tamaulipeca province followed by the Altiplano Chihuahuense, Sierra Madre Occidental, Costa Pacífica, and Depresión del Balsas. The results of this analysis could guide management strategies for the conservation and sustainable use of this species in extensive UMAs and ANPs, and also to test ecological hypotheses. However, applying more rigorous field design and statistical analysis is important to obtain confident estimates of population density and other demographic parameters to monitor population dynamics.

El venado cola blanca *Odocoileus virginianus* es una de las especies silvestres de mayor distribución geográfica e importancia económica en México. Este artículo presenta un análisis biogeográfico de las tendencias de densidad de población de venados por estado federativo, tipos de vegetación, provincias biogeográficas y método de campo, basado en 200 estudios. Las estimaciones de la densidad son muy variables y potencialmente sesgadas debido a los diferentes diseños de campo y análisis estadísticos. La densidad promedio nacional se estimó en 6.9 venados/km^2 (DE = 5.1); el 75.5 % de las estimaciones fueron inferiores a 10 venados/km^2, y sólo el 5.5 % fueron superiores a 15 venados/km^2. Las densidades más altas se obtuvieron en la región norte aplicando los conteos en transectos en franja; mientras que las estimaciones fueron más variable con los métodos de conteo de grupos fecales el cual es el más empleado en regiones de bosques templados y tropicales secos. Los estados con mayor densidad fueron Coahuila, Tamaulipas, Jalisco, Morelos, Michoacán y Durango. Las mayores densidades se estimaron en los matorrales xerófilos del noreste, intermedias para bosques templados, tropicales secos y subcaducifolios; y las más bajas en bosques tropicales húmedos. Las mayores densidades se reportaron para la provincia Tamaulipeca seguida del Altiplano Chihuahuense, Sierra Madre Occidental, Costa Pacífica y Depresión del Balsas. Los resultados de este estudio podrían orientar estrategias de manejo para la conservación y uso sustentable de esta especie en UMAs extensivas y Áreas Naturales Protegidas, y también para la inferencia de hipótesis ecológicas. Sin embargo, es importante aplicar un diseño de campo y un análisis estadístico más rigurosos para obtener estimaciones confiables de la densidad de población y otros parámetros demográficos para monitorear la dinámica de las poblaciones.

Keywords: Biogeographic provinces; conservation; federative states; limitations; management; sampling method; vegetation types.

Introduction

The white-tailed deer *Odocoileus virginianus* is a highly ecological and economically-valued species (Ortega-S. *et al.* 2011), and is the most studied deer species in México (Mandujano 2004). Published books on this deer species have been generated in the northeast region dominated by semi-arid scrubs lands (Villarreal-González 1999; Ramírez-Lozano 2004; Fulbright and Ortega-S. 2006), in temperate forests in the Sierra Madre Occidental in Durango (Folliot and Gallina 1981; Galindo-Leal and Weber 1997), the region of central México in the Mixteca Poblana (Villarreal-Espino 2006), and in Oaxaca (Mandujano 2016). Monographs have also been published on the natural history of this species in México and Latin America (Méndez 1984; Gallina *et al.* 2010; Ortega-S. *et al.* 2011; Mandujano *et al.* 2014; Gallina *et al.* 2019). In particular, a significant amount of information has been generated in protected natural areas (ANPs in Spanish), mainly Biosphere Reserves (Gallina *et al.* 2007).

Also, the white-tailed deer is the most important game species in México in the Wildlife Conservation, Management, and Sustainable Utilization Units (UMAs in Spanish; Villarreal-González 1999; Villarreal-Espino 2006). As a consequence, more studies have been generated because the management plans need evaluations of the populations and habitat to define the number of deer to be harvested each year in the UMAs (Gallina 2012), population dynamics, and the minimum viable population for conservation (Mandujano and González-Zamora 2009).

The estimation of white-tailed deer population density is a relatively common practice in México as the result of the ecological research interest in understanding factors affecting the abundance and population dynamics, principally in natural reserves, and also as a result of the need for sustainable management of this species in extensive UMAs. Population density is a key parameter in ecology and conservation, and estimates of density are required for a wide variety of applications in fundamental and applied ecology (Santini *et al.* 2022). Population density is the result of variation in survival, mortality, natality rates, sex proportion, age distribution, and other demographic parameters, and its relationships with habitat and human factors (Santini *et al.* 2022). Thus, density could vary through the years in the same site, and among populations inhabiting different regions, and usually, the density is expressed as the number of individuals per habitat area (DeYoung 2011). Based on the density estimations, inferences can be made about factors such as survival and birth rates that affect density and population dynamics, and whether the populations are within the carrying capacity of the habitat, a fundamental aspect of defining sustainable harvest rates (Mandujano 2007). Therefore, similar to other wildlife species, this parameter is central to the management and conservation of this species (Caughley and Sinclair 1994).

Therefore, a lot of biological and management information has been generated about the white-tailed deer in México, which deserves to be synthesized to describe ecological patterns and the mechanisms involved. The principal objective of this study was to analyze the available information on the population density of white-tailed deer in México. In particular, to know the population density depending on the types of vegetation, biogeographic provinces, federal states, and sampling methods. Additionally, some considerations concerning field method, statistical analysis, and density interpretation, are provided. This analysis could be important to the management and conservation of the white-tailed deer in ANPs and extensive UMAs.

Materials and methods

Sources of information. An intensive search was carried out on the studies reporting data on the population density (usually as ind/km^2) of white-tailed deer in México. The sources considered were published papers in journals, book chapters, theses, divulgation articles, symposiums, and some technical reports from the UMAs, from 1990 to 2016. The following information was recorded for each selected reference: density, federative state, locality, type of vegetation, biogeographic province, site (ANPs, extensive UMAs, communities, ejidos, private ranches), sampling method, field sampling design, total number of counts, and statistical analyses. Considering that the density information was estimated by applying four field methods (direct counts in transects, indirect counts of pellet groups and tracks, and photo trapping), we applied criteria to select the different reports. The criteria are detailed below.

