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Bat diversity (Order: Chiroptera) in a suburban area belonging to the Mexican Plateau

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Bats are the second most diverse order of mammals. There is evidence that bats assemblages are influenced by urbanization, exhibiting changes in species diversity. Some species show a strong degree of adaptation to urban habitats or are even favored by them. Our aim was to characterize the bat species composition present in the suburban park "Ecoparque Centenario"located on the Mexican Plateau, using two different methods of species identification. Over the course of one year, mist nets were set up, and echolocation pulses were recorded using an ultrasonic microphone. Species were identified based on their morphological characteristics and echolocation calls. Species accumulation curves were generated, and diversity indices were calculated based on both morphological and acoustic analyses. In total, 28 bat species belonging to four families were identified using both methods: Vespertilionidae (20 spp.), Molossidae (6 spp.), Mormoopidae (1 sp.) and Phyllostomidae (1 sp.). The family Vespertilionidae was more represented, and the diversity indices indicated moderated diversity without species dominance. In general, suburban areas have been shown to support higher bat diversity and activity due to an increase in potential prey availability, benefiting both generalist and specialist species. Most of the species identified are listed as Least Concern according to the IUCN, except *Choeronycteris mexicana* which is classified as Near Threatened. Considering this, Ecoparque Centenario represents an important area for bat conservation within a semiarid landscape.

Keywords: acoustic monitoring, echolocation calls, Ecoparque Centenario, semiarid landscape, species accumulation curves, Zacatecas.

Los murciélagos son el segundo orden más diverso de mamíferos. Existe evidencia de que los ensamblajes de murciélagos están influenciados por la urbanización, mostrando cambios en la diversidad de especies. Algunas especies presentan un alto grado de adaptación a los hábitats urbanos, o incluso se ven favorecidas por ellos. Nuestro objetivo fue caracterizar la composición de especies de murciélagos presente en el parque suburbano Ecoparque Centenario, ubicado en la Meseta Mexicana, utilizando dos métodos diferentes de identificación de especies. A lo largo de un año, se colocaron redes de niebla y se registraron pulsos de ecolocación mediante un micrófono ultrasónico. Las especies fueron identificadas con base en sus características morfológicas y en los llamados de ecolocación. Se generaron curvas de acumulación de especies y se calcularon índices de diversidad a partir de los análisis morfológicos y acústicos. En total, utilizando ambos métodos, se identificaron 28 especies de murciélagos pertenecientes a cuatro familias: Vespertilionidae (20 spp.), Molossidae (6 spp.), Mormoopidae (1 sp.) y Phyllostomidae (1 sp.). La familia Vespertilionidae fue la mejor representada, y los índices de diversidad indicaron una diversidad moderada sin dominancia de especies. En general, se ha demostrado que las áreas suburbanas mantienen una mayor diversidad y actividad de murciélagos debido al incremento en la disponibilidad de presas potenciales, lo que beneficia tanto a especies generalistas como especialistas. La mayoría de las especies identificadas están categorizadas como de Preocupación Menor según la UICN, excepto *Choeronycteris mexicana*, que está clasificada como Casi Amenazada. Considerando lo anterior, el Ecoparque Centenario representa un área importante para la conservación de murciélagos dentro de un paisaje semiárido.

Palabras clave: ambiente semiárido, curvas de acumulación, Ecoparque Centenario, llamados de ecolocalización, monitoreo acústico, Zacatecas.

Diversity patterns (henceforth, DPs) exist in all ecosystems around the planet and are constantly changing due to the interaction of abiotic and biotic factors in ecosystems (Chesson 2000; Dirzo and Raven 2003; Brown *et al.* 2004; Sibly *et al.* 2012; Villalobos and Rangel 2014). These changes are generally reflected in the fluctuations in abundance, diversity, or richness of the species distributed in a given area. A clear example occurs in urban areas (*i.e.* geographic spaces with human activity and presence, *sensu* Weeks) (Weeks 2010), where these types of environments may alter the habitat and therefore, the species composition and dynamics (Rosenzweig 1995; Challenger and Dirzo 2009; Faeth *et al.* 2011).

Bats are cosmopolitan, they are vagile and present different functional traits, which allows them to be distribute in different ecosystems, including urban environments where they constitute a key component of the mammalian fauna (Van der Ree and McCarthy 2005). It has been observed that in urban environments richness decreases for most bat species, whereas abundance increase only for some groups that are able to adapt to the new characteristics of the environment (generalist species) (Segura *et al.* 2007; Jung and Kalko 2011; Clavel *et al.* 2011; Threlfall *et al.* 2012; Büchi and Vuilleumier 2014; Jung and Threlfall 2016). However, within the urban matrix, suburban areas (*i.e.* areas of lower human population density located

