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Contribution of community monitoring to knowledge of mammal diversity in voluntarily conservation areas in Southern Mexico

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A B S T R A C T

In southern Mexico, Voluntarily Designated Conservation Areas (VCA) represent a biological conservation strategy wherein governance and management are entrusted to the territory. Within the VCAs of the La Chinantla region in the state of Oaxaca, Mexico, community monitoring utilizing camera traps has been conducted with the assistance of government programs. This initiative has yielded a substantial number of records for medium and large mammals. Nevertheless, the available information has not undergone systematic analysis, constraining its utility in strategic planning and the evaluation of biodiversity conservation endeavors. This study seeks to highlight the impact of community monitoring in 18 VCAs on understanding the altitudinal distribution of mammal diversity in La Chinantla. The analysis incorporates data from a community monitoring covering 129 camera trap stations (4,384 camera days) strategically positioned along an elevation gradient ranging from 50 to 2000 m above sea level, over the period 2011–2014. We assessed alpha and beta diversity, as well as the community structure of medium and large mammals within three distinct elevation zones. A total of 26 species of medium-sized mammals were documented, revealing distinct mammal assemblages in each zone. However, 15 species were common across all zones. We found that the highest species richness was observed below 400 m, where tropical rainforest vegetation predominates. We also found that the species turnover component had a significant impact on the total beta value. Despite the considerable involvement of local residents in the monitoring program and their acquisition of social, technical, and ecological knowledge, there is still a need to strengthen their capabilities to enhance community monitoring. Finally, fostering collaboration between local communities, academic institutions, and governmental initiatives is essential for the successful conservation of mammals in La Chinanlta.

1. Introduction

Biodiversity conservation has traditionally been approached through a top-down strategy, prioritizing the exclusion of human presence. This approach has gained considerable support from governments, conservationists, and academics, establishing itself as the foremost tool globally (Leverington et al., 2010). While the exclusionary approach has made valuable contributions to the preservation and protection of tropical forests (Bruner et al., 2001; Xavier da Silva et al., 2018), it is essential to recognize the significance of local indigenous communities and their extensive knowledge of the biodiversity with which they have coexisted for centuries or even millennia (Berkes et al., 2000), as is the case in megadiverse Mexico (Luis-Santiago and Duran, 2020). Ignoring the presence and socioeconomic contexts of Indigenous people within the same territories can impede the effectiveness of conservation efforts (Marshall et al., 2009; Hensler and Merçon, 2020).

In contexts where biodiversity and human populations coexist within the same territory, adopting a bottom-up approach is considered more realistic. This approach facilitates the conservation of biological legacies while not ignoring the intricate socio-economic contexts at play (Hensler and Merçon, 2020). It is widely acknowledged that sites inhabited by human communities and requiring biodiversity protection operate as socio-ecological systems (SES). Therefore, it is highly recommended to incorporate the perspectives and traditional knowledge of these communities (Berkes et al., 2000; Jiren et al., 2020; Baldauf, 2020). The ecological and social subsystems in a biodiverse SES maintain close

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relationships and aid the management strategies by local involvement in biodiversity protection processes (Chape et al., 2005; Hockings et al., 2006; Meehan et al., 2020; Harfoot et al., 2021). By recognizing and embracing these integrated dynamics, conservation efforts can effectively bridge ecological and social dimensions, promoting sustainable outcomes.

The effective practice of participatory conservation is based on the active involvement of community residents (Matarrita-Cascante et al., 2019). This inclusive approach should encompass the collaborative process of identifying biological and social indicators through participatory monitoring programs (Villaseñor et al., 2016). Monitoring programs involve local communities, academic institutions, and government organizations seeking to understand the biological and ecological characteristics of these territories, including vegetation, animals, rivers, and more (Evans and Guariguata, 2008; Dickinson et al., 2012a), with a particular emphasis on training local populations and indigenous peoples in data collection (Ortega-Álvarez et al., 2012; Lavariega et al., 2020; Moreno-Arzate et al., 2020). Participatory monitoring programs not only provide scientifically valuable information but also empower local communities to ask new questions about their environment and make informed decisions to improve the management of their natural resources (Danielsen et al., 2005; Evans and Guariguata, 2008; Dickinson et al., 2012b).

Community monitoring has proven to be a valuable approach in generating scientific knowledge. For example, in the Brazilian Amazon, community monitoring empowered wildlife monitors to conduct basic data analysis and interpretation, thereby influencing their perspectives on the value of monitoring, and conserving their fauna. This led to regulating hunting, including subsistence hunting in the reserve (Benchimol et al., 2017). In the Madrean Sky Islands, located on the border between Mexico and the United States, various actors, including local people, have recorded the presence of 25 species of medium and large mammals almost all known in the area (Caire William, 1997; Coronel-Arellano et al., 2018). In Oaxaca, community monitors collaboratively undertook jaguar density estimation. Residents' knowledge of jaguar tracking and habits contributed to an increase in successful jaguar camera trap detections. (Lavariega et al., 2020).

In southern Mexico, part of community monitoring initiatives initiated as part of the international project Integrating Ecosystem Management (IEM) in three Eco-Regions: Los Tuxtlas, Veracruz; La Montaña, Guerrero; and La Chinantla, Oaxaca (Velasco-Tapia, 2009; Vela et al., 2010). Indigenous communities in southern Mexico have a long-standing tradition of conserving forest areas with minimal human impact within their territories (Martin et al., 2011). In 1996, these zones were officially acknowledged as areas for conservation by the Mexican government through the Ministry of Environment and Natural Resources (SEMARNAT). However, it was not until 2008 that were legally recognized by the National Commission of Natural Protected Areas (CONANP, by its Spanish acronym) as Voluntarily Conservation Areas (VCA; CONANP, 2020). As of 2023, there are 545 certified VCAs in Mexico, collectively spanning 7182.8 km^2 (CONANP, 2023). In the state of Oaxaca, located in southern Mexico, there are 135 VCAs situated on socially owned lands, primarily under the ownership of Indigenous groups (Luis-Santiago and Duran, 2020).

In northern Oaxaca, La Chinantla is a mountainous region with an altitudinal gradient ranging from 40 to 3000 masl. It serves as a transition zone between the warm coastal plains of the Gulf of Mexico and the higher temperate zones of the Sierra Madre de Oaxaca. Based on the ecogeographic conditions of the area, the region has been classified into three subregions (Low Chinantla, Middle Chinantla, and High Chinantla). La Chinantla harbors the third-largest expanse of tropical rainforest and one of the most extensive Montane cloud forest areas in Mexico (Arriaga et al., 2000). This area is a hotspot of biodiversity (Briones-Salas and Sánchez-Cordero, 2004), with a notable richness of mammals (Briones-Salas et al., 2015); Briones-Salas et al., 2023). However, this wealth has so far not been evaluated at the regional level. Although there are local studies that have reported between 12 and 16 species of medium and large mammals (Alfaro et al., 2006; Del Rio-García et al., 2014).

