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Diversity and conservation of bats in a private protected area of southern México

Diversidad y conservación de murciélagos de un área privada protegida del sur de México

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Species inventories represents the first step for the study of biological diversity. Achieving bat completeness inventories requires the use of several sampling methods. The species inventories are particularly important in zone with scarce or without biological information. This work updates the inventory of bat species of Private Protected Area known as the Jaguaroundi Ecological Park (hereafter PEJ, by its Spanish acronym), located in southern Veracruz. The sampling for this study was carried out between August and November 2015, using two methods (mist nets and ultrasonic detectors). We registered 33 species of bats, 23 species with mist nets (20 registered only with this method), and 13 species with ultrasonic detectors (10 registered only with this method). We recorded 23 species in ever green seasonal forest, 20 species were founded in secondary forest and 17 species in areas near water bodies. Overall, the PEJ harbor 34 bat species including previous and new records. Three of this species (*Lophostoma brasiliense*, *Myotis albescens* and *M. nigricans*) are included in the Official Mexican Norm (NOM-059-SEMARNAT-2010) and one species (*Peromyotis subflavus*) on the IUCN Red List. This updated bat inventory of the PEJ represents a significant contribution to the knowledge of bats diversity in southern Veracruz as well as the role in conservation of Private Protected Areas in México.

Key words: Jaguaroundi Ecological Park; mist nets; species inventory; tropical rain forest; ultrasonic detector; Veracruz.

Los inventarios de especies representan el primer paso para el estudio de la diversidad biológica. Alcanzar inventarios completos de murciélagos requiere el empleo de diversos métodos de muestreo. Los inventarios de especies son particularmente importantes en zonas con escasa o nula información biológica. En este trabajo se actualiza el inventario de especies de murciélagos del Área Privada Protegida conocida como Parque Ecológico Jaguaroundi (de aquí en adelante PEJ, por su acrónimo) localizada en el sur de Veracruz. El muestreo para este estudio se realizó entre agosto y noviembre de 2015, empleando dos métodos (redes de niebla y detectores ultrasónicos). Se registraron 33 especies de murciélagos, 23 especies con redes de niebla (20 registradas solo con este método) y 13 especies con detectores ultrasónicos (10 registradas solo con este método). Se registraron 23 especies en selva, 20 especies fueron encontradas en bosques secundarios y 17 especies en áreas cercanas a cuerpos de agua. En total, el PEJ alberga 34 especies de murciélagos incluyendo registros previos y nuevos. Tres de estas especies (*Lophostoma brasiliense*, *Myotis albescens* and *M. nigricans*) están incluidas en la Norma Oficial Mexicana (NOM-059-SEMARNAT-2010) y una especie (*Peromyotis subflavus*) en la Lista Roja de la IUCN. Este inventario actualizado de los murciélagos del PEJ representa un aporte significativo al conocimiento de la diversidad de murciélagos en el sur de Veracruz, así como del papel de conservación de las Áreas Protegidas Privadas en México.

Palabras clave: Bosque lluvioso tropical; detector ultrasónico; inventario de especies; Parque Ecológico Jaguaroundi; redes de niebla; Veracruz.

Bats are considered key components of the ecosystems where they inhabit, since they fulfill various ecological functions (Kunz *et al.* 2011), particularly in the tropics, where they reach a high diversity and abundance (Coates *et al.* 2017). For instance, the state of Veracruz harbors 89 bat species (González-Christen and Delfín-Alonso 2016), but the diversity knowledge about this group is not homogeneous across the territory. Therefore, there are areas were the information of chiropterofauna composition is limited or non-existent. Having complete species inventories in areas with scarce or without biological information represents the first step in the study of biological diversity (Dirzo and Raven 1994) and for the design and implementation of conservation strategies. In the case of bats, reaching satisfactory level of species inventory completeness is complicated given their high diversity and the sampling difficulty due to their nocturnal and flying habits (Furey *et al.* 2009). Therefore, it is necessary to implement different sampling methods (MacSwiney *et al.* 2008; Pech-Canche *et al.* 2011).