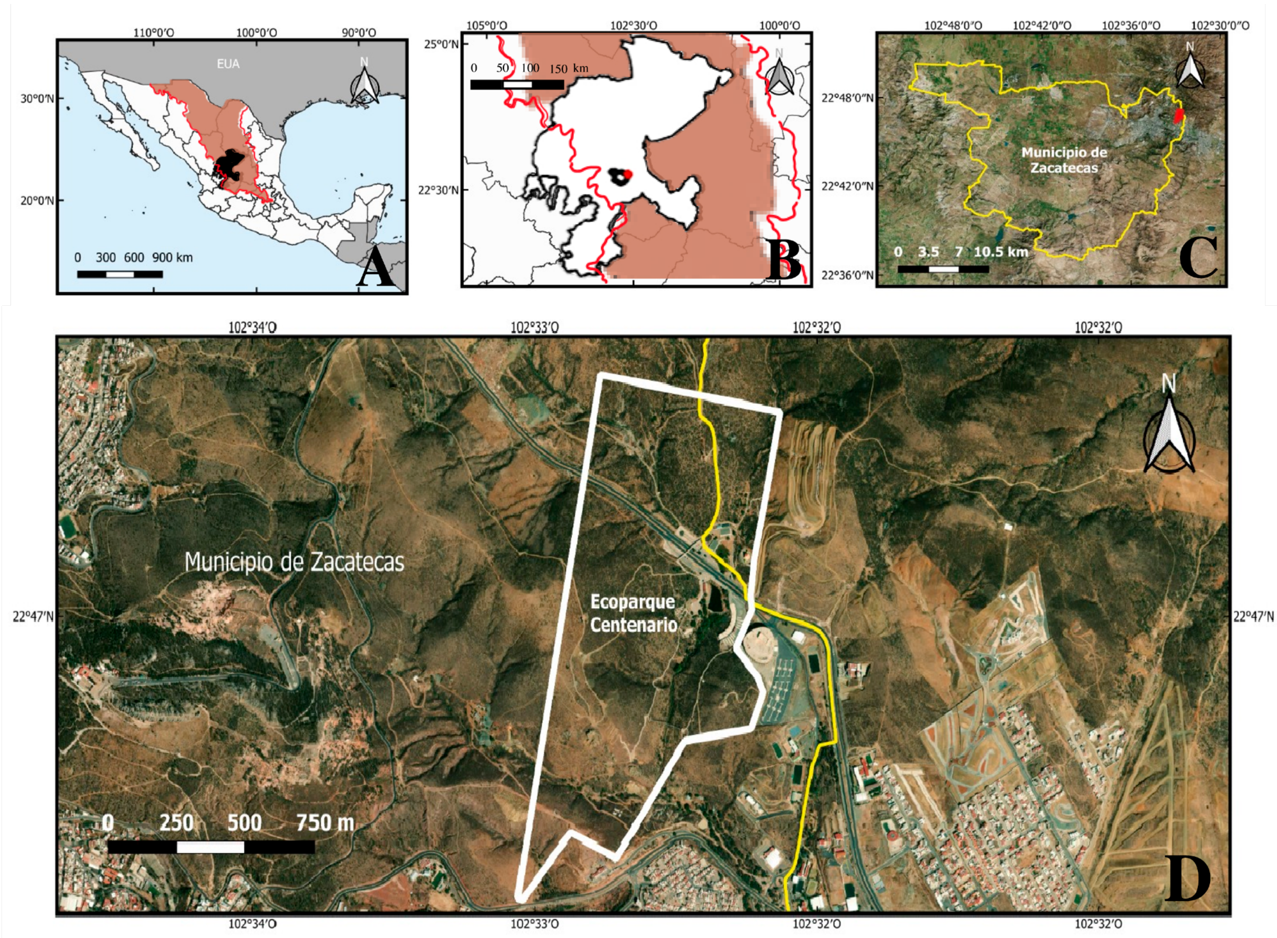

Figure 1. Geographic location of the "Ecoparque Centenario" (*ECO*) area. The Mexican Plateau is shown as the red silhouette. The state of Zacatecas is shown as black outline. The municipality of Zacatecas is shown as bold black line (b) and yellow line (c-d). The Ecoparque Centenario is shown as red dot (b-c) and white line (d)

on the periphery of cities or urban areas) have shown a higher bat species richness and abundance compared to urban areas sensu Weeks (2010).

The presence of bats could be related to the availability of food, shelter and foraging sites typical of urban environments (Violle *et al.* 2007). Furthermore, the modification of these sites and their characteristics can alter bat diversity and consequently generate certain diversity patterns (Russo and Ancillotto 2015). In general, suburban areas have been shown to support higher bat diversity and activity due to increase of potential prey's number, for generalist and specialist species equally (Shochat *et al.* 2004; Coleman and Barclay 2012; Luck *et al.* 2013).

Three hypotheses may explain this phenomenon: i) the heterogeneity hypothesis, ii) the intermediate disturbance hypothesis, and iii) the habitat productivity hypothesis. Together they describe how richness and abundance vary with the disturbance frequency and intensity. Disturbance creates heterogeneity in the environment that, combined with the addition of anthropogenic organic matter, increases primary productivity and provides a greater number of available resources (Connell 1978; Shochat *et al.* 2004; Shochat *et al.* 2006; McKinney 2008; Gaston and Gaston 2010; Threlfall *et al.* 2011). Such DPs have been observed in some vertebrate groups, such as bats (Duchamp *et al.* 2004).

In Mexico most studies aimed at characterizing bat diversity in urban or suburban environments, have focused on tropical regions (Medellín 1993; Arita 1993), even though, more than 50% of the national territory has a dry or semi-dry climate type, where such studies are scare (SEMARNAT 2015). The city of Zacatecas is characterized by semi-dry climate, and the only available information about bat diversity comes from the company URSAMEX (2014), which was the responsible for the construction of the suburban park "Ecoparque Centenario" (*ECO*), our study area. They report 5 bat species: *Mormoops megalophylla*, *Leptonycteris nivalis*, *Myotis auriculus*, *M. planiceps* and *Dermanura azteca*, although 3 species distribution (*L. nivalis*, *M. planiceps* and *D. azteca*) does not correspond to what has been previously reported (Medellín *et al.* 2008; Ortega *et al.* 2022). In addition, neither the identification methods nor the sampling effort is presented, so the information is incomplete and inaccurate. The *ECO* is surrounded by active mines, and this site was recognized as a natural protected area (URSAMEX 2014); it has been suggested that mines can be used by different species of bats as perching sites, which could favor their diversity. On the other hand, in addition to the recognition, the area requires constant and exhaustive diversity studies. Therefore, our aims were to determine the bat diversity using 2 identification methods

