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Medium- to large-bodied mammals in the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico

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The Barranca del Amatzinac is the principal hydrological system in northeastern Morelos, crossing several municipalities, including the recently established Indigenous municipality of Hueyapan. Despite its ecological importance, reliable information on the diversity of medium- to large-bodied mammals—and other taxonomic groups—is lacking. Here, we present the first report on the diversity of medium- to large-bodied mammals and describe the activity patterns of species recorded in the upper basin of the Barranca del Amatzinac. We deployed 15 camera traps strategically across the upper basin and conducted 12 monthly sampling sessions from May 2023 to April 2024, each lasting one week. In parallel, we performed transect-based sign surveys (track and sign identification) with two walks per month over the same period. Species richness was estimated using Hill numbers. We also calculated proportional capture rates for each species recorded by camera trapping and encounter rates for each species recorded from signs and inferred activity patterns using the Diel.Niche package in R. In total, we documented 15 species of medium- to large-bodied mammals. With 1,183 trap-days, camera traps recorded 12 species, and nearly 264 km of transect walks yielded 11 species. Alpha diversity (α, using Hill numbers) was 6.57 for camera-trap records and 6.52 for sign surveys. The most common species were *Dasypus mexicanus*, *Didelphis virginiana*, and *Bassariscus astutus*. Consistent activity patterns were obtained for most of the photographed species, as well as seasonal changes in some taxa (*Canis latrans* and *Nasua narica*), suggesting temporal partitioning and responses to seasonal environmental variation. This study provides the first formal data on medium- to large-bodied mammals for the Indigenous municipality of Hueyapan and northeastern Morelos, establishing a baseline for future biological research in the area.

Keywords: activity pattern, Barranca del Amatzinac, camera trapping, capture rate, diversity, signs.

La Barranca del Amatzinac es el principal sistema hídrico en el noreste del estado de Morelos, atraviesa varios municipios, incluido el recientemente creado municipio indígena de Hueyapan. A pesar de su importancia ecológica, carece de información verídica sobre la diversidad biológica de mamíferos medianos y grandes, así como de otros grupos taxonómicos. Por ello, el objetivo de esta investigación fue presentar el primer reporte sobre la diversidad de mamíferos medianos y grandes, y describir los patrones de actividad de las especies registradas en la parte alta de la Barranca del Amatzinac. Se emplearon 15 cámaras trampa, distribuidas estratégicamente en la parte alta de la barranca. Se realizaron 12 muestreos, uno por mes, cada uno de una semana, desde mayo de 2023 hasta abril de 2024. Asimismo, se efectuó un muestreo de búsqueda por transectos (identificación de rastros), con dos recorridos mensuales durante el mismo periodo. La riqueza específica se calculó con base en los números de Hill. También se calcularon tasas proporcionales de captura para cada especie registrada mediante fototrampeo y tasas de detección para cada especie registrada a partir de rastros, y se infirieron los patrones de actividad utilizando el paquete Diel.Niche en R. En total se registraron 15 especies de mamíferos medianos y grandes. Con un esfuerzo de 1,183 trampa-días se identificaron 12 especies mediante fototrampeo, y 11 especies tras un esfuerzo de casi 264 km de recorridos por transecto. La diversidad alfa (α, usando números de Hill) fue de 6.57 para registros fotográficos y 6.52 para rastros. Las especies más comunes fueron *Dasypus mexicanus*, *Didelphis virginiana* y *Bassariscus astutus*. Se obtuvieron patrones de actividad consistentes para la mayoría de las especies fotografiadas, así como cambios estacionales en algunos taxones (*Canis latrans* y *Nasua narica*), lo que sugiere una partición temporal y respuestas a la variación ambiental estacional. Este trabajo aporta la primera información formal sobre la diversidad de mastofauna de talla media-grande para el municipio indígena de Hueyapan y el noreste de Morelos, y sienta las bases para futuras investigaciones biológicas en el área de estudio.

Palabras clave: Barranca del Amatzinac, diversidad, fototrampeo, patrón de actividad, rastros, tasa de captura.

Although the state of Morelos is the second smallest of Mexico's federal entities, it harbors approximately 113 mammal species distributed across the region (CONABIO 2020; Guerrero *et al.* 2020, 2025), representing roughly 20% of the country's mammalian diversity. The region with the most biodiversity information is the Sierra de Huautla Biosphere Reserve—the most diverse area in the state—where ~66 mammal species have been recorded (CONANP and SEMARNAT 2005; Mason-Romo *et al.* 2008; Orozco-Lugo *et al.* 2013, 2014; Valenzuela-Galván *et al.* 2013, 2015, 2020; Guerrero *et al.* 2025), located in the southern portion of Morelos. In contrast, the forests of northeastern Morelos—dominated by temperate vegetation rather than by tropical dry forest, as in the south—are among the least studied in mammalogy, leaving a significant information gap regarding mammal diversity (Guerrero *et al.* 2020).

Accelerated urban expansion has prompted local communities to implement strategies to conserve their natural areas (Aguilar *et al.* 2000; Kays *et al.* 2022a). However, designing effective management and conservation mechanisms requires first identifying which species are present (Antos and Yuen 2014). In this regard, biological inventories of different taxonomic groups are essential to understand the structure and dynamics of local communities (Heywood and Watson 1995). The information they generate forms the basis for establishing conservation programs and actions, as well as for the sustainable use of biodiversity (Heywood and Watson 1995; Murillo *et al.* 2014).

The ecological importance of mammals is unquestionable: they participate in key processes such as pollination, seed dispersal, and trophic regulation, both as predators and prey (Rumiz 2010; Sánchez-Cordero *et al.* 2014; Escribano-Ávila *et al.* 2015; Cheyne *et al.* 2016). Moreover, many species are considered bioindicators of ecosystem quality (Gittleman *et al.* 2001; Cheyne *et al.* 2016). Although multiple methods exist to obtain records (e.g., specimen collection and track/sign identification; Walker *et al.* 2000; González 2005), the surge in the use of camera traps has proven particularly effective for inventorying species that are cryptic or occur at low densities (González 2005; Kays *et al.* 2022b). Camera trapping provides reliable estimates of species richness (Shek *et al.* 2007; Lyra-Jorge *et al.* 2008), especially for medium- to large-bodied mammals, and yields information on population dynamics (Varma *et al.* 2006), habitat use (Tobler *et al.* 2009), density (Trolle and Kery 2005), abundance (Marnewick *et al.* 2008), and activity patterns (Maffei *et al.* 2007; Arispe *et al.* 2008).

In addition, camera trapping can be complemented with other sampling methods. The use of indirect evidence such as signs (footprints, scats, carcasses, trails, burrows, and territorial marks) increases detection probability, particularly for species with low photographic capture rates or movement patterns that do not coincide with camera placement (Lyra-Jorge *et al.* 2008; Seidlitz *et al.* 2021). Furthermore, indirect signs can provide complementary information on habitat use and diet; genetic information can even be obtained through fecal analyses (Grajales-Tam and González-Romero 2014; Seidlitz *et al.* 2021; Ramírez-García *et al.* 2025). The combination of both methods reduces biases associated with interspecific differences in detectability and provides a more comprehensive assessment of mammal assemblages, strengthening richness estimates and the ecological interpretation of community structure (Lyra-Jorge *et al.* 2008; Burton *et al.* 2015; Cruz-Bazán *et al.* 2025).

