# Mammal diversity before the construction of a hydroelectric power dam in southern Mexico

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**Abstract**

*Mammal diversity before the construction of a hydroelectric power dam in southern Mexico.* Hydroelectric power is a widely used source of energy in tropical regions but the impact on biodiversity and the environment is significant. In the Río Verde basin, southwestern of Oaxaca, Mexico, a project to build a hydroelectric dam is a potential threat to biodiversity. The aim of this work was to determine the parameters of mammals in the main types of vegetation in the Río Verde basin. We studied richness, relative abundances, and diversity of the community in general and among groups (bats, small mammals and medium and large–sized mammals). In the temperate forests, small mammals were the most diverse while medium–sized mammals and large mammals were the most diverse in land transformed by humans. As the Río Verde basin shelters 15% of the land mammal species of Mexico, if the hydroelectric power dam is constructed, mitigation measures should include rescue programs, protection of the nearby similar forests, and population monitoring, particularly for endangered species (20%) and endemic species (14%). In a future scenario, whether the dam is constructed or not, management measures will be necessary to increase forest protection, vegetation corridors and corridors within the agricultural matrix in order to conserve the current high mammal diversity in the region.

Key words: Effective number of species, Río Verde basin, Oaxaca, Deciduous forest, Temperate forests, Mitigation

**Resumen**

*Diversidad de mamíferos antes de la construcción de una presa hidroeléctrica en el sur de México.* En las regiones tropicales la energía hidroeléctrica es una de las fuentes de energía más utilizadas; sin embargo, también ha afectado significativamente a la biodiversidad y el ambiente. En la cuenca de Río Verde, al suroeste de Oaxaca, en México, se ha proyectado la construcción de una presa hidroeléctrica que podría poner en peligro la biodiversidad. El objetivo de este trabajo fue determinar los parámetros de la comunidad de mamíferos en los principales tipos de vegetación en la cuenca del Río Verde. Estudiamos la riqueza de especies, las abundancias relativas y la diversidad en la comunidad en general y entre grupos (murciélagos, pequeños mamíferos, y mamíferos de talla mediana y grande). Los mamíferos de talla pequeña fueron los más diversos en los bosques templados, mientras que los de talla mediana y grande lo fueron en las tierras transformadas por los humanos. La cuenca del Río Verde alberga el 15% de las especies de mamíferos terrestres presentes en México, por lo que si la presa hidroeléctrica se construyera, las medidas de mitigación deberían comprender programas de rescate, la protección de bosques similares cercanos y un control poblacional, en particular de las especies amenazadas (el 20%) y las endémicas (el 14%). En el futuro, tanto si se construye la presa como si no, será necesario adoptar medidas de manejo encaminadas a aumentar la protección de los bosques y establecer corredores de vegetación y corredores dentro de la matriz agrícola con vistas a conservar la alta diversidad de mamíferos presente actualmente en la región.

Palabras clave: Número efectivo de especies, Cuenca del Río Verde, Oaxaca, Bosque caducifolio, Bosques templados, Mitigación

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## Introduction

Population growth, human activities, and development have triggered the need for greater quantities of non–renewable resources and energy in tropical regions. In these ecosystems, hydroelectricity is a major source of energy, but the serious impact of dams on biodiversity and the environment must be taken into account (Lehner et al., 2011; Tundisi et al., 2014).

Dams have a direct impact on hydrology by changing the flow of water to a non–natural, lotic to lentic system. They not only alter the flux sediment, biogeochemical processes and nutrient dynamics, but also affect the thermal regime, homogenizing the system, and affecting primary production. Dams also nullify the migration of aquatic species and flood the habitat of terrestrial species. The cascade effect includes the spread of cosmopolitan non–indigenous species, affecting the native aquatic species and the base of the food web (Dudgeon, 2000; Pringle, 2003; Agostinho et al., 2004; McCartney, 2009; Poff et al., 2007; Nilsson et al., 2005; Winemiller et al., 2016). Cumulative impacts are pollution and overfishing, relocation of human populations, and expanding deforestation associated with new roads and settlements (Dudgeon, 2000; Nilsson et al., 2005; Winemiller et al., 2016).

Measures of mitigation, compensation, and restoration are crucial factors to be taken into consideration to alleviate negative impacts on the environment (McCartney, 2009; Winemiller et al., 2016). For these measures to be successful, it is necessary to understand the composition of biological communities, to identify the most potentially vulnerable species, and to consider potential rescue before these facilities are be built (McCartney, 2009). Only with this knowledge can compensation and restoration measurements similar to initial conditions be designed (McCartney, 2009; Winemiller et al., 2016).

Southwestern Oaxaca, Mexico is in an area with high biodiversity. However, it is also threatened by the high likelihood of losing a greater quantity of plant and vertebrate species due to habitat loss (Flores–Villera and García–Vázquez, 2014; Navarro–Sigüenza et al., 2014; Sánchez–Cordero et al., 2014). Although in this region there is a Natural Protected Area (the Lagoons of Chacahua National Park, LCNP), areas around the region have been deforested (Contreras et al., 1997; Pérez, 2002). In contrast, several inaccessible areas maintain well–conserved semi–deciduous tropical forest (Lira–Torres et al., 2005).

Within this region, which constitutes the Río Verde basin, the construction of a hydroelectric dam is being planned. This dam would directly affect 3,100 hectares in 15 villages and six municipalities inhabited by Mixtec and Chatino people. Besides, it is unknown how dam construction would affect the vast biodiversity of the region. In sites near Río Verde basin, mammalian presence surveys have been conducted (Lira–Torres et al., 2005; Lira–Torres, 2006; Buenrostro–Silva et al., 2012), but a site study during the dam pre–construction phase is needed for later comparison of changes in the diversity of mammal assemblages in response to construction.

The aims of this work were to compare the parameters of the mammal community (species richness, relative abundance, and alpha diversity) between temperate forest, deciduous forest and agricultural areas in the Río Verde basin, southwestern Oaxaca, Mexico. Information will be useful to guide mitigation, restoration and compensation measures during the implementation of the hydroelectric project.

## Material and methods

### Study site

The Río Verde basin is an exorheic basin, located in the southwest of the State of Oaxaca, Mexico (15° 56' 55" N – 6° 18' 15" N, 97° 26' 23" W – 97° 58' 36" W). It has an approximate extension of 1,640 km$^2$ (fig. 1). The climate is warm semi–humid (Aw) and semi–warm semi–humid [(A)C(w)]; annual precipitation is 2,245 mm (Trejo, 2004).

The types of forest predominant in the middle of the Río Verde basin are pine forest, oak forest, montane cloud forest, deciduous tropical forest, semi deciduous tropical forest, savannas and areas of agricultural and rangelands. In the lowlands of the basin, deciduous and semi–deciduous tropical forest, areas of agricultural and pastureland, savannas and mangrove prevail (Arriaga et al., 2000; Ortiz–Pérez et al., 2004). Due to the complexity of the terrain, pine forest, oak forest and montane cloud forest fragments are interspersed up to 1,000 m a.s.l. Thus, in this study, these forests were grouped and named temperate forest, covering approximately 37.16% of the basin (609 km$^2$). The deciduous and semi–deciduous tropical forest was named deciduous forest (below 1,000 m a.s.l.) and cover approximately 27.06% of the basin (444 km$^2$). Finally, areas with corn crops, plots with fruit trees and pasture lands were grouped and named areas of agricultural areas that cover 33.68% of the basin (552 km$^2$).

### Methods

We conducted seven sampling visits in the Río Verde basin from January to November 2009. During each period we took at least one sample for each vegetation group at three locations, giving a total of 20 sampled locations, and covering the rainy season and the dry season: six in temperate forest, seven in deciduous forest, and seven in agricultural areas. Each locality was surveyed for three consecutive days. The sites were selected on the basis of the vegetation type and low human presence (fig. 1).