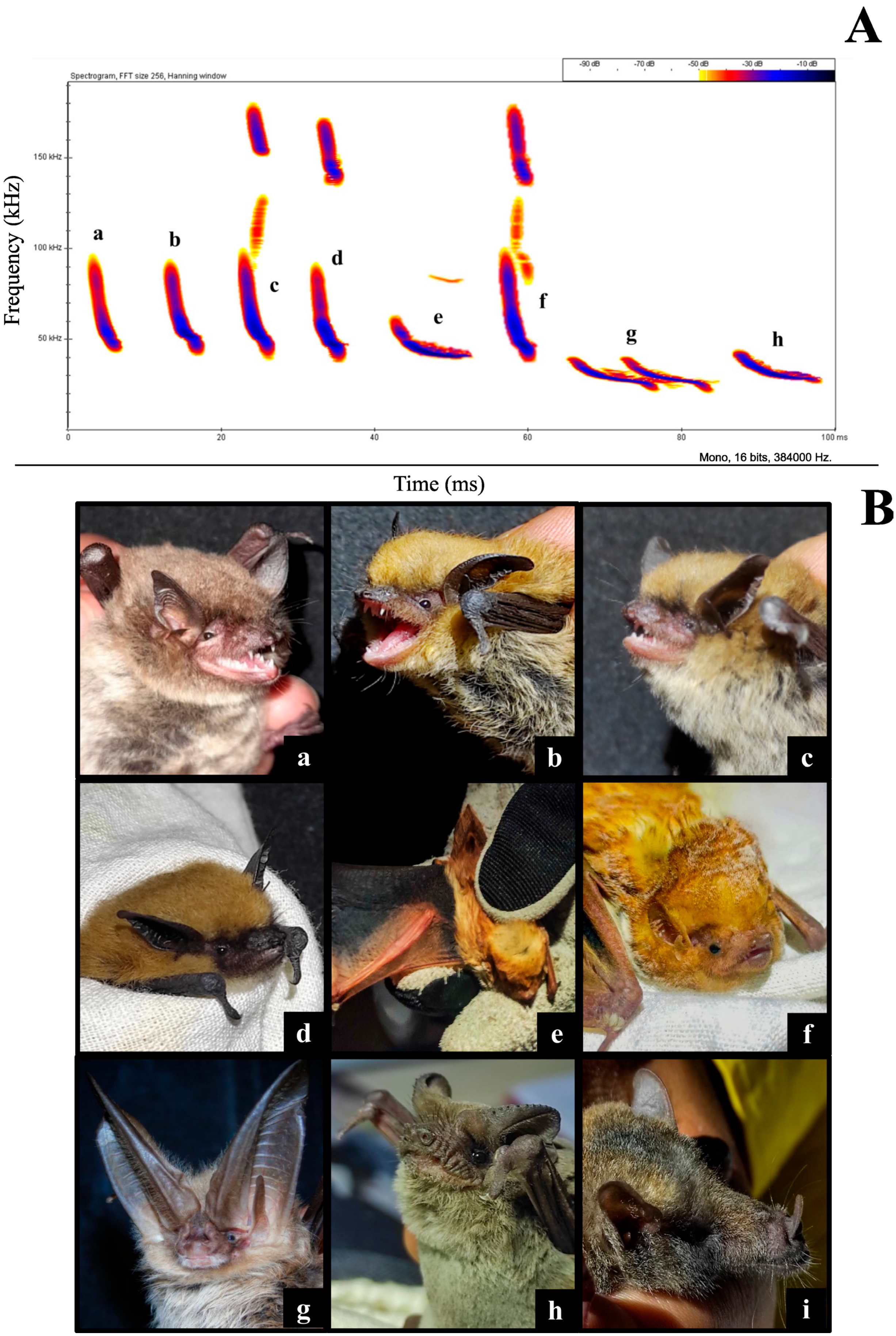

Figure 2. Echolocation calls (A) and photographs (B) of bat species captured. a) *M. yumanensis*, b) *M. californicus*, c) *M. volans*, d) *M. ciliolabrum*, e) *L. ega*, f) *L. frantzii*, g) *C. townsendii*, h) *T. brasiliensis,* and i) *C. mexicana*.

Table 1. List of bat species identified.

Family	Genus	Specie	Morphologic presences	Individuals captured	Acoustic presences	Acoustic records	Total presences	Total detections
Vespertilionidae	*Antrozous*	*pallidus*	0	0	4	6	4	6
	Baeodon	*alleni*	0	0	8	21	8	21
	Corynorhinus	*mexicanus*	0	0	1	1	1	1
		townsendii	4	6	8	23	11	29
	Eptesicus	*fuscus*	0	0	16	94	16	94
	Lasiurus	*cinereus*	0	0	32	330	32	330
		ega	1	1	8	48	9	49
		frantzii	1	1	14	36	14	37
		intermedius	0	0	41	623	41	623
		xanthinus	0	0	3	8	3	8
	Myotis	*auriculus*	0	0	22	127	22	127
		californicus	8	11	32	237	34	248
		fortidens	0	0	18	79	18	79
		ciliolabrum	3	3	19	53	20	56
		velifer	0	0	19	67	19	67
		volans	3	3	28	262	28	265
		yumanensis	6	10	31	341	35	351
	Neoeptesicus	*brasiliensis*	0	0	12	52	12	52
	Parastrellus	*hesperus*	0	0	4	9	4	9
	Rhogeessa	*parvula*	0	0	2	2	2	2
Mormoopidae	*Mormoops*	*megalophylla*	0	0	1	2	1	2
Molossidae	*Molossus*	*nigricans*	0	0	13	26	13	26
	Nyctinomops	*aurispinosus*	0	0	20	43	20	43
		femorosaccus	0	0	8	13	8	13
		laticaudatus	0	0	30	200	30	200
		macrotis	0	0	11	24	11	24
	Tadarida	*brasiliensis*	1	1	32	341	32	342
Phyllostomidae	*Choeronycteris*	*mexicana*	1	1	0	0	0	1
Total	**14**	**28**	**28**	**37**	**437**	**3068**	**449**	**3105**

