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Diversity and conservation status of terrestrial mammals in a wind farm in Tamaulipas, Mexico

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Abstract. We documented the diversity of medium-sized and large terrestrial mammals at the Tres Mesas wind farm in Tamaulipas, Mexico. Monitoring was conducted over three years (July 2019–October 2022) using camera traps. We estimated diversity using Hill numbers (q = 0, 1, 2) and calculated the relative abundance index (RAI) to compare species abundance among sampling periods. We recorded 17 species of mammals, including three species of protected felids. Species richness ($q0$) did not differ significantly among sampling periods; however, diversity at orders $q1$ and $q2$ increased significantly during the third sampling period. Most species showed an increase in abundance, particularly herbivores. Although the Tres Mesas wind farm represents a partially modified landscape, it supports a mammal diversity comparable to that of nearby protected natural areas in the region. These results highlight the ecological importance of this site and its potential contribution to wildlife conservation in northeastern Mexico.

Keywords. Abundance, carnivores, camera traps, community, wildlife

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Introduction

Medium-sized and large mammals play a crucial role in the structure and functioning of ecosystems, providing essential ecosystem services to all living organisms (Bennett et al. 2015; Lacher et al. 2019). Herbivores, for example, act as seed dispersers and directly influence landscape composition and structure, while carnivores regulate smaller vertebrate populations and maintain a balance in trophic interactions and ecosystems (Willson 1993; Terborgh and Estes 2010; Ripple and Beschta 2012). However, mammals face multiple threats from habitat fragmentation and loss caused by land-use changes, such as agricultural expansion, urban development, and infrastructure growth, as well as by the energy and extractive industries (Smith 1989; Benítez-López et al. 2019). In addition, illegal hunting and wildlife pose serious threats at both the species and population levels (Dirzo et al. 2014; Bogoni et al. 2020). Together, these drivers have led to population declines and even local and global extinctions (Ceballos et al. 2015; Ceballos and Ehrlich 2023).

Mexico hosts a high diversity of mammal species and is consistently ranks among the top countries worldwide in mammalian biodiversity (Burgin et al. 2025). According to current data from Burgin et al. (2025) approximately 34% of Mexico's mammal species are classified as at risk under Mexican environmental protection regulations (SEMARNAT 2019). In this context, the state of Tamaulipas is notable for its highly rich mammal fauna, ranking first among northern Mexican states and fifth nationally (Sánchez-Cordero et al. 2014; CONABIO 2024). This diversity is attributed mainly to the state's physiographic and climatic heterogeneity, which supports a wide variety of ecosystems, from coastal wetlands and mangroves to tropical and subtropical forests in the south, arid scrublands and grasslands in the central region, and temperate forests in the Sierra Madre Oriental (INEGI 2017; Morrone 2019). In the last 20 years, most research on medium-sized and large mammals in Tamaulipas has focused on the protected area El Cielo Biosphere Reserve and as a result knowledge of mammal populations

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and communities outside this protected area or in other protected areas in the state is limited (Carvajal-Villarreal et al. 2012; Carrera-Treviño et al. 2018; Branney et al. 2023; Ochoa-Espinoza et al. 2023).

Terrestrial mammal inventories are essential for providing baseline data on species presence, distribution, diversity, abundance, and conservation status (Bungartz et al. 2012; Barberousse and Bary 2015). Systematic monitoring enables the identification of population trends, the detection of emerging threats, and the evaluation of the effectiveness of conservation measures (Valdez et al. 2006; Koleff and Urquiza-Haas 2011). Different sampling techniques have been developed to address specific research goals, and over the past two decades, camera trapping has become one of the most widely used approaches for studying medium-sized and large mammals (Caravaggi et al. 2020; Cordier et al. 2022). This non-invasive technique is highly effective for detecting elusive, cryptic, and low-abundance species, such as large carnivores (Maffei et al. 2002; Karanth et al. 2006). Camera traps provide broad spatial coverage, are well suited for long-term monitoring, and generate data on species presence, abundance, and activity patterns. This technique also allows comparisons of community composition and changes in species abundance over time (O'Connell et al. 2011; Trolliet et al. 2014; Zwerts et al. 2021). The data obtained are crucial for designing and implementing conservation strategies in habitats affected by human activities (List et al. 2017; Moreno et al. 2017).

The impacts of wind farm activities on the medium-sized and large mammal community remain poorly studied compared to other taxonomic groups (i.e. birds and bats; Schuster et al. 2015; Pérez-García et al. 2022). Therefore, the objective of this study was to evaluate the species richness and abundance of medium-sized and large mammals at the Tres Mesas wind farm in Tamaulipas over a three-year sampling period that encompassed the construction, machinery removal, and operation and maintenance phases of the project. We did not analyze the direct effects of human activities associated with the installation and operation of the wind farm during the conduct of this study in this publication. This study is one of the first in Mexico to systematically document, over the medium term, the diversity of terrestrial mammals at a wind farm. It also highlights the importance of maintaining medium- and long-term monitoring in human-modified landscapes to support the development of appropriate conservation strategies.

Study area

The study area is located on a plateau known as Mesa La Sandía within the Tres Mesas wind farm (23.3831°N, 098.9952°W, at 400 m above sea level, WGS84 datum), north of Llera de Canales municipality, Tamaulipas. The wind farm covers an area of 89.2 km^2, making it one of the most significant of its kind in northeastern Mexico. This plateau is part of the northeastern coastal plain biogeographic province (Rzedowski 2006; Morrone 2019). The region has a warm, semi-arid climate with scarce summer rainfall. Annual temperatures range from 12 °C to 28 °C, with extremes temperatures from 0 °C to over 40 °C, and average annual precipitation ranges from 550 to 1,300 mm (INEGI 2017). The dominant vegetation on Mesa La Sandía consists of thorny submontane scrub with patches of grassland and mesquite (Rzedowski 2006; SGN 2011). The wind farm is located between two major federal natural protected areas; it lies approximately 20 km southwest of the El Cielo Biosphere Reserve and 30 km east of the Sierra de Tamaulipas Biosphere Reserve (Figure 1).

Methods

Monitoring design. To collect records (photos/videos) of medium-sized and large mammals, we used 38 camera traps installed at 28 stations (10 double stations and 18 single stations) across an area of 89.2 km^2. We used Cuddeback cameras, models E3 and C1 (Cuddeback, Green Bay, WI, USA), we recorded the geographical coordinates of each camera trap station (Table 1).

