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HERPETOFAUNISTIC DIVERSITY IN THE ECOLOGICAL PARK "LA JOYA–LA BARRETA", QUERÉTARO, MÉXICO: A COMPARISON BETWEEN TWO SAMPLING METHODS AND THREE VEGETATION TYPES

DIVERSIDAD HERPETOFAUNISTA EN EL PARQUE ECOLÓGICO "LA JOYA – LA BARRETA", QUERÉTARO, MÉXICO: COMPARACIÓN ENTRE DOS MÉTODOS DE MUESTREO Y TRES TIPOS DE VEGETACIÓN

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Resumen.– Por su diversidad topográfica y climática, el estado de Querétaro posee altos niveles de riqueza, abundancia y endemismo de anfibios y reptiles. Esta información debe actualizarse constantemente a medida que se exploran más las regiones con poca o ninguna información, utilizando métodos de muestreo que permiten un registro eficiente de la diversidad biológica. El objetivo de este estudio fue comparar la diversidad herpetofaunística entre tres tipos de vegetación (bosque de robles, pastizales y vegetación secundaria asociada) utilizando dos métodos de muestreo (trampas de caída y transectos). Registramos trece especies: cinco anfibios y ocho reptiles. Encontramos diferencias en la dominancia de especies con anfibios que muestran valores más altos de abundancia relativa en bosques de encino y pastizales para ambos métodos de muestreo. Los transectos mostraron un mayor número efectivo de especies para q^{o}, q^{1} y q^{2}, para ambos, anfibios y reptiles. El encinar y la vegetación secundaria poseen porcentajes de similitud comparables y no mostraron diferencias significativas. Observamos diferencias significativas entre el pastizal y la vegetación secundaria. Encontramos altos niveles de distinción (> 70%) entre las técnicas de muestreo. El presente estudio resalta la importancia de las áreas naturales protegidas como refugio para grupos amenazados como anfibios y reptiles, y destaca la importancia de utilizar métodos de muestreo complementarios.

Palabras clave.– Anfibios; áreas perturbadas; conservación; Áreas Naturales Protegidas; reptiles

Abstract.– Due to its topographic and climatic diversity, the state of Querétaro presents high levels of amphibian and reptile richness, abundance, and endemism. However, this information must be updated constantly as regions with previously little to no information are further explored, using sampling methods that allow efficient recording of biological diversity. The objective of this study was to compare herpetofaunistic diversity among three different vegetation types (oak-forest, grassland, and secondary vegetation) using two sampling methods (pitfall traps and transects). We recorded thirteen species: five amphibians, and eight reptiles. We found differences in dominance between herpetofaunal groups, with amphibians showing higher values of relative abundance in oak forest and grassland for both sampling methods. Transects showed a higher effective number of species for q0, q1, and q2, for both, amphibians and reptiles. The oak forest and secondary vegetation possess comparable similarity percentages and did not show significant differences. We observed significant differences between the grassland and secondary vegetation. We found high distinctness levels (> 70%) between sampling techniques. The present study shows the importance of protected natural areas as shelters for threatened groups such as amphibians and reptiles, and highlights the importance of using complementary sampling methods.

Keywords.– Amphibians; disturbed areas; conservation; Protected Areas; reptiles.

INTRODUCTION

Biological diversity is currently facing an unprecedented decline caused by global change that threatens richness and functioning of ecosystems (Dirzo et al., 2014). Loss of diversity is caused by alterations to primary ecological factors such as temperature and humidity that ultimately limit diversity patterns at different scales (Ochoa-Ochoa & Flores-Villela, 2009; McCain 2010; Ochoa-Ochoa et al., 2014), as well as anthropogenic factors such as pollution and habitat loss or degradation (Gibbons et al., 2000; Fischer & Lindermayer, 2007).

Amphibians and reptiles are among the most threatened groups of vertebrates and are especially susceptible to environmental disruptions, specifically to habitat modifications caused by humans that can have serious effects on the ecological, reproductive, and physiological attributes of these organisms (Berriozabal-Islas et al., 2017; Leyte-Manríquez et al., 2019). Therefore, studying them in areas with high levels of anthropogenic pressures may be useful to gauge the status of the ecosystems they inhabit (Andrews et al., 2008; Valencia-Aguilar et al., 2013).