Small mammals (< 100 g) were captured using 100 Sherman traps baited with a peanut butter, vanilla essence and oats mixture. Traps were set daily along two 500 m lineal transect. Throughout the study, a total of 3,800 Sherman/trap/days were set up. We also placed 100 pitfall traps, that were separated from each other by about 2 m and situated, in places with leaf litter and near fallen logs.

Bats were captured at each site using four mist nets (12 x 2.4 m) that were deployed for seven hours

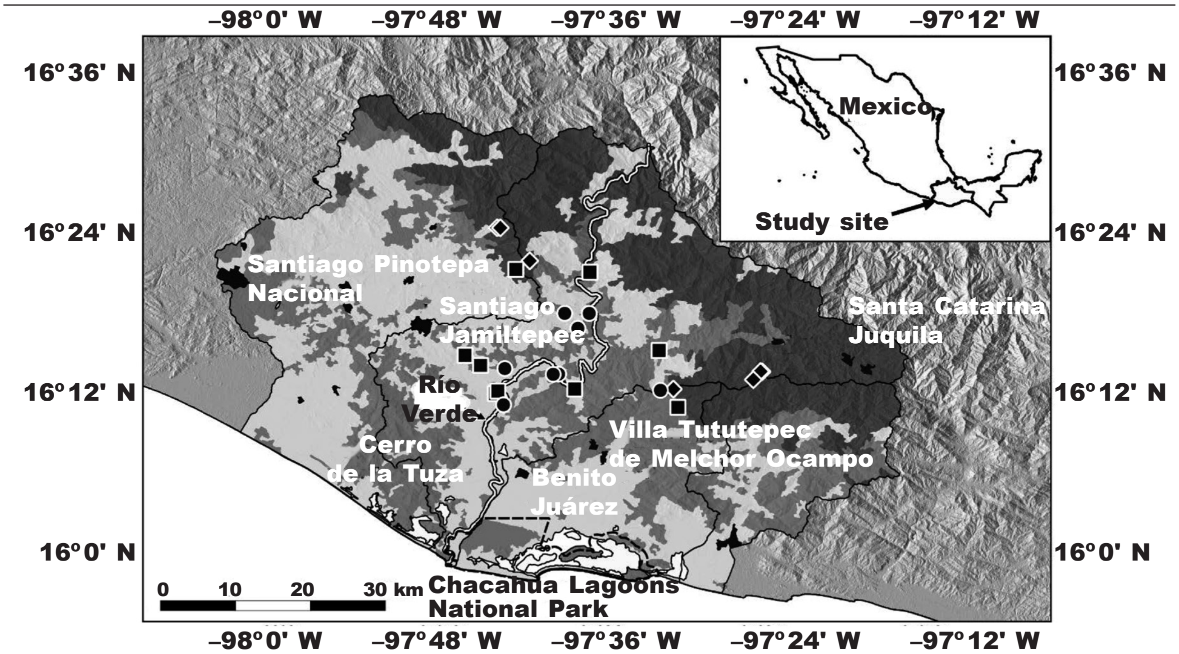


Fig. 1. Geographic location of the Río Verde basin, Mexico. Localities surveyed: circles, agricultural areas; diamonds, temperate forests; squares, deciduous forests. Type of vegetation and cover: light gray, agricultural areas; medium gray, deciduous forests; dark gray, temperate forests; black, human settlements.

*Fig. 1. Localización geográfica de la cuenca del Río Verde, en México. Localidades estudiadas: círculos, zonas agrícolas; rombos, bosques templados; cuadrados, bosques deciduos. Tipo de vegetación y cobertura: gris claro, zonas agrícolas; gris medio, bosques deciduos; gris oscuro, bosques templados; negro, asentamientos humanos.*

every night (19:00 a 02:00 h); the total sampling effort for bats was 10,944 m net/h.

In the case of medium and large–sized mammals (1,000–10,000 g), two linear transects of approximately 2.5 km in length were distributed randomly at each locality and walked for the signs of tracks and/or feces (Aranda, 2000). A total of 152 km of transects were walked. To complete the inventory, we placed five Tomahawk–type traps, with double–door folding, 24 x 6 x 6. The bait was sardine. In addition, five trap cameras (Cuddeback ®) were used. The cameras were set at a height between 30 and 50 cm from the ground along natural paths, and roads or sites where we observed tracks. Geographical coordinates and elevation were recorded with a global positioning system (GPS; Datum WGS84). Survey efforts were similar in deciduous forest and agricultural areas (1,400 Sherman/trap/days; 4,032 m net/h and 56 km in each one), while in the temperate forest the survey effort was lower (1,000 Sherman trap/day; 2,880 m net/h and 40 km). In the temperate forest it was not possible to perform a sampling period due to security problems.

Mammal individuals were taxonomically determined using specialized keys (Ceballos and Miranda, 1986; Álvarez et al., 1994; Medellín et al., 1997). Nomenclature was updated following Ramírez–Pulido et al. (2014). Most individuals were released at the site of capture; only a small sample was prepared as museum specimens following Hall (1981) recommendations. These specimens are deposited in the Mammals Collection at the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional (CIIDIR), Unidad Oaxaca (OAX.MA.026.0497), Instituto Politécnico Nacional. Specimens were captured and collected with the license for scientific collection issued by the Mexican Secretaría de Medio Ambiente y Recursos Naturales (FAUT–0037; SEMARNAT, 2010).

## Data analyses

Species richness for the whole community and between ensembles was counted as the total number of species at each vegetation type. The species relative abundance was calculated as the quotient of the number of individuals of every species and the survey effort applied to record it (Davis and Winstead, 1987; Medellín, 1993). In the case of small mammals, the effort applied was measured as the number of traps/day, whereas for bats was the number of m net/hour. Finally, for the medium and large–sized mammals, abundance was estimated considering the number of signs recorded per km walked. To compare the patterns of species abundance and composition between the different types of vegetation, we elaborated curves of rank abundance. These graphs are a useful tool to visualize attributes of the assemblage such as species richness (number of points), evenness (slope), number of rare species (tail of the curve), and relative abundance of each species (order of the species in the graph) (Feinsinger, 2001; Avila–Cabadilla et al., 2009).

We performed species accumulation curves using the iNEXT software program. The iNEXT performs sample curves based on the Hill numbers, based on rarefaction and extrapolation (Chao et al., 2016). Using iNEXT we computed the non–asymptotic approach due to large and heterogeneous study area.

Alpha diversity was estimated with the calculus of the effective number of species (${}^{q}D$), which measures the diversity that a virtual community would have integrated by *i* species. The values obtained by this diversity index could be interpreted as a virtual community in which all the species have the same abundance. The equation is (Jost, 2007):

$${}^{q}D = (\sum^{S} p_i^{q})^{1/(1-q)}$$

where $p_i$ is the abundance of the species *i* divided between the sum of the total of abundances of *S* species that compose the whole community; the *q* exponent is the order of the diversity. As this estimator is affected by the abundance of the species, three orders were considered: (i) $q = 0$, it does not consider the abundances of the species, so it is equivalent to the species richness (${}^{0}D$); (ii) $q = 1$, all the species are included with a weight exactly proportional to their abundance in the community (${}^{1}D$) exponential of Shannon´s entropy index; (iii) $q = 2$, it is the inverse of the Simpson index and considers only the commons species, excluding the rare species (${}^{2}D$) (Jost, 2007). Effective number of species allows to measure magnitudes of change in communities (García–Morales et al., 2011; Moreno et al., 2011).

In order to balance the variability in the survey effort due to logistic and environmental factors and low detectability of the rare species, we generated models to estimate the diversity in the communities. In the case of diversity ${}^{0}D$, we used the nonparametric abundance–based coverage estimator (ACE). To estimate ${}^{1}D$ and ${}^{2}D$, we used the maximum likelihood estimator (MLE; Chao and Shen, 2010).