Medium- to large-bodied mammal fauna includes non-volant terrestrial and arboreal species that are usually identifiable without capture and generally weigh >250 g (medium-sized) and >20 kg (large-sized) (Rumiz *et al.* 1998; Morrison *et al.* 2007; Benchimol 2016). This group exerts direct and indirect effects on vegetation and other species through herbivory, predation, and seed dispersal (Dirzo and Miranda 1990; Ripple *et al.* 2014). In Morelos, medium- to large-bodied mammals comprise approximately 29 species, of which 18 have potential presence in northeastern Morelos (Mason-Romo *et al.* 2008; Altamirano-Álvarez *et al.* 2009; Valenzuela-Galván *et al.* 2020).

The Barranca del Amatzinac is a key hydrological feature in northeastern Morelos (CONAGUA 2009; Velázquez-Gutiérrez *et al.* 2015). It crosses several municipalities, including the recently established Indigenous municipality of Hueyapan (CONAGUA 2009; Consejo Municipal de Hueyapan 2022). The system originates at ~3,900 masl on the slopes of the Popocatépetl volcano; its upper basin lies within the municipalities of Hueyapan and Tetela del Volcán (CONAGUA 2009; Velázquez-Gutiérrez *et al.* 2015). It is characterized by rugged relief and an assemblage of oyamel fir, pine, and pine–oak forests, vegetation typical of the state's high-elevation temperate zones (CONABIO and UAEM 2004; Rzedowski 2006). These communities are part of the Trans-Mexican Volcanic Belt, one of Mexico's most important biogeographic regions. Despite this, studies on medium- to large-bodied mammals in northeastern Morelos remain scarce (CONAGUA 2009; Guerrero *et al.* 2020), likely underestimating the group's true diversity. From a biocultural perspective, generating this information is key for municipalities and communities to recognize, value, and protect their natural heritage.

Accordingly, we focused on the medium- to large-bodied mammals of the Barranca del Amatzinac. Our objectives were to (i) inventory species and estimate species richness, diversity, and capture rates using camera trapping, and assess encounter rates using sign surveys, and (ii) characterize diel and seasonal activity patterns of the species recorded by camera trapping at the study site.

Materials and methods

Study area. The Amatzinac basin originates on the slopes of the Popocatépetl volcano at approximately 3,900 masl. It traverses several municipalities and communities in the northeastern and eastern regions of the state of Morelos. The basin covers an area of 241.55 km^2, extends 62.57 km in length, and is divided into three sections: upper, middle, and lower (CONAGUA 2009; Velázquez-Gutiérrez *et al.* 2015) (Figure 1).

This study was conducted in the upper part of the Amatzinac basin, within the Indigenous Communal Land of Hueyapan. Characteristic of temperate forests, this area harbors fir, pine, and pine–oak forest assemblages (INEGI 2021; Consejo Municipal Hueyapan 2022), interspersed with agricultural patches. Mean annual temperature ranges from 12 to 18 °C (INEGI 2021), and mean annual precipitation is between 1,500 and 2,000 mm. Precipitation is markedly seasonal, with most rainfall occurring during the rainy season (May–October), while the dry season extends from November to April and is characterized by substantially lower monthly precipitation (CONAGUA 2022). Temperature variation throughout the year is

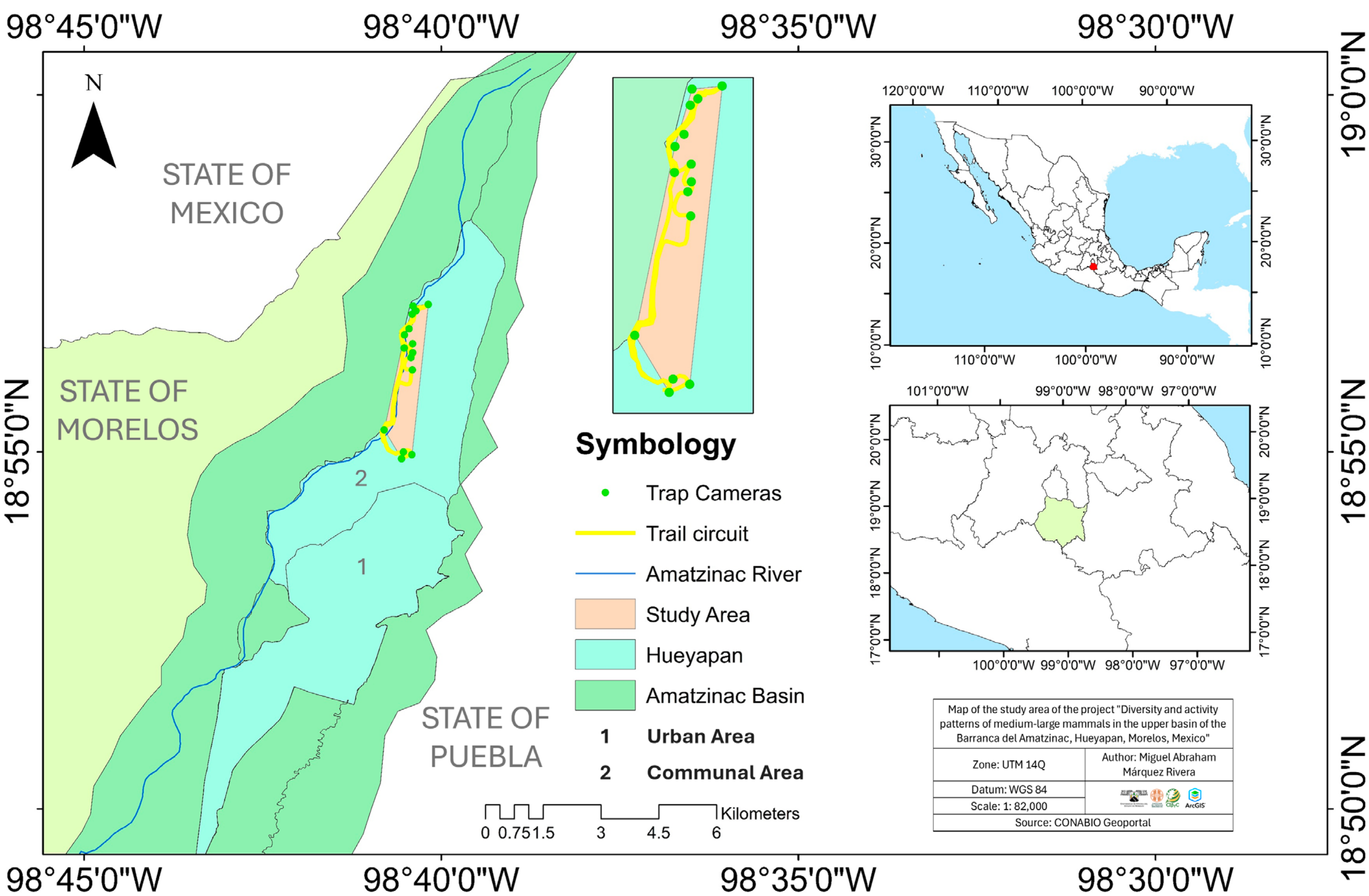

Figure 1. Geographic location of the study site and the Barranca del Amatzinac, Hueyapan, Morelos, Mexico.