Querétaro is the sixth smallest state in Mexico, with an area of 11,762 km2 (Gobierno del Estado de Querétaro, 2002). Regardless its small size, Querétaro harbors high levels of floral and faunal diversity (Dixon & Lemos, 2010; Jones & Serrano 2016; Zamudio, 1992). Despite the numerous studies of herpetofauna performed in Querétaro (e.g. Dixon & Lemos, 1972, 2010; Padilla, 1996; Padilla & Pineda, 1997; Cruz-Elizalde et al., 2016, 2019), basic information such as species inventories are still incomplete, especially in areas bordering urban developments that could potentially function as biodiversity reservoirs. This information is central to addressing research of current relevance, such as ecosystem degradation, habitat loss, and their effects on amphibian and reptile populations.

Due to the difficulty of performing herpetofaunistic surveys, numerous sampling techniques have been developed (e.g. time-constrained searches, quadrant searches, visual encounter surveys, pitfall and funnel traps, etc.), and these have allowed consistent improvements of species inventories (Heyer et al., 1994, McDiarmid et al., 2012). However, their use and analysis have focused on specific regions with high herpetofaunistic richness and abundance because sampling techniques respond to both, species intrinsic features (e.g. microhabitat use, activity hours, and type of foraging), and study area features (vegetation structure and composition). In this study, we analyzed the community structure of amphibians and reptiles in the ecological park "La Joya – La Barreta", comparing two sampling techniques (transects and pitfall traps) in three vegetation types (oak forest, grassland, and secondary vegetation).

MATERIALS AND METHODS

The ecological park "La Joya – La Barreta" (EPJB) is located in the northwest region of Querétaro municipality within the Protected Natural Area "Zona Occidental de Microcuencas" (Western Microbasin Zone; Fig. 1), and has an extension of 242.87 ha. It was designated as a site for Ecological Preservation under Special Protection since 1970. However, despite its designation, the park receives visitors throughout the year for ecotourism activities such as camping, hiking, and mountain biking, among others (Gobierno del Estado de Querétaro, 2012).

The EPJB covers 242.87 ha in the geographic coordinates 20.80898°N, 100.52866 ° W, and is located in the municipality of Querétaro, Santa Rosa Jauregui delegation (Gobierno del Estado de Querétaro, 2012). Over the last decades, this region was under strong anthropogenic pressures such as soil and wood extraction, as well as overgrazing. However, actions have been taken to maintain and preserve the area (UAQ, 2002). According to Köppen's classification, modified by García (2004), the climate of the region is BS1kw (w), and corresponds to general dry climates (B), specifically semidry (S1), and semidry temperate subtype (kw).

We analyzed three predominant vegetative associations described previously for the study area by Zamudio and Rzedowski (1992) and Hernández et al. (2000): grassland, oak forest, and secondary vegetation, in an elevational range of 2300 to 25000 masl. The oak forest habitat is restricted to the highest parts, and is dominated by a single species, *Quercus* aff. *castanea*, with other species scattered such as *Buddleja cordata* and *Condalia*