The estimators and standard error were calculated for each type of vegetation and mammal ensemble with SPADE software program (Chao and Shen, 2010). The beta diversity was obtained using Jaccard's qualitative similarity index; the range of values for this index is 0 when there are no shared species between the two sites, and up to 1 when the sites have the same composition, with the unweight pair–group method for arithmetic averages (UPGMA) was used. The measure of magnitudes of change between communities was analyzed through the selection of the cover with the highest value of diversity (orders 0, 1, and 2), and calculating the percentage representing the diversity value of the two remaining covers with respect to this.

The accumulated species richness for the whole Río Verde basin was obtained by comparing merging species of previous published works (Lira–Torres et al., 2005; Buenrostro–Silva et al., 2012). Conservation status and regulation of the species was consulted in the Norma Oficial Mexicana 059 (NOM–ECOL–059–2010; SEMARNAT, 2010), the Red List of the International Union for Conservation of Nature (IUCN, 2017), and the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2014).

## Results

### Species richness

Species richness differed in the types of forests studied. In the deciduous forest, 43 species, 34 genera, and 16 families were recorded; in the temperate forest there were 31 species, 22 genera, and 20 families; and in the agricultural areas, there were 30 species, 25 genera, and14 families. For the ensembles of bats and small mammals, the highest species richness was observed in the deciduous forests (21 and 12 species, respectively). Finally, for the ensemble of medium and large–sized mammals, the highest species richness was recorded in the agricultural areas (11 species).

### Relative abundance

Among the bats, *Artibeus jamaicensis* (Jamaican fruit–eating bat) was the most frequent species in both deciduous forest and agricultural areas, while in temperate forest it was *Sturnira parvidens* (little yellow–shouldered bat) (fig. 2).

The small mammals, *Peromyscus aztecus* (Aztec deermouse), *P. mexicanus* (Mexican deermouse), and *Heteromys pictus* (painted spiny pocket mouse) were the most frequent species in the temperate forests, deciduous forest and agricultural areas, respectively (fig. 2). Finally, for medium and large–sized mammals we did not observe any pattern in their relative abundance because in temperate forest three species had the same high relative abundance value. In the deciduous forest, *Dasypus novemcinctus* (nine–banded armadillo) and *Didelphis virginiana* (Virginia opossum) were the most frequent species; and *D. novemcinctus*, *Procyon lotor* (Raccoon) and *D. virginiana* in the agricultural areas (fig. 2).

### Alpha diversity

The extrapolation species curves suggest that temperate forests and agricultural areas have a similar species diversity and tend to an asymptote, whereas the deciduous have a higher species diversity and a likelihood to increase. For small mammals differences in species diversity were estimated, but confidence intervals overlap; only agricultural areas tend to an asymptote. The curves for medium and large–sized mammals suggest an asymptote for temperate forests, whereas for deciduous forests and agricultural areas the need for additional surveys was evident (fig. 3).

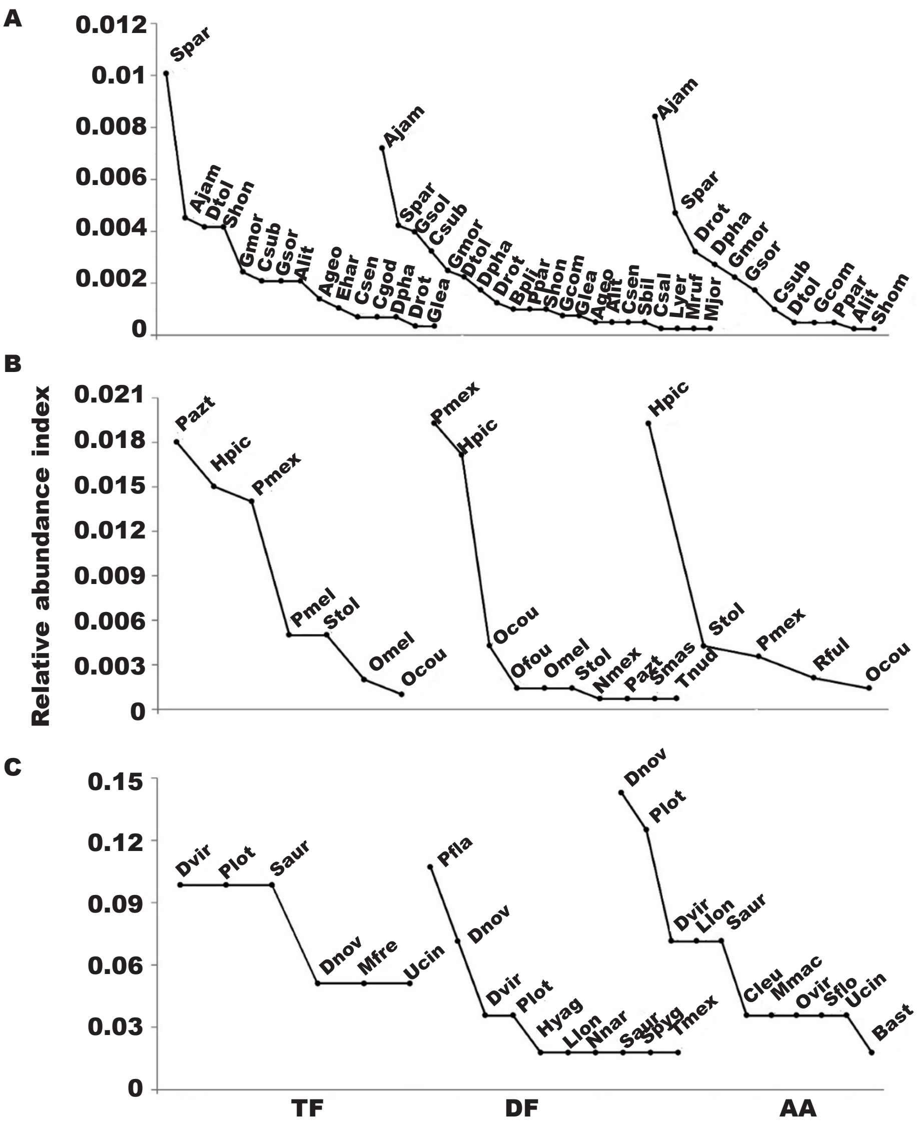


Fig. 2. Rank abundance curves of mammal communities in the Río Verde basin, Mexico: A, bats; B, small mammals; C, medium and large–sized mammals; TF, temperate forests; DF, deciduous forests; AA, agricultural areas. Letters on the curves indicate species (see list of abbreviations in table 3).

*Fig. 2. Curvas de rango–abundancia de las comunidades de mamíferos en la cuenca del Río Verde, en México: A, murciélagos; B, mamíferos pequeños; C, mamíferos de talla mediana y grande; TF, bosques templados; DF, bosques caducifolios; AA, zonas agrícolas. Las letras encima de las curvas indican las especies (véase la lista de abreviaturas en la tabla 3).*

Diversity of the order 0 was highest in the deciduous forest in the whole community, and in the ensembles of bats, small mammals, and medium and large–sized mammals. Considering the abundances of the species with the same proportional weight as their abundance in the community (diversity of the order 1) and only for the most common species (diversity of the order 2), we found that in the whole community and in bats that deciduous forest was the most diverse. However, small mammals were the most diverse in the temperate forest, while medium and large–sized mammals were most diverse in agricultural areas (table 1; fig. 4).