(acoustic and morphologic) and to estimate diversity index in order to establish the patterns present in a suburban area "Ecoparque Centenario" belonging to the Mexican plateau during an annual cycle.

Materials and Methods

The Mexican plateau is located between the Western and Eastern Sierras, and, in the south, it is limited by the transversal volcan axis. This is an extensive area characterized by altitudes near 2000 m asl. The predominant type of vegetation is xeric scrub, pine-oak forest and isolated patches of low deciduous forest (Rzedowski 2006). The *ECO,* protected natural area belonging to the Mexican plateau, is located in the Arroyo de la Plata micro-watershed, between the Central Mesa and Western Sierra Madre physiographic regions. The *ECO* is located at coordinates: 22º 46′ 49.14″ N, 102º 32′ 37.96″ W (Figure 1), between Zacatecas, Vetagrande and Guadalupe municipalities; the park is in the border area of the Zacatecas city, at an altitude of 2448 m asl, with an average annual rainfall of 400 mm to 450 mm. The climate type corresponds to *BS1kw* (dry or semi-dry with temperate regions and an average annual temperature that ranges between 12 and 18 ºC; García 2004).

The predominant vegetation is induced grassland, riparian vegetation, xerophytic scrub and *Opuntia* spp. scrub (Rzedowski 2006). The tree density is composed by pirul (*Schinus molle*) and mesquite (*Prosopis* sp.) along the stream banks (URSAMEX 2014). Six sampling points were selected near to water bodies and alternated according to the annual season to increase the probability of bat capture during the dry season. Four mist nets (2.5 × 6 m) were placed alternately at the 6 points (Bell 1980; Kurta and Kunz 1988; MacSwiney *et al.* 2008; Gilley and Kennedy 2010). Mist nets were sampled for 5 days, each month, for one year, from April 2022 to May 2023. They were opened during 5 hours, after sunset with monitoring every 30 minutes (Holloway and Barclay 2000; MacSwiney *et al.* 2008; Coleman and Barclay 2012; Barboza-Marquez *et al.* 2014).

Table 2. Characterization of echolocation pulses (EPs) from bat species identified.

Family	Genus	Specie	Maxium frequency (kHz)	Minium frequency (kHz)	Peak frequency (KHz)	Duration (ms)	Bandwidth (kHz)	n
Vespertilionidae	*Antrozous*	*pallidus*	59.1 ± 17.3	27.8 ± 2.8	36.7 ± 6.7	9.3 ± 2.6	31.3 ± 14.6	6
	Baeodon	*alleni*	98.5 ± 4.4	33.3 ± 2.1	46.5 ± 1.3	5.1 ± 0.6	65.2 ± 5.3	21
	Corynorhinus	*mexicanus*	46.9 ± 0.0	21.6 ± 0.0	33.3 ± 0.0	12.3 ± 0.0	25.3 ± 0.0	1
		townsendii	40.1 ± 2.4	23.9 ± 1.9	31.2 ± 1.3	11.7 ± 2.9	16.1 ± 2.6	23
	Eptesicus	*fuscus*	51.4 ± 5.3	27.7 ± 1.9	33.5 ± 1.9	9.8 ± 1.8	23.7 ± 5.8	94
	Lasiurus	*cinereus*	49.8 ± 6.9	25.6 ± 1.9	32.7 ± 2.6	11.9 ± 2.4	24.2 ± 6.8	330
		ega	55.8 ± 11.7	34 ± 4.8	38.2 ± 5.4	9.7 ± 4.5	21.7 ± 8.2	48
		frantzii	84.6 ± 13.9	37.3 ± 2.4	45.5 ± 2.3	5.9 ± 1.9	47.3 ± 15.3	36
		intermedius	41.2 ± 6.6	23.4 ± 1.5	28.2 ± 1.6	12.7 ± 2.2	17.9 ± 6.7	623
		xanthinus	72.9 ± 7.3	32.8 ± 1.0	39.1 ± 1.2	7.8 ± 0.7	40.1 ± 7.9	8
	Myotis	*auriculus*	86.6 ± 8.9	32.2 ± 2.2	43.9 ± 1.8	6.2 ± 1.0	54.4 ± 9.5	127
		californicus	94.9 ± 5.3	41.8 ± 2.3	54.3 ± 2.3	5.1 ± 2.7	53.1 ± 6.2	237
		fortidens	98.7 ± 4.6	42.9 ± 1.6	55.9 ± 1.2	4.4 ± 0.6	55.7 ± 5.1	79
		ciliolabrum	100.6 ± 5.2	39.7 ± 2.5	54.9 ± 3.6	4.6 ± 0.9	60.8 ± 5.2	53
		velifer	83.5 ± 11.3	37.8 ± 1.7	46.1 ± 2.9	5.7 ± 0.6	45.6 ± 11.1	67
		volans	93.1 ± 6.0	37.5 ± 2.7	47.7 ± 2.7	5.5 ± 0.7	55.6 ± 6.5	262
		yumanensis	96.9 ± 5.6	42.7 ± 2.8	54.6 ± 3.9	4.7 ± 0.6	54.2 ± 6.0	341
	Neoeptesicus	*brasiliensis*	53.7 ± 4.1	30.8 ± 1.9	37 ± 2.0	10.9 ± 1.7	22.9 ± 4.5	52
	Parastrellus	*hesperus*	69.9 ± 4.4	41.9 ± 0.9	47.1 ± 1.8	6.2 ± 2.3	27.9 ± 3.7	9
	Rhogeessa	*parvula*	87.9 ± 0.6	41.7 ± 1.5	53.9 ± 0.0	3.8 ± 0.2	46.2 ± 2.1	2
Mormoopidae	*Mormoops*	*megalophylla*	57.6 ± 1.2	41.5 ± 0.7	54 ± 0.2	6.4 ± 1.0	16.1 ± 1.8	2
Molossidae	*Molossus*	*nigricans*	35.1 ± 3.7	25.7 ± 1.6	30.1 ± 1.3	13.3 ± 2.3	9.4 ± 3.4	26
	Nyctinomops	*aurispinosus*	36.2 ± 6.1	19.7 ± 0.8	26.4 ± 1.8	14.3 ± 1.7	16.4 ± 6.3	43
		femorosaccus	32.9 ± 4.7	18 ± 1.0	23.9 ± 0.6	13.2 ± 1.9	14.9 ± 4.7	13
		laticaudatus	35.4 ± 6.6	20.7 ± 1.0	25.6 ± 1.8	13.8 ± 2.2	14.7 ± 6.8	200
		macrotis	27.7 ± 3.3	17.4 ± 2.8	21.5 ± 1.9	14.9 ± 2.3	10.3 ± 4.7	24
	Tadarida	*brasiliensis*	40.7 ± 8.6	24.1 ± 2.3	29.5 ± 3.7	12.8 ± 2.6	16.5 ± 7.3	341
Total								**3068**