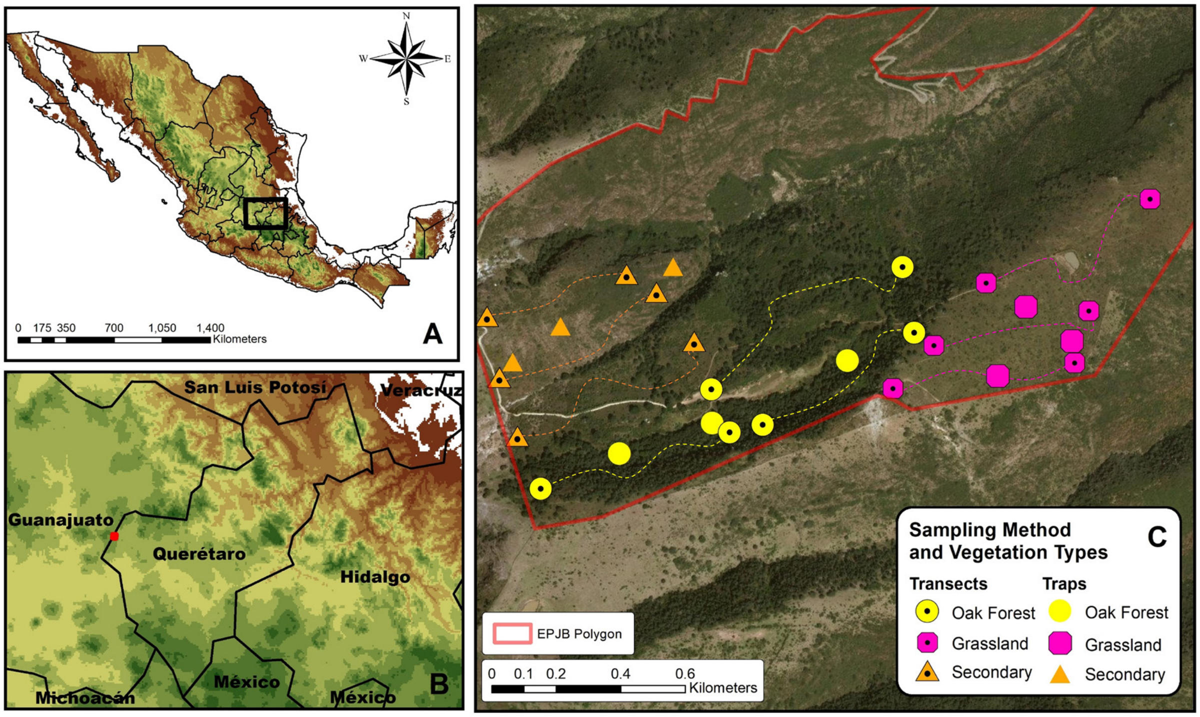

Figura 1. (A) Mapa de México mostrando la ubicación del estado de Querétaro. (B) Mapa de Querétaro y estados adyacentes mostrando en rojo la ubicación del PEJB al suroeste del estado. (C) Polígono del PEJB y disposición de los transectos y las trampas dentro del parque.

Figure 1. (A) Map of Mexico showing the location of Querétaro state. (B) Map of Queretaro and adjacent states showing in red the location of EPJB in the southwest part the state. (C) Polygon of EPJB, and placement of transects and traps within the park.

mexicana, and correspond to 59% of the total extension of the EPJB. The secondary vegetation is composed of species such as *Acacia schaffneri*, *A. farnesiana*, *Condalia mexicana*, *Prosopis laevigata*, *Ipomea murucoides*, *Myrtyllocactus geometrizans*, and some *Opuntia* spp and correspond to 24% of the total extension of the EPJB. Species registered in the grassland includes *Andropogon* sp., *Bouteloua* sp., *Eragrostis* sp., and *Aristida* sp and correspond to 17% of the total extension of the EPJB.

We performed two sampling methods: transects (500 x 30 m) and pitfall traps (a cross design with central bucket and four perimetral) associated with drift fences (metal sheets 0.5 x 5 m). We set up a total of nine transects and nine trapping stations, three for each vegetation type. We performed o total of six field trips composed of two sampling days each, with day (7:00-11:00 h) and night (19:00-23:00 h) surveys between June and October 2013. Two persons checked both, transects and traps, three times a day, accumulating a sampling effort of 192 person-hours for transects and 2754 trap-hours for pitfall traps. We performed intensive visual encounter surveys along transects in the most frequent microhabitats for herpetofauna (under logs and tree stumps, rocks, ponds, and pools; Jiménez-Velázquez & Sandoval 2010; Foster 2011). Traps remained open during the night and until noon of the next day, paying special attention to provide shelter from weather and potential predators in each trap. During the inactive period (noon to night), the traps were sealed to avoid accidental captures. Specimens were photographed and identified to species level using taxonomic keys for amphibians and reptiles of the State of Querétaro (Dixon & Lemos-Espinal, 2010). Species names were updated according to Amphibians of the World Data Base (Frost, 2020) and the Reptile Database (Uetz et al., 2020). Captured animals were released after observations were made. This study was conducted under the collection permit SGPA/DGVS/09960/12 issued by Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT).

To assess the overall inventory completeness for each sampling method, we used the non-parametric estimator Chao2 (Chao, 1987) using the software EstimateS 9.1 (Colwell, 2013). Non-parametric estimators are reliable methods for evaluating sampling completeness since they are the most rigorous and present less bias for small sample sizes than other estimators (Walther & Moore, 2005).