moderate, with cooler conditions from December to February and warmer temperatures preceding the onset of the rainy season (INEGI 2021). The sampling area covered by trap cameras comprised 222 ha within the upper basin of the Barranca del Amatzinac and was estimated using a minimum convex polygon based on camera trap locations in ArcGIS. Additionally, 24 surveys of 11 km each were conducted, totaling a cumulative distance of 264 km to identify signs within the study area.

Sampling Design. A total of 12 sampling periods were conducted, one per month, each lasting one week, from May 2023 to April 2024. Fifteen camera traps from Cuddeback® (Non Typical, Inc., Park Falls, Wisconsin) were deployed, specifically the Long-Range IR-E2, Attack Black Flash, and Attack IR models.

Sampling stations were systematically placed in locations with evidence of wildlife presence (e.g., latrines, burrows, tracks, and water bodies), following the relief of the upper basin. Each station consisted of one camera trap mounted on a tree or wooden stake at ~50 cm above ground level, with inter-station distances ranging from 200 to 250 m. The exact spacing was influenced by terrain conditions; similarly, comparable distances (200–500 m) have been reported and used to increase the probability of species detection (Chávez *et al.* 2013; Silva-Rodríguez *et al.* 2024; Yamashita *et al.* 2025). Cameras operated continuously (24 h/day), programmed to capture three photographs per detection event (1-min reactivation interval) and a 20-s video when available.

All stations were georeferenced using a Garmin® GPS device. During each sampling period, memory cards were downloaded and batteries replaced as needed. To enhance detection, attractants were systematically deployed at all stations. During the dry season, canned sardines, chicken pieces, and water containers were placed at each station, whereas during the rainy season only canned sardines and chicken pieces were used.

Complementary Field Surveys. In parallel with camera trapping, 24 field surveys (two per month) were conducted in the study area between May 2023 and April 2024, by walking a trail circuit of ~11 km within the study area. Surveys were conducted during the day between 09:00 and 13:00 h. On each survey, all observed mammalian evidence (signs) was recorded through photographs of footprints, scats, carcasses, and direct sightings. Of these, only well-preserved carcasses and some scats were collected for subsequent identification. Samples were collected under collecting permit FAUT-0136 issued to EA. Collected carcasses were prepared through taxidermy and deposited in the mammal collection of the Centro de Investigación en Biodiversidad y Conservación (CIByC) of the Universidad Autónoma del Estado de Morelos (UAEM). Collected scats were preserved dry and later analyzed morphologically at the Centro de Investigación en Biodiversidad y Conservación. Identification of these signs was carried out using field guides and relevant literature. For *Sylvilagus* species in particular, taxonomic identification was performed by comparing macroscopic morphological characteristics of field-collected fecal samples (Velázquez *et al.* 1996; Aranda 2000, 2012). An operational criterion of 100 m between records of the same species was established to consider them independent events, in order to avoid counting the same individual multiple times along the transect.

Data Processing. Species identity was assigned based on photographic records and species identification guides (Aranda 2000, 2012). A database was compiled, including coordinates, date and time, species taxonomy, and relevant observations for each record.

To avoid overestimation in subsequent analyses, only independent records per species were considered. Following established criteria, an independent record was defined as a single photograph from the same camera, separated by an exclusion interval of 24 h for all the species (Hernández-Pérez *et al.* 2015). If multiple individuals appeared in the same photograph, or if consecutive photographs depicted different individuals, each was treated as an independent record.

Richness and Diversity. Species richness was assessed using Hill numbers of order 0 (q = 0) (Hill 1973; Moreno *et al.* 2011; Ochoa-Espinoza *et al.* 2023), which are insensitive to species abundances/frequencies and correspond to raw species richness. Sample completeness (Ĉn) was also estimated, representing the proportion of the community sampled (Chao and Jost 2015; Serna-Lagunes *et al.* 2019). Analyses were conducted with the iNEXT package in R v.4.1.3 (Hsieh *et al.* 2016; R Core Team, 2023), and results were represented with rarefaction and extrapolation curves. Calculations were performed separately for camera trapping and sign surveys.

Alpha diversity (α) was estimated using Hill numbers of order 1 (q = 1), the exponential of Shannon's index (Hill 1973; Moreno *et al.* 2011; Bautista-Plazas 2020), which weights species by their relative incidence (independent events were used as incidence-frequency data in both methods). Analyses and graphical outputs were obtained with iNEXT in R. This approach provides both abundance-insensitive (q = 0) and abundance-weighted (q = 1) perspectives of the recorded species.

Sampling Effort and Capture Rate. For camera trapping, sampling effort (SE) was calculated by summing the number of days each camera trap was operational (cameras damaged or lost in the field were excluded from the calculation of sampling effort) (Medellín *et al.* 2006; Lira-Torres and Briones-Salas 2012). The capture rate (CR) per species was estimated as: $CR=(C/SE)\times 1000$ trap-days where C = captures or independent events, SE = sampling effort, and 1000 trap-days = standard unit (Lira-Torres and Briones-Salas 2012; Hernández-Pérez *et al.* 2015; Mandujano 2024).

For sign surveys, sampling effort (SE) was calculated as the product of the distance traveled and the number of surveys. The Sign Encounter Rate (SER) was then estimated by dividing the total number of independent signs recorded per species (including footprints, scats, carcasses, and direct sightings) by the total distance traveled (Carrillo *et al.* 2000; Lira-Torres and Briones-Salas 2012).

Activity Patterns. Activity patterns were obtained using the Diel.Niche package in R (R Core Team 2023; Gerber *et al.* 2024), based on photographic records obtained for each species with at least 1 h of interval on a given camera. Those records were categorized as diurnal, nocturnal, or crepuscular based on the printed hour of each record, corrected with reference to the solar time according to its specific geographic position and date. This classification was performed using the suncalc package in R (R Core Team 2023; Thieurmel and Elmarhraoui 2023). The Diel.Niche package evaluates seven alternative activity hypotheses: traditional diurnal, traditional crepuscular, traditional nocturnal, general cathemeral (irregular periods of activity throughout the 24-hour day), crepuscular–nocturnal, diurnal–nocturnal (a bimodal activity pattern with distinct activity during daytime and nighttime), and diurnal–crepuscular; The method relies on a Bayesian multinomial regression framework, which probabilistically assigns each species to an activity hypothesis and compares alternative models using Bayes factors, balancing fit and complexity (Berger 2013; Gerber *et al.* 2024). Following Gerber *et al.* (2024), a threshold probability of 0.80 was adopted to reduce uncertainty in hypothesis assignment, although the model with the highest probability was ultimately recommended.