Mountainous systems are recognized for their rich biodiversity, housing numerous endemics and threatened species (Mittermeier et al., 2011). The elevation gradients in these regions display diverse patterns of species diversity, which makes them compelling for investigating altitudinal variation mechanisms (Sanders & Rahbek, 2012). Various hypotheses, encompassing historical, latitudinal, climatic, disturbance, and food availability factors, among others, have been proposed to elicit altitude-related diversity patterns (Rosenzweig, 1995; Guo et al., 2013; Chen et al., 2020). Despite the consideration of multiple factors associated with altitude-related diversity patterns, it appears that diversity is dependent on taxa and scale (Rahbek, 1995; Hawkins et al., 2003; Guo et al., 2013).

McCain and Grytnes (2010) propose four primary patterns for altitudinal biodiversity distribution: decreasing richness with increasing elevation. A pattern of plateaus in richness across low elevations followed by decreases with or without a mid-elevation peak, and a unimodal pattern with a mid-elevational peak. Regarding mammals, various studies suggest a decline in species number with altitude (Paterson et al., 1989; Rickart, 1991; Briones-Salas, 2001), others indicate the highest richness at mid-elevation (Sánchez-Cordero, 2001; Li et al., 2003; McCain, 2004; Guo 2013), and yet others show an increase in species with altitude (Batteman et al., 2010; Rojas et al., 1998). Explanations for these patterns focus on factors such as habitat heterogeneity (Vargas-Contreras & Hernández-Huertas, 2001; Sánchez-Cordero, 2001; Ramos-Vizcano et al., 2007), climatic conditions, anthropogenic effects (Rojas et al., 1998), species-area relationships, or subsampling (Lomolino, 2001), among others. On a local scale, factors such as habitat complexity, precipitation, ecological interactions, and species dispersal capacity come into play (Krebs, 2009).

In 2011, the Chinantecos, in collaboration with CONANP, initiated participatory biological monitoring in Voluntarily Conservation Areas (VCAs) with the objective of documenting the current levels and diversity of mammal species in their territory. This initiative was facilitated through the Conservation Program for Sustainable Development (PROCODES), a subsidy program aimed at promoting ecosystem conservation through sustainable utilization, with equal opportunities for women and men, and a focus on the Indigenous population (DOF, 2011; CONANP, 2021). However, the collected information has remained largely unexplored, lacking a systematic analysis of its contribution to understanding the regional diversity of medium and large mammals associated with VCAs. The objective of our study was to estimate species diversity and community structure of medium and large mammals along an altitudinal gradient ranging from 50 to 3000 masl. To achieve this, we divided the region into three areas with contrasting characteristics in terms of altitude, vegetation associations, climate, and human presence. Given that we worked at a regional scale and with a highly mobile group, we expected that the diversity of mammals across the region would vary due to the broad altitudinal gradient of La Chinantla. We hypothesized a unimodal pattern with a mid-elevational peak for three reasons: 1) species with limited altitudinal ranges replace each other along an intermediate gradient; 2) in these middle zones, there is higher primary production, making it easier for mammals to coexist where resources are more abundant (Brown, 2001; Wu et al., 2013); and 3) sites with higher human presence exhibit lower species richness (Rojas et al., 1998). Concerning the beta diversity of the region, we hypothesized that sites adjacent to each other would have more similar faunas.

Additionally, given that, compared to biological indicators, there has been limited attention given to social indicators in evaluating the effectiveness of participatory conservation strategies (Rands et al., 2010; Corrigan et al., 2018), we evaluated social indicators to assess the effectiveness of participatory conservation strategies within these VCAs.

2. Methods

2.1. Study area

La Chinantla is an ethnic region of 616.39 Km^2, located in the Sierra Madre de Oaxaca and the Coastal Plain of the Gulf Mexico in Oaxaca, Mexico (Ortiz-Pérez et al., 2004) (Fig. 1). The region exhibits significant heterogeneity, characterized by an elevation gradient spanning from 40 to 3,000 m above sea level (masl). Temperature fluctuations range between 5 and 25 °C, while the average annual precipitation varies from 3,600 to 5,800 mm. This results in a warm and humid climate in the lowlands, contrasting with a cold and humid climate in the highlands (Meave et al., 2017). There is a distinctive gradient in vegetation and land uses, with tropical rainforests at lower elevations, montane cloud forests above 1,000 masl and patches of oak-pine forests; all intermixed with small-scale agriculture (milpas), fallow lands (acahuales), grasslands, and shade coffee plantations (Fig. 1; INEGI, 2016). Communal land ownership throughout the region (Bray et al., 2012).

2.2. Classification of the study area

We classified the region into three distinct zones based on a supervised classification of Landsat images from 2015. Zone 1 comprises 10 VCAs, spanning an elevation that ranges from 50 to 400 masl. This zone is characterized by native tropical rainforests and grasslands. The prevailing climate is Am, characterized as warm and humid with summer rainfall, featuring an annual temperature surpassing 22 °C and precipitation of less than 60 mm in the driest month. The population of the region is approximately117,155. Zone 2 comprises nine VCAs, spanning an elevation that ranges from 401 to 1,000 masl. This zone is characterized by a mosaic of tropical rainforest remnants intertwined with secondary vegetation and crops. The prevailing climates are Am, characterized by warm conditions throughout the year, with a short dry season followed by a wet one featuring heavy rain; and A(f), classified as warm-humid with summer rainfall. It is characterized by an annual temperature exceeding 22 °C, and precipitation in the driest month that surpasses 40 mm. The population of the region is approximately 45,298 inhabitants. Zone 3 comprises four VCAs, spanning an elevation that ranges from 1,000 to 1,900 masl. This zone is characterized by well-preserved cloud forests, secondary vegetation, and shade coffee plantations. The prevailing climate is (A) C(m), defined as semi-warm and humid with summer rainfall. It exhibits an annual average temperature exceeding 18 °C, a temperature in the coldest month of less than 18 °C, precipitation in the driest month exceeds 40 mm, and 5 to 10 % of the total annual precipitation occurring as winter rainfall. The population of the region is approximately 4,887(García and CONABIO, 1998, INEGI,