In the case of studies where the fecal or pellet groups counting method was used, the defecation rate used to transform this count into density was noted. The use of different rates is crucial to convert or calibrate the fecal group count index to the number of deer per km^2 (Mandujano 2014a). The lower the defecation rate value, the higher the density estimate, and vice versa. Consequently, for the same number of fecal groups counted in the sampling, the density calculation varies depending on the rate applied. To solve this problem, it would be necessary to: apply the same rate for all studies so that it was a constant, an aspect that could not be done given that the majority of authors do not report their field data, but only the final estimate of the density obtained; or assume a range of defecation rate for the species, which could fluctuate between 9 to 35 fecal groups/deer/day, according to numerous studies in different types of habitats (Mandujano 2014b). We assume that all population density estimates obtained with this method are biased and that the magnitude and direction of this bias are unknown. We also assume that the estimates are within the expected range, given the variation in the species' expected defecation rate. These assumptions allow the use of current estimates in the studies collected.

For the direct counting method, it was defined whether the count was used in strip transects or line transects. In the latter case, the program version used for the analysis was noted, and the algorithm used. This is important because, depending on the algorithm used, a different density calculation will be obtained (Mandujano and Gallina 1995). For the transect line usually used the program DISTANCE considered the dictation probability. While in the strip transect, it is assumed that 100 % of the deer were detected within the previously defined transect width. In the latter case, this restriction may be easily violated in fieldwork since the greater the perpendicular distance, the lower the probability of detection. Consequently, also for these methods, there are biased estimates of local population density.

The track and camera trap methods were the least used. Both convert the index of tracks or photos to the number of deer per area using different algorithms. The tracks count method is based on a series of assumptions about deer movements, which are not necessarily met in all cases (Mandujano 2005). Photo-trapping is based on the assumption of correctly identifying all photographed individuals, an aspect that is not easy given the lack of natural marks of the species (Soria-Díaz and Monroy-Vilchis 2015). Consequently, the estimates obtained with these methods are also biased.

Therefore, based on criteria that considered a lack of specific details in the field design, very few sampling units and observations, insufficient details of the numerical data analysis, the software used, and/or a combination of these factors, from the initial base of 250 references, we selected 200 references for the statistical analysis (Mandujano *et al.* 2016a). The database was incorporated into the National Biodiversity Information System (SNIB) available on the CONABIO website http://www.conabio.gob.mx/institucion/cgi-bin/datos2.cgi?Letras=JM&Numero=16.

Analysis of geographic and statistical data. Biogeographic maps of Floristic Divisions, Biogeographic Provinces, and State Political Divisions in México were taken from Rzedowski and Reina-Trujillo (1990), Arriaga *et al.* (1997), Palacio et al. (2000), and Morrone (2005). All maps were obtained from the databases of INEGI (National Institute of Statistics and Geography, http://mapserver.inegi.org.mx), and CONABIO (National Commission for the Understanding and Use of Biodiversity, http://www.conabio.gob.mx/informacion/gis/). Considering that population density values varied from 0 to positive continuous values, and the density estimates distribution is relatively normal (slightly right skewed, see Figure 2), we used parametric tests. As alternative statistical analyses first standardize the density (mean = 0, SD = 1), or use generalized linear models considering the beta distribution. However, in this study we tested significant differences among categories for each analyzed factor (field method, federative state, vegetation type, and biogeographic province), using a parametric approach. The categories with lower density estimations (n < 3 studies) were deleted, and then a one-way ANOVA was applied for each factor. The posterior Honest Significant Difference (HSD) test was applied to identify significant differences among categories for each variable. All analyses were performed in the R package version 4.2.2 (R Development Core Team 2022).

Results

The geographic distribution of the 200 reported white-tailed deer population densities, was not homogeneous in México (Figure 1). The major number of reports were biased to some regions and states, principal in the northeastern, Sierra Madre Occidental, Pacific Coast in Jalisco and Michoacán, in the central region in Puebla and Oaxaca. The statistical distribution of the 200 reports is positively skewed (Figure 2), and the national average density of white-tailed deer was estimated at 6.9 deer/km^2 (median = 6.0, SD = 5.1, range = 0.1 to 25.0). Mainly, 75.5 % of the estimates were