Bat diversity in natural protected areas of México has been studied mainly in governmental natural protected areas such as the biosphere reserves Los Tuxtlas, Veracruz (Coates *et al.* 2017) or Montes Azules, Chiapas (Medellín 1994), while knowledge of bat diversity in private protected areas is scarce (Ortiz-Lozada *et al.* 2017). Jaguaroundi Ecological Park (Parque Ecológico Jaguaroundi; hereafter PEJ, by its spanish acronym) is a Private Protected Area (PPA) that was the first voluntarily areas for

conservation (Área Destinada Voluntariamente a la Conservación; hereafter ADVC, by its Spanish acronym) in México. The PEJ is located in the south of the state of Veracruz, in an area severely modified by different human activities (*e.g.*, industrial activities and livestock; Nava and Rosas 2008). Little is known about species diversity, and the role of forest remnants in the maintenance of bats communities in this area. The PEJ has an extension of 960 hectares of diverse vegetation types and modified environments in different successional stages of passive restoration; however, there are hardly any preliminary inventories of the terrestrial vertebrates groups (mammals, birds, amphibians and reptiles; Herrera *et al.* 2008) which makes difficult to assess the role of PEJ on the conservation of biodiversity.

In the PEJ, in a preliminary study of the chiropterological fauna, 15 species were recorded using the mist net method (Herrera *et al.* 2008). In this study, we show the results of field work carried out in 2015, using two sampling methods (mist net trap and ultrasonic detector), we analyzed the complementarity between both methods, an updated inventory of bats of PEJ. Further we discuss the implications in terms of bat conservation. We expect that the information generated highlight the relevance of PEJ in the maintenance of bat diversity in a zone with continuous loss of original vegetation cover and help in the planning conservation strategies.

The PEJ is located in the Coatzacoalcos Municipality, in the south of the state of Veracruz, in southern México (Figure 1). The vegetation types present in the PEJ are evergreen forest, primary and secondary evergreen seasonal forest, oak forest, palm grove, swamp vegetation, savanna, as well as extensions of grasslands induced for livestock and small areas of bare ground (Ramos-Álvarez *et al.* 2008).

For the capture of bats in the PEJ, 9 sites were sampled between August and November 2015; one night per site placing 8 mist nets in each. Three sites were located in evergreen seasonal forest, three in secondary vegetation of ever green seasonal forest and three in areas near water bodies, located within the reserve. Each mist net was placed 30 minutes before dusk and remained active 4.5 hours on average (between 18:30 and 22:00 h) and was reviewed every 20 minutes.

Mist nets with a length of 12 m and a width of 2.5 m were used, starting from a few centimeters above the ground, with a mesh opening of 33 mm, installed with the help of posts secured with ropes. The sampling effort in each site was of 210 m^2 / net and the total sampling in all sites was of 1,890 m^2 / net. For each captured individual, the time of capture, as well as the measurements of weight and length of the forearm were recorded. We recorded the sex, age and reproductive status (males: scrotum or abdominal testicles; female: inactive, pregnant and lactating). The species iden-