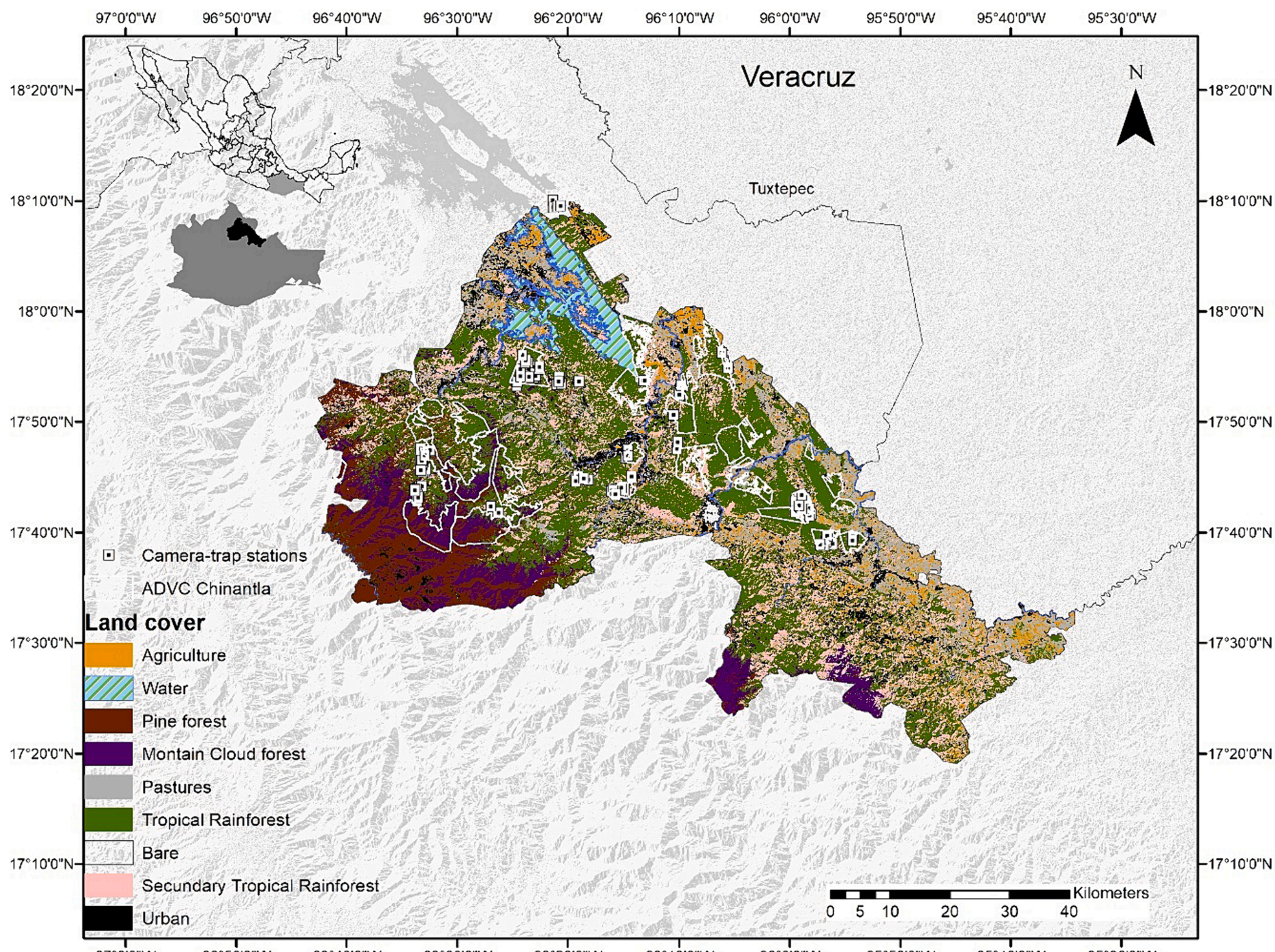

Fig. 1. Geographic location of La Chinantla, Oaxaca, Mexico. The map shows the types of vegetation in the area: tropical forests in green, these are located at elevations between 0 and 1000 m above sea level (masl), montane cloud forests in purple, located above 1000 (masl), with interspersed patches of brown pine forests. There are also mosaics of agricultural land in orange and grasslands in gray. Voluntary Conservation Areas (VCAs) are outlined in white polygons. The sites where camera traps were deployed are marked with white boxes and a black dot in the center. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2020) (Fig. 1; Supplementary Material A, Table S1).

2.3. Community monitoring of mammals

The Community Wildlife Monitoring with Camera Traps (hereinafter, CWMCT) initiative was implemented as part of the activities within the VCAs, with financial support from the Conservation Program for Sustainable Development (PROCODES) and promoted by CONANP. Between 2011 and 2014, CONANP-Chinantla technicians trained local individuals, including women, to become community monitors. The training included instructions on camera trap programming, field implementation, as well as the use of GPS and notebooks for data recording. Community monitors were also responsible for removing memory cards from cameras, which they delivered to CONANP technical personnel. Subsequently, the CONANP technician organized and stored the photographs in folders created for each of the communities. The 18 Chinantec communities benefited from the program at different time periods, with a different number of cameras (see details in Supplementary Materials A, Table S1 and Fig.S1). During these four years, a total of 129 camera trap stations were installed using four models: Bushnell Tropy Camera w Model 119,467 (n = 97), Moultrie Game Spy I-35 4.0MP 50-Foot Infrared Digital Game Trail Hunting Camera (n = 26), Wildview STC-TGLBC2 EZ-Cam (n = 3), Ltl Acorn Ltl-5310A (n = 2), and Stealth Cam (n = 1). Monitors placed camera traps on trees or stakes, between 10 and 40 cm above the ground, approximately one meter from paths where monitors reported wildlife observations or tracks. The cameras were set to capture photographs (1 to 5 photos) and/or videos (10 to 30 s) 24 h a day. Finally, monitors verified that the cameras were well-placed by 'crawling' in front of the camera. The complete process of this research is described in Supplementary Material A Fig.S2.

2.4. Analysis of mammal records obtained through community monitoring

The material for community monitoring (photographs and videos, along with associated information) was provided by CONANP (agreement DRFSIPS-0095–2019) to R.E.G.A in 2017. The management of this database, at the beginning, included its organization and debugging all photographs taken by the camera traps (N = 24,380 photographs and/or videos). They were reviewed by R.E.G.A to determine independent events (IE). These IE had the following characteristics: (1) consecutive photographs of different individuals of the same or different species, (2) consecutive photographs of individuals of the same species taken more than 24 h apart, (3) non-consecutive photographs of individuals of the same species (O'Brien et al., 2003). She created a database of mammals with information associated with each independent event: date, geographical location, site, vegetation type, lunar phase, sex, age, and other observations about the activity of the recorded species. We identified and corroborated species using specialized literature (Ceballos and Oliva, 2005; Aranda-Sánchez, 2012) and the photographic collection of the Mammal Collection of the Center for Interdisciplinary Research for Integral Regional Development, Oaxaca (CIIDIR, Oaxaca) of the National Polytechnic Institute (OAX-MA.026.0497). We followed the taxonomy proposed by Ramírez-Pulido et al., (2014). The risk categories of species at the national level were determined using the Mexican Official Standard 059 (NOM-059) and its modification, Annex Normative III, List of species at risk of the Mexican Official Standard NOM-059-SEMARNAT-2010 (SEMARNAT, 2010). At international level we used the Red List of the International Union for Conservation of Nature (IUCN) (Harfoot et al., 2021) and the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2021).".

2.5. Diversity of medium and large mammals among zones

We employed integrated sample size and coverage-based rarefaction and extrapolation methods to compare the species richness and diversity of mammals across the three zones. The analyses were conducted using iNEXT.3D version 1.0.2 and iNEXT version 2.0.20, using incidence matrices at a 95 % confidence interval (Chao and Jost, 2012) in R software version 4.0.2 (Team R Development Core 2012).