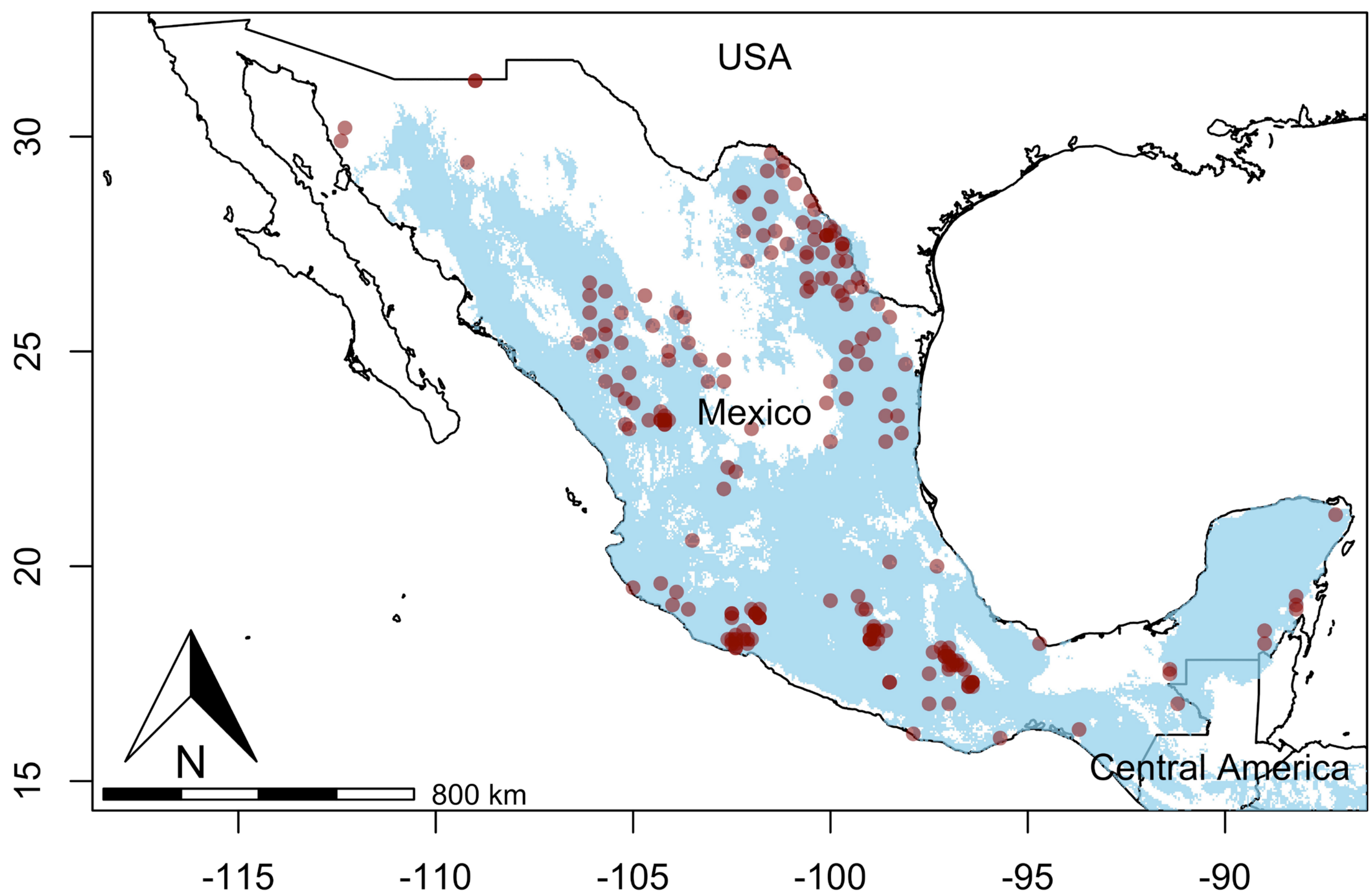

Figure 1. Distribution of locations with density estimates (red circles) in México. Potential geographical distribution of white-tailed deer in México (blue) according to ecological niche modeling (Mandujano *et al.* 2016a).

less than 10 deer/km^2, and only 5.5 % were greater than 15 deer/km^2. From 200 reports, 48.1 %, 38.5 %, and 13.5 % were in ANPs, other (communities, ejidos, private ranches), and extensive UMAs, respectively.

Four field methods were used as the principals to estimate deer density: fecal group counts, direct counts in strip or line transects, track counts, and camera trapping. The strip transects are the standard method in the northern of the country, while the count of fecal groups is used in areas of denser vegetation such as temperate forests and tropical forests. The highest densities were estimated with the direct counts of deer and were statistically significant in comparison to the estimates obtained with the fecal group and track count methods (Figure 3; $F = 11.01$, $df = 2, 185$, $P = 0.0001$). Even the actual intensive use surprisingly few population density estimations exist using the camera trap method.

The federal states with the highest number of estimates were Coahuila, Nuevo León, Durango, Oaxaca, Michoacán, Tamaulipas, and Puebla. The highest densities were in Coahuila, Tamaulipas, Jalisco, and Morelos; while the lowest was in the States of México, Veracruz, Tabasco, and Chiapas (Figure 4; $F = 7.45$, $df = 9, 170$, $P = 0.0001$).

The main vegetation types where densities were estimated were xerophilous scrublands, temperate forests, and tropical dry forests. The highest densities were found in the scrublands of the northeast, intermediate for temperate, tropical dry, and sub-deciduous forests, and the lowest in the humid forest and grasslands (Figure 5; $F = 7.39$, $df = 3, 188$, $P = 0.0001$).

The biogeographic provinces with the most significant number of data were the Tamaulipeca, the Sierra Madre Occidental, and the Depresión del Balsas. The highest densities were reported for the Tamaulipeca province followed by the Chihuahua Altiplano; the most variable for the Sierra Madre Occidental; while the lowest were in the Zacatecano Altiplano, Eje Neovolcánico, Oaxaca, Petén, Sierra Madre Oriental and Soconusco (Figure 6; $F = 5.10$, $df = 13, 186$, $P = 0.0001$).

Discussion

Biogeographic density trends. The data suggest that the highest densities are found in the northeastern region specifically in the vegetation type dominated by xerophilous scrubs in the Tamaulipeca biogeographic province in the states of Coahuila, Nuevo León, and Tamaulipas. This region is known as one of the principals in México where the white-tailed deer is used in extensive UMAs, principally because the subspecies *O. v .texanus* and *O. v. miquihuanensis* have greater antlers as the principal objective of the sport hunters (Villarreal-González 1999). In this region, deer populations and habitats are managed through different strategies such as control of illegal hunters, animal translocation, repopulation, artificial water supplies, food production in parcels, and salt resources, among the mains. Thus, it is possible that in many UMAs the population densities of this deer have increased as levels highest than carry-