When comparing magnitudes in the diversity, we found that for the order 0, temperate forests and agricultural areas represented between 40 and 77 % of the diversity estimated in deciduous forests. In the diversity of the orders 1 and 2, magnitudes between covers showed a similar pattern. First, the temperate forests had a higher proportion of the diversity esti-

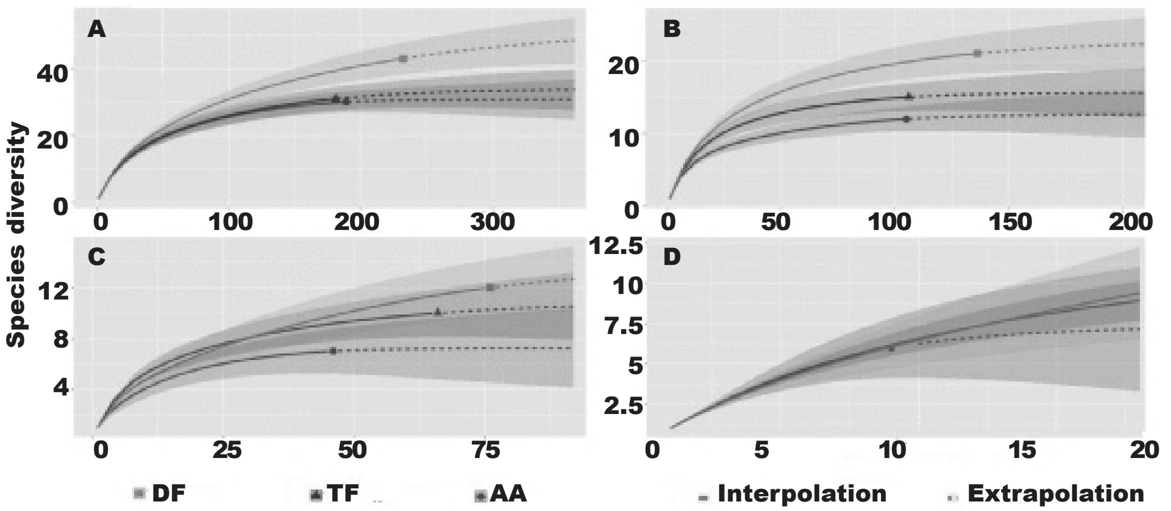


Fig. 3. Interpolation and extrapolation curves of diversity of species in mammal communities in the Río Verde basin, Mexico: A, whole community; B, bats; C, small mammals; D, medium and large–sized mammals; DF, deciduous forests; TF, temperate forests; AA, agricultural areas.

*Fig. 3. Curvas de interpolación y extrapolación de la diversidad de especies en las comunidades de mamíferos de la cuenca del Río Verde, en México: A, toda la comunidad; B, murciélagos; C, mamíferos pequeños; D, mamíferos de talla mediana y grande; DF, bosques caducifolios; TF, bosques templados; AA, zonas agrícolas.*

Table 1. Diversity values of mammals in the Río Verde basin, Mexico: N, number of individuals; S, observed diversity; ${}^0D$, species richness, order 0; ${}^1D$, exponential of Shannon entropy index; ${}^2D$, inverse of the Simpson index. (The standard error is shown in brackets).

*Tabla 1. Valores de diversidad de las comunidades de mamíferos en la cuenca del Río Verde, en México: N, número de individuos; S, diversidad observada; ${}^0D$, riqueza de especies, orden 0; ${}^1D$, exponencial del índice de entropía de Shannon; ${}^2D$, inverso del índice de Simpson. (El error estándar está entre paréntesis).*

| | N | S | ${}^0D$ | ${}^1D$ | ${}^2D$ |
|---|---|---|---|---|---|
| Whole community | | | | | |
| Temperate forests | 181 | 31 | 37.7 (4.2) | 19.56 (1.328) | 14.16 (0.157) |
| Deciduous forests | 232 | 43 | 57.6 (7.9) | 23.52 (1.579) | 15.96 (0.136) |
| Agricultural areas | 189 | 30 | 35 (3.2) | 17.95 (1.303) | 12.09 (0.15) |
| Bats | | | | | |
| Temperate forests | 106 | 15 | 17.7 (2) | 10.33 (0.872) | 7.57 (0.193) |
| Deciduous forests | 136 | 21 | 23.9 (2.8) | 13.24 (1.003) | 9.76 (0.171) |
| Agricultural areas | 105 | 12 | 18.3 (5.4) | 7.49 (0.652) | 5.61 (0.256) |
| Small mammals | | | | | |
| Temperate forests | 66 | 10 | 11.1 (1.7) | 6.62 (0.638) | 5.35 (0.202) |
| Deciduous forests | 76 | 12 | 16.7 (4.6) | 5.83 (0.703) | 4.09 (0.282) |
| Agricultural areas | 46 | 7 | 7.5 (0.9) | 3.87 (0.591) | 2.62 (0.224) |
| Medium and large–sized mammals | | | | | |
| Temperate forests | 9 | 6 | 9 (3.2) | 5.67 (0.618) | 5.40 (0.237) |
| Deciduous forests | 20 | 10 | 20.5 (9.8) | 7.71 (1.26) | 6.06 (0.247) |
| Agricultural areas | 38 | 11 | 11.5 (0.9) | 9.22 (0.865) | 7.93 (0.096) |

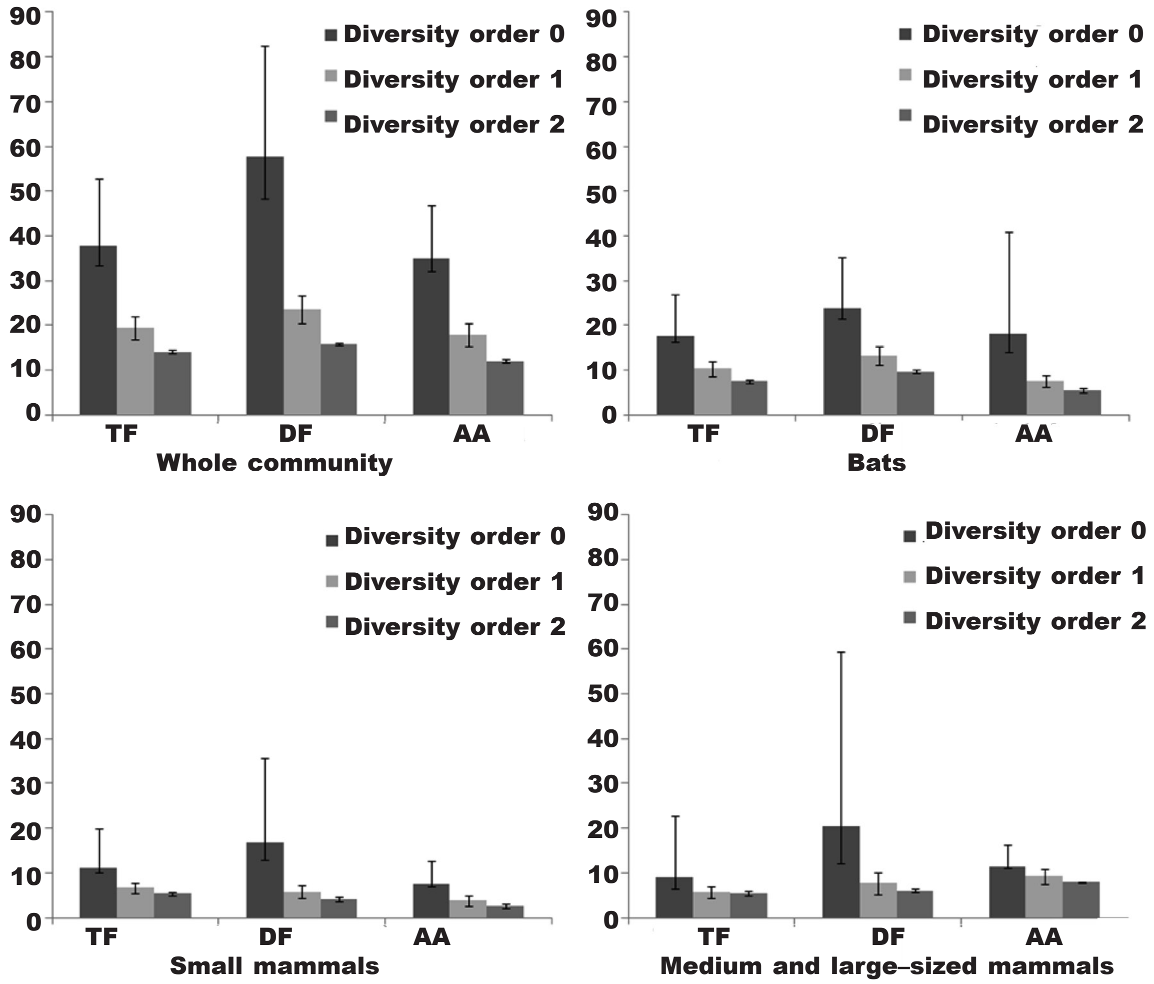


Fig. 4. Diversity index of the mammal communities in the Río Verde basin, Mexico: TF, temperate forests; DF, deciduous forests; AA, agricultural areas.