For acoustic monitoring, the Echo Meter Touch 2 Pro ultrasonic microphone (connected to a tablet Lenovo Xiaoxin Pad 2022) and Echo Meter software (Wildlife Acoustics, Inc. Maynard, Massachusetts) were used to record EPs. The detection range of echolocation calls was set to a minimum frequency of 15,000 *Hz* with a sampling rate of 384 *kHz* (Pettersson 2004). Acoustic monitoring was semi-active and was conducted by walking the trail from net to net and lasted as long as the mist nets remained open (five hours per day; MacSwiney *et al.* 2020).

BatSound V4.1 software (Pettersson 2004) was used to characterize search phases of the EPs, as they are relatively constant compared to other types of bat vocalizations (*e.g.* social pulses, feeding buzzes) (Fenton and Bell 1981; O'Farrell and Miller 1999; Barclay 1999; Papadopoulos and Allen 2007; Agranat 2013). EPs with an intensity less than 30 dB were not considered for characterization, since it has been determined that frequencies less than this value tend to attenuate at short distances, therefore higher intensity frequencies can travel farther in the environment and consequently, be recorded by ultrasonic microphones (Surlykke and Kalko 2008). These parameters (measured in *kHz*) were: maximum frequency (Fmax), minimum frequency (Fmin), peak frequency, and bandwidth (the difference between Fmax and Fmin), whereas intensity was expressed in *dB*, and duration (*DUR*) in milliseconds (*ms*) (Corben 2004; Miller 2004). The values of each pulse were checked against the "Compendio de Llamados de Ecolocalización de los murciélagos insectívoros mexicanos" (Ortega *et al.* 2022) and the SONOZOTZ echolocation call library (Zamora-Gutiérrez *et al.* 2020). A species was assigned under the concept of sonospecies in the case of meeting the above assumptions, particularly Fmin, peak frequency and DUR (Thomas *et al.* 1987). Morphological bat identifications were made using the field keys in Medellín *et al.* (2008), according to the diagnostic morphological characteristics (Martínez-Rodríguez *et al.* 2024).