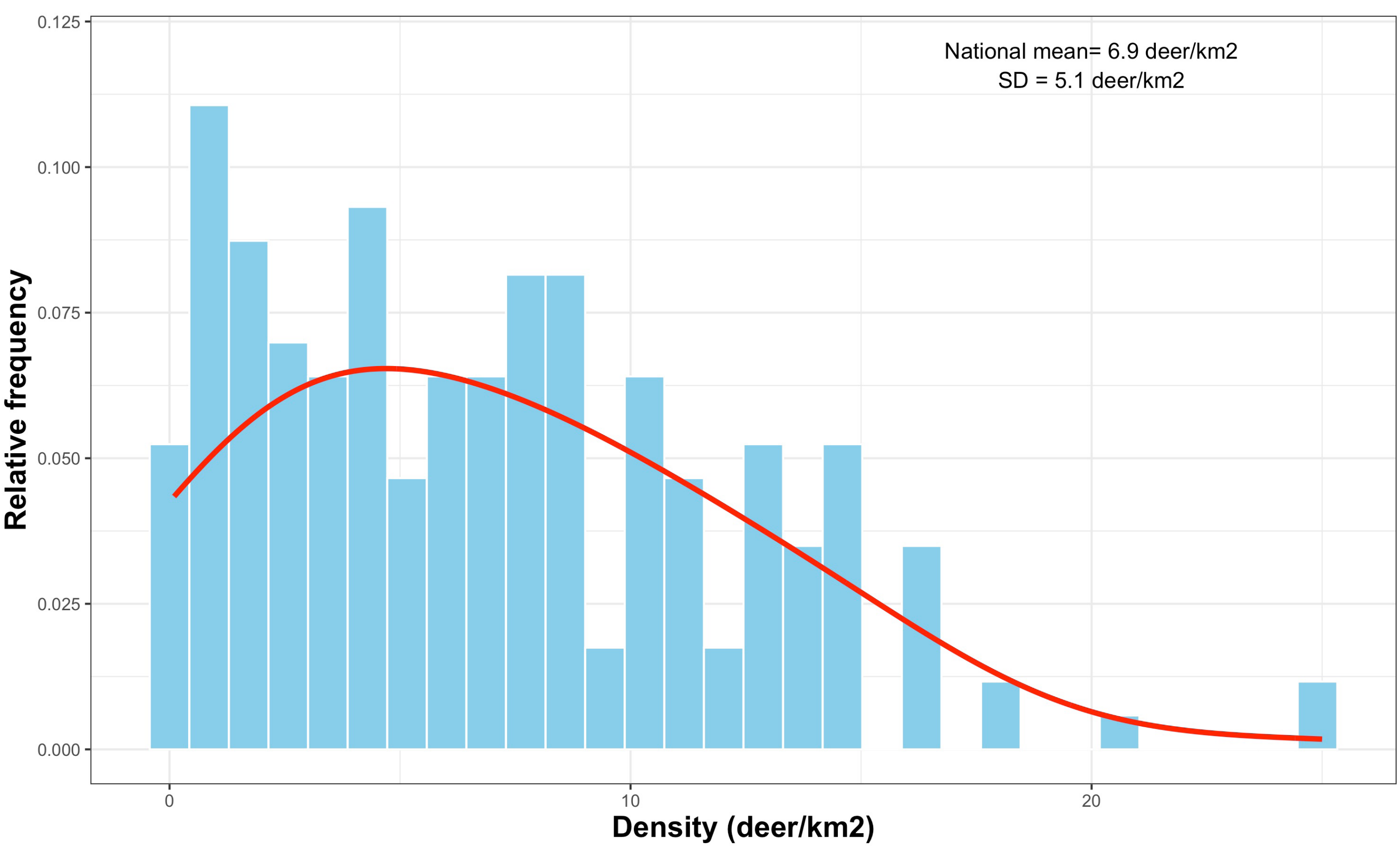

Figure 2. Statistical distribution of the population density estimates ($n = 200$) of the white-tailed deer in México. The red line represents the best fit model to field data.

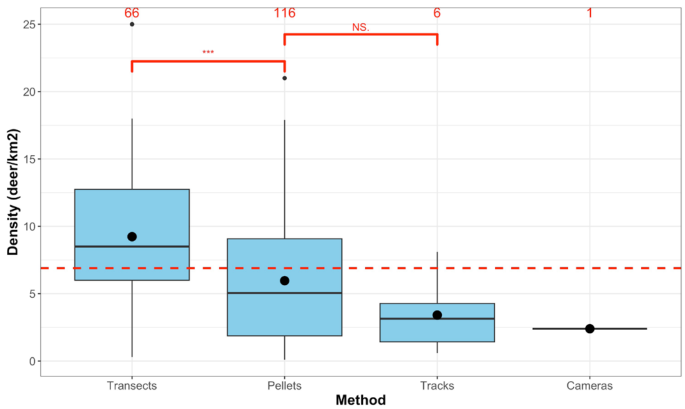

Figure 3. Estimates of the white-tailed deer density by direct observation in transects; fecal groups in plots; tracks on trails and transects; and photos in camera traps. The dotted horizontal red line represents the average density value estimated for the entire country. Symbols: mean (black circle), median (horizontal line), 25 % and 75 % percentile (box), range (vertical line), extreme values (small black dots), and sample size (red color numbers). Continuous horizontal red line grouping categories represent the posterior HSD test with a significant probability $P < 0.01$ (*), $P < 0.0001$ (***), and no differences (NS). Categories with $n < 3$ references, were not considered for statistical inferences.

ing capacity (K) or overpopulation (Martínez *et al.* 1997). In this region is common to apply the field method of counting deer in strip transects. Both strip-transect and distance-transect count methods are used in open habitats around the world. The principal advantage is that direct counts of animals are used for density estimations, and there is no need to correct factors for example the indirect counts of tracks and pellet groups.

The estimations of white-tailed deer densities in the template forest are variable in the different regions. For example, at La Michilía in Durango (Galindo-Leal *et al.* 1993; Gallina 1994), Sierra Gorda in Querétaro (Arroyo-Quiroz *et al.* 2017), La Primavera in Jalisco (Valenzuela 1994), Hidalgo (Sánchez-Rojas *et al.* 2009), Corredor Biológico Chichinautzin in Morelos (Flores-Armillas *et al.* 2011), and Sierra de Juarez in Oaxaca (Briones and García-Cruz 2005; Ortíz-Martínez *et al.* 2005), the application of indirect counts of pellet groups were the common method.