To compare species richness, we calculated the effective numbers of species or Hill numbers (Jost, 2006), at a sampling coverage level of 80% and using 95% confidence intervals obtained through resampling with 1000 randomizations in the iNext software (Chao & Jost, 2012; Hsieh et al., 2015). These numbers are useful because they are a simple measure that allows direct comparison of the obtained results (Jost, 2006; Moreno et al., 2011). For this analysis, we considered three diversity orders that estimate the effective numbers of species: 1) according to the net species richness (q^0), 2) according to the number of common species (q^1), and 3) according to abundant species (q^2; Jost, 2006).

To compare community composition, we created range-abundance curves (Magurran, 1998), and dendrograms employing the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm using the Jaccard similarity index, which considers species incidence (Rohlf & Fisher, 1968; Birks, 1987, Real & Vargas, 1996). Additionally, to establish whether there are differences between the species registered with both sampling methods and between vegetation types, we performed a non–parametric analysis of similarities (ANOSIM; Clarke, 1993) using the software PAST (Hammer et al., 2001).

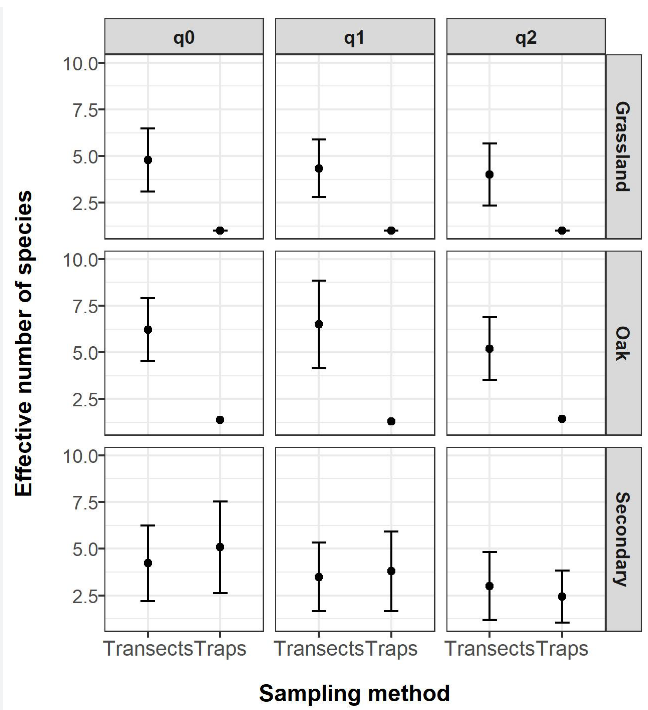

Figura 2. Número efectivo de especies estimado de acuerdo con diferentes órdenes de diversidad, método de muestreo y tipo de vegetación. Se muestran intervalos de confianza del 95%.

Figure 2. Estimated effective number of species according to diversity orders, sampling method, and vegetation type. 95% CI are shown.

To calculate complementarity between sampling methods we used the formula proposed by Colwell and Coddington (1994), which weighs the presence and absence of every species in each site in the following manner:

$$C= [(S_j + S_k) - 2V_{jk} / (S_j + S_k) - V_{jk}] * 100$$

where Sj and Sk are the numbers of species in sites j and k, respectively, and Vjk is the number of species in common between both sites. To visualize the differences between the methods and vegetation type, we used range-abundance curves that show in a simple way the species richness, abundance, and relative equitability (Magurran 2004; Stoner 2005). Dominant species were determined by their relative abundance regarding to the total number of organisms observed in this study.

RESULTS

We recorded thirteen species for the EPJB: five amphibians and eight reptiles. Pitfall traps were slightly more effective than transects for amphibian detection (four vs three species,), transects were more effective for reptile detection (seven vs three species), while pooling amphibians and reptiles, transects were more effective (six vs ten species). However, homogeneity test did not show significant differences assessing for abundance between traps (N=27) and transects (N=42; X^2 = 3.26; df=1; p = 0.07).

Amphibian and reptile diversity is represented by four families each. Four species (31%), two amphibians and two reptiles, are listed in some category of protection under Mexican Government (SEMARNAT, 2010). Eight species (61%), two amphibians, and five reptiles, are endemic to Mexico (Table 1). Transects registered 10 species while traps registered six species. Overall sampling completeness observed was about 79% for transects and 59% for traps.