To capture the subtleties of temporal activity beyond simple categorical labels, we used the best-supported model for each species (selected from the general hypothesis set of the Diel.Niche package) to estimate activity probabilities for each diel period (diurnal, nocturnal, and crepuscular). These model-based probabilities provide a quantitative and comparable framework, allowing us to describe species-specific patterns and their seasonal variation in greater detail. This analysis was performed using the Diel.Niche package (Gerber *et al.* 2024).

Only species with ≥15 independent photographic records (at least 1 h of interval between them for this calculation) were included, a conservative criterion commonly used to ensure sufficient statistical power and reliability in estimating activity patterns. Additionally, circular histograms (rose plots) divided into 24 classes, each representing one hour of the day, were generated for each species to visualize activity patterns. These were created in R using the tidyverse, lubridate, and ggplot2 packages (R Core Team 2023).

Results

Richness and Diversity. A total of 15 medium- to large-sized mammal species were recorded, belonging to six orders, 11 families, and 14 genera. Of these, 12 species were detected using camera trapping (Table 1; Supplementary Data SD1) and 11 species using sign surveys (Table 2; Supplementary Data SD2). Eight species were recorded by both sampling methods; only *Lynx rufus, Urocyon cinereoargenteus, Neogale frenata* and *Bassariscus astutus* were recorded by camera trapping. In contrast, *Otospermophilus variegatus, Conepatus leuconotus, Sylvilagus cunicularius* and *Sylvilagus floridanus* were identified from signs (It was not possible to distinguish between the two species of the genus *Sylvilagus* in the photographic records).

Sample coverage (Ĉn) values were 100% for camera trapping and 93% for sign surveys, indicating high sampling completeness. Alpha diversity (α) was estimated at 6.57 (95% CI: 6.06–7.08) for camera trapping (12 species recorded) and 6.52 (95% CI: 4.35–8.58) for sign surveys (11 species recorded). According to season, alpha diversity (α) metrics for the camera trapping method were 6.83 (95% CI: 6.20–7.46) in the dry season and 5.72 (95% CI: 5.08–6.36) in the rainy season. In the case of sign surveys, a value of 5.24 (95% CI: 2.46–8.03) was obtained in the dry season and 6.03 (95% CI: 3.98–8.08) in the rainy season (Figure 2).

Sampling Effort and Capture Rate. Based on photographic records, a total sampling effort of 1,183 trap-days was achieved, yielding 513 independent records corresponding to 12 medium- to large-sized mammal species. The most common species were *D. mexicanus* (N = 162, CR = 136.94), *D. virginiana* (N = 112, CR = 94.67), and *B. astutus* (N = 80, CR = 67.62). Conversely, the least frequent species were *U. cinereoargenteus* (N = 7, CR = 5.92), *L. rufus* and *N. frenata* (N = 2, CR = 1.69) (Figure 3; Tables 1 and 3).

During the dry season, with a sampling effort of 567 trap-days, a total of 300 independent records were obtained, corresponding to 12 mammal species. The most

Table 1. Medium-large-sized mammals recorded in the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico. Total independent photographs (TIP), and Capture Rate (CR) total and by season (Dry-Rainy). IUCN status (LC = Least Concern).

Species	Photo-trapping						IUCN
	TIP	CR(T)	TIP(D)	CR(D)	TIP(R)	CR(R)	
Didelphimorphia							
Didelphidae							
Didelphis virginiana Kerr, 1792	112	**94.67**	79	**139.33**	33	**53.57**	LC
Cingulata							
Dasypodidae							
Dasypus mexicanus W. C. H. Peters, 1865	162	**136.94**	77	**135.8**	85	**137.99**	LC
Lagomorpha							
Leporidae							
Sylvilagus sp.	10	**8.45**	6	**10.58**	4	**6.49**	LC
Rodentia							
Sciuridae							
Sciurus aureogaster F. Cuvier, 1829	15	**12.68**	8	**14.11**	7	**11.36**	LC
Carnivora							
Felidae							
Lynx rufus (Schreber, 1777)	2	**1.69**	1	**1.76**	1	**1.62**	LC
Canidae							
Canis latrans Say, 1823	30	**25.36**	18	**31.75**	12	**19.48**	LC
Urocyon cinereoargenteus (Schreber, 1775)	7	**5.92**	6	**10.58**	1	**1.62**	LC
Mustelidae							
Neogale frenata (H. Lichtenstein, 1831)	2	**1.69**	2	**3.53**	-	-	LC
Procyonidae							
Bassariscus astutus (H. Lichtenstein, 1830)	80	**67.62**	57	**100.53**	23	**37.34**	LC
Nasua narica (Linnaeus, 1776)	68	**57.48**	28	**49.38**	40	**64.94**	LC
Procyon lotor (Linnaeus, 1758)	12	**10.14**	8	**14.11**	4	**6.49**	LC
Artiodactyla							
Cervidae							
Odocoileus virginianus (Zimmermann, 1780)	13	**10.99**	10	**17.64**	3	**4.87**	LC

Note: *Mustela frenata* (Sheffield and Thomas 1997) is currently recognized as *Neogale frenata* (Patterson *et al.* 2021), and *Dasypus novemcinctus* (McBee and Baker 1982) is currently recognized as *Dasypus mexicanus* (Barthe *et al.* 2025).