White-tailed deer inhabit the Pacific and Central regions from the scrubland of Sonora (Coronel-Arellano *et al.* 2008; Lara-Díaz *et al.* 2011) to the tropical dry forest of Nayarit, Chamela-Cuixmala in Jalisco (Mandujano and Gallina 1995), Zicuirán-Infiernillo in the Balsas region of Michoacán (Yañez-Arenas *et al.* 2012b; Mandujano *et al.* 2013), La Montañana in Guerrero (Bustamante-González 2018), the coast of Oaxaca (Buenrostro-Silva and García-Grajales 2016), Sierra Huautla in Morelos (Malacara-Velázquez *et al.* 2023), Nanchichitla in Estado de México (Soria-Díaz and Monroy-Vilchis 2015), in the region of the Mixteca in Puebla (Villarreal-Espino 2002), and in Tehuacán-Cuicatlán in the states of Puebla and Oaxaca (Mandujano *et al.* 2016b, 2019). In these tropical regions, the estimations have been obtained principally through indirect methods such as counts of tracks in dirt roads (Mandujano 2005), and the pellet-groups (Camargo and Mandujano 2011) counts and

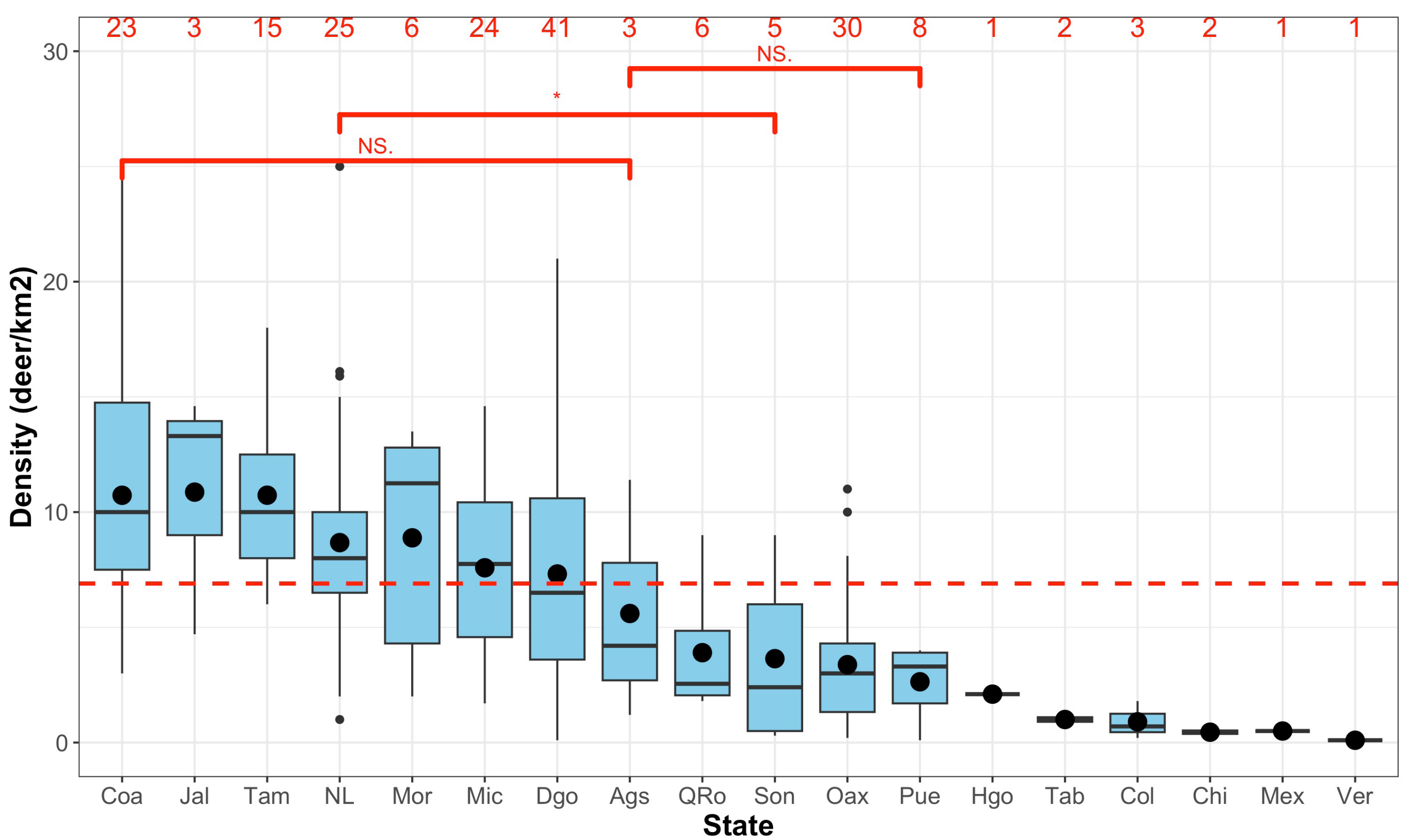

Figure 4. Estimates of the white-tailed deer density obtained in the federal states. Abbreviations: Coahuila (Coa), Jalisco (Jal), Tamaulipas (Tam), Nuevo León (NL), Morelos (Mor), Michoacán (Mic), Durango (Dgo), Aguascalientes (Ags), Quintana Roo (QRo), Sonora (Son), Oaxaca (Oax), Puebla (Pue), Hidalgo (Hgo), Tabasco (Tab), Colima (Col), Chiapas (Chi), Mexico State (Mex), and Veracruz (Ver).