Rank-abundance curves. Rank-abundance curves (diversity-dominance) were constructed for each zone following the methodology described by Feinsinger (2001). This graph allows for comparisons of species richness (points on the graph), evenness (slope), the number of rare species (tail of the curve), and the relative abundance of each species (species order on the graph). The analyses were conducted using BiodiversityR version 2.13-1and vegan' version 2.6–4 in R software version 4.0.2 (Team R Development Core 2012).

Beta diversity. To compare patterns in species composition and turnover among the three zones, a non-metric scaling analysis (NMDS) using the Bray-Curtis dissimilarity index was conducted. To evaluate significant differences in species composition among the zones, a permutational multivariate analysis of variance (PERMANOVA) was performed. The NMDS and PERMANOVA analyses were conducted using version 2.6–4 in R software version 4.0.2 (Team R Development Core 2012). Furthermore, we measured total beta diversity, the turnover and nestedness components between zones based on the Dissimilarity Jaccard index (Baselga et al., 2018). The βJ index represents the proportion of shared species of the total richness present in two communities. Therefore, dissimilarity is calculated as 1-βJ, ranging from 0 (when species composition is identical) to 1 (when species composition is completely different). We calculated: (1) total beta diversity (β ju), (2) turnover diversity (βtu), and (3) nestedness diversity (βne). These parameters were computed using the betapart package version 1.6 package (Baselga et al., 2018) in R software version 4.0.2 (R Core Team 2017), utilizing the Incidence-based pair-wise dissimilarities function, beta.pair.

2.6. Community monitoring and social indicators in VCAS

The experiences of community monitors were captured during a workshop held in 2016, which was part of the project 'Conservation of the jaguar in the RPC, Chinantla, Oaxaca' (PROYECTO PROCER/RFSIPS/08/2016), executed with funding from the Conservation Program for Species at Risk (PROCER, in Spanish). The report was authored by R.E.G.A, whom synthesized the information provided by the monitors. A total of nine communities participated: Santa Cruz Tepetotutla, San Antonio del Barrio, San Antonio Analco, Cerro Concha, Vega del Sol, Nopalera del Rosario, Paso Nuevo La Hamaca, Monte Negro, and San Cristóbal la Vega.

Each community was represented by two monitors who shared their experiences with the audience. They were assigned six topics to discuss: monitoring brigade objectives, project duration, lessons learned, support to achieve the project, challenges, and shared experiences. Using inductive analysis approach (following, Patton, 2014), we characterized the responses into five themes that we deemed relevant for understanding the social indicators of community monitoring in La Chinantla: 1) Participation (inclusion), 2) Technical learning, 3) Social learning, 4) Ecological learning, 5) Feedback on conservation initiatives, and 6) Future perspectives (Supplementary Material A, Table S2).

3. Results

The total sampling effort (4,373 camera-days) in 18 VCAs generated a total of 1,719 independent events. Twenty-six species of medium and large mammals were identified, grouped into seven orders and 14 families. The best-represented order was Carnivora (n = 14), followed by Rodentia (n = 4). On the other hand, only one species was recorded for the orders Cingulata, Pilosa, and Lagomorpha (Table 1). The mammals with the highest number of independent events were *Dasyprocta mexicana* (n = 377) and *Dicotyles* spp. (n = 339), while the species with

Table 1
Medium and large mammals and threat category along three elevation zones in La Chinantla, Oaxaca, Mexico. Type of vegetation: AGR: Agriculture; DTR: Disturbed Tropical Rainforest; MCF: Mountain Cloud Forest, O-PF: Oak-Pine Forest, PAS: Pastures; TR: Tropical Rainforest; URB: Urban area. Altitude (masl). Minimum-maximum. Conservation status: SEMARNAT (NOM-059: S): A: Threatened; P: Danger of extinction; Pr: Special protection. CITES (C): I: could be extinguished by trafficking; IUCN: LC: Least Concern; NT: Near threatened; EN: Endangered; CR: Critically Endangered.

Order Family Species	Independents events (frequency)			Vegetation	Threat category		
	Zone 1 (50–400 masl)	Zone 2 (401–1000 masl)	Zone 3 (>1000 masl)		SEMARNAT	CITES	IUCN
Didelphimorphia							
Didelphidae							
Caluromys debianus	2	0	0	TR	A		LC
Didelphis marsupialis	27	4	45	MCF, TR, DTR, PAS, URB			LC
Philander opossum	46	2	0	TR, DTR, PAS, URB			LC
Cingulata							
Dasypodidae							
Dasypus novemcinctus	23	8	3	MCF, TR, DTR, PAS			
Pilosa							
Myrmecophagidae							
Tamandua mexicana	5	0	2	MCF, DTR, PAS	P		LC
Rodentia							
Sciuridae							
Sciurus aureogaster	11	1	2	MCF, TR			
Sciurus depeii	2	32	49	MCF, O-PF, TR, DTR, URB			
Agoutidae							
Dasyprocta mexicana	301	61	15	AGR, TR, DTR, PAS, URB			CR
Cuniculidae							
Cuniculus paca	113	53	29	MCF, O-PF, TR, DTR, PAS, URB			
Lagomorpha							
Leporidae							
Sylvilagus floridanus	56	6	1	TR, DTR, PAS			LC
Carnívora							
Felidae							
Leopardus pardalis	52	11	4	MCF, O-PF, TR, DTR, PAS	P	I	LC
Leopardus wiedii	3	4	18	MCF, O-PF, TR, DTR, URB	P	I	NT
Herpailurus jagouaroundi	0	5	1	MCF, DTR	A	I	LC
Puma concolor	44	9	13	MCF, O-PF, TR, DTR, PAS			
Panthera onca	51	6	5	MCF, O-PF, TR, DTR, PAS	P	I	NT
Canidae							
Canis latrans	17	0	0	TR, DTR, PAS			LC
Mustelidae							
Eira barbara	14	7	3	MCF, O-PF, TR, DTR, PAS	P		LC
Galictis vittata	3	0	0	TR, DTR	A		LC
Mustela frenata	0	2	0	TR			
Mephitidae							
Conepatus semistriatus	3	4	0	TR, DTR	Pr		LC
Procyonidae							
Potos flavus	0	2	0	TR	Pr		LC
Bassariscus sumichrasti	0	0	3	MCF	Pr		LC
Nassua narica	30	45	15	MCF, O-PF, TR, DTR, PAS, URB			
Procyon lotor	27	0	0	TR			
Artiodactyla							
Tayassuidae							
Dicotyles tajacu	298	34	1	MCF, TR, DTR, PAS			
Cervidae							
Mazama temama	6	24	4	MCF, O-PF, TR, DTR, PAS, URB			LC

the lowest number were *Caluromys derbianus*, *Potos flavus*, and *Mustela frenata* (n = 2 in all cases; Table 1). Twelve species fell into some category of national or international risk. Notable cases include the felines *Leopardus wiedii* and *Panthera onca*, classified as near threatened, and *D. mexicana*, classified as critically endangered by the IUCN (IUCN, 2021).