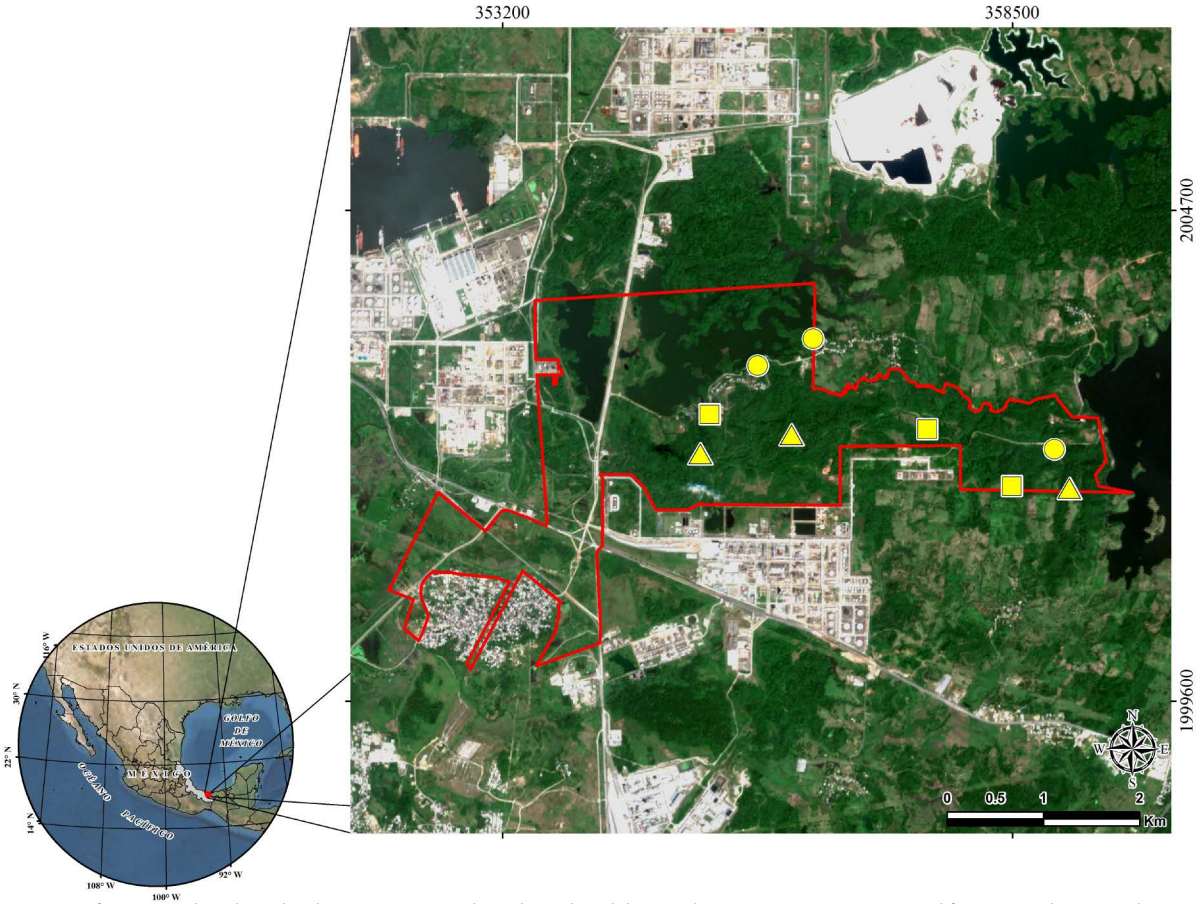

Figure 1. Location of Jaguaroundi Ecological Park (PEJ, perimeter indicated in red) and the sampling sites in ever-green seasonal forest (triangles), secondary vegetation of ever-green seasonal forest (squares) and areas near water bodies (circles).

tity of captured individuals was determined based on identification keys such as Medellín *et al.* (2008) and Álvarez-Castañeda *et al.* (2015) and later the specimens were released.

For the acoustic recording of bats, simultaneous samplings were carried out with the net method, in the months of August, September, and November of the same year at nine sites in the same environments, close to the sites where the samplings were carried out by the mist nets method. For this sampling, a SongMeter 2M + (Wildlife Acoustics) was used, which was installed on a tripod at a height of approximately 1.5 meters. The recordings were made continuously for a period of 2.5 hours, from the first 20 minutes before dusk, since it is the time interval considered the first peak of activity of insectivorous bats (Hayes 1997; Estrada-Villegas *et al.* 2010). The total sampling effort using this method was of 1,500 minutes. The recordings obtained were analyzed with the BatSound Pro 3.31 program (Petterson Elektronik AB), where the characteristics of the pulses were measured (*e.g.*, initial frequency, final frequency, interval between calls and duration of the call); later they were compared with the information in specialized literature and reference recordings previously obtained for the identification of species. The general taxonomic classification was based on the publication of Ramírez-Pulido *et al.* (2014), and on later taxonomic studies. In the case of *Pteronotus* genus taxonomy we based on the studies with molecular evidence of López-Wilchis *et al.* (2016) whose recognize to *P. mexicanus* as the species with distribution in southern Veracruz, and on the study of Pavan and Marroig (2016) whose recognize the subspecies *P. davyi fulvus* as a valid species.

To determine the degree of completeness of the bat species inventory for the PEJ, the expected richness was estimated, calculated with the first and second order Jacknife and Chao 2, non-parametric estimators (Moreno 2001), based on presence-absence data grouped in samples (sampling days), using the EstimateS version 9.0 program (Colwell 2013).