Camera traps were attached to trees at a height of approximately 50 cm in sites where signs of mammal's presence were detected (e.g. tracks, droppings, latrines, scratch marks). These sites included dirt roads, trails, wildlife paths, abandoned tracks, and areas near water bodies; cameras were not installed on main vehicle roads. We did not use baits or attractants in order to avoid influencing species detection (O'Connell et al. 2011; Chávez et al. 2013). Double stations consisted of two camera traps placed opposite each other on either side of the path to record both flanks of individuals (Maffei et al. 2002; O'Connell et al. 2011; Bárcenas and De la Torre 2015). The mean linear distance between the camera-trap stations and the wind turbines, control center, or high-voltage towers was 390 m. To ensure uniform spatial coverage, the linear distance between camera-trap station was approximately

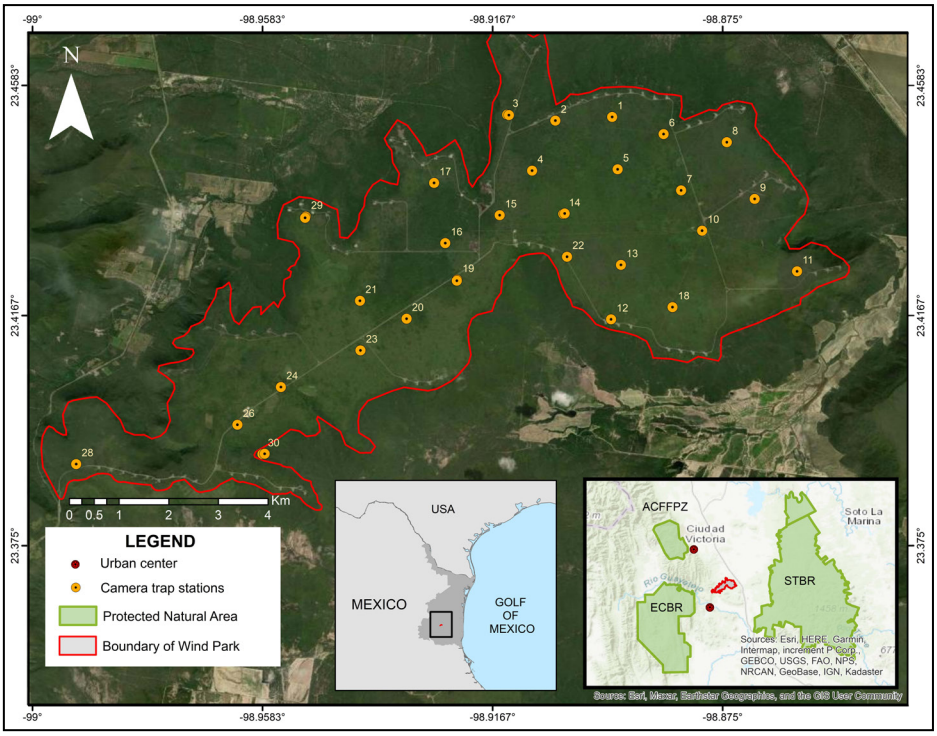

Figure 1. Aerial view of the Tres Mesas wind farm, Tamaulipas, Mexico. The location of the camera trap stations (*n* = 28) is shown. The lower right inset indicates the location of nearby federal protected natural areas: El Cielo Biosphere Reserve (ECBR), Sierra de Tamaulipas Biosphere Reserve (STBR) and Altas Cumbres Flora and Fauna Protection Zone (ACFFPZ).

Table 1. Geographic coordinates in decimal degrees of the camera-trap stations placed in the Tres Mesas Wind Farm, Tamaulipas.

ID	Latitude	Longitude	Elevation (m) a.s.l.	ID	Latitude	Longitude	Elevation (m) a.s.l.
1	23.4526	−098.8950	443	15	23.4348	−098.9153	461
2	23.4519	−098.9052	498	16	23.4297	−098.9252	464
3	23.4530	−098.9140	437	17	23.4406	−098.9272	459
4	23.4429	−098.9095	458	18	23.4285	−098.9382	476
5	23.4431	−098.8940	451	19	23.4231	−098.9231	475
6	23.4495	−098.8856	436	20	23.4159	−098.9324	481
7	23.4393	−098.8825	435	21	23.4193	−098.9406	487
8	23.4480	−098.8742	432	22	23.4273	−098.9031	498
9	23.4377	−098.8692	422	23	23.4103	−098.9405	488
10	23.4320	−098.8787	447	24	23.4037	−098.9550	487
11	23.4246	−098.8615	422	26	23.3969	−098.9628	487
12	23.4159	−098.8952	436	28	23.3897	−098.9920	487
13	23.4258	−098.8934	458	29	23.4345	−098.9505	474
14	23.4350	−098.9038	461	30	23.3915	−098.9583	390

1.5 km (Chávez et al. 2013; Sunarto et al. 2013). Camera traps were active 24 h/day. Ten C1 model cameras were programmed to record 10-second videos during the day and to capture photographs at night, with a 30-minute delay between recordings. Eighteen E3 model cameras were programmed to record 10-second videos both day and at night, also with a 30-minute delay between recordings. The PIR sensitivity was left at the default setting. We conducted three sampling periods from July 2019 to October 2022: July 2019 – March 2020 (253 days); October 2020 – June 2021 (240 days); and November 2021 – October 2022 (309 days). The same design was maintained throughout all periods. Significant activities occurred within the wind farm during each of these sampling periods: during the first period, construction of 39 wind turbines was completed; during the second, machinery, personnel, and material were withdrawn; and during the third, the number of people present at the wind farm decreased significantly and only personnel for operations and maintenance remained onsite.

Analysis. We considered only medium-sized (>0.1 < 10 kg) and large mammals (>10 kg) for the analysis of records (photos and videos) (Medellín 1994; Kays and Wilson 2009). We used specialized literature for species identification (Hall 1981; Reid 2006). We followed the taxonomic classification of mammal species of the world (Wilson and Reeder 2005), except for *Spilogale interrupta*, for which we followed McDonough and colleagues, who recognize seven species within the genus *Spilogale* (McDonough et al. 2022). To determine the conservation status, we followed the Mexican Official

Standard NOM-059-SEMARNAT-2010, updated in 2019 (SEMARNAT 2019), and the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN 2025). In addition, we included the levels of protection against international trade according to Appendices I, II, and III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2025).

To avoid pseudo-replication of the records, the criteria used to determine a photographic event as an independent record were as follows: i) a minimum interval of 120 minutes between detections of the same species in the same camera trap; ii) individual identification based on distinctive markings, such as spots, rosettes, or scars; and (iii) for double camera-trap stations, when a species was recorded by both cameras, the date and time of the records were compared to confirm independence (O'Brien et al. 2003; Jenks et al. 2011).

To estimate mammal diversity curves, we used Hill series numbers ($q0$, $q1$, $q2$) (Hill 1973). We used Hill numbers because they provide an integrated framework that combines different aspects of diversity. Order $q = 0$ represents species richness, whereas orders $q = 1$ and $q = 2$ incorporate relative species abundance, progressively weighting the contribution of common species ($q1$, equivalent to Shannon's diversity index) and dominant species ($q2$, equivalent to Simpson's diversity index) within the community (Moreno et al. 2011; Chao et al. 2014).The use of rarefaction and extrapolation allowed us to obtain standardized and comparable diversity estimates among sampling periods, correcting for differences in sampling effort and providing a more robust assessment of community structure (Hsieh et al. 2016; Chao et al. 2021). We used species abundance data, so the curves were based on sample size. To standardize the curves, twice as many of the smallest samples were used, and a bootstrap of 100 randomizations was established. Significant differences among diversity orders and sampling periods were evaluated using 95% confidence intervals. Analyses were performed with the iNEXT package (Hsieh et al. 2024), available for R Studio v. 4.3.1 (R Core Team 2023).