3.1. Diversity of medium and large mammals among zones

Species count varied with altitude, with Zone 1 showing the highest number of species (n = 22), followed by Zone 2 (n = 20), and Zone 3 (n = 18; Table 1). The interpolation and extrapolation curves did not show significant differences in species richness (0 D) among the three zones, as their confidence intervals overlapped (Fig. 2). In two cases, the sampling of medium and large mammal diversity was reliable: zones 1 and 2, with a sampling coverage of 99 % for each zone; however, in zone 3, it was 94 %, indicating the need for more sampling effort in this area.

Concerning Hill numbers, the assessment of species richness alone (0 D) revealed that Zone 1 exhibited the highest diversity, followed by Zones 2 and 3. However, when accounting for species abundance (1 D), the diversity of Zone 3 (16.78 effective species) resembled that of Zone 2 (16.63 effective species). This observed pattern changed when evaluating the values of the dominant species (2 D), Zone 3 had greater diversity than zone 2. (Fig. 3).

Rank-abundance curves. Analysis of the rank-abundance curves revealed variations in species richness and composition across zones. We found differences in dominance and rare species among the three zones (Fig. 4). *Dicotyles* spp. dominated in Zones 1 and 2, whit *Siurus deppei* dominating in Zone 3. In Zones 1 and 2, the second dominant species was *D. mexicana*, followed by *Cuniculus paca*. In Zone 3, *C. paca* the was

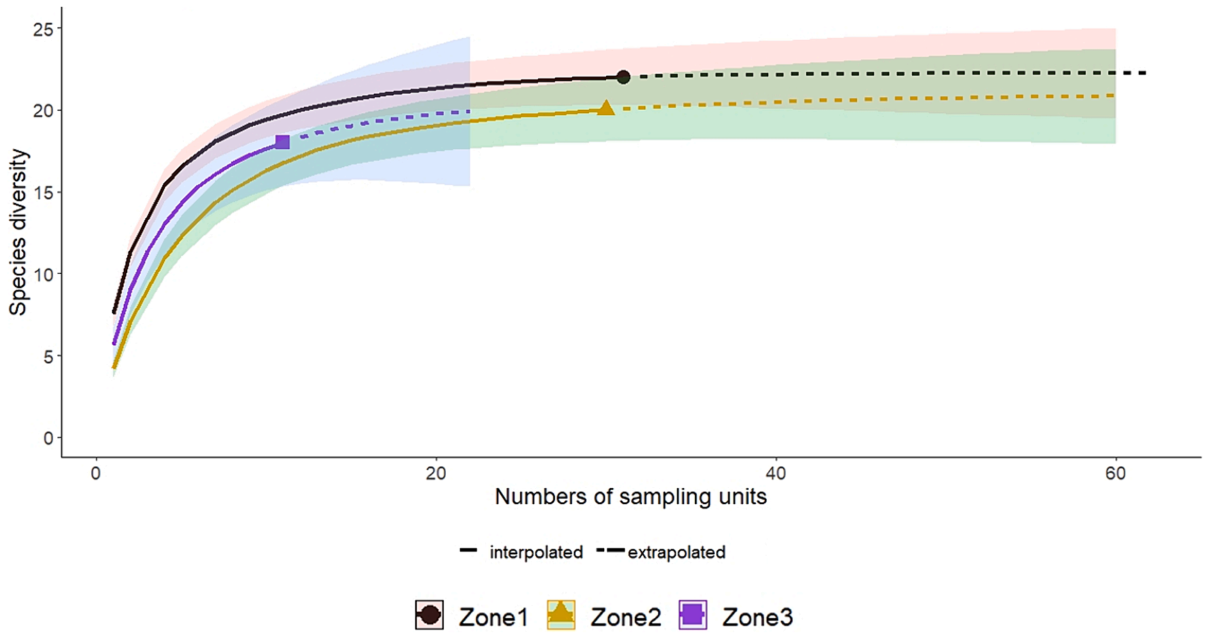

Fig. 2. The interpolation and extrapolation curves indicated that species richness (0 D) among the three zones is similar, as their confidence intervals overlapped. In zones 1 and 2, the sampling of medium and large mammal diversity was reliable, as the curve almost reached the asymptote; however, this was not the case in zone 3. The solid lines correspond to the interpolation of the richness of medium and large mammal registered in the three zones of La Chinantla. The dashed lines represent the extrapolated values of richness generated by the model. The shaded areas indicate the 95% confidence intervals.

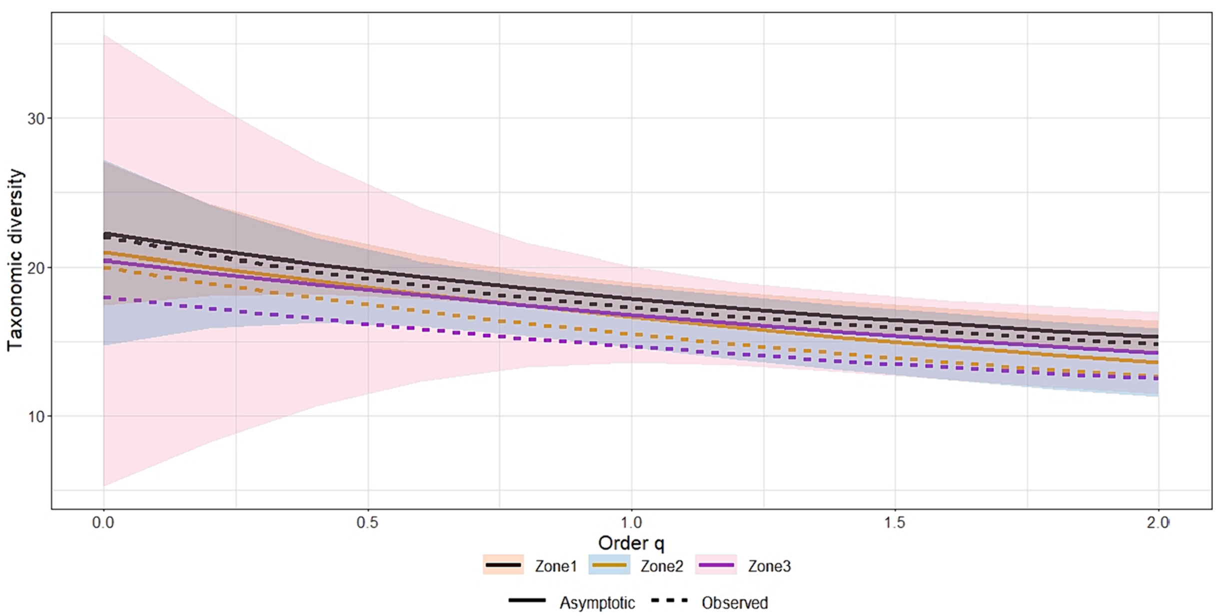

Fig. 3. Diversity according to the Hill numbers of the three zones of La Chinantla, Oaxaca, Mexico. The Hill numbers 0, 1 and 2 D show that Zone 1 has greater species diversity. With 0D, the second zone with the greatest diversity is Zone 2 followed by Zone 3. On the other hand, with 1 D, the diversity of Zone 3 is like Zone 2. This pattern changes with 2 D, Zone 3 had greater diversity than zone 2. Shaded areas represent 95% confidence intervals.

the second most dominant species. In each zone, distinct rare species were identified: Zone 1 featured *Puma yaguarondi, P. flavus,* and *M. frenata*; Zone 2 included *Tamandua mexicana, Procyon lotor, and Galictis vittata*; and Zone 3 included *P. flavus, Philander opossum,* and *P. lotor* (Fig. 4).