*Fig. 4. Índices de diversidad de las comunidades de mamíferos en la cuenca del Rio Verde, en México: TF, bosques templados; DF, bosques caducifolios; AA, zonas agrícolas.*

mated in deciduous forests for the whole community (order 1 = 83 %, order 2 = 89 %) and for bats (order 1 = 78 %, order 2 = 78 %) than the agricultural areas (76 % and 76 %, and 57 % and 58 %, respectively). We also found that deciduous forests had a higher proportion of diversity of small mammals (order 1 = 88 %, order 2 = 77 %) in temperate forests than in agricultural areas (order 1 = 58 %, order 2 = 49 %). Finally, the deciduous forests had higher a proportion of diversity of medium and large–sized mammals (order 1 = 84 %, order 2 = 76 %) in agricultural areas than in temperate forests (order 1 = 62 %, order 2 = 68 %) (fig. 5).

## Beta diversity

Nineteen species were shared in the three types of cover studied. Six species were found in the temperate forest only, 15 in the deciduous forest only, and six in the agricultural areas only (table 2). In the whole community, the highest similitude was observed between temperate forest and agricultural areas (0.488). For the ensemble of bats, the highest similitude was between temperate forest and agricultural areas (0.588). For the ensemble of small mammals, the highest similitude was observed between temperate forests and deciduous forests (0.467). Finally, for the ensemble of medium and large–sized mammals, the highest similitude was between temperate forest and agricultural areas (0.416) (table 2). On the other hand, dendograms had the same shape for the whole community, for bats and for the medium and large–sized mammals: a node formed by the temperate forest and agricultural areas. In the case of the small mammals, the temperate forests and the deciduous forests formed a group (fig. 6).

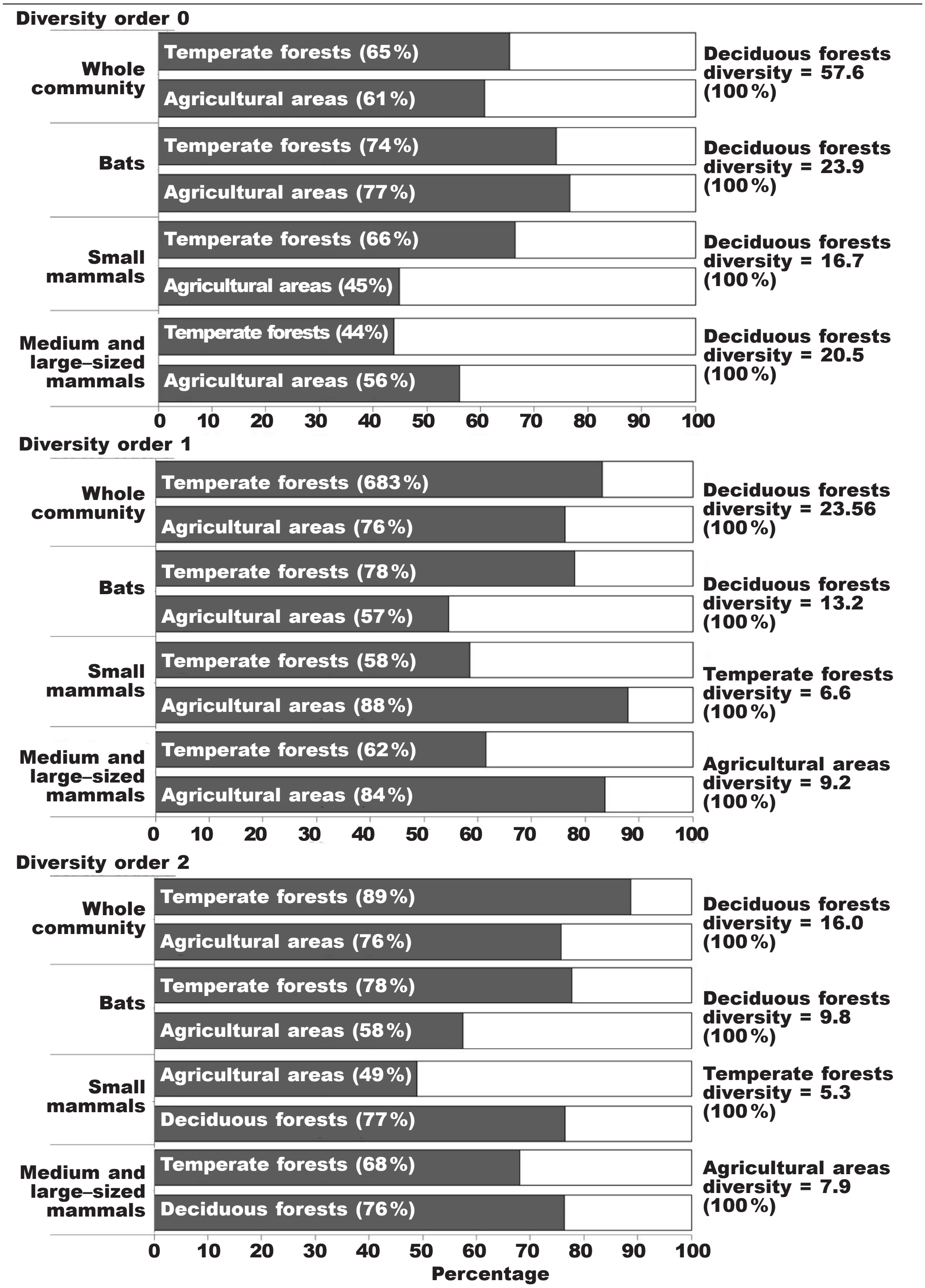


Fig. 5. Magnitudes of the diversity of mammal communities in the Río Verde basin, Mexico.

*Fig. 5. Magnitudes de la diversidad de las comunidades de mamíferos en la cuenca del Río Verde, en México.*

Accumulated species richness

In this study we report the presence of 58 mammal species, 19 of which were not recorded in previous surveys (table 1s in supplementary material). If we consider the 52 species reported by Lira–Torres et al. (2005), and the 42 species by Buenrostro–Silva et al. (2012), the mammalian accumulated species richness for the Río Verde basin is 73 species, belonging to 56 genera, 24 families and 10 orders.

Conservation status

According to the Mexican Official Norm 059 (SEMARNAT, 2010), five species are Endangered (*Tamandua mexicana*, *Leopardus pardalis*, *L. wiedii*, *Potos flavus*, *Tapirella bairdii*), six species are Threatened (*Leptonycteris nivalis*, *L. yerbabuenae, Coendou mexicanus, Herpailurus yagouaroundi, Spilogale pygmaea and Lontra longicaudis*), and two are Subject to special protection (*Enchisthenes hartii, Bassariscus sumichrasti*). In the Red List of the IUCN, five species are Endangered, two species are Vulnerable and two species are Near threatened. The CITES Appendices included four species in Appendix I, one species in Appendix II, and five species in Appendix III (table 1s in supplementary material).

Table 2. Affinity matrix of the mammalian species in the different types of vegetation and land use in the coast of Oaxaca, México: TF, temperate forests; DF, deciduous forests; AA, agricultural areas. (The numbers in bold correspond to the total species in each forest, and the exclusive species are shown in brackets.)