We grouped the recorded species according to the number of independent records into three categories: rare, common, and abundant. The classification was based on a data dispersion analysis, using the value of one-third as a reference threshold. This approach allowed for comparisons among different frequency levels of photographic records across species. We also calculated naïve occupancy, defined as a measure of the spatial distribution of each species within the study area, estimated as the percentage of camera traps in which the species was detected. When a species was recorded in all camera traps, the naïve occupancy value was 1.0, corresponding to 100% occupancy.

To estimate species abundance, we calculated the mean relative abundance index (RAI_{ij}) for each species across the three sampling periods, following the formula: $RAI_{ij} = (N_j / ET_j)$ *100 nights traps. Where i represents each species and j each camera trap. Therefore, N_j corresponds to the number of independent photographic records of each species per camera, while ET_j represents the sampling effort for each camera trap, multiplied by 100 to standardize the values (Mandujano 2019; Soto-Werschitz et al. 2023).

Subsequently, we used the Kruskal–Wallis test and Dunn's post hoc test to compare multiple samples and assess differences in RAI values across sampling periods. In Dunn's test, a Bonferroni correction was applied to adjust for multiple comparisons. For both tests, we used a significance level of $\alpha = 0.05$, and p-values were graphically represented as follows: "ns" when no significant differences were found, $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***, and $p \leq 0.0001$ = ****. All RAI analyses and naïve occupancy estimates were performed using the RAI.2 package (Mandujano 2019) in RStudio v. 4.3.1 (R Core Team 2023).

Results

Richness. The total sampling effort was 23,743 trap-days during the entire study: 7,627 trap-days (with 1,644 independent records) during the first sampling period; 8,766 trap-days (with 3,070 independent records) during the second sampling period; and 7,350 trap-days (with 3,499 independent records) during the third sampling period. We recorded 17 species of medium-sized and large mammals belonging to 9 families, with the family Felidae represented by five species. The estimated richness ($q = 0$) was 15 identified species (95% CI = 13.08–16.91) during the first sampling, 16 identified species (95% CI = 14.97–17.02) in the second sampling and 16 species (95% CI = 15.31–16.68) in the third sampling period. There were no significant differences in estimated richness among the three sampling periods (Figure 2). Regarding the conservation status, three species are listed under the Mexican federal environmental protection regulation: *Panthera onca* (Linnaeus, 1758) (Endangered), *Leopardus pardalis* (Linnaeus, 1758) (Endangered), and *Herpailurus yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803) (Threatened). According to the IUCN Red List of Threatened Species, only *P. onca* is categorized as Near

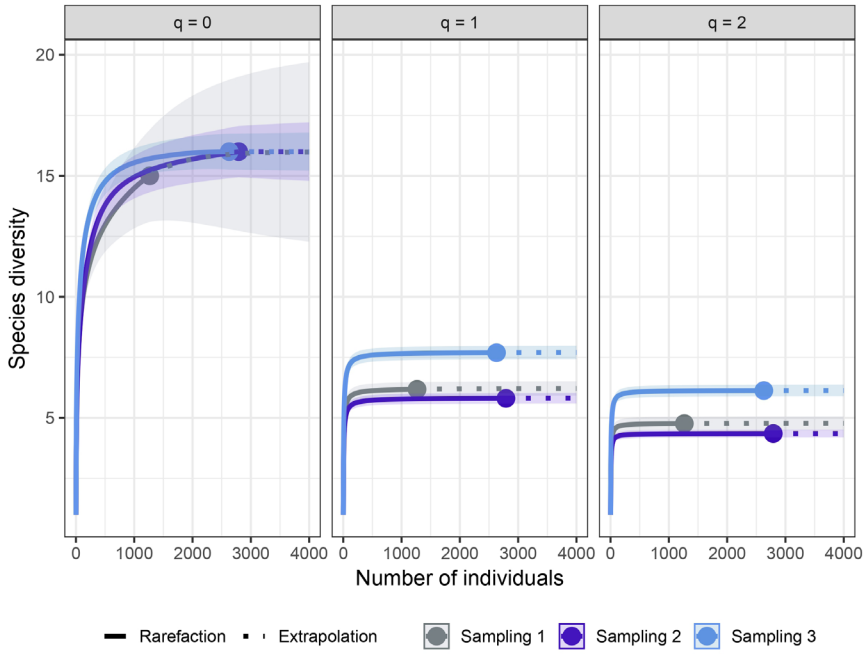

Figure 2. Species-diversity curves (Hill numbers) of medium-sized and large terrestrial mammals for each sampling period at the Tres Mesas. Hill numbers are shown as $q = 0$ (species richness), $q = 1$ (Shannon diversity), and $q = 2$ (Simpson diversity). The shaded area represents the 95% confidence intervals.

Threatened. Based on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) criteria, three species were listed in Appendix I and two species in Appendix II (Table 2).

Diversity. Species diversity was estimated using Hill numbers of order $q = 0, 1, 2$ for each sampling period. In the first sampling, the estimated effective species diversity values were: $q0$ = 15 species (95% CI = 13.04–16.95), $q1$ = 6.18 species (95% CI = 5.81–6.54), $q2$ = 4.76 species (95% CI = 4.44–5.08). In the second sampling, $q0$ = 16 species (95% CI = 14.97–17.02), $q1$ = 5.80 species (95% CI = 5.62–5.92), $q2$ = 4.35 species (95% CI = 4.20–4.50). And in the third sampling, $q0$ = 16 species (95% CI = 15.31–16.68), $q1$ = 7.69 species (95% CI = 7.38–8.0), $q2$ = 6.12 species (95% CI = 5.86–6.40). Based on the 95% confidence interval, there were no significant differences in order $q0$ diversity among the three sampling periods, and the diversity of orders $q1$ and $q2$ between the first and second samplings also did not differ significantly. However, diversity in the third sampling period was significantly higher than in both the first and second sampling periods in orders $q1$ and $q2$ (Figure 2).