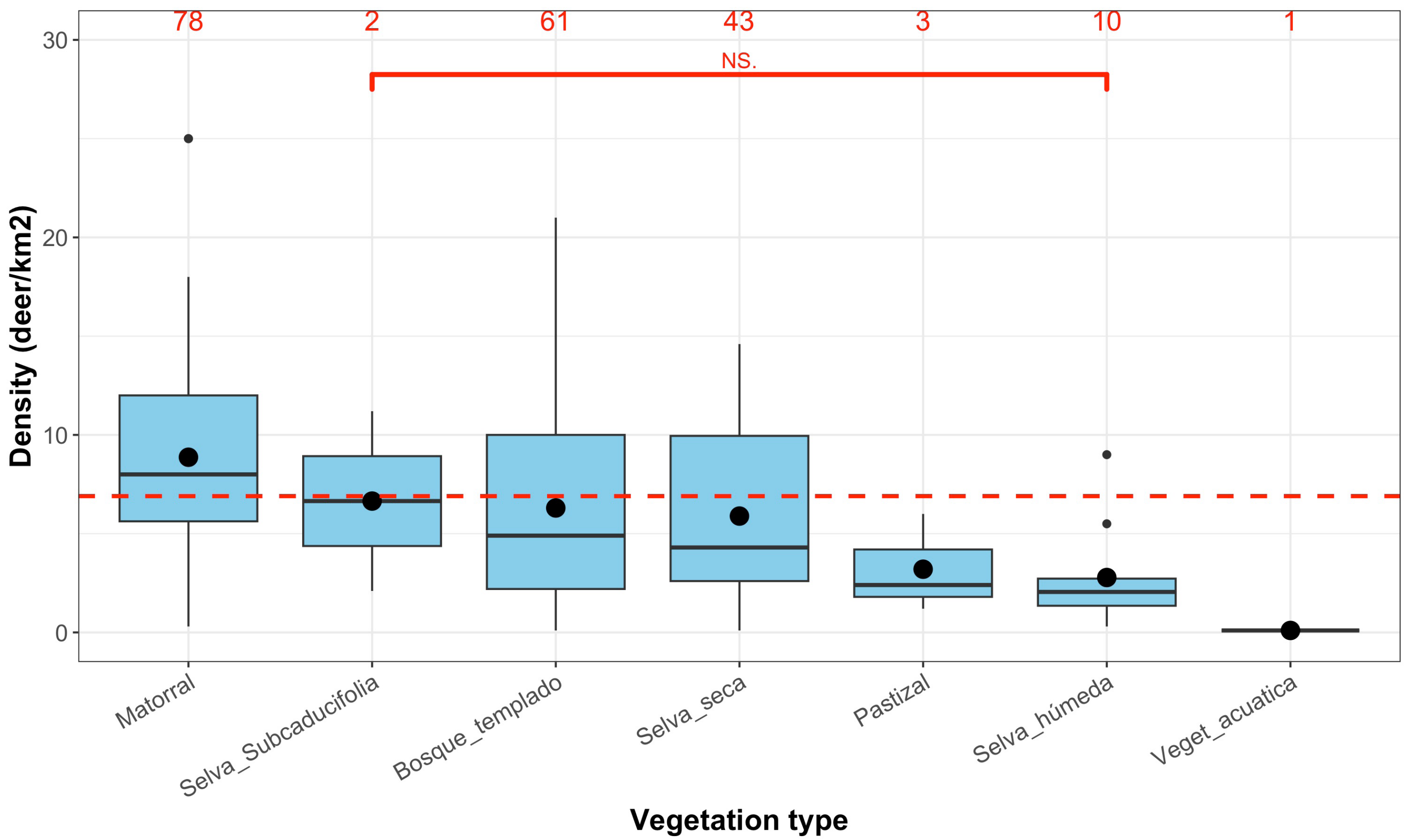

Figure 5. Estimates of the white-tailed deer density obtained in the main types of vegetation. Scrubland ("Matorral"), tropical semi-deciduous forest ("Selva subcaducifolia"), temperate forest ("Bosque templado"), tropical dry forest ("Selva seca"), grassland ("Pastizal"), tropical rain forest ("Selva húmeda), and aquatic vegetation ("Vegetación acuática").

data suggest that this type of habitat has a higher potential for deer production (Mandujano 2007, 2010). Also, in these regions, the white-tailed deer is hunted principally as subsistence and also as a trophy in extensive UMAs (López-Téllez *et al.* 2016).

In comparison with other regions in México, the densities estimations of this species are scarce in the southeastern states of Oaxaca (Yáñez-Arenas *et al.* 2016; González-Pérez and Briones 2000), Tabasco (Contreras-Moreno *et al.* 2015), Chiapas (Chávez-Hernández *et al.* 2011), Campeche (Retana-Guiascón *et al.* 2015) and Yucatán (González-Marín *et al.* 2008). In particular, the utilization of relative index based on track counts along transects has been used in some sites such as Lacandon forest (Naranjo *et al.* 2004a, 2004b), and Calakmul (Reyna-Hurtado and Sánchez-Pinzón 2019). This scarce information contrasts with the enormous interest of this species in subsistence hunting (Montiel-Ortega *et al.* 1999; Segovía *et al.* 2003), and the traditional knowledge of this deer shows the deep relationship between the local people and their landscape (Mandujano and Rico-Gray 1991; Greenberg 1992; Retana-Guiascón and Lorenzo 2016).

The results suggest a mean density of 6.9 ind/km^2 of white-tailed deer in México. Particularly, only 5.5 % of the reports were greater than 15 deer/km^2. In a previous study, Galindo-Leal (1993) reported that 51 % of the estimates analyzed were less than 10 deer/km^2; finding low variation between habitat types. Population density and biomass could vary depending on climatic factors such as the rain pattern and temperature (Mandujano and Naranjo 2010; Yáñez-Arenas *et al.* 2012a), ecological variables such as vegetation type, topographic features, and human factors such as habitat transformation, presence of livestock and illegal hunting (López-Téllez *et al.* 2007; Coronel-Arellano *et al.* 2008; Ramos-Robles *et al.* 2013). The densities of this species are between 5 and 17 deer/km^2 in the United States (Adams and Hamilton 2011). The differences between countries could be the result of different habitat-carrying capacity (K) and management politics which affect the local population dynamics (DeYoung 2011). Therefore, the mean population density in México suggests a possible lower K in comparison to northern regions of the geographical distribution of this species or possible overexploitation that maintains lower densities.