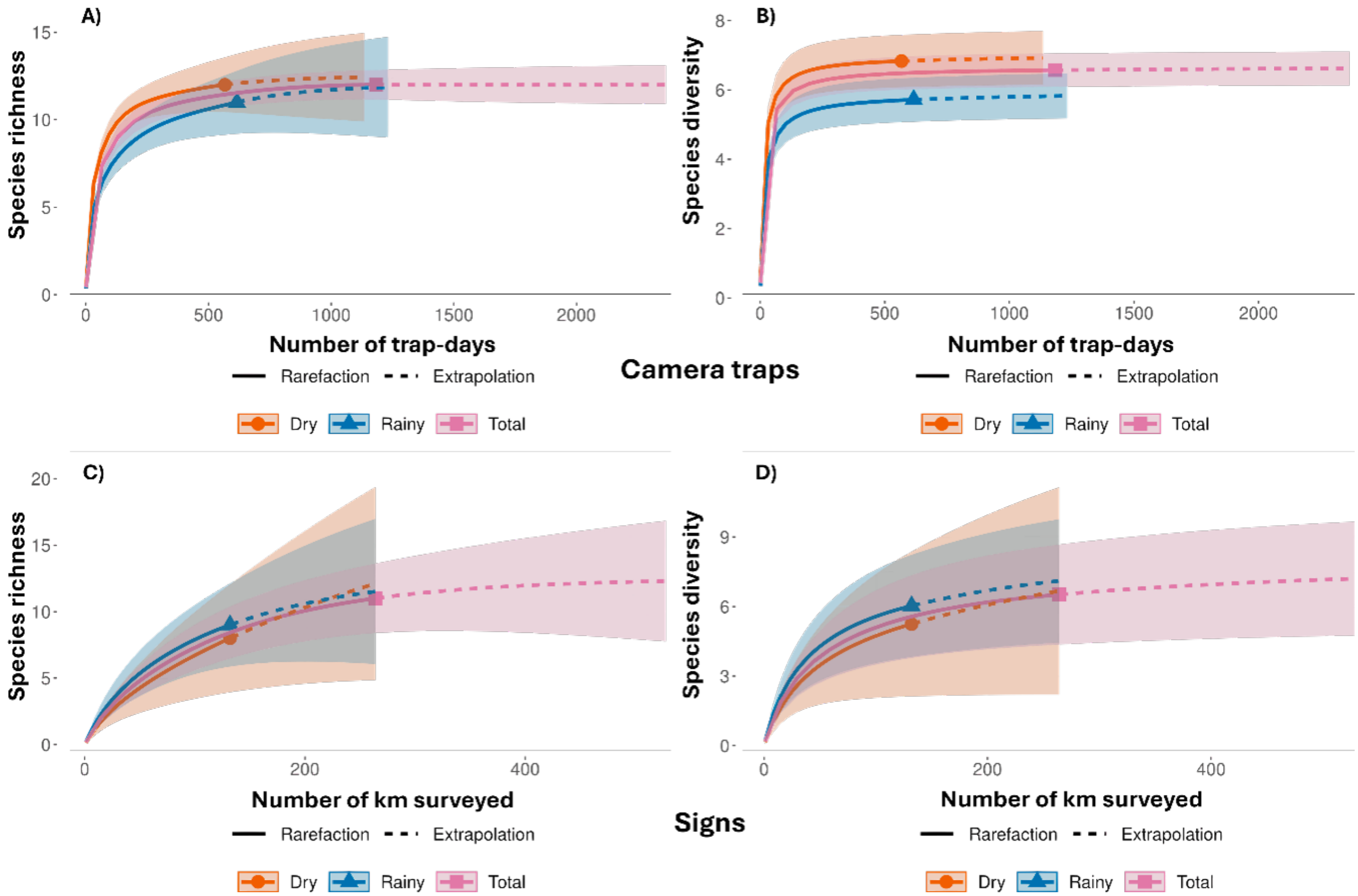

Figure 2. Species richness (A, C) and alpha diversity (B, D) of medium- to large-sized mammals recorded in the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico, using camera trapping (A, B) and sign surveys (C, D). Sampling curves are based on rarefaction and extrapolation using sample size. Shaded areas represent 95% confidence intervals derived from 100 bootstrap replicates.

frequent species were *D. virginiana* (N = 79, CR = 139.33), *D. mexicanus* (N = 77, CR= 135.80) and *B. astutus* (N = 57, CR = 100.53). The least common species were *U. cinereoargenteus* (N = 6, CR = 10.58), *N. frenata* (N = 2, CR = 3.53), and *L. rufus* (N = 1, CR = 1.76) (Figure 3; Tables 1 and 3).

For the rainy season, a sampling effort of 616 trap-days produced 213 independent records, corresponding to 11 mammal species. The most frequent species during this period were *D. mexicanus* (N = 85, CR = 137.99), *D. virginiana* (N = 33, CR = 53.57), and *Nasua narica* (N = 40, CR = 64.94). In contrast, the least frequent species were *Sylvilagus sp*. (N = 4, CR = 6.49) and *Odocoileus virginianus* (N = 3, CR= 4.87), as well as *L. rufus* and *U. cinereoargenteus* (N = 1, CR = 1.62) (Figure 3; Tables 1 and 3).

Sign Encounter Rate. Using the sign survey method, a total sampling effort of 264 km was covered, yielding 45 independent records corresponding to 11 medium-to large-sized mammal species. The highest encounter rate from signs (SER) was recorded for *Sciurus aureogaster* (N = 20, SER = 0.076), followed by *O. variegatus* (N = 6, SER= 0.023) and *O. virginianus* (N = 4, SER = 0.015). In contrast, the least frequent species were *D. virginiana*, *Conepatus leuconotus*, and *Procyon lotor* (N = 1, SER = 0.004) (Tables 2 and 3).

During the dry season, a sampling effort of 132 km yielded 19 records, corresponding to eight mammal species. The most frequent species were *S. aureogaster* (N = 9, SER = 0.068) and *O. virginianus* (N = 3, SER = 0.023). The least frequent species were *D. virginiana*, *Sylvilagus cunicularius*, *S. floridanus*, *Canis latrans*, and *P. lotor* (N = 1, SER = 0.008).

In the rainy season, with the same sampling effort of 132 km, 26 independent records were obtained, corresponding to nine mammal species. The highest SER values in this period were observed for *S. aureogaster* (N = 11, SER = 0.083) and *O. variegatus* (N = 4, SER = 0.030). Conversely, the least frequent species were *S. floridanus*, *C. latrans*, *C. leuconotus*, and *O. virginianus* (N = 1, SER = 0.008).

Activity Patterns. Activity patterns were estimated for seven of the 12 species recorded through camera trapping. Based on model fit, *B. astutus*, *D. mexicanus*, *D. virginiana*, and *P. lotor* were classified as nocturnal (model probabilities: 0.95, 1.00, 1.00, and 0.98, respectively). *S. aureogaster* was classified as diurnal (0.97). *C. latrans* was classified as diurnal–nocturnal with a lower model probability (0.66); likewise, *N. narica* was classified as diurnal–nocturnal (0.82) (Table 4; Supplementary Data SD3).

Activity patterns were obtained for five species in both

Table 2. Medium-large size mammals recorded in the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico. Total mammalian signs records (TS), and Sign Encounter Rate (SER) total and by season (Dry-Rainy). Type of sign (C= Carcass, SI= Sighting, F= Footprint, S= Scat, B= Burrow). IUCN status (LC= Least Concern).