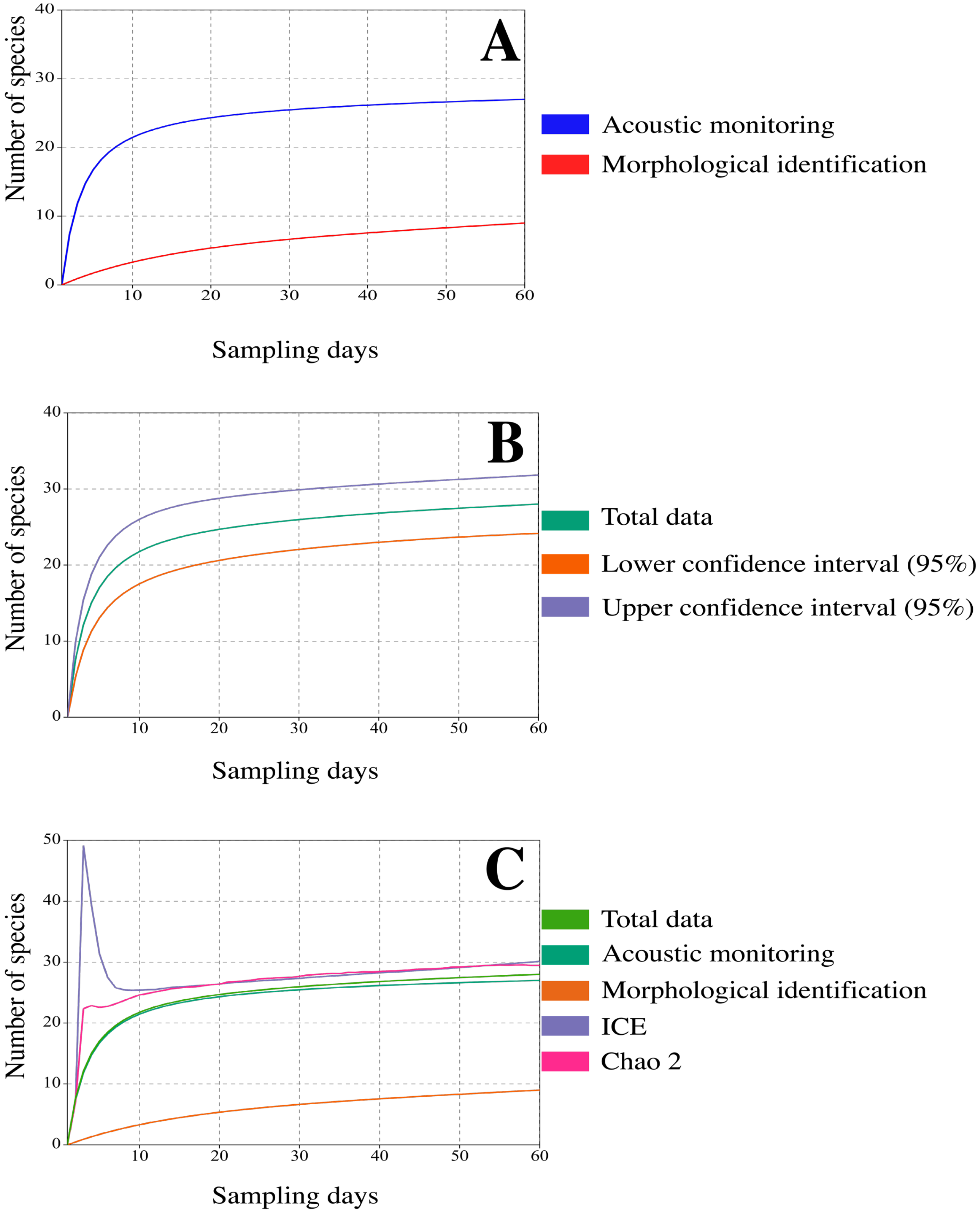

Figure 3. Species accumulation curves and diversity estimators. (A) shows the identified species by acoustic monitoring (blue line = 27 spp.) and morphological identification (red line = 9 spp.). (B) shows the total presences data with both methods (green line = 28 spp.), upper confidence interval at 95% (blue line = 31.83) and lower confidence interval at 95% (orange line = 24.17 spp.). (C) shows the total data (green line = 28 spp.), acoustic monitoring (cian line = 27 spp.), morphological identification (orange line = 9 spp.), ICE estimator (purple line = 30.14 spp.) and Chao 2 estimator (pink line = 29.47 spp.).

Presence/absence data matrices were constructed for the species identified by both methods. The diversity estimators *ICE* (Incidence-based Coverage Estimators) and *Chao 2* (Lee and Chao 1994) were calculated using the EstimateS v 9.1 software (Colwell 2013). Species accumulation curves were generated using the PAST v 4.17 software (Hammer and Harper 2001) with i) acoustic and morphological data, ii) the total observed data for the number of species and 95% confidence intervals, and iii) the non-parametric estimators (*ICE* and *Chao 2*), acoustic, morphological and the total data observations with both methods (Chao *et al.* 2009). Shannon, Margalef, Gini-Simpson and Berger-Parker indices were calculated (Margalef 1972; Moreno 2001; Magurran 2007; Magurran *et al.* 2019) in order to elucidate the diversity patterns in the suburban area.

Results

The total sampling effort was 59 days, 17,700 net-hours and 10,215 acoustic recordings of which 3,068 met the characteristics described in the methodology. Twenty-eight species, 14 genera and 4 families were identified (Table 1). Only 19 species were identified by analysis of their EPs (Table 2); 8 species were identified using both methods and one species was identified only by taxonomic keys (*Choeronycteris mexicana;* Figure 2). The family Vespertilionidae was the most represented with 9 genera and 20 species (71.4 %), with 7 species correspond to the genus *Myotis* (25 %) and 5 to the genus *Lasiurus* (17.8 %). Three genera and 6 species were included in the Molossidae family (21 %), and the most represented genus was *Nyctinomops* with 4 species (14.2 %). Only one species was recorded in the families Mormoopidae and Phyllostomidae, *Mormoops megalophylla* and *C. mexicana*, respectively (7.1 %).

In the context of acoustic monitoring, the species with highest number of occurrences were *Lasiurus intermedius* (n = 630), *Myotis yumanensis* (n = 341), *Tadarida brasiliensis* (n = 341), *L. cinereus* (n = 330), *M. volans* (n = 262), *M. californicus* (n = 237), and *N. laticaudatus* (n = 200). The species with the fewest recorded occurrences were *Corynorhinus mexicanus* (n = 1), *Rhogeessa parvula* (n = 2), and *M. megalophylla* (n = 2). We also recorded *L. ega* (Figure 2 B, e), which has not been previously registered in the north-central region of the country.