Beta Diversity. The three examined zones exhibited a common set of 15 species (57.7 %); however, each zone also featured exclusive species. These species were *C. derbianus, Canis latrans, G. vittata,* and *P. lotor* in Zone 1; *M. frenta* and *P. flavus* in Zone 2; and *Bassariscus sumichrasti* in Zone 3 (Table 2). The PERMANOVA analysis yielded statistical significance ($R^2 = 0.02$; $p = 0.04$), suggesting that mammalian composition did significantly differ among the three zones (Fig. 5). The dissimilarity values among the three zones were close to 0, indicating that they are highly similar communities. In general terms, it was observed that the species turnover component had a much greater impact on the total beta value for the three zones compared to the nestedness component (Table 2).

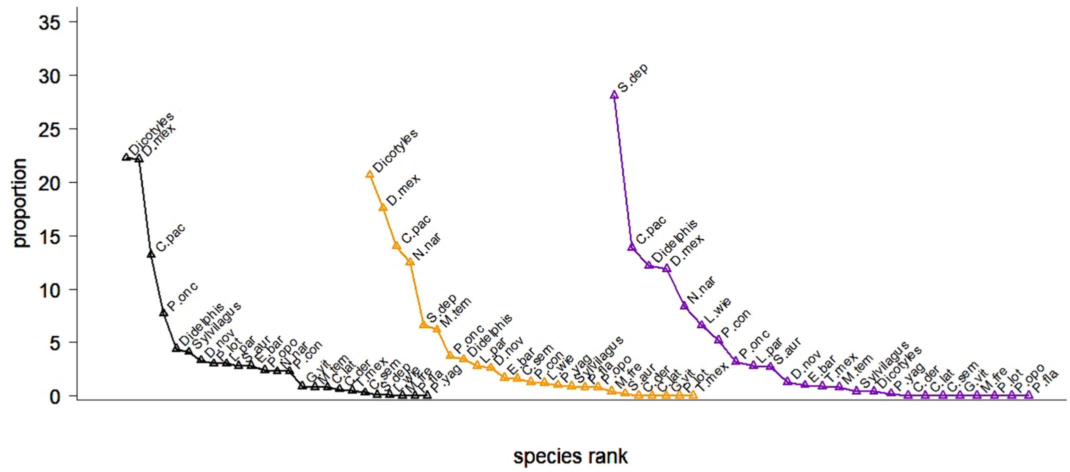

Fig. 4. Range-abundance curves of medium and large mammal assemblages in three zones of Chinantla, Oaxaca, Mexico. The curves revealed notable variations in species richness and composition across zones. *Dicotyles* spp. dominated in Zones 1 and 2, whit *Siurus deppei* dominating in Zone 3. The rare species in each zone were distinct. In Zone 1 featured *Puma yaguarondi, P. flavus,* and *Mustela frenata*; Zone 2 included *Tamandua mexicana, Procyon lotor, and Galictis vittata*; and Zone 3 included *P. flavus, Philander opossum,* and *P. lotor*. Black line: Zone 1; orange line: Zone 2 and purple line: Zone 3. *Dmex = Dasyprocta mexicana, Cpac = Cuniculis paca, Plot = Procyon lotor, Syl = Sylvilagus, Mtem = Mazama temama, Dnov = Dasypus novemcinctus, Ebar = Eira barbara, Lpar = Leopardus pardalis, Clat = Canis latrans, Nnar = Nasua narica, Ponca = Panthera onca, Did = Didelphis, Pops = Philander opossum, Saur = Sciurus aureogaster, Lwie = Leopardus wiedii, Csem = Conepatus semistriatus, Gvit = Galictis vittata, Pcon = Puma concolor, Pyag = Puma yagouaroundi, Pflav = Potos flavus, Bsum = Basariscus sumichrasti, Sdep = Sciurus deppei, Tmex = Tamandua mexicana and Cder = Caluromys derbianus.* (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Total Beta diversity, turnover and nestedness components of the medium and large-sized mammals in the three zones of La Chinantla, Oaxaca. The bold values on the diagonal entries represent the total number of species in each zone, with the number of exclusive species noted in brackets. The Jaccard dissimilarity index values are italicized in the lower triangle, and values in the upper triangle refer to the number of species shared between zones.

	Zone 1	Zone 2	Zone 3
beta.total			
Zone 1	**22** (4)	17	16
Zona.2	*0.320*	**20** (2)	16
Zona.3	*0.333*	*0.272*	**18** (1)
beta.turnover			
Zone 1			
Zona.2	*0.260*		
Zona.3	*0.200*	*0.200*	
beta.nestedness			
Zone 1			
Zona.2	*0.059*		
Zona.3	*0.133*	*0.072*	

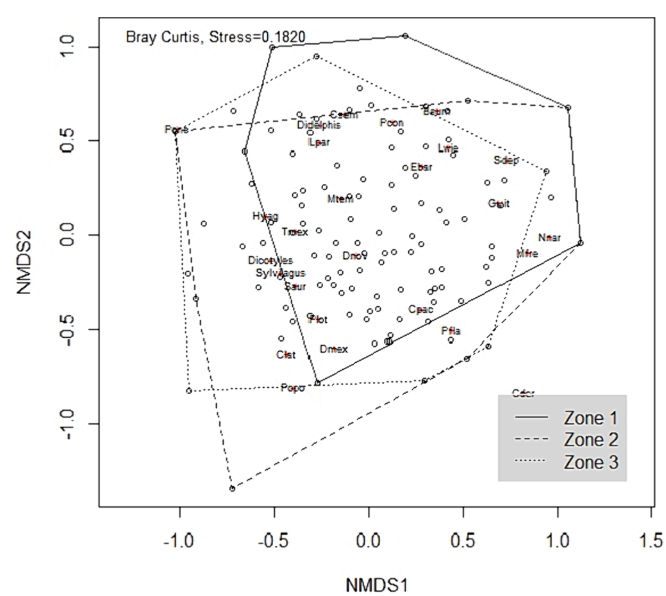

Fig. 5. The Nonmetric multidimensional scaling (NMDS, stress-value = 0.1820) diagram showing that mammalian composition did differ among the three zones of La Chinantla, Oaxaca, Mexico. *Dmex = Dasyprocta mexicana, Cpac = Cuniculis paca, Plot = Procyon lotor, Syl = Sylvilagus, Mtem = Mazama temama, Dnov = Dasypus novemcinctus, Ebar = Eira barbara, Lpar = Leopardus pardalis, Clat = Canis latrans, Nnar = Nasua narica, Ponca = Panthera onca, Did = Didelphis, Pops = Philander opossum, Saur = Sciurus aureogaster, Lwie = Leopardus wiedii, Csem = Conepatus semistriatus, Gvit = Galictis vittata, Pcon = Puma concolor, Pyag = Puma yagouaroundi, Pflav = Potos flavus, Bsum = Basariscus sumichrasti, Sdep = Sciurus deppei, Tmex = Tamandua mexicana and Cder = Caluromys derbianus.*