Species	Signs						Type of Sign	IUCN
	TS	SER(T)	TS(D)	SER(D)	TS(R)	SER(R)		
Didelphimorphia								
Didelphidae								
Didelphis virginiana Kerr, 1792	1	**0.004**	1	**0.008**	-	**-**	C, F	LC
Cingulata								
Dasypodidae								
Dasypus mexicanus W. C. H. Peters, 1865	3	**0.011**	-	**-**	3	**0.023**	C, SI, F	LC
Lagomorpha								
Leporidae								
Sylvilagus cunicularius (Waterhouse, 1848)	3	**0.011**	1	**0.008**	2	**0.015**	S	LC
Sylvilagus floridanus (J. A. Allen, 1890)	2	**0.008**	1	**0.008**	1	**0.008**	S	LC
Rodentia								
Sciuridae								
Sciurus aureogaster F. Cuvier, 1829	20	**0.076**	9	**0.068**	11	**0.083**	SI	LC
Otospermophilus variegatus (Erxleben, 1777)	6	**0.023**	2	**0.015**	4	**0.03**	C, SI	LC
Geomyidae							B	
Carnivora								
Canidae								
Canis latrans Say, 1823	2	**0.008**	1	**0.008**	1	**0.008**	SI, F	LC
Mephitidae								
Conepatus leuconotus (H. Lichtenstein, 1832)	1	**0.004**	-	**-**	1	**0.008**	C	LC
Procyonidae								
Nasua narica (Linnaeus, 1776)	2	**0.008**	-	**-**	2	**0.015**	C, F	LC
Procyon lotor (Linnaeus, 1758)	1	**0.004**	1	**0.008**	-	**-**	F	LC
Artiodactyla								
Cervidae								
Odocoileus virginianus (Zimmermann, 1780)	4	**0.015**	3	**0.023**	1	**0.008**	SI, F, S	LC

seasons. *D. mexicanus*, *B. astutus* and *D. virginiana* were classified as nocturnal in both seasons, as in their general pattern, these species presented model supports above 0.9 in both seasons, except for *B. astutus*, which showed a lower support (0.77) during the rainy season. *C. latrans* presented a different classification between seasons; it was classified as nocturnal during the dry season, although with a much lower model probability (0.47), while in the rainy season it showed a diurnal–nocturnal activity with lower support (0.76), similar to that reported in its general activity. *N. narica* exhibited an activity pattern during the dry season similar to the general activity, being classified as diurnal–nocturnal with lower support (0.78); in contrast, during the rainy season it was classified as diurnal (0.82), differing from its general pattern.

Based on the best-supported model for each evaluated species, the estimated probabilities of diel activity were obtained for the three activity periods (diurnal, nocturnal, and crepuscular). *D. mexicanus*, *B. astutus*, *D. virginiana* and *P. lotor* showed predominantly nocturnal activity with probabilities higher than 0.8. *N. narica* was mainly diurnal (0.66), although it also showed a considerable nocturnal probability (0.26), while *S. aureogaster* exhibited a strong diurnal activity probability (0.92). In contrast to *N. narica*, *C. latrans* showed a higher nocturnal probability (0.65) than diurnal activity (0.25). Total and seasonal activity probabilities are presented in Table 4.

Table 3. Sampling effort (in trap-days for photo-trapping and in kilometers of sampling for sign surveys), independent records and species recorded in each sampling method used in the record of medium-large mammals for the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico.

	Photo-trapping			Signs		
	Total	**Dry**	**Rainy**	**Total**	**Dry**	**Rainy**
Sampling effort	1183	567	616	264	132	132
Independent records	513	300	213	45	19	26
Registered species	12	12	11	11	8	9
Exclusive species	4	4	3	4	3	4

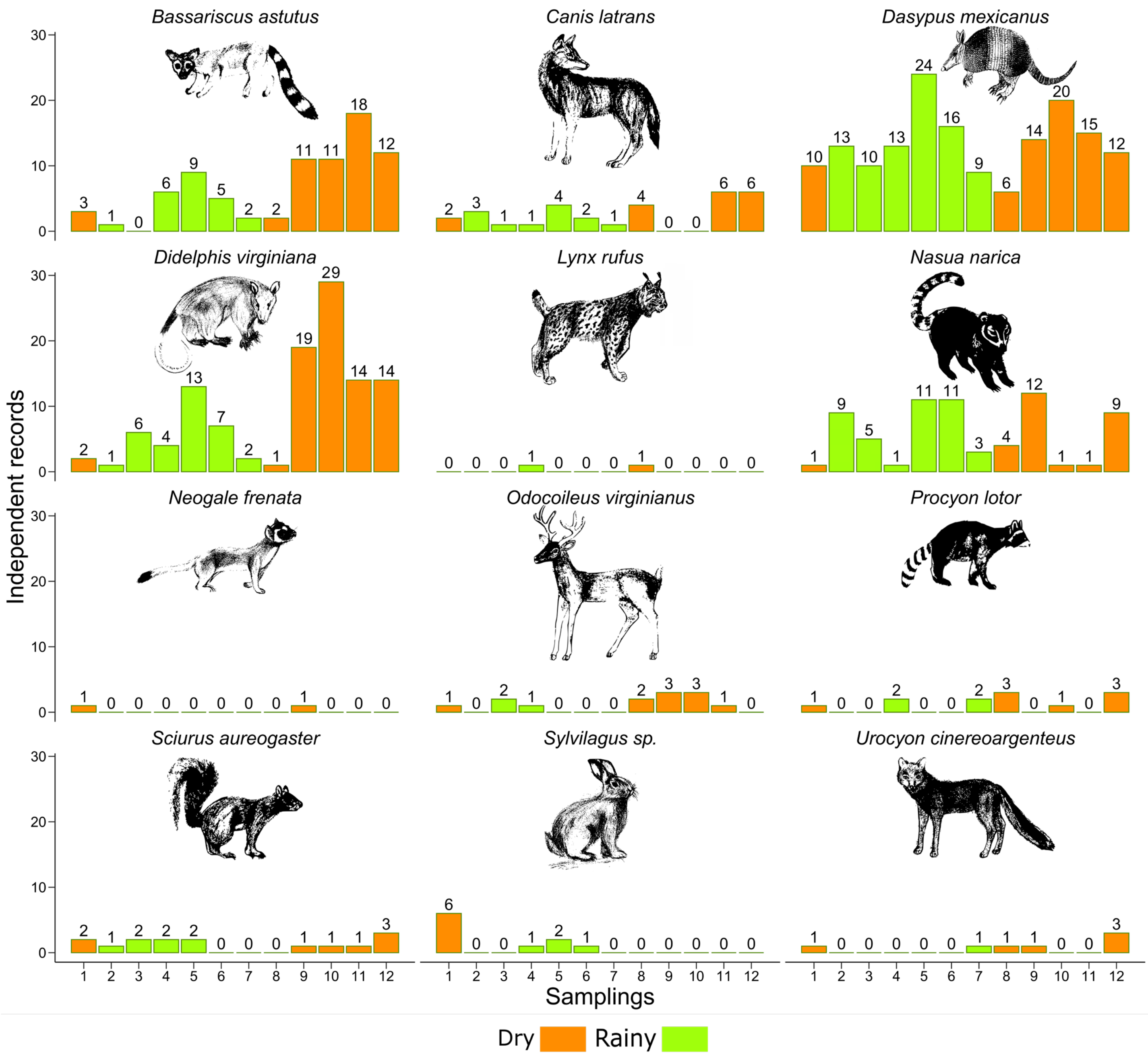

Figure 3. Total frequency of medium and large mammal species recorded in the upper basin of the Barranca del Amatzinac by photo-trapping. X axis= Sampling carried out (one per month from May 2023 to April 2024), Y axis= Number of independent records for each species. Orange indicates the dry season; green indicates the rainy season.