Abundance. According to the defined categories, rare species presented between 1 and 13 independent records, common species between 14 and 96 records, and abundant species from 97 records onward. The species with the highest abundance across the three samplings were *Odocoileus virginianus* (Zimmermann, 1780), *Sylvilagus floridanus* (Allen, 1890), *Leopardus pardalis*, and *Pecari tajacu* (Linnaeus, 1758). The common species included *Panthera onca*, *Lynx rufus* (Schreber, 1777), *Herpailurus yagouaroundi*, *Canis latrans* (Say, 1822), *Nasua narica* (Linnaeus, 1766), *Urocyon cinereoargenteus* (Schreber, 1775), and *Procyon lotor* (Linnaeus, 1754). The rare species were *Conepatus leuconotus* (Lichtenstein, 1832), *Mephitis macroura* (Lichtenstein, 1832), *Spilogale interrupta* (Rafinesque, 1820), *Puma concolor* (Linnaeus, 1771), *Dasypus novemcinctus* (Linnaeus, 1754) and *Didelphis virginiana* (Kerr, 1792) (Figure 3). The species with the highest occupancy index (OccNaive) was *O. virginianus* present in 82% of the camera traps in the first sampling. In the second sampling, both *O. virginianus* and *S. floridanus* were present in 98% of the camera traps, while in the third sampling, *L. pardalis* had the highest occupancy, found in 95% of the traps. The relative abundance indices (RAI) for each sampling are presented in Table 3.

Annotated List. All records of medium-sized and large mammals were obtained through camera traps during three sampling periods from July 2019 to October 2022. For the description and identification of the recorded species, we used specialized mammal literature (Hall 1981; Ceballos 2014) and field guides (Reid 2006; Kays and Wilson 2009). The geographical coordinates of each camera trap station and identification are provided in Table 1. Below, we present the list of medium-sized and large mammal species recorded at the Tres Mesas wind farm.

Table 2. List of terrestrial mammals recorded at the Tres Mesas. Conservation status according to NOM-059-SEMARNAT-2010, IUCN, and CITES. *NOM-059 categories: Threatened (TH) and Endangered (EN). *IUCN categories: Least Concern (LC), Near Threatened (NT), and Endangered (EN). *CITES appendices: (I) species for which international trade is prohibited; (II) species not currently threatened with extinction but that may become so unless trade is strictly regulated. Appendix II also includes species that are similar in appearance ("look-alike species").

Taxon	Common name	*NOM-059	*IUCN	*CITES
Didelphimorphia				
Family Didelphidae				
Didelphis virginiana (Kerr, 1792)	Virginia Opossum	—	LC	—
Cingulata				
Family Dasypodidae				
Dasypus novemcinctus (Linnaeus, 1758)	Nine-banded Armadillo	—	LC	—
Lagomorpha				
Family Leporidae				
Sylvilagus floridanus (Allen, 1890)	Eastern Cottontail	—	LC	—
Carnivora				
Family Felidae				
Herpailurus yagouaroundi (È. Geoffroy Saint–Hilaire, 1803)	Jaguarundi	TH	LC	I
Leopardus pardalis (Linnaeus, 1758)	Ocelot	EN	LC	I
Lynx rufus (Schreber, 1777)	Bobcat		LC	II
Panthera onca (Linnaeus, 1758)	Jaguar	EN	NT	I
Puma concolor (Linnaeus, 1771)	Puma	—	LC	II
Family Canidae				
Canis latrans (Say, 1822)	Coyote	—	LC	—
Urocyon cinereoargenteus (Schreber, 1775)	Gray Fox	—	LC	—
Family Mephitidae				
Conepatus leuconotus (Lichtenstein, 1832)	Hog-nosed Skunk	—	LC	—
Mephitis macroura (Lichtenstein, 1832)	Hooded Skunk	—	LC	—
Spilogale interrupta (Rafinesque, 1820)	Eastern Spotted Skunk	—	LC	—
Family Procyonidae				
Nasua narica (Linnaeus, 1766)	White-nosed Coati	—	LC	—
Procyon lotor (Linnaeus, 1758)	Common Raccoon	—	LC	—
Artiodactyla				
Family Tayassuidae				
Pecari tajacu (Linnaeus, 1758)	Collared Peccary	—	LC	—
Family Cervidae				
Odocoileus virginianus (Zimmermann, 1780)	White-tailed Deer	—	LC	—

Table 3. Results of the Relative Abundance Index (RAI_{ij}) for each species across the three sampling periods, ordered from the most to the least abundant species; *n* represents the number of independent records, and the Occupancy Index (OccNaive) indicates the percentage of camera traps in that recorded the species of interest.

Scientific name	First sampling			Second sampling			Third sampling		
	n	**RAI_{ij}**	**OccNaive**	***n***	**RAI_{ij}**	**OccNaive**	***n***	**RAI_{ij}**	**OccNaive**
Didelphis virginiana	0	—	—	0	—	—	12	0.21	0.20
Dasypus novemcinctus	1	0.01	0.03	9	0.1	0.09	7	0.09	0.12
Puma concolor	2	0.02	0.05	5	0.06	0.12	24	0.27	0.35
Conepatus leuconotus	8	0.18	0.18	14	0.14	0.16	7	0.10	0.15
Mephitis macroura	2	0.06	0.05	16	0.16	0.19	0	—	—
Spilogale interrupta	0	—	—	1	0.03	0.02	2	0.02	0.05
Panthera onca	30	0.44	0.34	22	0.31	0.30	68	0.87	0.45
Lynx rufus	119	1.78	0.81	20	0.22	0.33	15	0.19	0.17
Herpailurus yagouaroundi	27	0.31	0.39	100	1.13	0.67	87	1.51	0.70
Canis latrans	1	0.01	0.03	3	0.07	0.05	46	0.72	0.45
Urocyon cinereoargenteus	31	0.54	0.39	57	0.66	0.44	32	0.37	0.38
Nasua narica	8	0.08	0.08	192	3.19	0.35	257	2.88	0.22
Procyon lotor	6	0.11	0.11	100	1.05	0.47	78	1.32	0.35
Leopardus pardalis	246	3.15	0.79	407	4.79	0.88	442	6.79	0.95
Odocoileus virginianus	439	5.14	0.82	819	9.49	0.98	662	8.43	0.92
Sylvilagus floridanus	231	3.66	0.68	931	9.49	0.98	391	6.99	0.72
Pecari tajacu	112	1.35	0.34	185	2.23	0.58	495	5.26	0.70