3.2. Community monitoring to generate biological indicators in VCAs

In general, community monitors reported that participation mainly involved adult men, with limited involvement of women, young men, or the elderly. Regarding technical learning, it was highlighted that community monitors possessed the skills to operate and program cameras and GPS devices. In terms of social learning, there was consensus on the importance of sharing monitoring results with the inhabitants of their community and other communities. Additionally, there was agreement on the contribution of monitoring activities to their ecological understanding. Finally, valuable feedback was provided, offering constructive suggestions to improve conservation initiatives and address community needs (Supplementary Material A; Table S2).

4. Discussion

Although La Chinantla has been acknowledged as a region characterized by high biodiversity and ecological integrity (Arriaga et al., 2000; Briones-Salas et al., 2015; de Albuquerque et al., 2015), a comprehensive regional examination of medium and large mammal richness had been notably absent until now. Previous local studies utilizing camera-trap reported fewer species, ranging from 15 to 18; (Figel et al., 2011; Pérez-Irineo and Santos-Moreno, 2012; Del Rio-García et al., 2014). In contrast, the present study documented 26 species of medium and large mammals, constituting 49 % of the 53 species known to inhabit the entire state of Oaxaca (Briones-Salas et al., 2015).

It is essential to recognize that the absence of certain species in specific zones, as observed in our study, does not conclusively imply their absence from those areas. Species such as *T. mexicana, G. vittata, P. lotor, L. wieddi, M. frenata, P. flavus and P. opossum*, which were not recorded in some zones, are known to have lower capture rates in camera trap studies (Meyer et al., 2015), likely attributed to its small size and arboreal habits (Srbek-Araujo & Chiarello, 2005). Other non-detected species in this study are *Ateles geoffroyi*, *Sphiggurus mexicanus*, *Spilogale putorius*, *Tapirella bairdii*, and *Urocyon cinereoargenteus* recorded in the region by Briones-Salas et al., (2015). However, there are previous studies that support the presence of some of this species in the region. For instance, *S. mexicanus* was reported by Galindo-Aguilar et al., (2019); there is indirect evidence of *T. bairdii* presence from interviews and footprints (Lira-Torres et al., 2006, Galindo-Aguilar, 2012); and there are records of spider monkeys in lowland adjacent to this region (Ortiz-Martínez et al., 2012). The absences of other species such as *U. cinereoargenteus* in our study may be attributed to the placement of camera traps in well-conserved forest areas, while this species prefers open habitats close to human populations (Harmsen et al., 2019). As for *M. temama*, which is commonly recorded in camera traps (Romero-Calderón et al., 2021), the fewer records may exemplify the case of a social subsystem's interaction with a biological population. This is because this species is commonly hunted for food or damaging crops (Ibarra et al., 2011; Galindo-Aguilar, 2012). Thus, the absences of records of some species in this study could be the result of multiple factors attributed to specieś small size and arboreal habits, or that detection by camera traps are infrequent due to interactions with humans.

Considering the species documented by Briones-Salas et al., (2015, 2023), and those identified in the present study, a cumulative total of 41 species has been documented for La Chinantla. These records represent 75.5 % of the known medium and large mammals recorded for the state of Oaxaca. Consequently, La Chinantla emerges as one of the regions with the highest species richness within this taxonomic group in both Mexico and Central America. It is noteworthy that La Chinantla's diversity is surpassed only by the Selva Zoque in Oaxaca, Mexico ($n = 43$; Lira-Torres et al., 2012), and marginally exceeds the richness found in Piedras Blancas National Park in Costa Rica ($n = 39$; Landmann et al., 2008). Remarkably, within 18 VCAs in La Chinantla, a greater diversity of species has been identified compared to relatively diverse sites in Mexico, such as Los Chimalapas with 20 species (Lira-Torres and Briones-Salas, 2012); La Encrucijada with 19 (Hernández-Hernández et al., 2018); La Selva Lacandona with 18 (Garmendia et al., 2013).

Alpha diversity. There is little difference in species richness among the three zones. Only a few medium and large mammal species are unique to each zone (<4 species). These slight differences could be attributed to each region experiencing distinct anthropogenic pressures, rather than variations in vegetation types. Tropical rainforests and montane cloud forests, despite having different vegetation, tend to harbor similar species diversity (Medellín and Equihua, 1998; Ceballos and Oliva, 2005; Almazán-Núñez et al., 2018). Fragmentation may provide an explanation for this variation. In areas adjacent to La Selva Lacandona in Mexico, research indicates that patches with more complex and larger shapes –particularly those surrounded by secondary forests– maintain a greater richness of medium and large terrestrial mammals (Garmendia et al., 2013). Another influential factor could be vegetation structure, where mature secondary forests contribute to increased mammal richness, while young secondary forests exhibit lower richness, mainly represented by medium-sized mammals, particularly insectivores and omnivores (Brindis, 2016).

Rank-abundance curves. In Zones 1 and 2, the prevailing species, *D. mexicana* and *C. paca*, are frequently encountered in well-preserved tropical forests and areas subject to certain human disturbances (Lira-Torres and Briones-Salas, 2011; Gallina, S., & González-Romero 2018; Pozo-Montuy et al., 2019). Notably, *D. mexicana* appears to be more adversely affected by human activities, as it is notably absent in regions with remnants of tropical forest, in contrast to the adaptable nature of *C. paca* (Gallina & González-Romero, 2018). The observed preference for disturbed areas might be associated with increased food availability, contributing to the population growth of both species, albeit to varying extents. The adaptability of *D. mexicana* to environments with a certain degree of disturbance is evident; however, its survival is contingent on factors such as the intensity of hunting pressure and the degree of isolation in its habitat. In contrast, *C. paca* demonstrates a higher resilience to such challenges (Gallina & González-Romero, 2018). In Zone 3, the non-dominance of *D. mexicana* can be attributed to the prevailing montane cloud forest vegetation at altitudes above 1,000 m, a habitat not favored by this species (Salazar-Ortiz et al., 2020). Conversely, the broader altitudinal and ecological range of *C. paca*, including habitats like pine-oak forests (Botello et al., 2005; Padilla-Gómez et al., 2019), aligns with the expectation of its presence and dominance in this zone.