The conservation status of registered species was determined based on the list of Species at Risk (Official Mexican Norm; NOM-059-SEMARNAT-2010), published by the Ministry of the Environment and Natural Resources updated in 2018 (SEMARNAT 2010, 2019) and the Red List of the International Union for Conservation of Nature (IUCN 2020). The trophic guild of each species was defined based on the classification proposed by Kalko (1996).

As result of the fieldwork carried out in this study, 33 bat species were registered, belonging to 20 genera and 5 families. Of the 33 bat species, 23 species were registered in the mist nets, 20 recorded only using this sampling method. On the other hand, 13 species were registered with the ultrasonic detector, 10 of which were registered only using this method, and three species were registered by both methods. We recorded 23 species in ever-green seasonal forest areas, 20 species in secondary vegetation and 17 species in areas near water bodies. We found 10 species distributed in the three environments, 7 species were found in two environments and 16 species were recorded in one environment (Table 1). According to the number of species calculated with non-parametric estimators (Chao 2 = 37.5, Jacknife of first order = 42, Jacknife of second order = 44.6), the level of completeness varied between 74 %, and 88 %, respectively. Based on the recorded species on 2015, sampling effort altogether with the previously known species list for the reserve (Herrera *et al*. 2008), the inventory of chiropterofauna of the PEJ includes a total of 34 species. The best represented genus was *Myotis* with four species, followed by *Molossus*, and *Glossophaga* with three species each, while other genera such as *Saccopteryx*, *Mormoops*, *Centurio*, *Chiroderma*, *Desmodus*, *Lophostoma*, *Micronycteris*, *Platyrrhinus*, *Uroderma*, *Eptesicus,* and *Perimyotis* are represented by a single species. The best represented family was the Phyllostomidae with 19 species, followed by Vespertilionidae with eight species, while Emballonuridae is only represented by one species (Table 1). Of the recorded species, 15 are considered aerial insectivore, 13 frugivore, 3 nectarivore, 2 foliage insectivore and 1 species sanguivore (Table 1).

Three species are included in the NOM-059-SEMARNAT-2010: *Lophostoma brasiliense* in the Threatened category (Amenazada; A), *Myotis albescens* and *M. nigricans* in the Subject to Special Protection category (Sujeta a Protección Especial; Pr); while *Perimyotis subflavus* is in the Vulnerable category (VU), and *Pteronotus fulvus* has not been evaluated (NE) according to the IUCN red list (Table 1).

Updating the species inventory of the PEJ represents a significant contribution to the knowledge of bats at the extreme south of Veracruz, where there is no recent information. Most of the studies that explore species richness, and different aspects of diversity and bat ecology are mostly concentrated in Los Tuxtlas region in Veracruz (Estrada and Coates-Estrada 2002; Coates *et al.* 2017; Ramírez-Lucho *et al.* 2017). The species richness recorded in PEJ is equivalent to 51 % of the 65 bat species recorded for Los Tuxtlas region (Coates *et al.* 2017), 37 % of the 89 bat species recorded for Veracruz (González-Christen and Delfín-Alonso 2016), and 24 % of the 137 bat species recorded for México (Ceballos *et al.* 2014; Ramírez-Pulido *et al.* 2014; Álvarez-Castañeda *et al.* 2015). The diversity of bats recorded in PEJ highlight their relevance for the conservation of bats from local to national scale. Additionally, this study represents a contribution to the knowledge of the role of Private Protected Areas in the conservation of bats, which has been scarcely explored (Durán *et al.* 2012; Cruz-Bazán *et al.* 2017).

The effectiveness of each type of sampling (acoustic, mist nets) for the recording of bats can be explained by species characteristics, such as the type of feeding and echolocation system. For example, insectivorous bats of Molossidae and Vespertilionidae families can fly higher, faster, and have a more developed echolocation system that allows them to avoid nets (Silva and Bernard 2017), than species of the family Phyllostomidae, which was the most abundant family in this study (Table 1), and in others (MacSwiney *et al.* 2008;

Table 1. Bat species registered in the Jaguaroundi Ecological Park, Veracruz, México. Environment of records: Evergreen Seasonal Forest (FST); Secondary Vegetation of Evergreen Seasonal Forest (SF); Areas near Water Bodies (AWB). Guild: InsAe: Aerial Insectivore; InsFol: Foliage Insectivore; Nec: Nectarivore; Fru: Frugivore; San: Sanguivore. Source of the record: 1 = Herrera *et al.* 2008, 2 = this study. Sampling methods (Method): Ac = acoustic, Ne = nets. Species risk category according to the Mexican Ministry of the Environment (NOM): A = Threatened (amenazada), Pr = Subject to Special Protection (sujeta a protección especial) and according to the Red List of the International Union for Conservation of Nature (IUCN), LC = Least Concern, VU = Vulnerable, NE = Not evaluated.