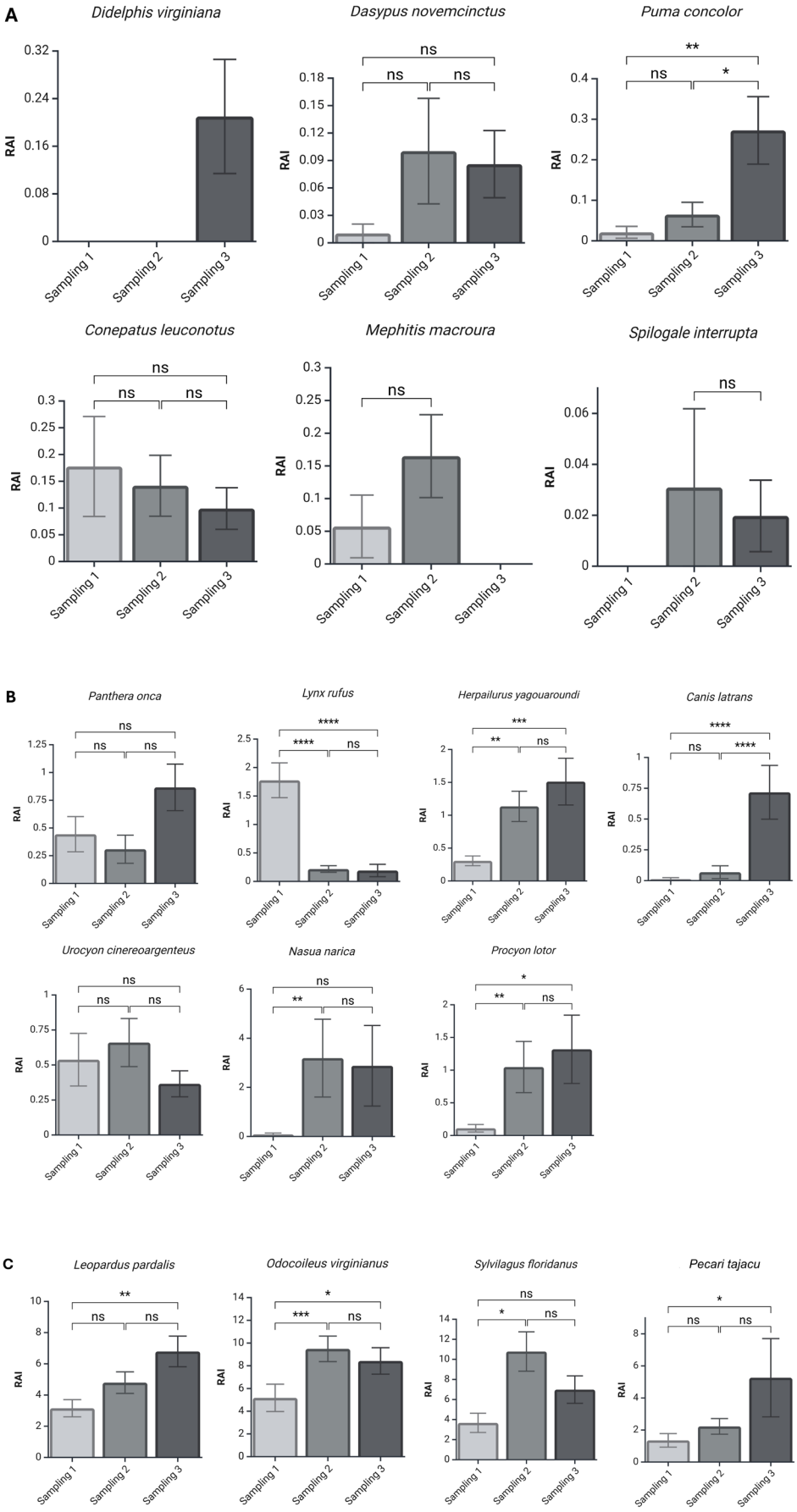

Figure 3. Relative Abundance Index (RAI_{ij}) and standard error (SE) of terrestrial mammals recorded at the Tres Mesas wind farm, Tamaulipas. **A.** Rare species. **B.** Common species. **C.** Abundant species. Results of Dunn's post hoc test indicate the degree of significant differences among sampling periods, marked with asterisks (*), while "ns" denotes non-significant differences. Created in https://BioRender.com

Order Didelphimorphia
Family Didelphidae

***Didelphis virginiana* (Kerr, 1792)**
Virginia Opossum
Figure 5F

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4429, −098.9095; 458 m elevation; first record on 13.I.2022; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 4, 30, 17, 29, 16, 28).

Identification. Adults are medium-sized and weigh 1–4 kg. They have a robust body and elongated snout and are characterized by white cheeks and black eye rings. The fur is grey or grey with black and features whitish hair tips. The base of the tail is bushy and black and covers less than half its length, while the remainder is scaly with a whitish colouration.