Discussion

This study documents for the first time the presence of 15 medium- to large-sized mammal species in the upper Barranca del Amatzinac basin, representing six orders and 11 families. This richness corresponds to approximately 51.7% of the species reported for the state of Morelos (Álvarez-Castañeda 1996; Altamirano-Álvarez *et al.* 2009; Guerrero *et al.* 2020; Valenzuela-Galván *et al.* 2020). The diversity detected likely reflects the basin's location within the Trans-Mexican Volcanic Belt, one of the most biodiverse biogeographic regions in Mexico (Suárez-Mota and Téllez-Valdés 2014). Comparable richness has been reported in subhumid temperate forests, such as the 20 species recorded in the Sierra Madre de Oaxaca (Cruz-Espinoza *et al.* 2012), 11 species in the Sierra de Juárez Oaxaca (Hernández-Rodríguez *et al.* 2019), and 10 species in Pico de Orizaba National Park (Serna-Lagunes *et al.* 2019).

Sample coverage (Ĉn) analyses indicated high sampling completeness for both sampling methods. Camera trapping detected 12 taxa (11 identified to species level and one to genus level), whereas sign surveys recorded 11 species (Chao and Jost 2012; Serna-Lagunes *et al.* 2019). Although only 15 of the 18 potential species expected for the region were documented, coverage estimates suggest that most detectable species were likely captured. Richness extrapolations (q = 0) also indicated that only a few additional species would be expected with further sampling. Alpha diversity (α) values were similar for the

Table 4. Activity patterns of medium-large mammals in the upper basin of the Barranca del Amatzinac, Hueyapan, Morelos, Mexico. TIP (total independent photographs for the entire sampling and by seasons) (D= diurnal, N= nocturnal and D-N= diurnal-nocturnal).

	Species	Photographic events				Model support	Activity pattern (best-supported model)	Activity probability (based on the best-supported model)		
		TIP	Day	Night	Twilight			Diurnal	Nocturnal	Crepuscular
Total	*Dasypus mexicanus*	212	11	196	5	1	**N**	0.05	0.92	0.03
	Canis latrans	35	8	24	3	0.66	**D-N**	0.25	0.68	0.07
	Bassariscus astutus	129	5	109	15	0.95	**N**	0.04	0.84	0.11
	Didelphis virginiana	205	8	179	18	1	**N**	0.04	0.87	0.09
	Nasua narica	98	64	25	9	0.82	**D-N**	0.66	0.26	0.08
	Procyon lotor	18	0	18	0	0.98	**N**	0.03	0.92	0.03
	Sciurus aureogaster	16	16	0	0	0.97	**D**	0.92	0.03	0.03
Dry	*Dasypus mexicanus*	90	4	84	2	1	**N**	0.05	0.92	0.03
	Canis latrans	20	3	15	2	0.47	**N**	0.09	0.83	0.07
	Bassariscus astutus	95	3	81	11	0.94	**N**	0.04	0.85	0.11
	Didelphis virginiana	144	8	120	16	0.93	**N**	0.06	0.83	0.11
	Nasua narica	42	18	20	4	0.78	**D-N**	0.44	0.49	0.07
Rainy	*Dasypus mexicanus*	122	7	112	3	1	**N**	0.06	0.91	0.03
	Canis latrans	15	5	9	1	0.76	**D-N**	0.35	0.59	0.06
	Bassariscus astutus	34	2	28	4	0.77	**N**	0.06	0.84	0.09
	Didelphis virginiana	61	0	59	2	1	**N**	0.01	0.94	0.04
	Nasua narica	56	46	5	5	0.82	**D**	0.83	0.08	0.08

Activity pattern assigned according to the best-supported model; activity probability for the three diel periods was calculated using the best-supported model from the hypothesis set of the Diel.Niche package.

overall results of both methods. The overlap of confidence intervals suggests that no clear differences in diversity between seasons were detected for each method employed (Chao and Jost 2012; Cultid-Medina and Escobar 2019).

Camera trapping proved effective for detecting a wide range of mammals, including widely distributed species such as *O. virginianus*, *C. latrans*, and *D. mexicanus* (Cruz-Espinoza *et al.* 2012; Cortés-Marcial and Briones-Salas 2014; Grajales-Tam and González-Romero 2014; Hernández-Pérez *et al.* 2015; Ochoa-Espinoza *et al.* 2023), as well as elusive species, such as *N. frenata* (Sheffield and Thomas 1997; Contreras-Moreno *et al.* 2015) and *L. rufus*, a bioindicator species of ecosystem quality (Pacheco 2003; Ríos-Carrillo 2014; Díaz-Bernal 2017). However, no photographic records were obtained for *Mephitis macroura*, *Spilogale angustifrons*, or *Herpailurus yagouaroundi*, species previously reported for Morelos (Altamirano-Álvarez *et al.* 2009). Greater sampling effort and complementary methods may therefore increase detection probability.

Species-level identification of the genus *Sylvilagus* was not possible from photographic records, as *S. cunicularius* and *S. floridanus* share similar morphological traits (Aranda 2012; Kays *et al.* 2022b). Species determination was achieved through fecal samples, which exhibit diagnostic characteristics (Velázquez *et al.* 1996; Aranda 2012) (Supplementary Data SD2). Sign surveys also documented the presence of Geomyidae, identified by characteristic soil mounds produced by their fossorial habits (Aranda 2012).

Capture Rates (CR) indicated that *D. mexicanus*, *D. virginiana* and *B. astutus* were the most common species. Although camera trapping has been suggested to be suboptimal for recording *D. mexicanus* (Monroy-Vilchis *et al.* 2011; Cortés-Marcial and Briones-Salas 2014), other studies have reported it as frequent using the same method (Lira-Torres and Briones-Salas 2012; Ochoa-Espinoza *et al.* 2023), consistent with our findings. Its high frequency may relate to its insectivorous and generalist diet (McBee and Baker 1982), along with its preference for humid habitats with dense vegetation cover (Weckel *et al.* 2006; Harmsen *et al.* 2010), conditions present at the study site. Similar for *D. virginiana* and *B. astutus*, both described as ecologically plastic and tolerant of human-modified environments (McManus 1974; Castellanos-Morales *et al.* 2009; Cisneros-Moreno and Martínez-Coronel 2019), their high CR may reflect adaptability and resource availability.