Beta diversity. The beta diversity analysis underscores that the principal component driving turnover in medium and large mammals is species replacement (βsim). This turnover is primarily influenced by the substitution of species across the three altitudinal levels, a phenomenon likely attributed to variations in vegetation types, climatic conditions, and the distinct disturbance gradient associated with varying human populations in each zone. While most medium and large mammals found in tropical rainforests also inhabit montane cloud forests (Ceballos and Oliva, 2005; Briones-Salas et al., 2015), specific altitude preferences are evident. Species such as *E. barbara* and *G. vittata* exhibit a preference for lower elevations (Bornholdt et al., 2013; Braga Lima et al., 2020). Additionally, certain species thrive in areas dominated by human disturbance, such as coffee plantations, which create a mosaic of vegetation providing food and shelter for mammals (García Burgos et al., 2014). We observed that the Voluntary Conservation Areas (VCA) within the Chinantla region can function as an archipelago reserve as suggested by Briones-Salas et al., (2023). This characterization stems from their role in forming a mosaic of landscapes that mutually complement one another, contributing to the preservation of beta diversity in medium and large mammals (Halffter, 2007). The unique ecological dynamics of each zone, influenced by altitude, vegetation types, and anthropogenic factors, collectively contribute to the intricate beta diversity observed in the study area.

In accordance with McCain and Grytnes (2010), studies addressing species richness along elevation gradients are susceptible to substantial influences from methodological aspects related to scale, sampling, and disturbance. These factors may have implications for the outcomes observed in our study, given the regional scale at which we conducted our research. Regional compilations can be significantly impacted by the larger area at the mountain base, potentially resulting in an overestimation of richness at lower elevations, as observed in our findings. Another factor affecting species richness estimates is the sampling effort, where uneven distribution along the gradient can lead to higher richness in intensively sampled areas and lower richness in areas with limited sampling. In our study there was uneven sampling effort, with more sampling effort occurring in Zone 1 (low elevation) and less in the higher zone (Zone 3). Although the difference in the number of recorded species is minimal ($n = 4$), we acknowledge that our results could have been influenced by the unevenness sampling effort. However, reduced sampling at higher elevations tends to exert less influence on species richness estimates, as diversity generally decreases at these elevations. These methodological nuances emphasize the importance of careful consideration and standardization when interpreting and comparing altitudinal species richness patterns.

The importance of strengthening local technical capacity to generate biological indicators of the "success" of the VCA strategy. Our results reinforce the importance of the La Chinantla VCAs for the conservation of medium and large mammals in Mexico, aligning with global Open Science recommendations (UNESCO 2021). This alignment is based on the recognition of the importance of traditional knowledge and conservation systems, especially those of underrepresented or excluded groups, such as women, Indigenous peoples, and local communities, and their active participation. Therefore, considering the perspectives of the Socioecological System, it is imperative to guide VCA managers in three key areas: 1) understanding its mammal diversity, 2) enhancing its technical capacity to generate biological indicators, and 3) implementing participatory strategies for conservation. These strategies, in addition to protecting habitat, could include temporary hunting bans.

The selected topics aimed at capturing the perspectives of community monitors offer valuable insights into their monitoring practices, level of engagement, acquired knowledge (technical, social, and ecological), and their collective needs within a community context (feedback on conservation initiatives and future perspectives). Evaluating these parameters is pivotal in gauging the extent to which monitoring has been embraced by the community, a critical determinant of success (Lindenmayer et al., 2020), and underscores the importance of active community participation (Dyer et al., 2014).

The analysis of monitor responses (Supplementary Material A; Table S2) revealed that, although not all age and gender groups are consistently represented in all monitoring groups, the inclusion of diverse demographic data tends to yield more favorable results. For instance, the involvement of older adults selecting camera placement sites capitalizes on their knowledge of fauna, while the energy of younger monitors facilitates access to remote or challenging areas. It is noteworthy to highlight the inclusion of women in some monitoring groups, acknowledging their unique perspectives, knowledge, experiences, and needs compared to men (Dyer et al., 2014; Goldman et al., 2021).

In terms of social learning, monitors acknowledged the importance of sharing monitoring results with the community (Dyer et al., 2014). They also highlighted how monitoring contributes to their ecological learning, serving as a motivating factor to sustain their engagement. Additionally, their feedback on conservation initiatives emphasizes the importance of addressing community needs, a crucial step toward fostering greater community inclusion and contributing to effective governance (Dyer et al., 2014).

Recommendations for Future Research. In the Mexican context, the National Commission of Natural Protected Areas (CONANP) safeguards an extensive collection of photographs compiled during monitoring processes in Natural Protected Areas (ANP) and Voluntarily Conservation Areas (VCA). We recommend active participation of the academic community in the systematization of these data. To conduct research of this nature, it is advisable to have prior experience in the region where the monitoring has taken place. Here, we provide some recommendations: 1) Officially request data from CONANP, establishing effective collaboration between the academia and the institution responsible for monitoring, 2) Conduct field verifications at the sites where camera traps were installed to validate and contextualize the collected information, 3) Share the obtained results with local communities to encourage ongoing participation in monitoring processes and strengthen the relationship between research and communities, and 4) Provide CONANP with specific recommendations to enhance monitoring practices, enabling a more effective assessment of trends in mammal populations, as well as proposing the possibility of publishing monitoring data for future research.

5. Conclusions

This study highlights collective efforts: collaboration between government institutions, academia and community residents can contribute to knowledge of the diversity of mammals in VCA. The data acquired through camera traps operated by community monitors, once organized systematically, facilitates the analysis of richness and diversity within the studied biological groups, exemplified in this study by medium and large mammals. This information establishes a crucial baseline, which is valuable for residents, the scientific community and decision-makers. Our findings highlight La Chinantla as one of the regions boasting the highest richness of medium and large mammals in the country. It is home to ecologically significant species, *including P. onca*, and hosts several species under protection status. Furthermore, our observations reveal a remarkable similarity in species richness across all three altitudinal ranges, with species turnover playing a pivotal role in the region's beta diversity. Despite minimal species variation among the three altitude levels analyzed, the predominant pattern observed for the altitudinal distribution of medium and large mammals in La Chinantla was a decrease in richness with increasing elevation. We argue that the Voluntary Conservation Areas (VCAs) collectively contribute to conserving the beta diversity of medium and large Neotropical mammals.

The competence demonstrated by community monitors suggests their capability for successful mammal monitoring. However, a more in-depth exploration from the Socio-Ecological System perspective is warranted to evaluate the status of mammal species. This would offer valuable guidance to community monitors and VCA managers, aiding in the implementation of potential strategies such as temporary hunting bans or other participatory measures for effective conservation.

CRediT authorship contribution statement

R. Elena Galindo-Aguilar: Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing. **Miguel Briones-Salas:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing. **Elvira Durán:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. **J. Roberto Sosa-López:** Conceptualization, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is available at CONANP, in our case we prepare a request to access them.

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Author Contributions

All authors contributed to the study conception and design., Rosa

Elena Galindo Aguilar and Miguel Briones-Salas performed material preparation, data collection and analysis. The first draft of the manuscript was written by Rosa Elena Galindo Aguilar and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2024.126604.

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