Order Cingulata
Family Dasypodidae

***Dasypus novemcinctus* (Linnaeus, 1758)**
Nine-banded Armadillo
Figure 5D

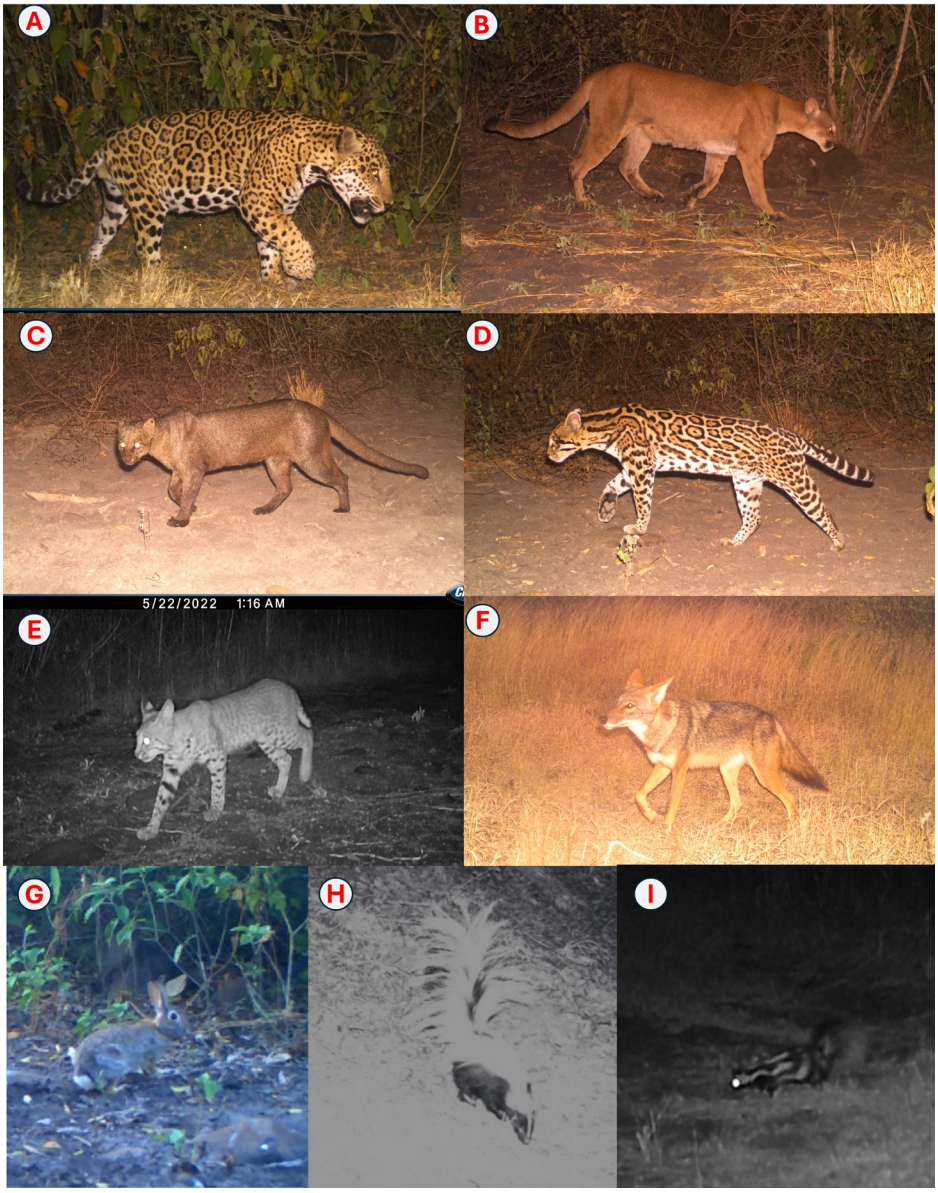

Figure 4. Terrestrial mammal species recorded with camera traps at the Tres Mesas wind farm, Tamaulipas, Mexico. **A.** *Panthera onca*. **B.** *Puma concolor*. **C.** *Herpailurus yagouaroundi*. **D.** *Leopardus pardalis*. **E.** *Lynx rufus*. **F.** *Canis latrans*. **G.** *Sylvilagus floridanus*. **H**. *Mephitis macroura*. **I.** *Spilogale interrupta*.

Figure 5. Terrestrial mammal species recorded with camera traps at the Tres Mesas wind farm, Tamaulipas, Mexico. **A.** *Urocyon cinereoargenteus.* **B.** *Procyon lotor*. **C.** *Nasua narica*. **D.** *Dasypus novemcinctus*. **E**. *Conepatus leuconotus.* **F.** *Didelphis virginiana.* **G.** *Odocoileus virginianus.* **H.** *Pecari tajacu.*

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.3969, −098.9629; 487 m elevation; first record on 6.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 26, 4, 6, 18, 17, 26, 28, 29).

Identification. Adults are medium-sized and weigh 2–7 kg. They are the only mammals in the Americas whose bodies are covered by osseous dermal plates on the back, tail, head, and sides. This armour can have 7–9 flexible dorsal bands, and its common colour is greyish-brown.

Order Lagomorpha
Family Leporidae

***Sylvilagus floridanus* (Allen,1890)**
Eastern Cottontail
Figure 4G

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4495; −098.8857; 436 m elevation; first record on 8.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (All camera traps).

Identification. This is a medium-sized rabbit, with adults weighing between 1-2 kg. The fur is long and dense, and the colour ranges from brown to grey on the back, white on the belly and tail, and often with a reddish spot on the nape.

Order Carnivora
Family Felidae

***Herpailurus yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803)**
Jaguarundi
Figure 4C

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4530, −098.9140; 437 m elevation; first record on 10.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1-9, 11-26, 29, 30).

Identification. Adults are medium-sized and weigh between 3.5-9 kg. They have a slender body, a long tail, and small head and ears. The fur colour is uniform, without patterns or spots, and usually in two tones: dark grey and reddish-brown. This species is one of the least studied felines in Mexico due to its low population densities.

***Leopardus pardalis* (Linnaeus, 1758)**
Ocelot
Figure 4D

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4429, −098.9095; 458 m elevation; first record on 5.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (All camera traps).

Identification. This is a medium-sized feline and adults weigh between 6-13 kg. It has a robust body, small head, and a relatively short tail in proportion to its overall body length. The fur colour can vary from light brown to pale yellow with black or dark brown spots across the body, exhibiting different spot patterns among individuals. It is differentiated from the Margay (*L. wiedii*) mainly by its larger size, shorter tail, and pattern of spots.

***Lynx rufus* (Schreber, 1777)**
Bobcat
Figure 4E

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4520; −098.9053; 498 m elevation; first record on 10.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 2–10, 11, 12, 13, 16–21, 24, 26, 29).

Identification. This is a medium-sized feline. Adults weigh between 4.1-18.3 kg, with males heavier than females. They have a slender body, small head, pointed ears, very short tail, and long legs relative to their body. The fur is dense, with colour varying from light brown, yellowish brown, and greyish, to reddish, often featuring spots or bands of darker shades.

***Panthera onca* (Linnaeus, 1758)**
Jaguar
Figure 4A

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4530, −098.9140; 437 m elevation; first record on 7.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 2–5, 8-15, 17, 19–21, 29, 30).

Identification. The largest feline in the Americas, and adult individuals in Mexico weigh between 35-70 kg. The fur varies from pale yellow to sandy brown, with darker rosettes and a lighter-coloured underside.

***Puma concolor* (Linnaeus, 1771)**
Puma
Figure 4B

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4258, −098.8934; 458 m elevation; first record on 24.XII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 3, 5, 6, 10, 13, 15, 20, 21, 26, 28, 30).

Identification. This is a large feline, with adults weighing between 35-65 kg. It fas a long body, tail, and legs. The fur colour is uniform and varies from greyish, sandy yellow, to light brown with a lighter underside. Juvenile individuals may show spots or markings.

Family Canidae

Canis latrans **(Say, 1822)**
Coyote
Figure 4F

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4320, −098.8787; 447 m elevation; first record on 24.X.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1, 2, 4–6, 12, 17, 20, 21, 28, 29).

Identification. This is a medium-sized canid, with adults weighing 8-16 kg. It has a slender body, elongated snout, pointed ears, and a bushy tail. The fur colour varies from grey to reddish-brown.

Urocyon cinereoargenteus **(Schreber, 1775)**
Gray Fox
Figure 5A

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4526, −098.8950; 443 m elevation; first record on 17.VII.2019. H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1–11, 14, 16, 17, 19, 20, 28, 29).

Identification. This is a medium-sized canid, smaller in build than *C. latrans*. Adults weigh 2–7 kg. It has a small head and snout, pointed ears, long tail, and dense fur. The dorsal fur is greyish, while the ventral side and legs are white, with reddish tones on the sides.

Family Mephitidae

Conepatus leuconotus **(Lichtenstein, 1832)**
Hog-nosed Skunk
Figure 5E

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4429, −098.90951; 458 m elevation; first record on 29.IX.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 3, 4, 7, 10, 13, 14, 17, 18, 20, 21, 24, 28).

Identification. This is a medium-sized skunk species and the largest in Mexico, with adults weighing 1–5 kg. The colour pattern is primarily black and white, typically featuring a white stripe running down the back from the head to the tail. The snout is elongated and with a naked nose.

Mephitis macroura **(Lichtenstein, 1832)**
Hooded Skunk
Figure 4H

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4378, −098.8692; 422 m elevation; first record on 9.IX.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1, 4, 5, 14, 16, 18, 19, 21, 24).

Identification. This is a medium-sized skunk, with adults weighing between 1-4 kg. They have an elongated body, short legs, and a long, bushy tail. The fur colouration is highly variable but generally black with white, typically featuring a black body with two variable-length white stripes on the sides, although individuals that are nearly all-black with thin white stripes or individuals with white backs and tails can also occur. It differs from *C. leuconotus* by its longer snout and a small white stripe on the forehead.