Family	Species	FST	SF	AWB	Guild	Source	Method	NOM	IUCN
Emballonuridae	*Saccopteryx bilineata* (Temminck, 1838)	X			InsAe	2	Ac		LC
Molossidae	*Molossus molossus* (Pallas, 1766)	X	X	X	InsAe	2	Ac		LC
	Molossus rufus Geoffroy, 1805	X	X	X	InsAe	2	Ac		LC
	Molossus sinaloae Allen, 1906			X	InsAe	2	Ac		LC
Mormoopidae	*Mormoops megalophylla* (Peters, 1864)		X		InsAe	2	Ac		LC
	Pteronotus fulvus (Thomas, 1892)	X	X		InsAe	2	Ac		NE
	Pteronotus mexicanus (Miller, 1902)	X	X	X	InsAe	1, 2	Ac, Ne		LC
Phyllostomidae	*Artibeus jamaicensis* Leach, 1821	X	X	X	Fru	2	Ne		LC
	Artibeus lituratus (Olfers, 1818)	X	X	X	Fru	1, 2	Ne		LC
	Carollia perspicillata (Linnaeus, 1758)	X			Fru	1, 2	Ne		LC
	Carollia sowelli Baker, Solari and Hoffmann, 2002	X	X	X	Fru	1, 2	Ne		LC
	Centurio senex Gray, 1842	X	X	X	Fru	1, 2	Ne		LC
	Chiroderma salvini Dobson, 1878				Fru	1			LC
	Dermanura phaeotis Miller,1902	X	X	X	Fru	1, 2	Ne		LC
	Dermanura tolteca (Saussure, 1860)	X			Fru	2	Ne		LC
	Dermanura watsoni (Thomas, 1901)	X	X	X	Fru	1, 2	Ne		LC
	Desmodus rotundus (Geoffroy, 1810)		X		San	2	Ne		LC
	Glossophaga commissarisi Gardner, 1962	X		X	Nec	1, 2	Ne		LC
	Glossophaga leachii (Gray, 1844)		X	X	Nec	2	Ne		LC
	Glossophaga soricina (Pallas, 1766)		X	X	Nec	1, 2	Ne		LC
	Lophostoma brasiliense Peters, 1867	X			InsFol	2	Ne	A	LC
	Micronycteris microtis Miller, 1898	X			InsFol	2	Ne		LC
	Platyrrhinus helleri (Peters, 1866)	X		X	Fru	1, 2	Ne		LC
	Sturnira hondurensis Goodwin, 1940	X	X		Fru	2	Ne		LC
	Sturnira parvidens Goldman, 1917		X		Fru	2	Ne		LC
	Uroderma bilobatum Peters, 1866		X		Fru	2	Ne		LC
Vespertilionidae	*Eptesicus furinalis* (d´Orbigny, 1847)	X	X	X	InsAe	2	Ac		LC
	Lasiurus cinereus (Beauvois, 1796)			X	InsAe	2	Ac		LC
	Lasiurus ega (Gervais, 1856)	X			InsAe	2	Ac		LC
	Myotis albescens (Geoffroy, 1806)	X	X		InsAe	2	Ac, Ne	Pr	LC
	Myotis keaysi Allen, 1914	X			InsAe	1, 2	Ne		LC
	Myotis nigricans (Schinz, 1821)			X	InsAe	2	Ac	Pr	LC
	Myotis velifer (Allen, 1890)		X		InsAe	2	Ne		LC
	Perimyotis subflavus (Cuvier, 1832)	X			InsAe	2	Ac, Ne		VU

Ramírez-Lucho *et al.* 2017). Phyllostomid probably are easier to capture in mist nets due to their feeding habits based mostly on fruits and nectar produced by plants of the lower strata of vegetation (Simmons and Voss 1998; Giannini and Kalko 2004). Our results indicate the importance of using complementary sampling methods to obtain complete inventories of bat species (O´Farrell and Gannon 1999; Furey *et al.* 2009), including ultrasonic sampling method (MacSwiney *et al.* 2008; Pech-Canche *et al.* 2010).