*Table 2. Matriz de afinidad de las especies de mamíferos en los diferentes tipos de vegetación y uso de suelo en la cuenca del Rio Verde, México: TF, bosques templados; DF, bosques caducifolios; AA, zonas agrícolas. (Los números en negritas corresponden al total de especies en cada tipo de cobertura y ente paréntesis el número de especies exclusivas.)*

| | TF | DF | AA |
|---|---|---|---|
| Whole community | | | |
| Temperate forests | **31(6)** | 0.480 | 0.488 |
| Deciduous forests | 5 | **43(15)** | 0.460 |
| Agricultural areas | 1 | 4 | **30(6)** |
| Bats | | | |
| Temperate forests | **15(2)** | 0.565 | 0.588 |
| Deciduous forests | 3 | **21(6)** | 0.571 |
| Agricultural areas | 0 | 2 | **12(0)** |
| Small mammals | | | |
| Temperate forests | **10(3)** | 0.467 | 0.416 |
| Deciduous forests | 2 | **12(4)** | 0.461 |
| Agricultural areas | 0 | 0 | **7 (1)** |
| Medium and large–sized mammals | | | |
| Temperate forests | **6(1)** | 0.333 | 0.416 |
| Deciduous forests | 0 | **10(5)** | 0.312 |
| Agricultural areas | 1 | 1 | **11(5)** |

## Discussion

Species richness and composition

The Río Verde basin is located within a region of high biodiversity (Olson and Dinerstein, 1998; Mittermeir et al., 2011). With respect to mammalian species richness, in Mexico there are 496 species (Ramírez–Pulido et al., 2014), 73 of which (14.7 %) inhabiting the Río Verde basin were collected in this study or are recorded in literature. The mammalian species richness accumulated in this basin is higher than reported for any other site along the Mexican Pacific coast (59–70 species; Ceballos, 1995; Cervantes and Yépez, 1995; Lira–Torres et al., 2008; López et al., 2009; Briones–Salas et al., 2016). This high species richness could be explained by the latitudinal pattern of mammalian species richness along the Pacific coast, which increases as latitude decreases (Ceballos, 1995). The landscape heterogeneity, with several types of vegetation in the study site, also contributes to the high species richness.

In the Río Verde basin, we found differences in species richness between the forests studied, with richness being higher in the deciduous forests than in the temperate forests or agricultural areas. In particular, agricultural areas had 33 % fewer species than deciduous forests; differences between this cover land were most notable for bats (43 %) and small mammals (42 %). Furthermore, the effective number of species shows a similar pattern of loss of diversity in these mammal groups. This loss of mammal diversity due to change of land use has frequently been observed in the neotropics, where the degree of change and configuration of the landscape has been seen to affect both species richness and their abundance (Estavillo et al., 2013; Roque et al., 2018).

Although the temperate forests had few small mammal species, relative abundance was distributed more evenly than for species in the deciduous forests or in the agricultural areas. In turn, the deciduous forests presented a greater species richness and a highest number of rare species. In contrast, the agricultural areas were characterized by one very dominant species and lower species richness. In this study, the small species loss reached 50% between deciduous forests and agricultural areas. Such results fit findings from one of the most notable studies in human–altered environments, where a small number of species benefit from the disturbances while other more sensitive species disappear (McKinney and Lockwood, 1999; McGill et al., 2015).

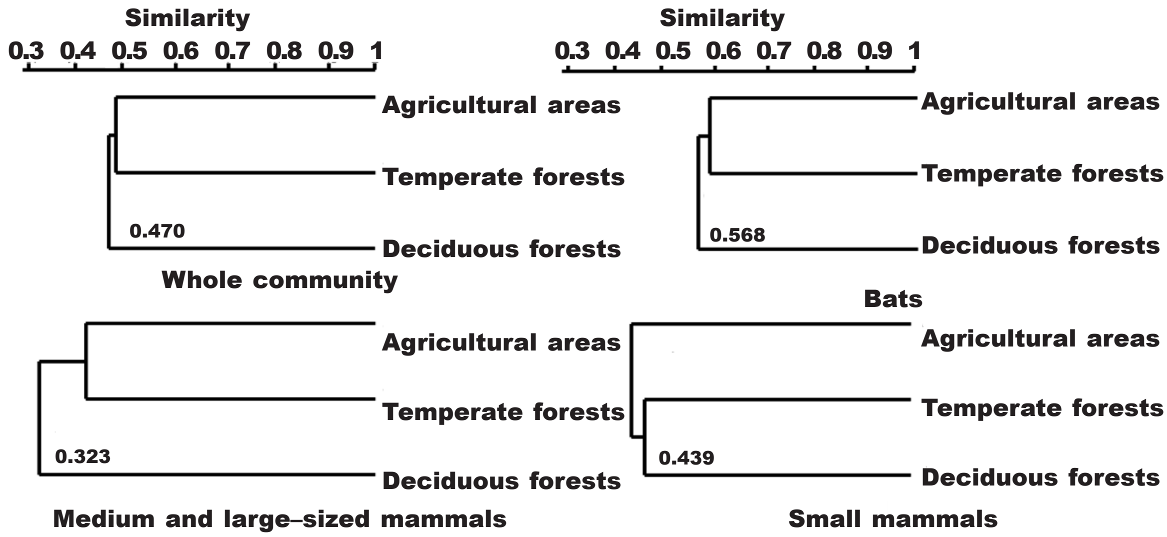


Fig. 6. Specific similarity in mammal communities in the Río Verde basin, Mexico: A, whole community; B, bats; C, small mammals; D, medium and large–sized mammals.

*Fig. 6. Similitud específica en las comunidades de mamíferos de la cuenca del Río Verde, en México: A, toda la comunidad; B, murciélagos; C, mamíferos pequeños; D, mamíferos medianos y grandes.*

With respect to the ensemble of bats, we found that the deciduous forest and the agricultural areas showed a similar pattern in the relative abundance of species, *A. jamaicensis* was the dominant species, followed by *S. parvidens*. *A. jamaicensis* showed higher relative abundance in sites within agricultural areas, a finding coincides with other studies that established that abundance of *A. jamaicensis* increases with the level of perturbation (Fenton et al., 1992; Vargas et al., 2008; Murillo–García and Bedoya–Durán, 2014). Gorresen and Willing (2004) suggest that adaptability of *Artibeus* to perturbation is due to its ability to perform long flights, which allows them to explore large fragments of vegetation within the landscape. Another similitude with the works cited was the high frequency of *Desmodus rotundus* (common vampire bat) in agricultural areas, a consequence of the highest availability of food (Fenton et al., 1992). For these reasons, *A. jamaicensis* and *D. rotundus* are recognized as able to adapt to habitat fragmentation and as indicator of sites with perturbation (Wilson et al., 1996; Galindo–González, 2004).

In contrast with other neotropical regions, in this study, rare species, such as Phyllostominae subfamily species, which are good indicators of non–perturbed sites, were not recorded (Wilson et al., 1996; Castro–Luna et al., 2007). This is because on the Mexican Pacific coast there are currently no representatives of this subfamily. Instead, the composition of nectarivorous species (the Glossophaginae subfamily) changed between deciduous forests and agricultural areas, with higher species richness and abundance in the former. Although overall nectarivorous species are adaptable to human land–use, their response to the type of perturbation is variable, showing a preference for an agroforestry crop system when compared with well–preserved forest; these bats select well–preserved forest over monocultures, silvopastoril systems or induced grasslands (García–Morales et al., 2013). The usefulness of Glossophaginae species as an indicator group in deciduous forest throughout the Pacific coast should be explored in further studies.

In the ensemble of small mammal, the species with higher relative abundance are known to be common in the forests surveyed; *Peromyscus aztecus* in temperate forests at elevations from 1,000 to 2,700 m a.s.l. (Vázquez et al., 2001) and *P. mexicanus* in deciduous forest (Trujano–Alvarez and Alvarez–Castañeda, 2010). *Heteromys pictus* occupied place regarding highest relative abundance in both deciduous and temperate forests but dominated broadly in the ensemble of small mammals in the agricultural areas. This species is capable of taking advantage of secondary vegetation, and agriculture and pasture lands, with higher densities due to the high availability of food (Briones–Salas and González–Pérez, 2016).