Spilogale interrupta **(Rafinesque, 1820)**
Eastern Spotted Skunk
Figure 4I

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4160, −098.8952; 436 m elevation; first observation on 19.III.2021; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 12, 22, 30).

Identification. This is a small skunk species, with adults weighing between 200-800 g. It has short limbs and a short tail. The fur is black with white stripes and spots of various patterns. It features large white spots on the face, back, and tail, which are roughly parallel along the back and interrupted at the hips.

Family Procyonidae

***Nasua narica* (Linnaeus, 1766)**
White-nosed Coati
Figure 5C

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4520, −098.9053; 498 m elevation; first record on 13.IX.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1-8, 15-17, 19, 21, 22, 24, 26, 30).

Identification. Adults of this medium-sized mammal weigh between 3-6 kg. It has a long, slender body, and both the tail and snout are elongated. The fur colour ranges from dark brown to dark reddish on the dorsal side, with lighter tones such as yellowish brown on the neck, snout, and ears.

***Procyon lotor* (Linnaeus, 1758)**
Common raccoon
Figure 5B

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4104, −098.9406; 488 m elevation; first record on 31.VIII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1, 2, 4–7, 19–21, 24).

Identification. Adults of this medium-sized mammal weigh 3–9 kg. They have robust bodies with short limbs and a long tail. Fur colours include grey, dark brown, and black, and a characteristic white and grey facial mask extending over the face and snout. Bands of light and dark colour tones extend down the full length of the tail.

Order Artiodactyla
Family Tayassuidae

***Pecari tajacu* (Linnaeus, 1758)**
Collared Peccary
Figure 5H

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4232, −098.9231; 475 m elevation; first record on 16.IX.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (ID 1, 3–19, 21, 30).

Identification. This is a medium-sized artiodactyl, with adults weighing between 15-30 kg. It has a robust body, a large head, short limbs, and a vestigial tail. The snout is long, with a disc-shaped nose, and the canine teeth are highly developed. The fur colour ranges from paler to dark grey and features a lighter band around the neck. The young are brown or reddish with a yellow or white stripe along the back.

Family Cervidae

***Odocoileus virginianus* (Zimmermann, 1780)**
White-tailed Deer
Figure 5G

Observations. MEXICO — **Tamaulipas** • Llera de Canales, Tres Mesas wind farm; 23.4495, −098.8857; 436 m elevation; first record on 6.VII.2019; H. Bárcenas and O. Cruz Oropeza obs.; recorded by camera traps (All camera traps).

Identification. This is a large deer species, with adults in Mexico weighing between 25-100 kg. It has a slender body, long neck, elongated head, and long, narrow legs. There is sexual dimorphism; only males possess antlers, which can have 2–6 points. The fur colour is uniform and varies from light grey to reddish brown, with white fur on the underside and the insides of the legs, as well as on the underside of the tail. The young have reddish fur with lighter spots.

Discussion

Thirty-three species of medium-sized and large mammals have been recorded in the state of Tamaulipas (Sánchez-Cordero et al. 2014; CONABIO 2024). In this study, we successfully documented 50% of the medium-sized and large mammal species reported from the state. At the Tres Mesas wind farm, we recorded 17 species of medium-sized and large mammals, a richness similar to the 18 species reported

for the tropical montane cloud forest of the El Cielo Biosphere Reserve (Ochoa-Espinoza et al. 2023), as well as to the 20 species recorded in the submontane scrub and lowland forest of the Sierra de Tamaulipas Biosphere Reserve (CONANP 2005), which are the nearest protected areas to our study site. It is worth noting that the sampling effort in Tres Mesas was lower than that implemented by Ochoa-Espinoza and colleagues in the El Cielo Biosphere Reserve, where the same monitoring technique was used. In contrast, for the Sierra de Tamaulipas Biosphere Reserve, the specific methods and sampling effort employed for the mammal inventory were not reported.

Among the 17 species recorded at the Tres Mesas wind farm, *Panthera onca*, *Leopardus pardalis*, and *Herpailurus yagouaroundi* are notable because they are listed under the official Mexican environmental protection regulations (SEMARNAT 2019). The sympatric presence of these felids species is often considered an indicator of the habitat quality. Their presence and abundance are sensitive to habitat fragmentation and to the availability of prey (Ripple et al. 2014). Several studies have reported that their presence and abundance are sensitive to habitat fragmentation and prey availability (Sanderson et al. 2002; Morato et al. 2018). For example, in Mexico, male Jaguars can have annual home ranges of up to approximately 600 km^2 in well-conserved vegetation zones (De la Torre et al. 2017; Ceballos et al. 2022). The sympatric presence of these species at the wind farm, and particularly the increase in their relative abundance over the three years of sampling, suggests that the habitat has maintained the minimum conditions necessary to support populations of wild felids. The same pattern can also be observed in the species that constitute their prey.

It is important to note the absence of records for some medium-sized and large terrestrial mammal species documented in other recent studies for the state of Tamaulipas. For example, the Margay (*Leopardus wiedii*), Red Brocket Deer (*Mazama temama*), American Black Bear (*Ursus americanus*), Anteater (*Tamandua mexicana*), Badger (*Taxidea taxus*), and Paca (*Cuniculus paca*) have not been recorded (Rodríguez-Ruíz et al. 2013; Ochoa-Espinoza et al. 2023; Hernández-Jasso et al. 2024). The absence of *C. paca*, *M. temama*, *T. mexicana*, and *L. wiedii* can be attributed to their biology; these species prefer tropical and subtropical habitats (Reid 1997), whereas the vegetation at the Tres Mesas wind farm consists of submontane scrub. Moreover, both *T. mexicana* and *L. wiedii* are arboreal species, making them difficult to detect at ground level (Aranda 2012). The American black bear (*U. americanus*), on the other hand, has primarily been recorded in temperate forests (Lira-Torres et al. 2015; Juárez-Casillas and Varas 2013).

Regarding diversity, species richness ($q0$) remained relatively constant throughout the three sampling periods, with only minor changes in species composition. For example, *D. virginiana* was recorded during the last sampling period but was absent from the previous ones, while *S. interrupta* appeared from the second period onward, though it was detected only once during the entire year. In contrast, *M. macroura* was no longer recorded in the third sampling period. The significant increase in diversity for orders $q1$ and $q2$ during the third period indicates greater community evenness and reduced dominance by a few species. Higher $q1$ and $q1$ values reflect a more balanced distribution of abundances among species, which is often associated with improved habitat conditions and greater resource availability (Jost 2006; Chao et al. 2014). This increase in evenness may also have enhanced prey availability for mesocarnivores and large felids, contributing to a more stable trophic structure (Linnell and Strand 2000; Ripple et al. 2014). Indeed, higher abundances of *C. latrans*, *H. yagouaroundi*, *P. concolor*, and *P. onca* were observed during the third sampling period. Similar patterns have been reported in studies conducted in human-modified landscapes, where mammal communities gradually recover in abundance and evenness once construction activities cease and disturbance intensity decreases (Alves et al. 2020; Almeida-Maués et al. 2022; Barceló et al. 2025).