Since species accumulation curves, generated based on the sampling effort made in 2015, indicated that there are still between 3 and 11 species to registered, it would be desirable to make a greater sampling effort in all environments of PEJ including as many months of the year as possible, in order to record a more complete species inventory. There are some species that may elude detection in our sampling effort, and it is possible than they occur in PEJ. For instance, *Chiroderma salvini* was previously reported by Herrera *et al.* (2008) in the PEJ. Similarly, Ortiz-Lozada *et al.* (2017) reported *Pteronotus personatus*, *Choeroniscus godmani* and *Rhogeesa tumida* in the Ceratozamia Protection and Development Area (Área

de Protección y Desarrollo de Ceratozamia; APDC by its spanish acronym), and APP located 5 km south to PEJ.

Among the species registered in the PEJ, *Centurio senex*, *Dermanura phaeotis*, *Eptesicus furinalis*, *Lophostoma brasiliense*, *Micronycteris microtis*, *Platyrrhinus helleri* and *Saccopteryx bilineata*, are considered vulnerable species, since they inhabit forest fragments, but avoid the open fields (Galindo-González 2007). In our study only *L. brasiliense*, *M. microtis* and *S. bilineata* were recorded exclusively in evergreen seasonal forest sites, while the other species were recorded in the entire landscape, except *P. helleri* which was recorded in forest and in areas near water bodies (Table 1). Other species as *Artibeus jamaicensis*, *A. lituratus*, *Carollia sowelli*, *C. perspicillata*, *Dermanura tolteca*, *Desmodus rotundus*, *Glossophaga soricina*, *Molossus rufus*, *Mormoops megalophylla*, *Myotis keaysi*, *Pteronotus fulvus*, *P. mesoamericanus* and *Uroderma bilobatum* are considered adaptable, generalist species, with greater tolerance to the environment transformation (Galindo-González 2007). However, in our study *C. perspicillata*, *D. tolteca* and *M. keaysi* were only recorded in forest sites (Table 1). The patterns of species distribution observed in the PEJ could be explained by the composition and heterogeneous configuration of the landscape matrix, and maybe due to the home range amplitude and the feeding habits of bat species, but future studies are necessary to determine the way the species move across the landscape.

From a conservation perspective, the species richness and the number of species included in categories of risk of extinction in national or international protection initiatives recorded so far in PEJ (Table 1), highlight the role of PEJ in the conservation of bats in a landscape severely modified by human activities (Nava and Rosas 2008; Sommer and Oropeza-Orozco 2010). Additionally, this study lays the base line for the development of conservation programs within the park at the local level and their possible inclusion in regional conservation programs as the Mesoamerican Biological Corridor (Miller *et al.* 2001).

A desirable future task is to evaluate the role of PEJ in conjunction with PPAs, the Tuzandepetl Ecological Park (Parque Ecológico Tuzandepetl; PET by its spanish acronym) and the APDC (5 km away between the three reserves; Figure 1), in the bat conservation of extreme south of Veracruz. These three reserves are the only Natural Protected Areas in the region, where the closest natural protected area is Los Tuxtlas Biosphere Reserve, located 50 km to the west, and La Chontalpa Ecological Park, located 85 km to the southeast. For this purpose, it is necessary to do sampling effort in several consecutive years considering all seasons, in the three PPAs, particularly in the PET where bat inventory species are lacking. For Ceratozamia Protection and Development Area, we recommend using the method of ultrasonic detectors, in order to have a more complete inventory of chiropterological fauna, because only 15 species were recorded using the mist nets sampling method (Ortiz-Lozada *et al.* 2017). But also, is desirable to carry out sampling effort in unprotected land in PPAs surrounding areas, considering all environments as forest patches, live fences, livestock grasslands and even urban areas to determine the landscape spatiotemporal use pattern that bats make.

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