Unexpectedly, the agricultural areas had the highest species richness and relative abundances of medium and large-sized mammals. These findings, however, could be an artifact of the sampling technique, the search for tracks. Tracks are more visible on uncovered terrain in the agricultural areas and species common and tolerant to perturbations (e.g. *Urocyon cinereoargenteus,* gray fox; *Odocoileus virginianus,* white–tailed deer) usually visit this types of land cover in search of food (Lira–Torres, 2006).

Despite the sampling technique, endemic (*Spilogale pygmaea,* pygmy skunk) and endangered species (*Potos flavus*, *H. yagouaroundi,* jaguarondi; and *Tamandua mexicana,* Northern anteater) were only recorded in the deciduous forests by means of tracks and visual observations. In turn, the temperate forests had few species, all of which are common in several types of ecosystems (Briones–Salas et al., 2015). Surveys for medium and large–sized mammals in the three cover types could be improved with the use of complementary techniques such as camera trapping (Silveira et al., 2003; Cortés–Marcial et al., 2014).

Species diversity

Effective number of species showed a generalized loss of diversity with respect to land–use change for agricultural purposes, except for the ensemble of medium and large–sized mammals, which showed the highest diversity in this type of cover. For the ensemble of bats, both species richness and diversity were highest in the deciduous forests.

Differences in diversity in perturbed and unperturbed sites have been found in Yucatán, Mexico (Fenton et al., 1992), but near the study site, Barragán et al. (2010) found no difference in the abundance and diversity of small mammals and bats with respect to perturbation. Castro–Luna et al. (2007) found similar results in successional stages of vegetation, with no differences in diversity. Likewise, in a semi–deciduous forest in Nicaragua, Medina et al. (2007) did not find any differences in diversity between perturbed and unperturbed sites. However, in these studies, estimators that do not allow a direct comparison were applied. Thus, a reanalysis could give different conclusions (Moreno et al., 2011). In this study, the loss of bat diversity was noteworthy, with a difference of nine species between deciduous forests and agricultural areas, and a decrease in the diversity of order 1 in 23.7% in agricultural areas. On the contrary, diversity of medium and large–sized mammals was highest in sites with agricultural areas, followed by deciduous forests and temperate forests. As mentioned above, sampling favored agricultural areas, affecting measures of diversity. Using complementary methods, tracks and camera trapping in the Isthmus of Tehuantepec, Oaxaca, Cortés–Marcial et al. (2014) found that the diversity of this group of mammals was high in low–degradation environments and in environments with a low density of livestock.

Conservation status

Thirteen species (18.05%) have a certain level of protection. Seven of these species belong to the Carnivora order; two are *Leopardus* genus*,* whose main threat is habitat loss and the illegal hunting for their fur (Aranda, 2005a, 2005b). The presence of *Tapirella bairdii* (Baird's tapir), an endangered species, is also noteworthy because the study site could host the northern–most population (Lira–Torres et al., 2006). The protection of this and other endangered species, such as *Panthera onca* (jaguar), was the impetus for creating the LCNP (Mexican Government, 1937). However, habitat loss within and around the park has been significant.

Management implications

Due to the planned construction of a dam and the current land–use change rates in the Río Verde basin (Salas–Morales and Casariego–Madorell, 2010), it is necessary to apply conservation policies that guarantee the functionality of the ecosystem and the perpetuity of wildlife populations and to take strong actions to protect the endangered species. Given the imminent hydroelectric development in the study site, as a mitigation measureand on the basis of the results here presented, action should be focused on avoiding loss and fragmentation of the tropical deciduous forests.Furthermore, connectivity through corridors into agricultural areas should be promoted in this type of land cover (Estrada and Coates–Estrada, 2001).

As a final consideration, during the dam filling several species of low mobility such as small mammals would likely drown. A wildlife rescue program should therefore be established for this phase. Particularly for terrestrial fauna, wildlife rescue is an undeniable measure. During the filling of the Chiew Larn dam in Thailand, for example, 1,364 animals were captured and translocated (Nakhasathien, 1989), and in the construction of the Petit Saut dam in French Guiana 5,500 animals were rescued (Vié, 1999).

A compensatory measure should be to establish a protected area of fauna and flora through partnership between government and local communities. The protected area should have a similar extension to the dam and provide the same type of covers. Such an area will help the translocation actions and serve as a refuge to displaced animals. In addition, considering these translocations and the displacement of medium and large–sized mammals to new areas, a post–construction survey could be advisable for management and conservation. The carrying capacity of habitats may be another issue of concern.

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## Supplementary material

Table 1s. List of mammals recorded in the Río Verde basin, Mexico. Risk categories NOM–59 (SP, subject to special protection; A, threatened; P, endangered). Risk categories IUCN (VU, vulnerable; NT, near threatened; EN, endangered). Type of record (TR: L, literature; C, collected; P, photography/visual; T, tracks; * roadkill).

*Tabla 1s. Lista de las especies de mamíferos registrados en la cuenca del Río Verde, en México. Categorías de riesgo NOM–59: Pr, Sujeta a protección especial; A, Amenazada; P, En peligro de extinción. Categorías de riesgo IUCN: VU, Vulnerable; NT, Near threatened; EN, Endangered. Tipo de registro (TR: L, literatura; C, colectado; P, fotografía/visual; T, huella; * muerte en carretera).*

| Order, Family | | | | | | |
|---|---|---|---|---|---|---|
| Scientific name | Code | Common name | NOM–59 | IUCN | CITES | TR |
| Order Didelphimorphia | | | | | | |
| Family Didelphidae | | | | | | |
| *Didelphis marsupialis* Linnaeus, 1758 | | Common opossum | | | | L, P |
| *Didelphis virginiana* Kerr, 1792Dvir | | Virginia opossum | | | | C, L |
| *Marmosa mexicana* Merrian, 1897 | | Mexican mouse opossum | | | | C |
| *Tlacuatzin canescens* (J. A. Allen, 1893) | | Gray mouse opossum | | | | L |
| Order Cingulata | | | | | | |
| Family Dasypodidae | | | | | | |
| *Dasypus novemcinctus* Linnaeus, 1758 | Dnov | Nine–banded armadillo | | | | C, L, T, P |
| Order Pilosa | | | | | | |
| Family Myrmecophagidae | | | | | | |
| *Tamandua mexicana* (de Saussure, 1860) | Tmex | Northern tamandua | P | III | | C*, L |
| Order Soricomorpha | | | | | | |
| Family Soricidae | | | | | | |
| *Cryptotis mexicanus* (Coues, 1877) | | Mexican small–eared shrew | | | | C |
| *Cryptotis parvus* (Say, 1822) | | North american least shrew | | | | C |
| *Sorex ventralis* Merriam, 1895 | | Chestnut–bellied shrew | | | | C |
| Order Chiroptera | | | | | | |
| Family Emballonuridae | | | | | | |
| *Balantiopteryx plicata* Peters, 1867 | Bpli | Gray sac–winged bat | | | | C, L |
| *Saccopteryx bilineata* (Temminck, 1838) | Sbil | Greater sac–winged bat | | | | C, L |
| Family Mormoopidae | | | | | | |
| *Pteronotus parnellii* Gray, 1843 | Ppar | Common mustached bat | | | | C, L |
| Family Noctilionidae | | | | | | |
| *Noctilio leporinus* (Linnaeus, 1758) | | Greater bulldog bat | | | | L |

Table 1s. (Cont.)