Nevertheless, these results should be interpreted with caution, as potential differences in species detectability among sampling periods could influence estimates of relative abundance and diversity (Burton et al. 2015; Mandujano 2024). Future studies should incorporate detectability-corrected metrics for abundance and diversity, along with occupancy models, to provide more robust interpretations. Despite these limitations, the results of this study offer a general perspective on the changes in richness and abundance observed among medium-sized and large mammals that are able to persist in human-modified habitats.

The relative abundance of recorded species varied significantly across three abundance categories reflecting a community where few species were highly dominant throughout the three years of sampling, while others showed few records per period. However, most mammal species were classified as common due to variability in their abundances. The most abundant mammal species throughout the study were *O. virginianus*, *S. floridanus*, and *L. pardalis*. In contrast, the rarest species were *D. novemcinctus*, *D. virginiana*, and *S. interrupta*, the latter recorded in only three photographic events during

the entire study. In this regard, the most abundant species at the Tres Mesas wind farm are similar to those described for the Laguna Madre and Delta del Río Bravo Flora and Fauna Protection Area in Tamaulipas (Ocañas-García 2019). While species richness was similar to that in the El Cielo Biosphere Reserve (RBEC), relative abundances differed for several species. For example, *Didelphis virginiana* had a low relative abundance of 0.21 at the Tres Mesas wind farm, compared to 2.98 in the RBEC; *D. novemcinctus* had a relative abundance of 0.09 at Tres Mesas and 1.52 in the RBEC, where it is one of the most abundant species.

Other species that showed marked contrasts include *O. virginianus*, which had the highest relative abundance (9.49) in its peak sampling at the wind farm, while it recorded one of the lowest relative abundances (0.02) in the RBEC. Similarly, *P. tajacu* had a relative abundance of 5.26 at the Tres Mesas wind farm, compared to 0.04 in the RBEC. The high values of the relative abundance index for *O. virginianus* at the Tres Mesas wind farm is consistent with this deer species' tolerance for environments modified by human activities. Additionally, it is highly adaptable to a variety of habitat types, such as grasslands and xerophytic vegetation (Mandujano et al. 2013; Potapov et al. 2014). The abundance of *S. floridanus* may benefit from habitats with secondary vegetation, grasslands, and reed beds where they find food and refuge from predators (Abu-Baker et al. 2015; Hidalgo-Mihart et al. 2017). The presence of *L. pardalis* has been recorded in several locations across Tamaulipas, and the relative abundance of this species has also been variable. However, its relative abundance in this region tends to be higher (9.15) in habitats with xerophytic vegetation (Carvajal-Villarreal 2016; Ocañas-García 2019) compared to temperate forests (0.36) (Martínez-González 2023; Ochoa-Espinoza et al. 2023).

Due to its proximity to the El Cielo Biosphere Reserve and the Sierra de Tamaulipas Biosphere Reserve, the Tres Mesas wind farm by of its geographic location, represent a key complementary area for maintaining habitat connectivity in northeastern Mexico. The ecological importance of this region has been highlighted for its potential as a major biological corridor for *P. onca* populations, their prey, and other large carnivores (Ceballos et al. 2021, 2024). Habitat fragmentation in northeastern Mexico has increased in recent decades, mainly as a result of agricultural and livestock activities expansion and the establishment of energy projects such as wind and solar farms (Castro-Navarro et al. 2017; Robles Guerrero 2019; Requena Lara et al. 2020). This process represents one of the main threats to biodiversity, with particularly strong effects on large carnivores by displacing and isolating their populations, potentially leading to local extinctions (Carroll 2006; González-Saucedo et al. 2021). As observed in other protected areas throughout the Americas (Diniz et al. 2021; Finnegan et al. 2021), the presence of adjacent areas that are not under formal protection but still capable of supporting terrestrial mammals contributes to conserving these species' populations and helps maintain biodiversity within the fragmented landscape of northeastern Mexico.

Currently, the wind farm preserves primary natural vegetation that supports populations of medium-sized and large mammals as evidenced by the results of three years of sampling. Due to the activities that are carried out, certain habitat management measures implemented may be benefiting the medium-sized and large mammal community. Among these measures undertaken by the wind farm's concessionaire is the removal of domestic animals (e.g. cows, goats, dogs), and the prohibition of hunting, both examples of human activities that are major threats to wildlife (Ripple et al. 2016). In addition, speed limits are enforced for vehicles traveling on the roads, and since 2022, artificial watering stations have been installed for wildlife, which are now monitored regularly.

Maintaining and conserving areas outside of protected natural areas is essential to ensure the dispersal of individuals, migration of subpopulations, gene flow, and the maintenance of ecological interactions (Crooks and Sanjayan 2006; Diniz et al. 2021). These efforts endeavor to promote habitat connectivity and the preservation of populations of endangered species while also safeguarding the integrity, resilience, and functioning of ecosystems (Zeller et al. 2020; Liang et al. 2023).

Our three-year study at the Tres Mesas wind farm provides valuable insights into the changes that can occur in the structure of terrestrial mammal communities within habitats modified by energy industry activities. In total, we recorded 17 species of medium-sized and large mammals, including three felid species listed under conservation status, highlighting the importance of this site for the conservation of terrestrial mammal diversity.

In terms of diversity, Hill number analyses showed that order 0 (species richness) remained relatively constant among sampling periods, indicating stability in species richness. However, orders 1 and 2 increased significantly during the third sampling period, a pattern associated with greater evenness in species abundances, particularly among dominant herbivore species, which maintained high abundances throughout the study.

This study is particularly relevant as one of the first medium-term monitoring efforts of medium-sized and large mammal communities conducted in a wind farm in Mexico. The results allow us to identify trends and patterns in community structure within transformed habitats, providing key information for designing appropriate mitigation and conservation strategies that contribute to maintaining biodiversity in areas modified for electric power generation and similar environments.

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Additional information

Conflict of interest

The authors declare that there are no conflict of interest.

Ethical statement

No ethical statement is reported.

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Author contributions

Conceptualization: OCO, HB, HZ, GC. Data curation: OCO, HB. Formal analysis: OCO. Funding acquisition: GC. Investigation: OCO, HB, HZ. Methodology: OCO, HB, HZ. Resources: HB, GC. Supervision: HB, HZ, GC. Project administration: HB, HZ, GC. Software: OCO. Validation: HB, HZ, GC. Visualization: OCO, HZ. Writing – original draft: OCO, HB, HZ. Writing – review and editing: OCO, HB, HZ, GC.

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Data availability

All data that support the findings of this study are available in the main text and Supplementary materials.

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