For the morphological analysis, 37 specimens were captured which corresponded to 3 families, 5 genera and 9 species; 35 specimens and 7 species belong to the Vespertilionidae (94.5%): *M. yumanensis* (n=10), *M. californicus* (n=11), *M. ciliolabrum* (n=3), *M. volans* (n=3), *L. ega* (n=1), *L. frantzii* (n=1), and *C. townsendii* (n=6). In the families Molossidae and Phyllostomidae only 1 species was captured: *T. brasiliensis* (n=1) and *C. mexicana* (n=1), respectively. The photographs and EPs corresponding to each species are shown in Figure 2, except for *C. mexicana* (Figure 2 B, i) considered a "whispering" species due to its *EP's* characteristics (low intensity and high frequency).

The first accumulation curve (Figure 3 A) shows the differences in the number of species recorded between the identification methods used. While acoustic monitoring (blue line = 27) tends to asymptote, morphological identification (red line = 9) shows no signs of saturation. Figure 3 B shows the total data (green line = 28), which indicates that both methods cover 87.96% of diversity according to the upper confidence interval (blue line = 31.83). However, figure 3 C shows that the sampling effort was satisfactory according to the diversity estimators *ICE* (blue line = 30.12) and *Chao 2* (pink line = 29.47), which suggest that between 92.89 % and 95 % of the richness was recorded in the study area. Acoustic monitoring (cyan line = 27) recovered between 89.58% (*ICE*) and 91.6% (*Chao 2*) of the richness. Morphological identification (orange line = 9) recorded between 29.86% (*ICE*) and 30.5% (*Chao 2)* of the richness.

The value for Margalef specific diversity index was R = 4.421, which indicates a moderate diversity. The Shannon diversity index had a value of H' = 3.073, which also indicates moderate diversity in the study area. For the Gini-Simpson index, a value of *1-D* = 0.9474 was obtained; this value indicates that there is a high probability of obtaining two different species from a random sample, thus indicating that there is no species dominance in the study area.

Finally, the value obtained for the Berger-Parker index was D = 0.09131, indicating that the species with the highest proportion of occurrences in the sample represents 9.1% of the recorded richness, therefore, there is no indication of dominance of any species in the study area. With these values, together with the bat diversity composition, we can infer that the *ECO* complies with the hypothesis of intermediate disturbance.

Discussion

The most represented bat family in our sample was Vespertilionidae (20 spp.), followed by the Molossidae (6 spp.). The diversity composition recorded in this study is consistent with previously described diversity patterns in arid and semiarid climates of the Mexican plateau and the south of Arizona (USA) (e.g. Ortega and Arita 1998; López-González *et al.* 2015; Segura-Trujillo *et al.* 2016; Bazelman 2016; Dwyer 2021; Segura-Trujillo *et al.* 2022; Ramos-H *et al.* 2024). Because the study site is nearby to the transitional zone between the Nearctic and Neotropical biogeographic regions, it is possible to find elements of Neotropical origin, such as species of the families Molossidae, Mormoopidae, and Phyllostomidae (Ortega and Arita 1998; López-González *et al.* 2015). In this study these elements represent only 8 species (*i.e.* 28.5% of the total sample).

In relation with the generalist and specialist bat species, previous studies have determined that at least 10 of the 28 identified species in this study are generalists, whose presence is correlated with suburban environments (*T. brasiliensis, E. fuscus, M. yumanensis, M. californicus, M. velifer, M. volans, N. macrotis, L. xanthinus, L. intermedius* and *M. megalophylla*) (Avila-Flores and Fenton 2005;

Dixon 2012; Bazelman 2016; Rodríguez-Aguilar *et al.* 2017; Adams 2021; Dwyer 2021; Dwyer *et al.* 2024; Briones-Salas *et al.* 2024). However, it has been reported that the species *N. femorosaccus, C. townsendii, N. brasiliensis, M. auriculus, P. hesperus* and *C. mexicana* have specialized habits, with relatively low activity levels in urban areas (Husar 1976; Arroyo-Cabrales *et al.* 1987; Bazelman 2016; Rodríguez-Aguilar *et al.* 2017; Dwyer 2021; Dwyer *et al.* 2024). In addition to having specialist habits, *C. mexicana* has been classified as near threatened by the IUCN (Solari 2018). Therefore, this work contributes to generating information to make decisions about conservation strategies for species that can inhabit suburban habitats in the Mexican plateau.

Evidence suggests that species of the genus *Lasiurus* (*L. frantzii, L. ega, L. cinereus* and *L. intermedius*) tolerate intermediate levels of urbanization. However, given their foraging and refuge site characteristics, they tend to avoid such environments. The exception is *L. xanthinus*, which has not been reported reduce its presence in habitats due to increased urbanization (Aguilar *et al.* 2013; Dwyer 2021).

According to Moreno and Halffter (2001), it is necessary to recover a minimum of 90 to 95 % of the bat diversity to ascertain that the sampling effort was sufficient. We recovered between 92.89 % (ICE) and 95 % (Chao 2), indicating a satisfactory sampling effort. This is due to the use of two identification methods, which have been deemed optimal in suburban environments or areas characterized by minimal vegetation cover, such as xerophytic scrub vegetation (Rautenbach *et al.* 1996; Kuenzi and Morrison 1998; Rydell *et al.* 2002; Berry *et al.* 2004; MacSwiney *et al.* 2020). Furthermore, these methods are complementary to each other, and their efficiency varies depending on habitat characteristics and the trophic guild to which the bat species belong (*i.e.* open space aerial foragers, closed space aerial foragers, surface foragers, and edge space foragers). For instance, numerous authors (*e.g.* O'Farrell and Miller 1999; Kalko *et al.* 2008; MacSwiney *et al.* 2008) have mentioned that acoustic monitoring has been found to be the most efficient in recording species that forage in open spaces, while mist nets have been determined to be optimal for capturing species that forage in closed or surface spaces (La Val 1970; Kunz 1973; Kunz and Brock 1975; Kuenzi and Morrison 1998; Rydell *et al.* 2002; Larsen *et al.* 2007). This distinction is evident in the accumulation curves of each method and the feeding habits reported in previous studies (Mora-Villa *et al.* 2014; Segura-Trujillo *et al.* 2016). Acoustic monitoring recorded 13 genera and 27 species (96.4% of the sample), of which six molossid species belonged to the guild of open-space aerial foragers and at least 17 species of Vespertilionids belonged to the guild of edge-space foragers.