For the three diversity orders (^{0}Q, ^{1}Q and ^{2}Q), at a sample coverage of 80%, we observed significantly lower values for traps than those reported for transects, in grassland and oak forest. We did not observe differences in secondary vegetation (Fig. 2). The oak forest vegetation type showed the highest richness value (nine species), followed by secondary vegetation (six species), and finally grassland (five species). Richness in oak forest is fully represented in transects, while secondary vegetation richness was best represented using pitfall traps. Higher abundance values were registered in the grassland, followed by oak forest and secondary vegetation. Pitfall traps registered more species in the grassland and secondary vegetation.

Tabla 1. Especies de anfibios y reptiles del Parque Ecológico Joya - La Barreta. Las especies endémicas de México están marcadas con un asterisco (*). Estado de conservación (entre paréntesis) según SEMARNAT (2010): Pr = sujeto a protección especial.

Table 1. Amphibian and reptile species in the Ecologic Park Joya–La Barreta. Endemic species to Mexico are marked with an asterisk (*). Conservation status (in parentheses) according to SEMARNAT (2010): Pr = subject to special protection.

Amphibia
Order Caudata
Ambystomatidae
*Ambystoma velasci** (Pr)
Order Anura
Eleutherodactylidae
*Eleutherodactylus verrucipes** (Pr)
Hylidae
Dryophytes arenicolor
Dryophytes eximius
Scaphiopodidae
Spea multiplicata
Reptilia
Order Squamata
Anguidae
Gerrhonotus ophiurus
Phrynosomatidae
*Sceloporus dugesii**
*Sceloporus torquatus**
*Sceloporus spinosus**
Colubridae
*Conopsis nasus**
Tantilla rubra
Viperidae
*Crotalus aquilus** (Pr)
Crotalus molossus (Pr)

Dendrograms were very similar across both methods (Fig. 3). The oak forest and secondary vegetation showed medium values of similarity (0.4-0.5). The grassland showed a low similarity (0.2) with respect to oak forest and secondary vegetation. However, significant differences were only found between grassland and secondary vegetation (p = 0.02) in each method. Although differences in species presence were observed between both sampling methods, these differences were not significant (R = 0.51; p = 0.09) according to the ANOSIM.

The pitfall traps registered 42 captures representing six species. *Spea multiplicata* was the most abundant species, followed by *Sceloporus spinosus*. Two species, *Ambystoma velasci* and *Eleutherodactylus verrucipes*, were detected exclusively with this methodology and represent 16% of the total species encountered in this study.

The transect surveys resulted in 26 specimens representing 10 species recorded. *Dryophytes eximius, S. multiplicata* and *Sceloporus torquatus* were the most abundant species. Of all the species registered by this methodology, *Dryophytes arenicolor, Crotalus aquilus, C. molossus, Gerrhonotus ophiurus, Sceloporus dugesii*, and *Tantilla rubra* appeared only once, and combined represent 46% of the total species registered. The dominant species using traps was *Spea multiplicata* in the oak forest and grassland, and *Ambystoma velasci* in secondary vegetation.

The dominant species using transects were *Dryophytes arenicolor* and *Crotalus aquilus* in the oak forest, *Dryophytes eximius* and *S. multiplicata* in the grasslands, and *Sceloporus torquatus* in secondary vegetation (Fig. 4). Species registered with both methods obtained a 77% complementarity percentage, indicating important differences in the species composition registered with each sampling method.

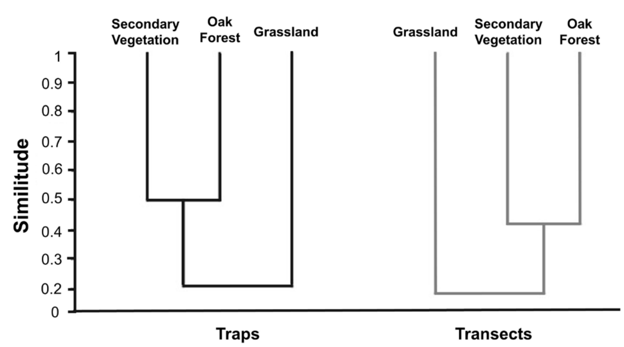

Figura 3. Dendrogramas recuperados utilizando el método UPGMA. Se muestra relaciones de similitud en riqueza de especies utilizando dos métodos de muestreo (estaciones de trampeo y transectos).

Figure 3. Dendrograms recovered using the UPGMA method showing similarity relationships of species richness among vegetation communities using two sampling methods (trapping stations and transects).