Importance of Natural Protected Areas and extensive UMAs. An important aspect is that many of the population density estimations were generated in studies realized in Biosphere Reserves. For example, La Michilía (Ezcurra and Gallina 1981; Galindo-Leal *et al.* 1993), Sierra de Huautla (Malacara-Velázquez *et al.* 2023), Sierra Gorda (Arroyo-Quiroz *et al.* 2017), Chamela-Cuixmala (Mandujano and Gallina 1995; Mandujano *et al.* 2002), Zicuirán-Infiernillo (Mandujano *et al.* 2013; Yáñez-Arenas *et al.* 2012b), Tehuacán-Cuicatlán (Mandujano *et al.* 2016b, 2019), Montes Azules (Naranjo *et al.* 2004a), Calakmul (Escamilla *et al.* 2000; Reyna-Hurtado and Sanchez-Pinzón 2019), Pantanos de Central (Contreras-Moreno *et al.* 2015), and Los Petenes (Oliva *et al.* 2014). These studies show the importance of the ANPs as sites to study this deer species (Gallina *et al.* 2007).

The analysis of advantages and limitations of the extensive UMA has been discussed extensively (Sisk *et al.* 2007; Gallina *et al.* 2008; Villarreal-Espino *et al.* 2008; Avila-Foucat and Pérez-Campusano 2015; Ortega-Argueta *et al.* 2016; Pineda-Vazquez *et al.* 2019; Romero-de-Diego *et al.* 2020; Gallina *et al.* 2022; Leal-Elizondo *et al.* 2023). In particular, given the ecological, social, and cultural conditions of the central, southeast, and Yucatán peninsula regions of México, the operating criteria of the UMAs have particular considerations (González-Marín *et al.* 2003; Weber *et al.* 2006; García-Marmolejo *et al.* 2008; Álvarez-Peredo *et al.* 2018), and focused on the management of white-tailed deer (López-Tellez *et al.* 2016; Malacara-Velázquez *et al.* 2023). Thus, UMAs emerge as an important model for managing this deer and other wildlife species but they also have important limitations.

An important question is: Is the density the best or adequate parameter to manage deer populations in the extensive UMAs? To answer this crucial question is necessary to define what is population density (D) and its differences but the relational parameter population abundance (N). The key factor to the difference between both D and N is the surface (S) of the habitat for the managed population. N is the total number of individuals in the population, and D is the average number of individuals in the S usually expressed as deer/km^2. The important point is that high density does not imply high abundance, this last would depend on how the population is delimited in the area (S). As a simple first example, if the density is estimated at 10 deer/km^2 (very good density), but the UMA surface is small (*e. g.* 200 ha), the expected abundance is only 20 deer in that population. As a second example, if D = 3 deer/km^2 and S = 10,000 (or 100 km^2), then the expected N = 300 deer. This calculation is based on the supposition of

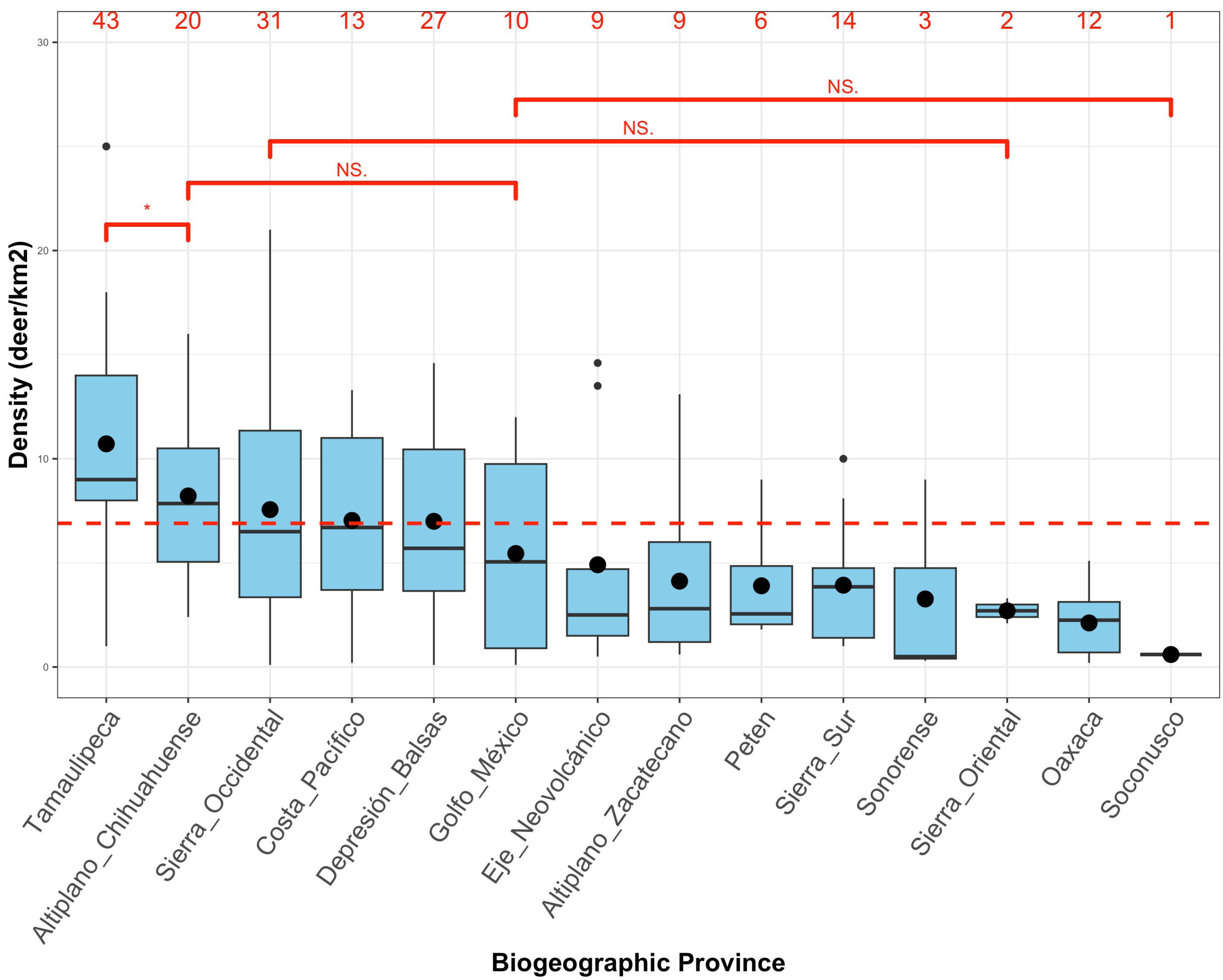

Figure 6. Estimates of the white-tailed deer density obtained in the biogeographic provinces.

homogeneous density distribution in the total area, which is not the natural condition in almost all locations. Therefore, the definition of hunting rates in the UMAs based on population density (usually biased due to the previously commented sampling or an observational error), is a matter that demerits further deep discussion by the authorities that administer the wildlife in México (Ortega-S. *et al.* 2019).