Carnivora was the most diverse order in this study, with eight species recorded. *C. latrans* was the fifth most frequent species (N = 30, CR = 25.36), likely due to the availability of prey such as *D. mexicanus*, *S. cunicularius*, and *S. floridanus* (Monroy *et al.* 2003; Watine and Giuliano 2017; Serna-Lagunes *et al.* 2019). Its populations may also inhibit those of *U. cinereoargenteus* due to competition and resource overlap, potentially explaining the latter's low CR (Grajales-Tam and González-Romero 2014; Egan *et al.* 2021). Temporal segregation may further reduce direct interactions and facilitate coexistence (Rodríguez-Luna *et al.* 2024). Similarly, *L. rufus* showed a low CR, likely constrained by its specialist carnivorous niche, particularly its reliance on lagomorphs (Delibes *et al.* 1997; CONANP 2010; Ríos-Carrillo 2014). For *N. frenata*, the low number of records may reflect its elusive behavior and low detectability in conventional surveys (Sheffield and Thomas 1997; Estrada *et al.* 2002; Jesús-Espinosa *et al.* 2023). Among procyonids, *N. narica* showed relatively high CR (N = 68, CR = 57.48), likely related to its matriarchal social structure, which produces multiple independent events in a single record (Valenzuela-Galván 2002). *B. astutus* also showed multiple events, as young remain with the mother for several months (Pacheco 2003). In contrast, *P. lotor* (N = 12, CR= 10.14) had lower capture rate than other procyonids, possibly reflecting competition with other carnivores or preference for less-represented habitats. Overall, most species exhibited higher CR during the dry season; only *D. mexicanus* and *N. narica* showed greater frequency during the rainy season. Notably, *N. frenata* was not recorded during the rainy season in camera traps.

Sign surveys showed *S. aureogaster*, *O. variegatus*, and *O. virginianus* as the most frequent species. The high frequency of *S. aureogaster* may relate to its diurnal activity pattern and the fact that surveys were conducted during daytime (Mora-Ascencio *et al.* 2010; Ramos-Lara and Cervantes 2011). *O. variegatus* was regularly detected in sign surveys but not by camera traps, likely because cameras were placed inside forest stands, whereas this species was mainly observed along open trails and edge habitats. Future sampling designs should therefore consider different forest strata to increase detection probability. Sign-based encounter rates differed between seasons for most species, partly because many were recorded only once. Consequently, SER values were lower than CR, reflecting fewer overall records. Although sign surveys are valuable for mammal inventories (Lyra-Jorge *et al.* 2008; Cortés-Marcial and Briones-Salas 2014; Swan *et al.* 2014), the low number of records suggests refining the local design (e.g., longer transects, standardized substrates, optimized timing) and combining complementary methods.

Evidence of local reproductive activity was obtained for *D. mexicanus* and *N. narica*. A juvenile *D. mexicanus* was observed in August 2023, and for *N. narica*, one juvenile was photographed in June 2023 and the carcass of another juvenile was found in August 2023. These events occurred during the rainy season, when resource availability is higher, suggesting stable local populations.

Regarding activity patterns, *B. astutus*, *D. mexicanus*, *D. virginiana*, and *P. lotor* were classified as nocturnal (model probability > 0.9). These species have been described as primarily nocturnal in other regions of Mexico (Lira-Torres and Briones-Salas 2012; Hernández-Pérez *et al.* 2015; Hernández-Hernández *et al.* 2018). These results support the idea that species weighing <10 kg tend to be nocturnal–crepuscular (Monroy-Vilchis *et al.* 2011). *Canis latrans* was classified as diurnal–nocturnal, although this pattern can also be considered a specific form of cathemerality (González-Pérez *et al.* 1992; Cortés-Marcial and Briones-Salas 2014; Gerber *et al.* 2024). *N. narica* was classified as diurnal–nocturnal (model probability = 0.82), although it is commonly described as diurnal (Valenzuela-Galván 2002; Reid 2009; Lira-Torres and Briones-Salas 2012), which may reflect sexual and contextual differences in activity (e.g., greater nocturnal activity in adult males) and behavioral adjustments to local conditions (Hernández-Pérez *et al.* 2015). Across seasons, *B. astutus*, *D. mexicanus*, and *D. virginiana* maintained consistent activity patterns, whereas *N. narica* and *C. latrans* exhibited seasonal variation. These shifts may reflect changes in resource availability, temperature, humidity, geographic conditions, population traits (sex, age, reproductive status, mate availability), and human disturbance (Valenzuela 2005; Ridout and Linkie 2009; Monroy-Vilchis *et al.* 2011; Rowcliffe *et al.* 2014).

We observed that activity patterns probabilities (based on the model with the highest support) varied considerably among species: *B. astutus, D. mexicanus, D. virginiana,* and *P. lotor* were predominantly nocturnal (probabilities > 0.8) in both seasons and in the overall dataset. However, *P. lotor* was classified only in the total dataset. For *C. latrans*, nocturnal (~0.7) and diurnal (~0.3) activity probabilities were not similar and consistent between seasons. For *N. narica*, overall probabilities were similar among the three periods, but seasonal variation was observed: in the dry season values were equivalent, whereas in the rainy season diurnal probability was higher (0.83) than nocturnal (0.08) and crepuscular (0.08), explaining its classification as diurnal in that period.

Conclusions

This study provides baseline information on the richness, diversity, capture rates, and activity patterns of medium- to large-sized mammals in the upper Amatzinac basin, Hueyapan, Morelos. Fifteen species were documented in a relatively small area outside a protected natural area, underscoring the biological relevance of the site. Given that this region contributes to aquifer recharge ("water forests") in northeastern Morelos, ecological assessments of different taxonomic groups will support local communities in designing programs and strategies for the sustainable management of natural resources in the upper Barranca del Amatzinac.

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Declaration of Artificial Intelligence use

Grammarly Pro was used solely to check English spelling and grammar.

Author contributions

Miguel A. Márquez-Rivera: Conceptualization, Formal analysis, Investigation, Methodology and Writing – Original Draft Preparation. Elizabeth Arellano: Conceptualization, Project administration, Resources, Reviewing and Editing. David Valenzuela-Galván: Methodology, Resources, Reviewing and Editing. Daryl D. Cruz: Conceptualization, Methodology, Project administration, Supervision, Writing-Reviewing and Editing.

Supplementary data

SD1. Medium- to large-sized mammals recorded by camera traps in the study area: (A) *Didelphis virginiana,* (B) *Dasypus mexicanus,* (C) *Sylvilagus sp.,* (D) *Sciurus aureogaster,* (E) *Lynx rufus*, (F) *Canis latrans,* (G) *Urocyon cinereoargenteus,* (H) *Neogale frenata,* (I) *Bassariscus astutus,* (J) *Nasua narica, (k) Procyon lotor,* (L) *Odocoileus virginianus.*

SD2. Medium- to large-sized mammal species recorded from traces in the study area: (A) *Dasypus mexicanus,* (B) *Didelphis virginiana*, (C) *Conepatus leuconotus*, (D) *Nasua narica*, (E) *Odocoileus virginianus*, (F) *Sciurus aureogaster*, (G) *Otospermophilus variegatus*, (H) *Procyon lotor*, (I) *Canis latrans*, (J) *Sylvilagus floridanus* vs *Sylvilagus cunicularius* and (K) Geomyidae.

SD3. Activity patterns of medium-large mammals recorded by photo-trapping, in the Barranca del Amatzinac, Hueyapan, Morelos, Mexico. (Nocturnal: *D. mexicanus, B. astutus, D. virginiana* and *P. lotor*; Diurnal-Nocturnal: *C. latrans* and *N. narica*; Diurnal: *S. aureogaster*).

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