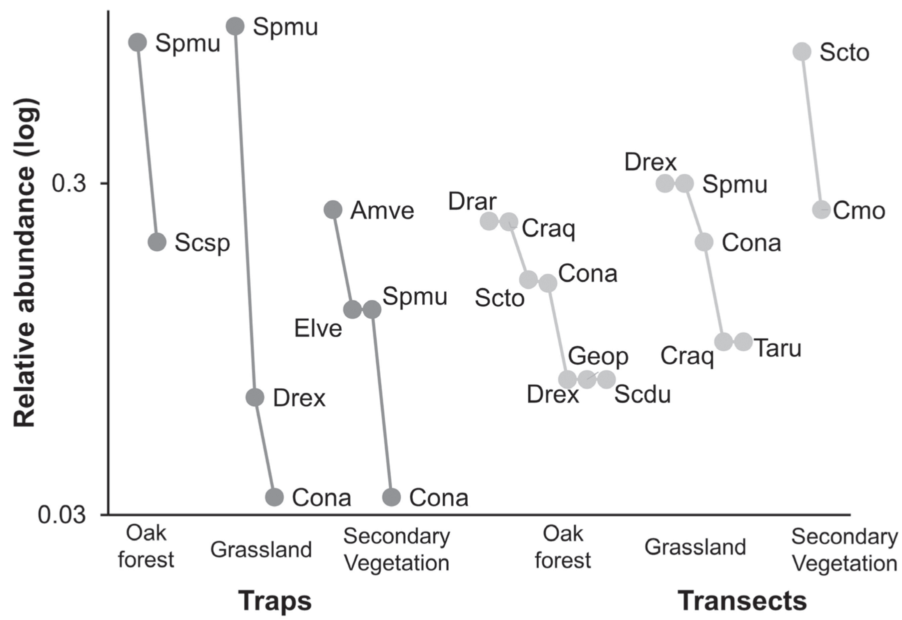

Figura 4. Curvas de rango abundancia basadas en el logaritmo de la abundancia relativa de las especies para cada tipo de vegetación y método de muestreo. Las abreviaciones de las especies representan las dos primeras letras del género y la especies para cada taxón.

Figure 4. Rank abundance curves showing species composition based on the logarithm of relative abundance for every species grouped for vegetation type and sampling method. Species abbreviations are coded following first two letters of genus and species for each taxon.

DISCUSSION

Species encountered in this study represent 9.4% of the species registered for the state of Querétaro (Cruz-Elizalde et al., 2016). The highest richness values were found in oak forest habitats, despite its restriction to the highlands within the study area, and the considerable degree of anthropogenic alterations in the surrounding areas. Several studies have shown that Protected Natural Areas (PNA's) harbor important levels of species richness on a global scale, and therefore constitute the main tool for conservation, in addition to offering diverse environmental and sociocultural services (Böhm et al., 2013; Stolton & Dudley, 2010; Wilson et al., 2013a, 2013b). Protected Areas are particularly important in environments closely associated with human activities; for example, they have been shown to provide vital habitat to protect native amphibian and reptile populations persisting in urban areas (Domínguez-Vega et al., 2017; Mitchell et al., 2008). Going forward, it will be necessary to integrate conservation strategies within these protected areas (e.g. besides richness and abundance, take into account aspects such as ecosystem functionality and services; Stolton & Dudley, 2010). To reach these goals, we must acknowledge that PNA's cannot function as isolated elements in the landscape. To maximize their importance as biodiversity shelters, it is imperative to create plans for their integration into the anthropized landscapes that surround them.

We observed differences in effective numbers of species estimated between sampling methods at the same sample coverage. These differences are the product of high net richness (q^0), high proportion of rare species (q^1), and differences in relative abundance (q^2). Active searching via transects proved to be more effective than pitfall traps in registering species richness, suggesting lower probabilities to record some species using traps due to their ability to escape or avoid trapping stations. Our results are congruent with Carpio et al. (2015), who report that transects are more effective in determining reptile diversity in olive groves in Spain; but contrast those reported by Hutchens & dePerno (2009), who reported more species registered by pitfall traps in wetlands of Washington County, North Carolina. Despite these differences, other authors report transects and pitfall traps to be equally effective in detecting reptile species (Sung et al., 2011).