In the other hand, the morphological identification recorded 9 spp. of which 8 were also identified through their EPs, and which mostly belong to the guild of closed-space foragers and edge-space foragers. The only exception was *C. mexicana* which feeds on pollen and nectar from Agavaceae flowers and has EPs that are complicated to record, like other Phyllostomids species, but they are relatively easy to capture with mist nets (Kunz and Kurta 1988; Simmons and Voss 1998; Clarke *et al.* 2005; MacSwiney *et al.* 2008; Pérez-Hernández and Martínez-Coronel 2023). In addition, the combined methods allowed us to identify acoustically and morphologically the species *L. ega*, which some authors have reported that it is distributed mainly on the slope of the Gulf of Mexico (Medellín *et al.* 2008; Barquez and Diaz 2016; Ortega *et al.* 2022), although others mention that its distribution includes the north-central region of the country (Kurta and Lehr 1995). Because of this uncertainty and the migratory habits of this species, it is imperative to provide information on the distribution of the species in the arid and semiarid regions of the country, where studies are limited.

In the context of acoustic characterization, it was observed that the Fmin values recorded for all the 27 species matched the values of the "Compendio de Llamados de Ecolocalización de los murciélagos insectívoros mexicanos" and the SONOZOTZ echolocation call library (Ortega *et al.* 2022). The recorded Fmax values differ in 5 species (*Lasiurus xanthinus, L. cinereus*, *M. megalophylla, Molossus nigricans* and *N. laticaudatus*). Conversely, peak frequency values differ in one species (*Corynorhinus townsendii*) and the recorded DUR values differ in 17 spp. (*Antrozous pallidus*, *Baeodon alleni*, *C. mexicanus*, *C. townsendii*, *Eptesicus fuscus*, *L. cinereus*, *L. ega*, *L. frantzii*, *M. ciliolabrum, M. auriculus*, *Parastrellus hesperus*, *R. parvula*, *N. aurispinosus*, *N. femorosaccus*, *N. laticaudatus*, *N. macrotis* and *T. brasiliensis*).

The parameters that exhibited the most discrepancy was Fmax and DUR, which may be associated with the capacity of bats to decrease Fmax and increase DUR in response to the climatic and structural characteristics of the site. This phenomenon can be a strategy employed by bats to mitigate atmospheric attenuation and avert the masking of their EPs by anthropogenic sounds in this context (Thomas *et al.* 1987; Wund 2006; Gillam *et al.* 2009).

The calculated diversity indices values suggest that the study area has a moderate bat diversity (H' = 3.073, R = 4.421, 1-D = 0.9474 and, D = 0.09131). There is a possibility that this is due to the suburban park characteristics (*i.e.* moderate levels of urbanization, tree cover, water bodies and streetlights) and the presence of caves and abandoned mines in the vicinity of the *ECO*. Several studies have documented that these features may explain why the richness of bat species was higher in suburban parks or in suburban areas due the presence of available roost and foraging sites for different species of bats (Kurta and Teramino 1992; Gehrt and Chelsvig 2008; Loeb *et al.* 2009; Russo and Ancillotto 2015). In addition, we inferred from the calculated values of each index and the suburban characteristics of the environment, the diversity pattern present in the *ECO* polygon corresponds to the hypothesis of intermediate disturbance.

This hypothesis states that species can take advantage of moderately altered habitats and increase the richness and diversity in general (Connell 1978; Castro-Luna *et al.* 2007; Threlfall *et al.* 2011; Dodd *et al.* 2012). Our study is an example of how systematic and formal studies about diversity of bats using 2 methods of identification, can elucidate and provide information about the species distribution and their EPs characteristics in regions where these types of studies are limited. In addition, it is important to highlight the importance of its implementation to reduce bias regarding the diversity of bats present. In our case, for example, the company URSAMEX (2014) mentions that they identified five species of bats, but three species do not correspond to the reported distribution, moreover statistical methods were not used to evaluate the sampling effort, and only one identification method was used, which could have underestimated the diversity of bats present in the park. In fact, we only identified two of these mentioned species which correspond to *Myotis auriculus* and *Mormoops megalophylla*. This is an example of how the use of complementary methods for bat species identification can expand and provide accurate information about the actual knowledge of diversity at the local level in this type of environment which cover a Mexican plateau.

Conclusions

We registered 28 bat species with two methods of identification. Our study represents the first formal and systematic listing of bat species in a suburban environment in the Mexican plateau region and particularly in the state of Zacatecas. In addition, we registered the species *L. ega* which was not reported in the region. Finally, our sampling effort was satisfactory, and the bat diversity pattern identified in the *ECO* corresponds to the pattern observed in the north-central region of the country, that is, a greater representation of the families Vespertilionidae and Molossidae. Furthermore, according to the calculated diversity indexes values, it is inferred that the suburban characteristics of Park maintain a moderate diversity of chiropteran species and it is suggested that it corresponds to the pattern of the intermediate disturbance hypothesis.

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