Limitations and suggestions. An important factor that limited obtaining conclusive density trends of this deer species in the different vegetation types, biogeographic provinces, and federative states, was the great variation in the methods and sample designs, the sample size obtained, and the numerical analysis performed. A particular statistical parameter is the variation around the mean, specifically the variance or standard deviation (SD) of the density. However, in many studies, this important statistical parameter is not reported. Thus, it is difficult to know the confidence of density estimations. The estimation of the population density (or any other ecological parameter) is the consequence of the ecological process and the observation or methodological process (Kéry and Royle 2016). These are inherent to counts but the magnitude of each is fundamental to defining the confidence of any estimation (Ahrestani *et al.* 2013). Therefore, understanding the ecological and methodological process is essential because it reflects the variation in climatic year conditions, seasonal habitat features, human intervention, and how this affects the demographic parameters of the deer, and also the detection probability of the animals (Link and Nichols 1994). A possible solution to reduce observation error includes having people with enough experience during the fieldwork, an adequate sample design, applying adequate statistical analysis, and reporting the variation around the density estimations, among others. Some standardized data collection protocols to monitor the white-tailed deer population in different habitats (Rojo-Curiel *et al.* 2007; Gallina *et al. 2014*), and to analyze procedures such as the pellet-groups counts (Mandujano 2014a; 2014b) using different field methods (Camargo-Sanabria and Mandujano 2011), are available. In particular, Villarreal-González (1999) provides a guide to using the strip transect method in the northeastern region.

Another consideration is the actual increase in the use of the camera trap (CT) method as a technique to obtain data on medium and large-size mammal species (Mandujano 2019; Mendoza *et al.* 2022). It is very frequent to calculate the relative abundance index with this technique. However, this index does not estimate the number of deer (or any other species) in a specific location, limiting its usefulness for some ecological and management objectives (Kéry and Royle 2016). Alternatives to estimate the population density of white-tailed deer using CT could be 1) techniques that allow identifying natural or artificial marked individuals and using spatial-explicit capture-recapture models (SCR). 2) the distance method. 3) the random encounter model (REM; Lucas *et al.* 2015; Royle *et al.* 2015; Kéry and Royle 2016). Of the analyzed data in this study, only two studies used CT to estimate white-tailed deer density using classic capture-recapture models (Lara-Díaz *et al.* 2011; Soria-Díaz and Monroy-Vilchis 2015) but in a non-hierarchical framework. Therefore, HMs (Hierarchical Models) open the possibility of estimating deer density for both ecological and management propose (Jimenez *et al.* 2013; Royle *et al.* 2015).

Traditionally, estimation of density usually is obtained at the population level delimited by a specific area (usually called "study area"). However, it is possible to estimate the distribution of the potential abundance in the form of geographic maps using other analytical alternatives. For example, it is known that precipitation could be used to predict ungulate biomass across continental regions (Coe *et al.* 1976; Olff *et al.* 2002; Mandujano and Naranjo 2010). This approach has been applied to a regional level in a Tehuacán-Cuicatlán Biosphere Reserve (Mortero-Montiel 2016). Another approach is through ecological niche modeling, specifically the distance to the centroid of the niche. This has been applied to predict the potential density of this deer at the level of biosphere reserves (Yáñez-Arenas *et al.* 2012a), at the state level in Oaxaca (Yáñez-Arenas *et al.* 2016), and at biogeographic provinces (Mandujano *et al.* 2016a). This approach has been proposed as potentially useful for deer management in UMAs of Campeche (Escalante and Martínez-Meyer 2013). Finally, again considering the actual increase of camera traps to sample this deer and other mammal species, the application of hierarchical models as occupancy, abundance through N-mixture, and Royle-Nichols models, emerge as opportunities for spatial-temporal monitoring of the white-tailed deer (Keever *et al.* 2017; Mandujano *et al.* 2023).

The revision and analysis of studies and reports on the population density of white-tailed deer in this study, bring a general vision of the possible trends of the density in the different federative states, vegetation types, and biogeographic provinces. However, important limitations exist to confidently conclude this trend because of the severe limitations in field designs and statistical data analysis. However, it seems that in México the white-tailed deer population density is generally relatively low (on average 6 to 7 deer/km^2) even in naturally perturbed sites, in comparison to those estimated in the northern region (United States and Canada) of the geographical distribution of this species. An important aspect is that much of the information is the results of specific studies in ANPs, principally Biosphere Reserves, which could be considered ideal sites to study deer populations in relatively better natural conditions. In contrast, the estimation of deer density is very important for the management of this species in extensive UMAs and needs the application of a standardized sampling field and numerical analysis protocols to obtain confident data.

Acknowledgments

This work is part of the CONABIO-JM016 project "Modeling the distribution and abundance of subspecies of white-tailed deer in México: implications for conservation and management." I thank P. Rodríguez and H. E. Pérez-Ponce, and the Red de Biología y Conservación de Vertebrados of the Instituto de Ecología A. C. for the facilities to carry out the study. In particular, to O. Mortero-Montiel in some aspects of searching and capturing information for the database.

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Associated editor: Rafael Reyna
Submitted: October 20, 2023; Reviewed: November 8, 2023
Accepted: January 20, 2023; Published on line: January 30, 2024