Sampling techniques are designed to collect information from wild populations (e.g. richness and abundance) based on intrinsic characteristics of the species and habitat types they occupy (Heyer et al., 1994; McDiarmid et al., 2012). Therefore, no single technique can provide all the information concerning a study site's diversity. Both sampling techniques used in this study gave complementary information regarding herpetofaunistic diversity in EPJB. This is highlighted by the high complementarity of sampling methods, and the fact that total species richness could not have been registered with just one of the techniques employed. Our results strongly highlight the necessity to carefully consider different sampling methods, and we suggest that future studies aimed at the management and conservation of amphibians and reptiles utilize different techniques in line with the goals of investigation.

EPJB species richness deferred significantly among vegetation types. Despite numerous authors reporting that oak forests contain some of the highest levels of diversity and endemism in Mexico (Ochoa-Ochoa & Flores-Villela, 2006; Wilson 2013a, 2013b; Flores-Villela & García-Vázquez, 2014), we did not find high richness values in this vegetation type, although being the most extensive vegetation type in the study area, and unlike results from similar studies (Cruz-Elizalde & Ramírez-Bautista, 2012). However, most of these studies surveyed pine-oak forest and not oak exclusively. Therefore, it is likely that differences in richness and abundance values are determined by this factor, in addition to the isolation and the extension of the oak forest in the EPJB.

Other authors have suggested that high diversity values in temperate montane ecosystems can be explained by disturbance degree (makes available more microhabitat types) and tolerances of certain groups, like some species of *Sceloporus* lizards, to abiotic variations (Mitchell et al. 2008; Cruz-Elizalde & Ramírez-Bautista 2012). Even though we did not assess the relationship between disturbance degree and richness in the EPJB, we did not observe high diversity values associated with recurrent anthropic impact areas such as camping sites or mountain bike trails, which may be related to the fact that these types of disturbance do not necessarily produce a greater number of suitable microhabitats for amphibians or reptiles. More research is needed related to the anthropic impact on amphibian and reptile populations in peri-urban and rural areas of Mexico.

Both methods showed similar results in terms of comparing species composition between vegetation, with high levels of complementarity, with the oak forest grouping with secondary vegetation, both distinct from grassland. These results are concordant with those reported by Nieto-Montes de Oca and Pérez-Ramos (1999), where species composition reported for the grassland differed drastically from that of other vegetation types. However, many studies consider grasslands to be an induced vegetation type, which is not the case in EPJB and share some elements with oak forests.

Community structure observed in this study is similar to the results reported by Cruz-Elizalde and Ramírez-Bautista (2012), and Vite-Silva et al. (2010) for oak forest in the state of Hidalgo, showing dominant species with temperate affinities that include genera such as *Dryophytes* for amphibians, and *Sceloporus* for reptiles. We did not find previous records of community structure for grassland and secondary vegetation in adjacent areas, but dominant species observed for these vegetation types correspond to those with arid semi-arid affinities, such as *Spea multiplicata* (the most abundant species in this study). This species is associated with semiarid ecosystems and exhibits biological traits such as estivation, limited annual activity time, and local migrations that likely contribute to making it a dominant species in EPJB (Dixon & Lemos, 2010). Overall, most species abundances were low, which may be a consequence of environmental degradation within EPJB and adjacent areas.

Herpetofaunistic distribution in EPJB is heterogeneous in terms of abundance, with the grassland habitats showing remarkably high values in comparison to the other vegetation types. However, this abundance is mainly explained by two species (*S. multiplicata* and *D. eximus*). Both species are commonly found in abundant populations that are spatially restricted to a specific habitat, such as water reservoirs (Dixon & Lemos-Espinal, 2010; Lemos-Espinal & Smith, 2016), which, in the EPJB, are restricted to grassland habitats.

Despite the low richness values in the EPJB, it should be considered an important regional spot for herpetological conservation due to the number of species listed under protection or endemic to Mexico. However, a greater number of studies are needed in surrounding areas to allow comparison of the levels of herpetological diversity in areas with similar characteristics. Sampling techniques employed provided complementary information about local herpetofauna.

Future studies aimed at the management and conservation of these vertebrates should incorporate a sampling scheme that includes multiple techniques, due to the environmental heterogeneity of the study site and the low similarity of species among vegetation types. Studies like this provide insights that may enhance biological conservation in anthropized environments, especially considering the species decline to degradation and habitat loss.

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