| Order, Family<br>Scientific name | Code | Common name | NOM–59 | IUCN | CITES | TR |
|---|---|---|---|---|---|---|
| Family Phyllostomidae | | | | | | |
| *Carollia subrufa* (Hahn, 1905) | Csub | Gray short–tailed bat | | | | C, L |
| *Desmodus rotundus* É. Geoffroy y St. Hilaire, 1810 | | Common vampire bat | | | | C, L |
| *Anoura geoffroyi* Gray, 1838 | Ageo | Geoffroy's tailless bat | | | | C |
| *Choeroniscus godmani* (Thomas, 1903) | Cgod | Godman's long–tongued bat | | | | C |
| *Glossophaga commissarisi* Gardner, 1962 | Gcom | Commissaris's long–tongued bat | | | | C, L |
| *Glossophaga leachii* (Gray, 1844) | Glea | Gray's long–tongued bat | | | | C, L |
| *Glossophaga morenoi* Martinez y Villa, 1938 | Gmor | Western long–tongued bat | | | | C |
| *Glossophaga soricina* Pallas, 1766 | Gsor | Pallas's long–tongued bat | | | | C, L |
| *Leptonycteris nivalis* (de Saussure, 1860) | | Mexican long–nosed bat | A | EN | | L |
| *Leptonycteris yerbabuenae* Martínez y Villa, 1940 | Lyer | Lesser long–nosed bat | A | VU | | C, L |
| *Micronycteris microtis* Miller, 1898 | | Common little big–eared bats | | | | L |
| *Artibeus jamaicensis* Leach, 1821 | Ajam | Jamaican fruit–eating bat | | | | C, L |
| *Artibeus lituratus* (Olfers, 1818) | Alit | Great fruit–eating bat | | | | C, L |
| *Dermanura phaeotis* Miller, 1902 | Dpha | Pygmy fruit–eating bat | | | | C |
| *Dermanura tolteca* (de Saussure, 1860) | Dtol | Toltec fruit–eating bat | | | | C |
| *Enchisthenes hartii* (Thomas, 1892) | Ehar | Velvety fruit–eating bat | SP | | | C, L |
| *Centurio senex* Gray, 1842 | Csen | Wrinkle–faced bat | | | | C, L |
| *Chiroderma salvini* Dobson, 1878 | Csal | Salvin's big–eyed bat | | | | C |
| *Sturnira hondurensis* Goodwin, 1940 | Shon | Highland yellow–shouldered bat | | | | C |
| *Sturnira parvidens* Goldman, 1917 | Spar | Little yellow–shouldered bat | | | | C, L |
| Family Vespertilionidae | | | | | | |
| *Myotis fortidens* Miller y G. M. Allen, 1928 | Mfor | Cinnamon myotis | | | | C, L |
| Order Lagomorpha | | | | | | |
| Family Leporidae | | | | | | |
| *Sylvilagus cunicularius* (Waterhouse, 1848) | | Mexican cottontail | | | | L |
| *Sylvilagus floridanus* (J. A. Allen, 1890) | Sflo | Eastern cottontail | | | | C, P |

Table 1s. (Cont.)

| Order, Family<br>Scientific name | Code | Common name | NOM–59 | IUCN | CITES | TR |
|---|---|---|---|---|---|---|
| Order Rodentia | | | | | | |
| Family Sciuridae | | | | | | |
| *Sciurus aureogaster* F. Cuvier, 1829 | Saur | Red–bellied squirrel | | | | C, L |
| Family Geomyidae | | | | | | |
| *Orthogeomys grandis* (Thomas, 1893) | | Giant pocket gopher | | | | L |
| Family Heteromyidae | | | | | | |
| *Heteromys pictus* (Thomas, 1893) | | Painted spiny pocket mouse | | | | C |
| Family Erethizontidae | | | | | | |
| *Coendou mexicanus* (Kerr, 1792) | | Mexican hairy dwarf porcupine | A | | III | L |
| Family Cricetidae | | | | | | |
| *Baiomys musculus* (Merriam, 1892) | | Southern pygmy mouse | | | | L |
| *Neotoma mexicana* Baird, 1855 | Nmex | Mexican woodrat | | | | C |
| *Peromyscus aztecus* (de Saussure, 1860) | Pazt | Aztec deermouse | | | | C, L |
| *Peromyscus melanophrys* (Coues, 1874) | | Plateau deermouse | | | | L |
| *Peromyscus melanurus* Osgood, 1909 | Pmel | Black–tailed deermouse | | EN | | C |
| *Peromyscus mexicanus* (de Saussure, 1860) | Pmex | Mexican deermouse | | | | C, L |
| *Reithrodontomys fulvescens* J. A. Allen, 1894 | Rful | Fulvous harvest mouse | | | | C, L |
| *Reithrodontomys sumichrasti* (de Saussure, 1860) | | Sumichrast's harvest mouse | | | | L |
| *Oryzomys couesi* (Alston, 1877) | Ocou | Coues's rice rat | | | | C, L |
| *Oryzomys melanotis* Thomas, 1893 | Omel | Black–eared rice rat | | | | C |
| *Sigmodon alleni* Bailey, 1902 | | Allen's cotton rat | | | | C, L |
| *Sigmodon mascotensis* J. A. Allen, 1897 | Smas | West mexican cotton rat | | | | C |
| *Sigmodon toltecus* (de Saussure, 1814) | Stol | Toltec cotton rat | | | | C |
| *Tylomys nudicaudus* (Peters, 1866) | Tnud | Peters's climbing rat | | | | C, L |

Table 1s. (Cont.)

| Order, Family<br>Scientific name | Code | Common name | NOM–59 | IUCN | CITES | TR |
|---|---|---|---|---|---|---|
| Order Carnivora | | | | | | |
| Family Felidae | | | | | | |
| *Herpailurus yagouaroundi* (E. Geoffroy Saint–Hilaire, 1803) | Hyag | Jaguarundi | A | EN | I | C*, L |
| *Leopardus pardalis* (Linnaeus, 1758) | | Ocelot | P | EN | I | L |
| Family Felidae | | | | | | |
| *Leopardus wiedii* (Schinz, 1821) | | Margay, tigrillo | P | NT | I | C*, L |
| *Puma concolor* (Linnaeus, 1771) | | Cougar | | | | L, T |
| Family Canidae | | | | | | |
| *Canis latrans* Say, 1823 | | Coyote | | | | L, P |
| *Urocyon cinereoargenteus* (Schreber, 1775) | Ucin | Gray fox | | | | C, L, T |
| Family Mephitidae | | | | | | |
| *Conepatus leuconotus* (Lichtenstein, 1832) | Cleu | American hog–nosed skunk | | | | L, T |
| *Mephitis macroura* Lichtenstein, 1832 | Mmac | Hooded skunk | | | | C, T |
| *Spilogale pygmaea* Thomas, 1898 | Spyg | Pygmy spotted skunk | A | VU | | C, L |
| Family Mustelidae | | | | | | |
| *Lontra longicaudis* (Olfers, 1818) | Llon | Neotropical otter | A | NT | I | L, T |
| *Mustela frenata* Lichtenstein, 1831 | Mfre | Long–tailed weasel | | | | L, T |
| Family Procyonidae | | | | | | |
| *Bassariscus sumichrasti* (de Saussure, 1860) | | Ringtail, Cacomistle | PS | | III | L, T |
| *Bassariscus astutus* (Lichtnestein, 1830) | Bast | Ringtail, cacomistle | | | | T |
| *Potos flavus* (Schreber, 1774) | Pfla | Kinkajou | P | | III | F, L |
| *Nasua narica* (Linnaeus, 1766) | Nnar | Coati | | | III | F, L, T |
| *Procyon lotor* Linnaeus, 1758 | | Raccoon | | | | F, L, T |

Table 1s. (Cont.)

| Order, Family<br>Scientific name | Code | Common name | NOM–59 | IUCN | CITES | TR |
|---|---|---|---|---|---|---|
| Order Artiodactyla | | | | | | |
| Family Tayassuidae | | | | | | |
| *Dicotyles angulatus* Cope, 1889 | | Western collared peccary | | | II | F, L, T |
| Family Cervidae | | | | | | |
| *Odocoileus virginianus* Zimmermann, 1780 | Ovir | White–tailed deer | | | | F, C, L, T |
| Order Perissodactyla | | | | | | |
| Family Tapiridae | | | | | | |
| *Tapirella bairdii* Gill, 1865 | | Baird's tapir | P | EN | I | L |